Getting a handle on it

A first step towards understanding the cognitive evolutionary processes underlying changes in the archaeological record that relate to Pliocene and Pleistocene hand-held tool and hafted tool technologies

Thesis submitted by Joanna Elizabeth Fairlie in accordance with the requirements of the University of Liverpool for the degree of Doctor in Philosophy

30th June, 2017

Abstract

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The main aim of this project is to be able to describe the changes in cognitive ability that have to take place to enable a hominin group that was formerly only able to produce assemblages consisting of reductive or knapped hand-held stone tools, to become a group able to produce a mixed assemblage containing both reductive hand-held tools and also combinatorial hafted tools. Unlike reductive stone tools, hafted tools have pre-processed separate parts that are engineered to fit together to form a single object. Secondary project aims immediately became necessary to support this main aim. The first was to describe the two different groups of tools in a way that showed them as different stages of the same technological dynamic of change. The second was to describe how best to define the over-used word 'cognition' in evolutionary terms. The third was to describe how such cognition might change over time in biological terms and also in terms of new cognitive and action potential. It was then necessary to analyse the different technologies included in the period of change considered between 3.3Mya to 0.03Mya, with particular emphasis on the transition between Early to Middle Stone Age and hafted technologies in both Africa and Eurasia. This, and the nature of the cognitive theory chosen as most promising for the project, required the innovation of a new analytical method which focussed on the motor-action or gestural sequences of the technology manufacturer rather than on the finished morphology of the artefacts themselves. Each tool-type gestural sequence was manually coded and then carefully analysed in order to identify gestural pattern commonalities and changes over time.

Results show changes in the gestural patterns across the different coded technologies which suggest that evolutionary change is gradual and cumulative, but with moments of emergence when component parts come together to form something new and literally greater than the sum of its parts. Cognitive change is shown to move between a fast and highly effective but implicit, non-language-based cognitive system that relies heavily on rhythmic repetition (early knapping technologies), to a newer system that retains its original ability to use rhythmic repetition but can also incorporate conscious moments of planning, high-level action sequencing, and single discrete actions connected with

more derived brain-body systems. This new method of analysis amounts to an exciting innovation that offers up new opportunities to research the evolution of cognition in a more holistic framework both within a single species, and also between different species, particularly of course between modern humans, hominins and modern great apes.

Contents

Figures

Tables

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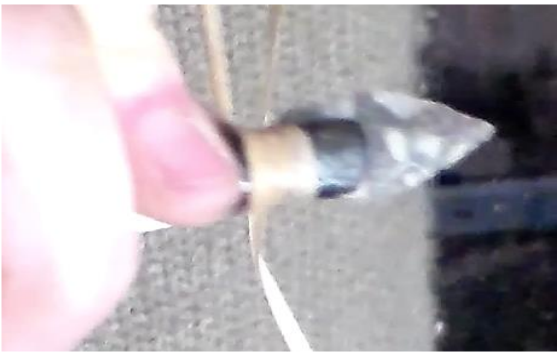

Chapter one

An introduction

"Ago, ergo sum"
(I act with purpose, therefore I am) Royeen (2003:Header)

"*a common focus on strategic modelling of human behavior is a powerful antidote to the centrifugal forces pulling anthropologists away from one another into ever more rarified specializations"*
Shea (2011:14)

1.1 The Question Being Addressed

This thesis belongs to a Palaeoanthropological tradition of using evidence from the archaeological record to infer the evolution of the cognitive capabilites of modern *Homo sapiens* (Wynn & Coolidge 2016). The main focus will be on two main groups of tool technology referred to respectively as 'reductive stone tools' and 'hafted tools'. The relevant time-span covers the Early to Middle Stone Age in Africa (3.3Mya – 0.03Mya) and the Lower to Middle Palaeolithic in Eurasia (1.8Mya – 0.04Mya). These chronological boundaries are broad given the longevity of the Palaeolithic on both continents, and especially in Africa where the archaeological record extends back well into the Pliocene (Harmand et al 2015).

It is intended to describe the development of tool technology throughout this period, and by implication the cognitive abilities of tool-makers, as a continuous dynamic of gradual change with marked passages of accelerated activity or emergences (Kelso 1995; Greenberg et al 1999; Grove 2012; Foley 2016). In particular there will be an attempt to identify the cognitive difference implied between a group of hominins that only makes and uses reductive tools, and a group whose assemblage includes hafted tools. This sounds relatively simple but is in fact a complex question. It requires a definition of cognition itself, of what increased cognitive ability actually consists of, and a description of how cognition emerges and changes over time in biological or evolutionary terms. Some well-established and widely-held assumptions about the nature of cognition will be challenged in the process.

Original research is used to establish both the gradual and continuous nature of change represented by tool technology over the time period, and the emergent nature of the transition between reductive and hafted tools. Established assumptions about the cognitive analysis of archaeological artefacts are challenged here and the research is based on approaches to cognition not previously tested in this context. This has required an observation-based methodology (Chapter 5). Expert modern tool-makers made a series of different tool-types from throughout the relevant chronological period. Their gestural sequences were recorded and analysed in two different pilot studies (Section 5.2) in order to assess for dynamic processes of change. Inferences about interconnected cognitive changes were then made on the basis of the models and theories set out in Chapters 3 and 4. If this approach is successful it will provide a framework for subsequent analyses of any type of behavioural sequences and associated cognitions, and should allow comparison across species boundaries.

The difference between reductive stone and hafted tools resides in their respective manufacturing processes and their chronological relationship. The Stone Age and Palaeolithic records contain large numbers of reductive stone artefacts made by removing flakes sequentially from a stone core. Flake removal requires a stone or organic hammer, and either or both the core and some removed flakes may subsequently be used as a tool. Additional small flake removals may be applied to flakes removed from the core in order to shape them further. Reductive processes continue to be used to make stone tools throughout the entire Stone Age and Palaeolithic (Shea 2011). Technological changes through time are directly driven by increasing skill and control over the flake removal process, the mounting complexity of reduction sequences and resulting techniques, and an increasingly sophisticated end-product morphology (Section 1.4; Lubbock 1865; Bordes 1961; Clark 1969; Gowlett 1992; Andrefsky 1998; Odell 2004; Klein 2009; Nonaka et al 2010).

Traditionally reductive stone tools made by non-*Homo sapiens* hominins were assumed to have been held in the hand during hammering, scraping, cutting, engraving, digging and piercing activities. However, this assumption has been increasingly challenged by microscopic methods of use-wear analysis used on a small portion of artefacts (Section 1.6.3). They show that reductive stone artefacts, including those made by Neanderthals, were sometimes 'hafted', or made as inserts or component parts for tools with biodegradable handles (Rots 2003; 2004; Rots and Williamson 2004; Rots 2010). Using a hafted tool would potentially have improved the accuracy and efficiency of the task being carried out and the longevity of the tool (Barham 2013b; Coe 2015). It would also have enabled the creation of new tool-types to carry out previously impossible tasks such as stone-tipped thrusting spears for killing large mammals (Barham 2013b).

However, stone inserts are not often sought out or identified during excavations (Keeley 1982; Barham 2013b), and very little is known about why and when hafted tools appear, how they were made and how they change over time or from site to site. Most studies of cognitive evolution have only used hand-held reductive tools as evidence (for example Moore 2011a and b; Wynn & Coolidge 2016). However, hafted tools are very different from reductive stone tools. They are not dependent on any particular raw material and are constructed from a range of different pre-processed parts in order to perform a specific task. The join between the different parts or 'haft' has to be engineered or adjusted so that the parts fit securely. It takes on a different form depending on the planned use of the completed tool, as each different use-type will impose different stresses on the haft (Barham 2013b). There is a possibility that hafted tool cognitive processes are different from those used in reductive tool manufacture.

1.2 Summary Contents of Chapters One to Eight

The rest of Chapter One acts as an introduction to archaeological and epistemological developments over the last century which have made the question being asked here necessary. Section 1.3 will give a brief summary of the time-periods, dates, hominin taxa and different technologies that feature in the archaeological record of the period under discussion. Section 1.4 will set out five reasons why cognitive analyses of hafting technology is imperative. Firstly, up until now cognition has only been analysed in relation to hand-held reductive technologies; secondly, assessing cognitive change for the Early and Middle MSA and Lower and Middle Palaeolithic has been low priority due to a perception of these periods as static; thirdly, technological and cognitive change has frequently been framed as stepped due to an assumption that it is related to speciation events; fourthly, even where change has been discussed as continuous it has been presented as linear rather than complex. Finally, no single explicit cognitive model has been consistently used, meaning that no useful definition of cognition has ever been provided or put to the test. Section 1.5 will discuss further the hidden variability in the archaeological record.

Section 1.6 gives more detail about hafted tools. This information is provided here as background detail to clarify the significance of the following chapters. In Chapter 2 theories about cognitive evolution currently used by archaeologists will be reviewed. Their relationship with an old and established model of cognition - 'cognitivism' - and their success or otherwise in explaining changes in the archaeological record will be discussed. The problems that this traditional cognitive model poses the analysis of hafted-tool technology will be clearer in the light of the Section 1.6 description. In Chapter 3 alternative models for understanding cognitive evolution will be suggested, including complex adaptive systems theory and ecological psychology. Chapter 4 will focus on biological and social mechanisms of cognitive change applicable to hominin groups, concentrating particularly on processes that improve learning skills related to technological behaviours. The next three Chapters set out the original observational research into the construction and gestural content of reductive and hafted-tool manufacturing processes. Chapter 5 discusses the innovatory observational methodology. Chapters 6 and 7 present the first and second pilot studies. Chapter 8 draws together results from the pilot studies, relating them to the theoretical structures set out in previous chapters and giving a final answer to the question set out in Section 1.1.

1.3 Hominin Species, Dates and Technology Types

For the purposes of this research it is not necessary to distinguish between different hominin species in detail. It is not likely that changes in cognition are the direct result of the presence of particular taxa at particular times (Foley 2016) although details will be given of rare direct connections in the archaeological record between a particular species and a particular technology. For the period of 3.3Mya to just over 2Mya potential tool-makers came from a range of early hominin species with physiologies and brain sizes closer to that of primates than modern humans, but who were bipedal and had an upper limb anatomy capable of reductive technology (Klein 2009; Harmand et al 2015; Section 3.2.3). From 2.3Mya and perhaps as early as 2.8Mya (Klein 2009) the genus *Homo* appears in the fossil record. Early *Homo* may have co-existed with other tool-making hominins such as australopithecines and paranthropines until about 1.5Mya (Klein 2009).

The earliest tools known pre-date the *Homo* lineage including the recently discovered Lomekwian technology at 3.3Mya (Section 1.5; Harmand et al 2015; Lewis and Harmand 2016), but after 2.8Mya the makers of a reductive technology known as the Oldowan in Africa and Eurasia (2.6Mya-1.7Mya) are likely to have been lineage members. At its most basic Oldowan technology is concerned with removing conchoidal (Schick & Toth 1993) flakes from a stone core using a hammer (Toth 1985). Acheulean technology in contrast is distinguished by a more systematic removal of flakes from both sides of a plane or edge producing the characteristic large bifaces including handaxes. Handaxes appear in the record at about 1.8Mya and *Homo erectus* is widely accepted as the innovator of the iconic tear-shaped reductive artefacts which continued to be made, probably by descendants *H. antecessor*, *H. heidelbergensis* and *H. neanderthalensis* in Africa and Eurasia until around 0.2Mya (de la Torre 2014) when they disappeared completely from the record.

There is no direct evidence as to the species responsible for the innovation of hafted technology in Africa but it is generally assumed to have been *H. heidelbergensis*. In Europe the earliest evidence of hafting is associated with Neanderthals (Barham 2013b; Wilkins et al 2012; Wragg Sykes 2015). There is still debate about the overall earliest dates (Wilkins et al 2012; Rots & Plisson 2014; Wilkins et al 2015), but there are confirmed dates at around 300Kya onwards both in Africa and Europe (Barham 2013b). Barham (2013b) would like to push the African date back to around 500Kya when the earliest examples of blade production (545Kya), prepared core technology and blade cores (509-285Kya) are found at different levels in the Kapthurin Formation in Kenya (McBrearty 2001; Johnson and McBrearty 2010). Barham (ibid) considers these tool-types as proxy markers for otherwise unevidenced hafting technology. Prepared core technology in particular produces flakes of a consistent thickness (Eren and Lycett 2012) and these may have been hafted early both in the African MSA (Wilkins et al 2012), and the Middle Palaeolithic (Rots 2013). The limited evidence for hafting available to-date means that we cannot be sure whether the technology had a common origin in Africa or was invented independently on both continents (Barham 2013b).

As more hominin species come to light older assumptions about a linear sequence of stand-out intelligent tool-making species following neatly through time will appear increasingly over-simplified (Stringer 2011; Foley 2016). Instead, we have a melting pot of widely spread groups of tool-making hominins, capable of long-distance migration and integration with other groups (Vernot et al 2016). The date for *H. sapiens'* first appearance has long stood at just over 200Kya in East Africa. However recent finds at Jebel Irhoud in Morocco have potentially pushed this date back to about 300Kya (Hublin et al 2017; Richter et al 2017). Early reports of these new fossil finds have limited technological detail, but *H. sapiens* has a good hafted tool-making record at later dates. As an example of this newly emerging taxonomic complexity we now know that new dates for *H. naledi* at 335-236Kya (Kruger et al 2016; Dirks et al 2017) mean that early *H. sapiens* may have been active at the same time as hominins with a distinctly primate appearance, small primate-like brains and hands still partially adapted to arboreal locomotion (Berger et al 2015; Hawks et al 2017 and see Moore and Brumm 2009; Brumm et al 2016 on *H. floresiensis*).

Stone tools are one of a range of different reductive technologies which also include wood or bone tools. Hafted tools are a 'combinatorial' technology in that they comprise different parts fitted together to construct a whole (Arthur 2009). Other combinatorial technologies are evidenced in the archaeological record (Section 1.6.1). A third type of technology is here categorised as 'induced-change' technology. This occurs when a raw material is placed in an altered environment such as fire or water in order to deliberately change its nature. Using fire to cook raw meat would be an example. Other examples of both combinatorial and induced-change technologies related to tool-making processes will be discussed. Reductive, induced-change and combinatorial processes are all nested together within preparatory operations on hafted tool components, and all hafted tools are in themselves examples of hierarchical combinatorial technology, as each one is made up from diverse parts each with individual but nested processing routines, all ultimately fitted together to make a whole (Haidle 2010; Lombard and Haidle 2012; Barham 2013a; Barham 2013b).

1.4 Why Does This Question Need to be Asked?

Only using evidence from reductive stone tools to analyse the evolution of cognition is not sufficient. Hierarchical combinatorial tools provide evidence of technological processes not available from reductive stone tools. Microanalysis of stone inserts offers information about otherwise untraceable biodegradable materials (Section 1.6.3). The greater the variability of technologies studied, the greater our chances of reaching sound conclusions about cognitive evolution. Ancient hafted tools also offer a link between hominin and historical human technologies which until recently in evolutionary terms were still dominated by hafting technologies. The clear need to study the origins and cognitive implications of hafting technology constitutes the first justification for the pursual of this project.

The second justification is that current analyses of cognitive evolution are founded on potentially misleading data. Technological progress up to about 40Kya (coincident with the European Upper Palaeolithic) has frequently been described as static (Mellars 1989; Klein 2009). The Oldowan is described as an initial change-free period (Semaw 2000) lasting until about 1.6Mya when a step change occurred with the speciation of a more human-like hominin (*H. erectus*) who developed new types of tools (Acheulean technology). This was followed by a further period of stasis before *H. sapiens* dispersed into Europe at around 40Kya and started to exhibit modern human-like behaviours, including the manufacture of hafted tools which was copied by the Neanderthals (Mellars 1989; McBrearty & Brooks 2000). This interpretation of the archaeological record has been consistently and successfully challenged by different authors (McBrearty & Brooks 2000; McBrearty 2007; Langley et al 2008; Tennie et al 2009; Nowell 2010; Shea 2011; Lombard 2012; Thornton 2012; Barham 2013a; Wragg Sykes 2015). However, it has left its mark on assemblage-analysis methodology. It may be that the failure to identify hafted tool inserts sooner (with a few honourable exceptions) may result from an assumption that the entire pre-*H. sapiens* record was one of stasis.

For De la Torre and Mora (2009), descriptions of Oldowan technology as static result from inferior or badly used methodologies. Stone tool analysis tends to be carried out at the level of the group rather than the individual tool-maker, and statistics are compiled that reinforce a continued 'norm' through time which would not be the case if indvidual or local variability were taken seriously (Stout et al 2010). Newer work however, uses established methodologies to investigate local variability. Högberg & Lombard (2016) use a *chaîne opératoire* methodology to investigate variability and consistency between the assemblages of two local groups in South Africa 80-70Kya, and to make deductions about knowledge-transfer between them on the basis of their results. It is now possible for authors to identify changes in recovered inserts as evidence of locally developing hafting technologies which vary in detail despite their apparent similarity (Mohapi 2012; Igreja & Porraz 2013; Scerri 2013). Both Scerri (ibid) and Shea (2014) are critical about the traditional classification of hafted and hand-held tools into 'named tool industries' which have little relevance to localised developmental trajectories revealed when variations are properly analysed.

Enquist et al (2011) describes innovation as a complex dynamic. It is a gradual and cumulative process, subject to local reversals depending on the state of the system's interdependent variables. Delagnes & Roche (2005) describe Oldowan technology system variables including raw material acquisition behaviours, the development of more complex flake removal routines and manual dexterity variability (and see Barsky 2009; Braun & Hovers 2009). McBrearty and Brooks (2000) reinforces the viewpoint that local variability throughout African sites is such that it is not possible to give a common date for the commencement of the MSA and the corresponding disappearance of Acheulean technology. They describe change as regionally variable (d'Errico & Stringer 2011; Scerri et al 2016).

The third justification concerns the tendency to associate technical change with species change when an older hominin species becomes extinct, and a newer one with genetically increased cognitive capacity becomes active. For D'Errico and Stringer (2011) significant change does not correspond to the speciation of particular hominins, indeed it appears as if archaic species' DNA is repeatedly re-mixed with more modern DNA sets through time. The gradual build-up of culture is more dependent on inter-generational cultural transmission or learning processes, which is behavioural rather than strictly genetic. For Foley (2016) Darwinian evolution is cumulative and continuous and not associated with speciation. He higlights two periods around 2-1.5Mya and 500Kya where change accelerated to a different level. The second period in particular is described as asynchronous, discontinuous and mosaic, driven by a high level of behavioural variability which allows for successful natural selection. He emphasises that change is not primarily a genetic process but is behaviour-led, meaning that any species can innovate by varying their behaviour for social or environmental reasons, and by passing on that new behaviour to subsequent generations.

The fourth justification is that a change in the archaeological record is going to be the visible tip of more complex interacting changes under the surface. We need to understand this complexity which has not yet been included in evolutionary cognitive archaeology analyses (Wynn and Coolidge 2016). Behavioural change is driven by high numbers of fluctuating and interacting component factors. All of them are variable and react to each others' variations, causing complex and unpredictable systemic change (Sections 2.5.3 and 3.1). Greenberg et al (1999) describes increasingly complex behaviours as the product of interactions between increasingly complex biological, psychological and central-nervous systems (CNSs). Complexity is the second law of evolution after natural selection (ibid). Andersson et al (2014) include ecological factors in their discussion of interacting drivers of change. For Kelso (1995) evolutionary models that rely on genetic change (Neo-Darwinism) ignore the systems within which biological organisms are immersed and the connections between them. Systemic patterns of change are founded on inherent instability which gives rise to unpredictability, flexibility and adaptation. Lifetime and evolutionary learning of new behaviours are processes that connect the embedded organism with its environment, connecting neurological substrates with behaviour. Change is behaviour-led, and genetic adaptation follows successful behavioural change (West-Eberhard 2003).

The fifth justification for analysing the cognitive implications of both reductive and hafted technologies is that existing cognitive analyses of hand held tools have not involved the use of explicit cognitive models, and cognition has never been defined. Bloch (2012) states that modern anthropologists have attempted to study culture without any attempt to understand cognition, and that cognitive scientists have ignored the implications of anthropological studies. Similar statements have been made about stone tool specialists (Bleed 2011; Soressi & Geneste 2011; Garofoli & Haidle 2014). Reed (1996) states that psychologists are unable to explain human or hominin behaviour because they use a Cartesian (or Cognitivist) model of cognition (Section 2.1) and have concentrated on minimalist and scientific explanations for phenomena which can't be applied to complex behaviours (Bassett and Gazzaniga 2011).

For Pfaffenberger (1992), anthropologists have failed to study technology in its own right. Culture and technology are two interdependent variables that together form the sociotechnical system. He mentions the presence of a nonverbal cognition concerned with technical activity at the roots of the sociotechnical system which has remained unstudied as a result (Section 4.4.3). Shea (2011) advocates a shift from trying to establish behaviours as *Homo sapiens*-specific or 'modern', to concentrating on the degree to which they vary over time.

Malafouris (2013) condemns the interpretation of artefacts as the products of labelled or conceptualised cognitive capacities which pre-exist in the artefact maker. Instead the nature of the artefact and the bringing together of its constituent raw materials cause change to the cognitive processes of the artefact-maker as manufacture unfolds (Section 2.5.4). The focus has been too much on form and typology and not enough on activity and how it affects cognition (Wynn 2009; Langbroek 2011; Lombard 2012). Nonaka et al (2010) illustrates this point neatly. The diversity of potential knapping routines available to a stone tool-maker is constrained by the characteristics of the particular core that she is working. Her main cognitive skill is the degree to which she is able to control each conchoidal fracture of the core, rather than any conceptualised sequence of reductions. Conchoidal fracture control implies long, socially embedded learning processes and a heightened ability to to perceive the features of the stone core. The skill acquired varies with the length of both her own ontogenetic experience and that of the group's phylogenetic experience. It is only achievable if the tool-maker's individual biological systems have responded to both ontogenetic and phylogenetic (or constructed niche – Section 2.5.5) challenges by developing neuronal networks that can cope with the learning and motor tasks involved in the knapping process.

1.5 Variability Rather Than Stasis in the Reductive Stone Tool Record

A tool-maker's control over conchoidal flake removal tasks increases with practice and becomes more flexible if she has had to use her skill in a variety of different knapping contexts. Her learning rate is likely to be proportionate to the degree of variability in the knapping tasks that she undertakes. This is true at an individual level (Forsythe et al 2015), and also at the level of sociotechnical dynamics of change (Arthur and Polak 2006). A certain amount of variability within a system (including neuronal network variability, ecological variability and social variability) will allow for at least some basic unit recombinations into new and adaptive sequences or techniques (Sambrook and Whiten 1997). Recombination increases variability to a new level and allows for an increased range of further recombinations in the future (Arthur and Polak 2006). A new stone tool-making dynamic starts out with low levels of variability. The tool-makers' skills are basic to start with and stone is a relatively inflexible raw material. The dynamic will be constrained by an initial slow variability increase. However, variability will inevitably be found if it is looked for rather than ignored, and the degree to which it is present in any part of the system will be an indication of the system's momentary potential to form the basis of a future increase in complexity.

There follows a brief review of papers concerned with identifying variability as opposed to stasis within reductive hand-held stone-tool technology. Several papers are also referenced which provide microscopic analyses of reductive tools and some hafted tool inserts. These analyses point the way to another type of variability latent in the system. They reveal other non-stone-based technological skills practised by the hominins in question which may not have have left direct traces in the archaeological record, but which form part of any hominin group's technological profile. These skills interact with stone-tool manufacturing processes and must increase variability, even before the raw materials in question are used together in combinatorial technologies.

Andersson et al (2014) uses a complexity model to summarise change across reductive stone-tool technologies. Oldowan technology is described as isolated instances of a non-hierarchical and thus low-variability technology which develops into Acheulean technology in any given region where groups start to hunt large mammals in addition to foraging. This change is managed by re-sequencing or recombining existing knapping techniques to produce more complex tools as the ecological challenges increase. Ultimately each local group focusses on hafting which is an already present variation or minor technology, and a new combinatorial type of variability emerges.

In terms of technologies that precede the Oldowan, Haslam (2012; 2014) discusses modern chimpanzee stone-tool-use history. Chimpanzee groups are acknowledged to have individual, variable cultures which can include tool-use, variability in the raw material from which the tool is made, whether the raw material of the tool is modified and how it is used. Currently only chimpanzees in Western Africa are known to use stone tools, a behaviour Haslam believes may date back to about 200Kya. He speculates that hominin groups inherited plant-based tool-use from their last common ancestor with chimpanzees and bonobos about 8Mya.

De la Torre (2010) also speculates on pre-Oldowan technology. He suggests a technology which is not reliant on skilled control over conchoidal fracture (and see Panger et al 2002). Harmand et al (2015) reports on the Lomekwian site (3.3Mya), predating Oldowan technology by about 700Ky. The authors describe a series of large stones which appear to have been used at different times alternatively as percussors, anvils and cores, an indication of a technology so lacking cultural definition that the objects involved were only categorized in their users' minds for the length of individual sessions, and not beyond. (Compare Carvalho et al 2009 where chimpanzees re-use the same pair of stones consistently as anvil and hammerstone respectively for every nut-cracking session). Recovered flakes include conchoidal removals but it is not clear that their conchoidal nature was intentional. Flake removals are often superimposed (described as unidirectional, unifacial partial exploitation) and evidence a lack of manual control with hinge and step fractures and mis-hits. No artefacts corresponding to hammerstones held in one hand are reported. The authors comment that "the average size and weight of the LOM3 cores…renders direct freehand percussion an arduous undertaking; however, it cannot be ruled out for some of the smaller cores" (ibid:312).

Lewis & Harmand (2016) describe passive hammer techniques, holding the core in both hands and hitting it against an anvil, and bipolar techniques where one hand stabilizes the core on the anvil, and the other hits the core with a percussor. They draw a comparison with chimpanzee nutcracking techniques and suggest that the tools were for plant and wood processing rather than cutting meat.

Key and Dunmore (2015) suggest that the *Homo*-lineage thumb is specifically adapted to gripping and repositioning the core unimanually during freehand knapping. In australopiths (possible Lomekwian tool-users) these manual operations would have been incompatible with the optimal thumb for arboreal locomotion. Given the size of the Lomekwian cores which are substantially larger than those tested by Key and Dunmore (ibid) it seems possible that Lomekwian hominins may have been restricted to two-handed manipulation of their stone tools and cores. Kivell (2015) mentions *Homo naledi* (c.300Kya). Fossil remains show a derived thumb related to object handling together with curved phalanges related to arboreal locomotion. In the same paper Kivell discusses the Lomekwian finds and suggests that the bi-polar technique of knapping required manual control and forceful loading, but not the same dexterity as that shown by hominins responsible for Oldowan technology (and see the evidence of inaccurate flake removals Harmand et al 2015). Other factors which would be relevant to the ability to hold a core or a hammerstone unimanually which have not yet been the subject of any kind of research, would be the actual hand size of the tool-users in relation to the objects, and the density of their hand sensory receptors which might be reduced in arboreal species compared with non-arboreal species (Section 3.2.3; Yekutiel 2000).

The presence or absence of freehand knapping is important as the technology requires manually differentiated control (Section 3.2.3; Pelegrin 2005) and potentially a higher cognitive load (Bril et al 2012; Rein et al 2013). It may be a more secure method for producing conchoidal flakes and thus be a proxy for intentionality, although this assumption needs testing. However, a habitual set of behaviours was carried out intentionally at Lomekwi, modifying large cores to make heavy tools, and or to produce sharp flakes. McPherron et al (2010) presents an Ethiopian site dated at 3.39Mya where two bones were found bearing what they interpreted as anthropogenic cut marks. Although this was disputed (Domínguez-Rodrigo et al 2012), the article's initial controversial quality should perhaps be re-addressed in the light of Harmand et al (2015) (Kivell 2015).

In respect of reconstructing Oldowan variability Barsky (2009) suggests that differences in raw material acquisition, conchoidal fracture skills, flaking methods, the presence or absence of flake retouch and configured tools, prepared flake removals, and multidirectional, bifacial and bifacial discoidal flaking are all good places to start. All these variables often associated with Acheulean technology, appear at some Oldowan technology sites (de la Torre et al 2003; Harmand 2009; Goldman-Neuman et al 2012), even if unpredictably.

Braun and Hovers (2009) report that new concepts and excellent fieldwork are now regular features of Oldowan analyses. Recognition of variability is on the increase. The earliest dates for the technology have extended back, and differences in artefacts, raw material acquisition, production organisation and different hominin species' involvement are all variable components. Oldowan hominins are competent tool users and makers and initiated their own dispersals out of Africa, as evidenced by sites in Dmanisi and China (Barham 2013b). Delagnes and Roche (2005) report on Lokalalei 2c (2.34Mya) which shows an advanced use of Oldowan technology resulting in a higher production rate of flakes from superior raw material cores. Refitting indicates a planned reduction process supported by the maintainence of a striking platform, and evidence of controlled conchoidal flaking and manual control. These results lead the authors to speculate about differences between local groups' cognitive developmental levels (Roche et al 1999).

Perreault et al (2013) set out to measure the increasing complexity of lithic tools over time, but do not use a complexity theory framework. In contrast Carbonell et al (2009) use complexity theory terms (Section 3.1) to describe emergent change between developmental stages depending on their respective levels of variability. Variability is described as the number of different methods available to obtain conchoidal flakes. They suggest a low variability Pre-Oldowan technology using only linear unidirectional techniques, comparable with chimpanzee nutcracking. Once this homogeneity is lost then Oldowan flake removal sequences start to take on a variable and hierarchical format. Acheulean technology marks a further increase in variability and hierarchical formats (Goren-Inbar 2011; Moore 2011b; Stout 2011; Stout et al 2014; Muller et al 2017). The boundary between Oldowan and Acheulean technology appears fluid, gradual, and permeable in that Oldowan technology persists alongside Acheulean technology (de la Torre 2014) thus allowing variability levels to be boosted further.

Stout (2011) recommends that rather than describing tool morphology we focus on the relative complexity of manufacturing processes and the comparative depth of their hierarchical structures. The roots of Acheulean technology can be found in Oldowan reductive processes. The rate of change at the early end of the technology evolution dynamic is slower than at the modern human end because variability rates are so much lower and selection for adaptive change takes relatively longer as a consequence. All tool-making skills need to be transmitted between generations and the relative success of this transmission in different groups will be a driver of cognitive variability. As increasingly hierarchical skills have to be learned, neuronal networks have to adapt to new challenges both ontogenetically and phylogenetically (Section 4.2).

Stout et al (2014) states that variability within Acheulean technology is present but is not well understood. The major variation through time is the increasing refinement of biface manufacture and biface variability or even absence at different sites. He mentions new techniques such as platform preparation and the use of soft hammers alongside stone hammers during the thinning process in order to obtain better control over conchoidal fracture. The Acheulean technology hierarchy is deeper than the Oldowan hierarchy (Stout 2011).

There are indications that the boundary between Acheulean technology and hafting technology is also difficult to define and just as locally variable as the Oldowan-Acheulean boundary. Barham (2013b) and Andersson et al (2014) suggest that hafting appeared in some localities as a new technology at around 500Kya (also see Foley 2016), but remained a subsidiary branch of tool-making, only used in particular circumstances (Arthur 2009) until it took on a more prominent role later (Section 1.6).

The need to create tools with greater precision even where hafting technology was not available can be seen in some handaxe types (Clark 2001; Matskevich et al 2001; Gowlett 2013). Additionally some Acheulean technology artefacts have been identified as proxies for hafting technologies which cannot otherwise be evidenced such as the presence of prepared flakes, blades, very small retouched flakes sometimes backed, and small proximally thinned bifaces (Clark 2001; Dominguez-Rodrigo et al 2001; Barham 2013b). While the Acheulean-hafted tool boundary remains permeable to Oldowan technology, it is not permeable to some types of hand-held bifaces which start to disappear from the archaeological record (Section 7.6.3; Barham 2013b).

Microscopic use-wear analyses methods can provide evidence about tool-use, and detect adhering residues (Section 1.6.3; Barham 2013b). These methods are time-consuming and expensive and are only used selectively at present meaning that we have a very limited view of artefact function for the full relevant time period and geographical areas. A brief review follows of papers that describe the results of such analyses on different hand-held and some mixed hand-held and hafted stone tool assemblages. The results reveal a consistently wide range of different tool-use activities through time supporting the assertion that other raw material technology-types have always been present alongside stone technologies. Where the variability of the sociotechnical system includes such technologies, a transition to combinatorial technology becomes inherently more likely to happen at earlier dates (Section 7.6.4).

Lemorini et al (2014) analysed an Oldowan assemblage from Kanjera South (2.0Mya) and found tools used on animal tissue, plants, underground storage organs (USOs), grass or sedge (possibly as a source of fibre), and wood probably for the making of other tool-types including digging sticks for recovering the plants and USOs. Domínguez-Rodrigo et al (2001) found wood residues on 1.6My handaxes in Tanzania. Bigga et al (2015) is an extraordinary review of the plants in the Schöningen area (c.300Kya) that may have made up the plant-based use-wear and residue traces on the stone-tool assemblage. The possible uses of each plant and tree named are given, opening a new line of sight onto the world that the wooden spear-making hominins inhabited.

Pawlik and Thissen (2011) analysed Neanderthal stone tool finds from the site of Inden-Altdorf (120Kya) which included hafting inserts. They describe evidence of hide working, cutting, chiselling, engraving, perforating, grinding, grass processing, meat processing and some multi-purpose tools (Hardy and Moncel 2011). Blasco et al (2013) discuss the presence on some post-Acheulean sites of processed bone tools used during the manufacture of stone tools, and Van Kolfschoten et al (2015) describe expedient bone tools at Schöningen used to repeatedly resharpen the highly curated flint tools and then discarded. (Compare Timberlake 2014 on the expedient use of subsequently discarded bone tools in copper mines for specific extraction processes, and Rots et al 2011; 2015). Miller (2014) deals with a Late Pleistocene Paleoindian site on the Great Lakes. Microanalysis reveals plant and wood processing and tools possibly used for fibre production, bone, hide and meat processing (and see Clark 1958).

1.6 Hafted Tools

"nothing is a tool except during use…It is not in the head of the hammer, nor in the handle, nor in the combination of the two…but in the recognition of its unity and in the force directed through it in virtue of this recognition"
(Baber 2006:4)

1.6.1 Hafting is a Hierarchical Technology

Arthur (2009) describes the development of combinatorial technologies over time. He does not refer to hominin or early human technology, but because he uses a suitable paradigm (complex adaptive systems theory, Section 3.1), the descriptions of the development of technology which he provides are universal (Garofoli & Haidle 2014). Arthur describes any new technology-type as a continuation or product of all preceding local technologies. It is always combinatorial in that it is made up of fragments of processes taken from older technologies, recombined in order to form something new. He relates this recombinatory pattern to the cognitive learning process known as 'chunking' (Forsythe et al 2015) where separate action units that have previously been successfully used together are subsequently processed by cognitive systems as a single unit. He describes combinatorial technologies as hierarchical. Each branch of the hierarchy or each component part, is completed separately so that the final product can be brought together for a final assembly stage. Assembly takes place in a particular space into which processed parts enter separately and from which they exit as a single entity.

For Arthur innovation can be a long process. The new technology may already be present in the system but so too are previous technologies which continue to have some value, and around which social and cultural systems are organised (Barham 2013b). Finally the balance of the system tips in favour of the new technology, and new social and cultural substrates start to develop. Innovation can only be truly effective where socio-cultural systems are open and flexible, communication levels are high and there is a need for the new technology. The innovation may be a local phenomenon initially, but micro groups start to network with other micro-groups carrying out related activities so that a macro or small-world system develops (Arthur & Polak 2006; Andersson et al 2014; Holland 2014).

Using a similar pattern to describe behavioural sequences, Reed (1996) suggests that biological organism behaviours are made up of highly variable combinations of very small action or gestural units. These are sequenced or patterned by the organism's cognitive system firstly to obtain environmental information about resource availability, and secondly to exploit the resources as effectively as possible taking account of local constraints. These action unit sequences are 'meaningful' because they always have a quality of intentionality. New behaviours are achieved by the reorganisation of past successful sequences of action units into new variants. The most successful variants are retained as new units and frequently reused in "systems of combination, recombination, and transformation" (ibid:123).

Hafted tools contain elements of reductive technologies. Knapping or flaking stone is reductive, as is the working of wood and bone. We have seen that these and other reductive technologies were already included in hominin technological profiles when hafting emerged. Making a hafted tool is a combinatorial process but it has other combinatorial processes embedded in its sequences. These include the manufacture of some types of adhesives, and the twisting of plant fibres together to make twine. Combinatorial adhesives may be a product of hafting technology (Rots et al 2011), but twine is likely to be a very early product (Sections 1.5 and 7.6.4) and the simple fact that it is used to fasten objects together points to a range of pre-existing combinatorial activities.

Induced-change technologies are present in variations on hide and sinew preparation sequences, food preparation, fire-hardening of wooden tools and the retting (immersion in running water for long periods of time) of plant products to extract their strong fibres (Hurcombe 2008). Induced-change processes directly associated with hafting include South African sites where insert blanks made from silcrete were heated at a controlled temperature in order to improve their knapping quality, and the heating of goethite (yellow ochre) in order to change its colour to red (Godfrey-Smith & Ilani 2004; Pomiès et al 1999; Brown et al 2009; Wadley & Prinsloo 2014; Schmidt et al 2015).

All of these different types of technologies are nested within various different levels of the hafted-tool making process. They are used during different task stages relating to the preparation and final assembly of the different pre-prepared component parts of the tool (Section 1.6.3). This means that the final version of a hafted tool is the top level of a hierarchical structure with each of its component parts at the next level down having been through several stages of its own manufacturing process. The entire process has depth and width in the way described for complex hierarchical structures (Section 3.1).

1.6.2 The Outline of a History of Hafting

Any attempt to outline a hafting dynamic at this stage is highly speculative. However, some patterns are emerging from confirmed hafting sites where microanalysis has been used. Despite early assumptions that only hunting weapons would be hafted (Barham 2013b), a large proportion of identified inserts belonged to tools used during a wide range of everyday activities. Rots (2009) describes the hafting dynamic as having three main stages. The earliest hafted tools were given handles because without them the task for which they were intended was impossible – examples would be axes for felling trees, and thrusting spears. During the next stage the new technology was also used in relation to existing tool-types whose efficiency benefitted substantially from a handle (Coe 2015). This stage includes woodworking tools for shaping wooden spears or the handles of other important hafted tools. The final stage included social and cultural hafting networks with potentially specialized local micro-groups forming a network (Arthur 2009). At this point the majority of tools were hafted, and non-hafted tools in an assemblage were likely to be expedient and non-curated. During this final stage the assembly stages (as opposed to the preparatory stages – Section 1.6.3) of making hafted tools may have required a designated space to which tool-users travelled with some prepared components in order to acquire new tools.

Rots et al (2011) and Wadley et al (2015) suggest that the earliest hafted tools just required binding. Adhesive came later when tools were made where binding alone would not be effective. Wadley et al (ibid) posit two stages of adhesive development, the first of which is effectively induced-change technology adhesives such as heated resin, and the second is combinatorial technology adhesives such as compound adhesives (for example a heated mixture of resin, wax and ochre). Birch bark tar and bitumen adhesives are not mentioned but would constitute induced-change technologies or combinatorial technology if other raw materials were added into the mix (Section 1.6.3; Lombard & Haidle 2012; Wragg Sykes 2015).

Claud et al (2015) describes an experimental comparison between the performance of replicated hand-held and hafted Late Middle Palaeolithic Neanderthal-style flake cleavers from South Western Europe, when used for heavy duty tasks including tree-felling. Successful tree-felling required the cleavers to be hafted (Coe 2015). The flake cleaver is a rare survivor at this time period except in this local area in the Pyrenees and Cantabrian mountains, but may have made it through the Acheulean technology boundary because in its hafted form it was irreplaceable. At the time it was first hafted this cleaver would have been an example of the first stage of hafting as might Wilkins et al (2012) if the use-wear issues surrounding the potential spear points (500Kya) could be successfully resolved, (and see Rots & van Peer 2006; van Peer et al 2004). Rots (2009) describes a late Middle Palaeolithic Neanderthal assemblage in Sesselfelsgrotte, Germany which includes axes or adzes hafted without adhesive for heavy woodwork. She comments that without hafting they would not have been usable for this function.

Rots et al (2015) describes micro and reside analysis of artefacts from the spear horizon of Schöningen (c.300Kya). There is some evidence for the hafting of tools used to shape wooden artefacts such as the spears found on site, but it is not conclusive. This would be an example of the second stage of hafting particularly because of the highly skilled shaping of complete tree trunks involved and because of the presence of unconfirmed wooden tool-handles on site (Thieme 2003; Schoch et al 2015). There is a potential example of the first stage here as well. Whole tree trunks of very dense wood were felled and then carefully reduced slightly off-centre to the trunk in order to avoid more spongey wood (Schoch et al 2015), and it seems unlikely that this was done without hafted axes (Rots 2009; Claud et al 2015; Coe 2016).

Several sites might be examples of the third stage. Rots (2013) describes an Early Middle Palaeolithic Neanderthal site at Biache-Saint-Vaast in France where a large proportion of tools were hafted indicating a good understanding of the benefits this conferred (and see Eren 2012). In addition the concept of a special place applies as the site may have been used during successive hunting seasons causing supplies on-site to accumulate. The authors suggest that it may have been part of a network of different sites (Pawlik and Thissen 2011; Rots et al 2011).

Rots and van Peer (2006) and van Peer et al (2004) describe the Late Middle Pleistocene Sudanese Sai Island site where inserts are found for heavy duty core axes thought to have been used for mining, along with other inserts (Rots et al 2011). This site is described as part of a well-established network of different hafting groups and a place where broken core axes, handles and binding were brought so that re-tooling could take place. Core axe inserts in non-local stone broken by heavy use were found together with local quartz core-axe inserts rejected during the knapping process. It is worth comparing Timberlake (2014) on copper mines. Despite the big time and geographical discrepancies, Timberlake's miners also used stone-age technology to extract resources from underground, but preservation is greatly improved and he is able to describe the multiple wood and bone tools used by the miners. The reconstructed hafted stone hammers are strikingly similar to Sai Island versions although the latter show more knapping skill (and see Craddock et al 2003).

Storage is a significant aspect of hafted technology. It is generally only associated with Northern hemisphere groups (Barham 2013b). But hafting is a hierarchical process requiring the use of components that have in themselves gone through several time-consuming technological processes. Some of the components will be made from plant matter only available at certain times of year (Hurcombe 2008). Birch bark tar can only be manufactured in small amounts and is likely to have been heavily curated and recycled (Wragg Sykes 2016). It seems logical that materials remaining unused during one hafting session were likely to be stored for future use. Clark (1954) describes multiple rolls of birch bark at the Early Mesolithic waterlogged site of Star Carr. Unpublished reports relating to modern excavations at this site also mention birch bark rolls, and see Rots & van Peer (2006) on the unused quartz cores at Sai Island.

Wadley (2005) speculates that ochre was frequently used in compound adhesives as a loading agent to reduce the brittle quality of the dried resin and to add distinctive colour to the tool (Zipkin et al 2014). She alludes to sites where unexplained large quantities of pigment have been found and suggests this may have been connected with storage for use in hafting processes (Barham 1998; 2002). Sanz & Morgan (2006), Carvalho et al (2009) and Sanz et al (2010) describe chimpanzees storing tools at the place where they are habitually used. Sanz & Morgan (ibid) describe how after the use of a tool kit accumulated to extract honey from a bees' nest, a chimpanzee stored just the heavy pounding tool in a tree near to the nest, possibly because it was the most difficult tool in the set to create.

1.6.3 The Preparatory and Assembly Stages of Hafting

The only exisiting analyses of hafted tool manufacture are in Haidle (2010) (a bone-pointed spear), and a bow and arrow set in Lombard & Haidle (2012). Haidle has developed a diagrammatic analysis method consisting of cognigrams which schematically illustrate different stages in the full tool-making process. For more complex tools, particularly the bow and arrow set, she uses hierarchical diagrams instead which show the component processes as separate units which don't have to be performed in any particular order until the last stage is reached (Section 5.3). However, all of the units are shown as part of a process carried out by a single tool-maker. It may not be fully productive to try and understand the making of hafted tool in this format, as we may miss the lessons in Section 1.6.1 that as technology becomes more complex so does the whole social and cultural environment that supports it.

It is suggested here that we try to understand the making of hafted tools as two quite separate preparatory and assembly stages. Preparatory stages deal with the processing of component parts and may not be carried out by hafted tool-makers at all, but rather by individuals specialising for example in twine manufacture, sinew and adhesive processing, or the provision of prepared-core flake blanks (Section 7.6.4; Fairlie & Barham 2016). Some components may well have been prepared and stored in bulk over relatively long periods of time (Section 1.6.2). The actual manufacture of a hafted tool consists of its assembly stages which are likely to be a variation on those carried out by the modern hafted tool makers observed in Chapters 6 and 7; the knapping of an insert (although this may also be a preparatory stage), the preparation of a shaft or handle, the creation of the haft by trying out and adjusting insert and cleft together, and the final putting together of shaft or handle and insert, using whatever binding and adhesive materials are appropriate or available.

Preparatory Stages

What follows is a brief review of some of the literature concerned with preparatory stage processes. All the technology types concerned had some kind of existence prior to the development of hafting, but it is likely that as hafting became an increasingly important skill, all of the component technologies also become more variable, more specific in relation to each tool made, and more skilfully practised. The new technology or change of behaviour, provides a material scaffolding for cognitive change (Section 2.5.4; Malafouris 2008a & b; 2010a & b; 2013).

Tool-makers who need adhesive are limited by their local resources and versions of this product will vary widely according to geographical areas. Groups travelling long distances are likely to have to find alternatives to established adhesive routines in new territories. There is a growing record of the Neanderthals in the Near East hafting with bitumen in areas where it erupts close to the surface. Later *H. sapiens* groups in the same areas also used it for hafting. This is contrary to established accounts of how Neanderthals learned complex behaviours by imitating *H. sapiens*. Instead we see what may have been a Neanderthal to modern human transmission of technology (Boeda et al 2008a & b; Boeda et al 1996; Carciumaru et al 2012; Monnier et al 2013). Hollander & Schwartz (2000) discuss a range of different bitumen products, giving a sense of how the variability of this particular technology may have developed over time.

Birch bark pitch is a product of heating birch bark at a controlled temperature in a reduced-oxygen environment. It is another Neanderthal technology which was subsequently used by *H. sapiens* after their arrival in Europe. The manufacturing process is exacting and only yields small amounts of pitch (Wragg Sykes 2015). Evidence goes back to the Middle Pleistocene. Mazza et al (2006) describe two flakes from this period found in association with the bones of an elephant in Italy. Recovered moulded pitch was probably used on the flakes as applied handles (Barham 2013b). Grunberg (2002) describes a kneaded lump of pitch bearing impressions left by contact with a retouched stone artefact, embedded shards of wood and what appears to be a Neanderthal thumb print. Pawlik & Thissen (2011) identify the presence of birch bark pitch in association with inserts at the Inden-Altdorf site. They describe three flat pebbles with pitch traces on them which may have been used to collect the molten product during distillation. A full review can be found in Barham (2013b) and Wragg Sykes (2015). Wragg Sykes gives a good account of the Neanderthal sociotechnical nature of pitch manufacture. The pitch cannot be made without specialist skills and group cooperation. She calls hafted tools "artefacts of connectedness" (ibid:135) and identifies them as scaffolds for cognitive development.

Early modern human sites in South Africa have yielded up many hafted tool inserts. The main adhesive used appears to have been tree resin which was subsequently heated up and mixed with a variety of filling agents (Charrie-Duhaut et al 2013, Lombard 2006). Wadley (2005), (2010) and Wadley et al (2009) discuss different possible resin adhesive compounds and their cognitive implications. Wadley et al (2015) is an observation of modern hunter gatherers using different local materials to make hafting adhesive and poison for arrow tips. Matheson and McCollum (2014) discusses Australian Aboriginal hafting adhesives including spinifex resin. Spinifex grass constitutes a combined binding and adhesive material when processed correctly (Barham 2013b).

Sections 1.6.1 and 1.6.2 include discussions about the use of wood in assemblages. Wood is likely to be the most common raw material for shafts and handles simply because of its availability and workability. However we should be careful to distinguish between types of wood, the area in which they grow and their suitability for hafting. The degree to which appropriate trees were curated by groups who relied on them may be a new area of research. It is interesting to note that where ground is freshly cleared in Northern Europe, the first new tree growth is often birch (good for adhesive), and hazel which is easily coppiced by animals, hominins and humans. It produces straight, strong branches from the roots which can be used for shafts and handles. Roebroeks & Bakels (2015) suggests that Neanderthals used fire to manage forest landscapes in the same way as Australian Aborigines. Also see Waguespack et al (2009) on projectile points made from wood.

There is very little literature on bindings which might be plant fibre or animal tissue. The closest thing to real evidence at the moment is Hardy et al (2013) which describes a Neanderthal site at Abri du Maras where a stone tool was found bearing a plant fibre shown to be twisted in a way which could only have been done anthropogenically, and might have represented the remains of twine (see also Hardy et al 2001; Hardy 2008; Hurcombe 2008). There was other clear evidence of hafting at the site. Vanhaeren et al (2013) is an interesting paper about shell beads from the Blombos Cave site in South Africa (c.40Kya).

Different groups of shell beads were found on site at separate levels. The use-wear on them indicates that each group had originally been strung together, but the method of stringing was different for each group, thus creating different designs through time. Perhaps a similar variability of detail using twine, ochre colouring and other design features was normal with hafted tools as well.

Assembly Stages

There is a large variety of ways in which a hafted tool can finally be assembled, and the method is likely to be a combined product of many different factors, including raw material availability, cultural preferences, the use to which the tool is to be put, the expected lifetime of the tool and whether re-tooling is likely. Barham (2013b) details a hierarchy of evidence of more to less useful evidence-types for establishing whether a stone artefact is a hafted tool insert or not. These evidence-types can give some information about how the complete tool was assembled because it is the assembly of all of the different components and the way that they meet at the haft which provides visible and microscopic traces.

The most secure evidence outside of the presence of residual adhesive traces that can be collected is of microscopic and visible traces of wear on the insert stone surfaces. The wear is caused by contact during use with other materials such as wood, binding or adhesive, or from small particles trapped in the haft. Such wear can help to identify the actual area of the insert covered by the hafting arrangement, and the relative positioning of insert and shaft and thus the forces the tool was made to conduct. Finally wear-patterns on the tip of potential hafted projectile points can be useful as they may indicate impact speeds that would not be reached by a hand-held tool.

Less secure evidence is provided by the morphology of the stone artefact and its similarity with known inserts. The proximal end of the artefact should not be bulky and there may be various moprphological arrangements that might be indicative such as attachments for binding or for penetrating the wood of a shaft. Edges that might have come in contact with binding or wood are also sometimes deliberately blunted or backed. The lowest level of certainty is that the artefact is too small to have been hand-held.

An over-reliance on morphology for identifying potential inserts may lead to an under-representation of hafted tool numbers. Not all identified inserts are carefully knapped or shaped, and include basic flakes perhaps with some retouch. Analysts are reporting that tool morphology and the actual use the tool was put to as identified by microanalysis, are not always strongly linked (Rots, 2009; Pawlik & Thissen 2011; Rots et al 2011; Eren 2012; Rots 2013; Barham 2013b; Rots et al 2015; Alperson-Afil and Goren-Inbar 2016). In particular there has been a strong tendency just to analyse stone points on the assumption that only hunting weapons were hafted (Barham 2013b). This assumption is fallacious and leads to a distorted understanding of the techno-social development of the hominin and human groups concerned, and thus almost certainly of any evolutionary cognitive changes that they underwent. It is hoped that in future many more partial assemblages will be analysed, and that the analyses will include more representative samples, (Hardy and Garufi 1998; Rots 2003; Rots 2004; Rots and Williamson 2004; Rots and van Peer 2006; Rots 2010; Rots et al 2011; Eren 2012; Wilkins et al 2012; Barham 2013b; Rots and Plisson 2014; Claud et al 2015; Rots et al 2015; Wilkins et al 2015; Alperson-Afil and Goren-Inbar 2016).

Chapter two

Existing theories relating to cognition

"the emergence of psychology as a science cannot properly be understood without a deep appreciation of evolutionary theory…yet in our present context, in the midst of the 'cognitive revolution'…such considerations are often lacking…modern cognitive scientists have largely ignored the selectionist's approach"
Reber (1993:74)

"The conceptual framework that we bring to the study of cognition can have profound empirical consequences on the practice of cognitive science. It influences the phenomena we choose to study, the questions we ask about these phenomena, the experiments we perform and the ways in which we interpret the results of these experiments. Until relatively recently, there was 'only one game in town' – the computational hypothesis that underlying cognition is the purely formal manipulation of quasi-linguistic symbolic representations by syntactic rules"
Beer (2000:91)

2. Chapter Summary

There is a current lack of a consistent cognitive model in current tool analyses, including hafted tool analyses (Section 1.4). This Chapter reviews the main theories relating to cognition available in the archaeological literature. Sections 2.1 and 2.2 provide more detail about the dominant cognitive model known as cognitivism which is implicit in many authors' theories even though they may not be aware of the fact. Section 2.3 examines a range of theories about step-changes supposed to result in modern human behaviour. Theoriticians presumably believe that they depend on some kind of genetic mutation as no other mechanism of change is discussed. Section 2.4 is a review of a methodology for stone tool analysis known as *chaîne opératoire*. This is a stand-alone methodology that can be used with a range of cognition theories and the discussion here concentrates on how its effectiveness has been reduced as a result of its use in a cognitivist context.

Section 2.5 explores new options not controlled by cognitivist theory which offer more constructive ways of understanding the archaeological record and hominin behaviours. These theories describe mechanisms of change based on biological and developmental phenomena and in doing so start to use non-linear or more complexity-based explanations. However, despite the presence of cognitive concepts in these theories there is still no definition given of cognition itself or of its precise relationship with gestural behaviour.

2.1 Cognitivism

This model is sometimes referred to as dualist as it represents the mind and body as essentially different, or 'Cartesian' as it is attributed to Descartes (Cottingham et al 1988). Reed (1996) states that cognitivism is so well-established as a model that even when its inability to explain newly discovered phenomena such as Darwinian evolution rendered it problematic, it was modified as minimally as possible and carried on being used. Cognitivism assumes an irreconcileable gulf between the cognitive systems of human beings and animals as the latter are presumed not to have 'minds'. Despite Darwin's proposal of a gradual evolution from great ape to human (Reed 1996; Jablonka and Lamb 2006), cognitivist adherents maintained this 'tyranny of dichotomy' (Malafouris 2013:15). Cognitivism developed a neo-Darwinist stance and posited a genetic mutation affecting only the brains of *H. sapiens*, rendering them substantially more effective than any animal or hominin brain. The mutation in question still remains unidentified but the theory lives on (Mellars 1989; Fitch et al 2005) . Malafouris (ibid:15) comments that archaeologists would like to take the position that gradual evolutionary change is possible. However, they remain "in a state of confusion about what this might imply in practice".

As computer technology became more pervasive cognitivism started to use related technological language to describe the uniqueness of the human brain. Thinking-processes were related to internalised softwares using algorithmic calculations of abstract concepts or symbols, and the body became a simple machine (Reed 1996) or decision-output slave system (Brooks 1991). For Reed (1996), cognitivism describes a brain that builds internal maps or representations of the world over time in order to reconstruct and unify the untrustworthy perceptual information supplied to it by our animal senses (Anderson 2003; Wilson and Golonka 2013). These constructed representations are manipulated by the brain or put through algorithmic rule-based transformations that result in internal decisions which are then acted out by the body. Brooks (1991), an expert in robotics, describes how robots cannot be made to behave 'intelligently' within a simple environment if their software only consists of internal representations of that environment, as a cognitivist would claim that the human brain does. Robots cannot start to carry out the simple tasks that they have been set until they have been given circuits which perceive aspects of the environment, respond immediately to acquired perceptual information and learn from the results of their own responses (Brooks 1991).

There has been a recent tendency by cognitivists to change the goalposts as to the definition of internal representations as challenges from other cognitive models increase. They are now capable of labelling any type of change in the brain a representation, even if it consists of a small change to a network or to the relative strengths of synapses. Anderson (2003) comments that the meaning of the word has now become so wide that it is not capable of forming the basis of a reliable description of cognitive processes (Edelman and Tononi 2001). Additionally it means that cognitivists can claim that their model already includes all of the work of any non-cognitivist researchers, who are bound to want to describe some kind of changes in the brain when discussing cognition (Clark 1997; 1999). We will see this kind of change in the brain described in the newer models and mechanisms of change set out in Chapters 3 and 4 in circumstances which it would have been impossible to generate under a cognitivist umbrella, and yet cognitivists are claiming that these theories as consistent with their theory (Section 2.2; Wynn and Coolidge 2016). We also see groups such as ideomotor and connectionist theorists who still use the word 'representation' alongside perception action and dynamic theories (Berry and Dienes 1993; Elman et al 1996; Bloch 2012; Prinz et al 2013). It is imperative that all cognitive scientists consider abandoning this now meaningless and over-burdened word and start to define their theory using a more precise and differentiated vocabulary based on actual neurological processes.

The effect of cognitivism on tool analyses has been extremely limiting. Baber (2006) comments that there has been practically no cognitive study of tool-use relevant to any historical period because of the Cartesian division between physical and mental activity. The actual use of tools is seen as a mechanical act of the slave-system body and does not require a cognitive explanation. We will see that even *chaîne opératoire* methodology is often more concerned with the conceptual contents of the tool-maker's mind (mental templates) than with the cognitive systems that control the gestural activity itself (Section 2.4). Malafouris (2013) adds that this initial failure to treat tool-use as a cognitive process results in a further problem – the potential effects that gestural activity have on cognitive systems used during tool-making are also not considered. In other words a potential evolutionary mechanism of feedback and change is completely ignored (Section 2.5.4; Pffafenberger 1992; Overmann 2013, 2016).

Roux and Bril (2005) state that it is not possible to extract information about technical skills simply by observing an artefact. Analysis must be via a recreation of the gestural sequences involved in constructing the artefact in the first place. Cognitivism is not concerned with performance because the cognitive content consists of a consciously constructed plan which is already completed before activity starts. However, Roux and Bril point out that while manual activity may involve some top-down or conceptual planning before starting, activity is so flexible and unpredictable that the sequencing of goals and sub-goals during performance (Roux and David 2005) or bottom-up planning (Stout et al 2011) (Sections 4.3.3 and 4.3.4) is in a continual state of flux. This element of task flexibility and expert tool-user adaptability is one which cognitivism has been particularly poor at explaning (see Rogers et al 2016 for a recent cognitivist attempt). And yet as we have seen in Section 1.5 it is flexibility and variability which is at the root of evolutionary change. Edelman (1993) stresses the need for a new theoretical model which can accurately describe the fundamental role of neuronal selection or learning in the process of cognitive adaptation. Such selection is not possible without a high variability of competing neuronal networks each offering their own solution to problems that are encountered during action (Section 4.4.4).

2.2 The State of Cognitivist Theory in Archaeology

This Section examines relatively recent cognitivist accounts used in archaeological contexts. They come from two authors (often co-authors), Thomas Wynn (an archaeologist) and Frederick Coolidge (a psychologist) who have consistently promoted a cognitive science approach to analysis, and been referred to by archaeologists in search of a coherent working model of cognition. Their papers are explicitly cognitivist (Wynn and Coolidge 2016). The authors (ibid) state without any supporting references, that all significant break-throughs in cognitive research have been made by cognitivist model adherents. Wynn (2009) describes the current state of evolutionary cognitive archaeology (ECA) as an amalgam of approaches that group around complex language development, *chaîne opératoire* methodology and cognitivist models based on internal representations. He stresses that in order to be effective ECA must focus on well-defined cognitive abilities derived from artefacts in the archaeological record. Wynn and Coolidge (2009) state that a rigorous analysis of archaeological artefacts should be carried out in order to identify the presence or absence of a particular modern human cognitive ability. The ability is called working memory (Section 2.3.2). By analysing technologies as either requiring or not requiring this ability the authors decide that the modern human mind only emerges after 30Kya, well after the arrival of *H. sapiens* in Europe. Despite their subsequent suggestion of earlier dates for this emergence (Section 2.3.2), this paper criticises other models that suggest an earlier date on the basis that they have not used a cognitive science analysis (for example symbolism – Section 2.3.3).

Wynn and Coolidge (2016) make no reference to current evolutionary developmental theory. Ecological psychology and embodied cognition theories are referred to as 'non-Cartesian' and by implication have not resulted in any useful applications. However, archaeologists are said to have found these theories interesting because they "reduce the sometimes troubling need to discuss 'what was going on in the heads' of long-extinct actors" (ibid:201). This last statement presumably means that archaeologists use these theories because they obviate the need to think about the cognitive aspects of behaviour at all (see Section 3.2 for a more accurate description). Ironically, much space is given to the brain-scanning work of Dietrich Stout who is in fact a self-professed adherent of the non-Cartesian ecological psychology model (Stout 2005a). Stout also uses the concept of the hierarchical complexity of technology, an approach characterised by Wynn and Coolidge (ibid) as a loose use of language (Stout 2011), (and see Section 3.1 for a more accurate description of complexity hierarchies). *Chaîne opératoire* methodology (Section 2.4) and theory of mind (ToM) (Section 2.3.4) are mentioned as having some analytical potential if used properly, but it is concluded that working memory theory (2.3.2) is the most useful model available. All of these three preferred theories have strong cognitivist roots and are examined further below.

2.3 Cognitivist Theory and Behaviour Change

2.3.1 Modern Human Revolution and Modern Human Behaviour

Modern human behaviour is a concept derived from a pervasive theory that a 'modern human revolution' took place at around 40Kya when the branch of *H. sapiens* resident in Europe started to exhibit modern behaviour as the result of some kind of genetic mutation in the brain (Mellars 1989; Wynn et al 2016). The behaviours in question included the use of external symbolic representations such as parietal paintings and the construction of combinatorial tools (Section

1.4). It is hard to avoid the conclusion that the structure of this theory was driven mainly by a cognitivist (and Eurocentric) need for it to be true rather than from the pressure of evidence, as from the start it was riven by major inconsistencies (McBrearty & Brooks 2000; McBrearty 2007; Langley et al 2008; Shea 2011; Barham 2013a; Garofoli 2016). In particular the assumption that a major behavioural change resulted from a genetic mutation in a relatively new species was problematic as the speciation in question occurred in East Africa at about 200Kya, or possibly now even 300Kya (Section 1.3; Hublin et al 2017; Richter et al 2017), leaving a substantial period of time when the postulated mutation was present but for some reason inactive (McBrearty 2007; Thornton 2012).

Russon et al (2014) describe a community of orangutans on two Bornean islands that catch fish with their hands or sometimes even with a tool. The suggestion is that they are imitating local humans. This behaviour represents a threat either to the cognitivist theory that great apes are unable to imitate (Byrne 2003), or to modern behaviour theory (Section 2.2.2) which sometimes includes fishing artefacts as evidence of mutatory step-change. Many valid and lucid arguments have been made by archaeologists rejecting the concept of a revolution, but they have been more reluctant to let go of the idea that there is a behaviour or set of behaviours that marks some sort of step-change in cognitive evolution. A large body of literature pursues multiple theories concerning the nature of modern behaviours which have been attributed at different times to both hominins and *H. sapiens* (for example Aiello and Wheeler 1995; Hawkes et al 1998; Henshilwood and Marean 2003; Powell et al 2009; Nowell 2010; Williams et al 2014). Garofoli (2016) suggests that the concept of behavioural modernity is one that should be removed from archaeologists' vocabulary. In philosophical terms it is not capable of reliable scientific analysis and cannot offer an explanatory role in the mapping of artefacts and cognitive structures. The author believes that the concept harms any domain in which it is deployed.

2.3.2 Working Memory Theory

Consistent with their belief that artefacts represent direct evidence of specific conceptual cognitive abilities, Wynn and Coolidge (2004) attempt to infer the relative working memory capacities of the makers of different tool technologies. Working memory capacity is the amount of time environmental information can be held together in Baddeley's visuo-spatial sketchpad (visual information) and phonological loop (auditory memory) (Baddeley and Hitch 1974), so that a task can be worked on before the relevant information is passed on to long-term memory and can no longer be used without retrieval. The capacity to hold information is presumed to have become extended after mutation in the human brain so that *H. sapiens* are more able than other hominins to concentrate on tasks, and thus produce more sophisticated technology. The authors claim to be able to establish the working memory capacity of a tool-maker by examining classes of artefacts, and conclude that just *H. sapiens* has an extended working memory capacity which became available only 30Kya (Wynn 2009), or 45Kya (Wynn et al 2016) or possibly nearer to 200Kya if *H. sapiens* hafted tools from South African sites are taken into account (Haidle 2010; Wynn and Coolidge 2017).

Hafted tools from Neanderthal sites in Europe however, do not count (Wragg Sykes 2015), and neither do earlier hafted tools made by pre-*H. sapiens* hominins in Africa. Neanderthal artefacts, (which include hafted tools) reveal a more restricted working memory (Wynn and Coolidge 2009). For the authors this means that Neanderthals could not have benefitted from the cognitivist representational system enjoyed by *H. sapiens*. Neanderthals had to use a system that Wynn and Coolidge call 'expert cognition' (for a more accurate account see Sections 4.4.1, 4.4.2 and 4.4.3) which only included information stored in long-term memory. Thus "a small but significant difference in cognition…made the difference in the respective fates of the two human species" (Wynn et al 2016:2). Yet despite statements made by the authors referred to in Section 2.2, Wynn et al (2016:7) state that H. *sapiens* and Neanderthals have 'indistinguishable' archaeological signatures. This begs the question as to how the proposed difference between working memory capacities has been established, and why they have contravened their own stipulations of needing evidence from the archaeological record to substantiate claims about cognition. The significance attributed to extended working memory has been the subject of several serious criticisms.

Beaman (2010) suggests that working memory theory cannot provide evidence of a cognitive ability of such significance that it makes a consistent difference in the way that two species interact with their environment. He states that it "seems in many ways an odd thing to propose as a necessary precursor for these material products [archaeological artefacts]" (Beaman 2010:S36). Baddeley's system is only one of several proposed working memory systems and only allows for the retention of small amounts of information for a matter of seconds even in modern humans. It has no explanatory power in respect of sophisticated artefacts with more than one maker whose construction has an extended duration (ibid), (Section 1.6.1 discusses both of these characteristics of hafted tool technology and see Wragg Sykes 2015). Beaman (2010) states that any laboratory testing of working memory has been carried out under controlled conditions and has involved extremely short-term manipulations unrelated to the kind of behaviours described by Wynn & Coolidge. Without further controlled experimentation the theory will remain at the level of a 'just-so story' (ibid:S36). Beaman (2007) concludes that even if Neanderthals had had reduced working memory capacity by comparison with *H. sapiens*, the effects of this inequality would not have been those predicted by Wynn and Coolidge (2009) (and see Martín-Loeches 2010; Koziol et al 2012).

Paas and Sweller (2012) are educational theory researchers who regard short-term memory in modern humans as a major constraint when teaching complicated material to students, because of the system's limited capacity and short duration. They believe that we acquire certain types of knowledge by an alternative 'long-term memory' route, including the learning of our native language (Sections 4.4.3 and 4.4.4). They propose that any teachers of complex and important new information should also utilise this route. Shettleworth (2012) proposes that adult human cognition shares basic processes with other animals including slower-developing, unique processes consistent with evolutionary developmental theory. These processes are not necessarily representational, and in humans just constitute a higher level on a sliding scale of animal-based cognitive ability. She comments that the proposed difference represented by extended working memory capacity cannnot explain the cognitive differences between humans and other animals.

Ambrose (2010) echoes concerns of Beaman (2010) that working memory theory without the additional prefrontal sub-goal and main-goal sequencing and planning skills (Section 4.3.4) is not capable of describing complex activity (Roux and David 2005). For Ambrose (ibid) working memory is too short-term to be the basis of combinatorial tool technology and complex language skills and the date given by Wynn and Coolidge for enhanced working memory is too late because it does not acknowledge the evidence-base provided by hafted tools. He suggests that the study of related activity planning and complex parsing skills associated with combinatorial technology and prefrontal brain activity, should be carried out independently of any consideration of working memory capacity.

2.3.3 External Symbols as Proxies for Internal Representations

Henshilwood and Marean (2003) support the concept of a step-change to modern human behaviour at some stage in hominin history (Section 2.2.2). However, they find the various 'trait lists' set out by different authors as markers of that behaviour problematic and too rigid. They suggest that the best proxy for the appearance of modern human behaviour is the cultural or social use of symbols. No consistent definition of a symbol is given in the literature although it is often associated with the use of personal ornamentation (Kuhn and Stiner 2007; Zilhao et al 2010), pigments (Barham 1998; 2002), and anthropogenic alterations to objects without apparent functional purpose (Bednarik 1995; 2003). The use of symbols also seems to be associated in the literature with personal and group identity (Nowell 2010).

The presence of external symbols is very important to cognitivist theory. It acts as a proxy for the unique human ability to create internal representations and heralds the arrival of complex language, the ultimate expression of human symbolic superiority (Mellars 1989). However some of the advocates of the search for symbolic behaviours seem unaware of the link with a dominant cognitive model. Nowell (2010) states that cognition is a black box the contents of which are never properly explained, and that as a result its presence is irrelevant to understanding cultural and demographic change. More important is 'symboling' which forms the core of modern behaviour.

Burdukiewicz (2014) points out that symbolic behaviour is not limited to modern humans but has been identified on Lower Palaeolithic and Neanderthal sites (and see Barham 2013a). Animals can also be considered as able to make use of symbols and "symbolic culture cannot be linked to specific human populations" (ibid:Final Remarks). Burdukiewicz considers that all archaeological artefacts have some kind of symbolic status within their own cultures, including combinatorial tools (500-400Kya).

In contrast to Nowell (2010), Thornton (2012) states that a cognitive model is there to guide the archaeologist's interpretation of the artefactual evidence, and that applying cognitive theory to artefact should have a feedback effect on the theory itself. Symbolic thought and language should be abandoned for more recent cognitive approaches which are now more concerned with cumulative development. There is no justification for the theory that cognition evolved as the result of a (cognitivist) centralised system dependent on symbolic reasoning, and much more justification for researching the efficient coding and re-use of information, the scaffolding effect of behaviours that provides a framework for ontogenetic cognitive development, and embodied cognition (and see Barham 2013a). Theories based on symbolic reasoning are seen as philosophically flawed (Botha 2008).

2.3.4 Theory of Mind (ToM)

ToM is often discussed in archaeological literature as a particular cognitive skill possessed only by modern humans which is the root cause of the differences between them and animals. Some authors have even developed a scoring system for it on the basis that this mutatory ability is so well-described and analysed that different levels of its appearance can be accurately monitored (Byrne and Whiten 1988; Dunbar 1998; 2007). However, more recent authors believe that the ability to assess the intentions and motivations of a conspecific is more productively considered as one of a series of social cognition processes possessed in some form by all social mammals rather than as a stand-alone product of human rationality (Barrett et al 2007; Emery et al 2008). Shettleworth (2012) describes ToM as one of many aspects of social cognition originally based on animal systems that exhibits higher levels of operation in modern humans. She mentions the Piagetian-style false-belief test which can supposedly only be passed by children of 4 years and which has been used to support claims that ToM is uniquely human. However, she adds that most of the time humans use their animal-level capacities to understand the actions of conspecifics.

Saxe (2006) emphasises that ToM function cannot be isolated to one specific brain area, and is made up instead of a network of different regions activating together. These networks are present at different levels in both humans and chimpanzees (or all animals Byrne 2016), which implies that ToM cannot be considered as a candidate for a late human brain mutation. The networks involve mirror neuron systems but do not require the presence of complex language skills (Gash and Deane 2015). Gallese (2007) emphasises the mainly animal-level nature of social cognition provided by mirror neuron systems. He mentions the false-belief test but suggests that there is evidence that this apparent Piagetian step-change is a construct of research methodology (see papers on positive false-belief assessments in children under four years without complex language and also great apes, which disprove the usefulness of the false-belief test - Wilson et al 2003; Reddy 2008; Zijing et al 2011; Scott et al 2012; Kano et al 2017; and compare Smith and Thelen 2003). Wereha and Racine (2012) state that claims have been made that ToM theory including Tomasello's 'joint attention theory', provides the one small difference between humans and animals that triggers modern human evolution. These claims are all undermined by their grounding in a classical neo-Darwinian perspective that is "problematic, if not inadequate" in a developmental context (ibid:part 1). The paper contains a detailed review of this misapplication of traditional ToM theory and proposes evolutionary developmental theory as a more appropriate theoretical grounding.

Forsythe et al (2015) prefer to talk about social cognition rather than ToM. They emphasise the biological basis of social cognition systems and quote recent research which describes the variability of human group-level intelligence. Group intelligence levels do not correlate with the combined intelligence-levels of group members, but with their social-cognitive ability to communicate on an equal basis with each other, and to read each others' body language via mirror neuron systems. Both skill-sets can be learned, practised and perfected together and would therefore fall easily into a perception action model (Section 3.2). The brain networks that support these functions have a higher baseline activity than non-social networks which means that they are more easily triggered into action. The authors speculate that these cognitions are present in infants of all ages at different levels. They do not explore the implications of these cognitions for lifetime social learning but it is clear that they must have an important role to play. Recent research is cited which establishes that in a situation where one individual listens to and understands a verbal report by another individual, the brain activity of both exhibits 'neural coupling'. In other words their high level of social integration is accompanied by a synchronising of neuronal activity fluctuations (Section 4.3.1; Hasson and Frith 2016). Neural coupling is also found in military groups carrying out highly rehearsed procedures and becomes more marked the more structured the activity becomes. It may also be connected with the activity of action parsing in gorillas (Section 4.4.2). These human abilities to bond so closely through behaviour that brain activity starts to synchronise are clearly powerful and may well be more advanced in our species than in other animals as our social interactions are so much more complex. However, they do not represent a mutatory step-change resulting in a rational *H. sapiens*, or a set of skills which can only be taught to human infants by adult humans. Rather they are a set of systems that are present to some extent in all social mammals but which vary in their application from species to species according to specific niche-requirements.

2.4 The Effect of Cognitivism on *Chaîne Opératoire* Methodology

Chaîne opératoire methodology has developed from a theory set out by Leroi-Gourhan (1964). Soressi and Geneste (2011) give a brief history. They believe that Leroi-Gourhan's intention was to provide a method which analysed stone tool reduction sequences, establish standardised versions of them and as a consequence be able to illustrate the conceptual processes of the tool-maker. The cognitivist model usually employed with this methodology imposes the existence of universal mental templates for each tool-type, present as representations in the maker's mind before knapping begins.

Wynn (2009) endorses the methodology's usefulness in establishing mental templates, but criticises practitioners for not using consistent methods or sufficiently analysing their results. Bleed (2011) disagrees with Wynn and states that unlike psychological theories, the methodology is not capable of isolating tool-makers' cognitive processes. Braun and Hovers (2009) have problems with the aim of establishing standardised mental templates for tool-manufacture which inhibits the collection of information about variability (Section 1.4). Tostevin (2011) adds that it is not possible to infer decision-making processes just because the modern analyst perceives potential options about how to proceed. Current use of the methodology has resulted in the construction of abstract typological rules with no evidential basis and prevented the development of a comparative methodology for analysing variability (Bar-Yosef and van Peer 2009). Malafouris (2013) finds the use of *chaîne opératoire* methodology linear, unidirectional, teleological and cognitivist. For him it is not possible to make a reductive tool by applying a mental template. Instead the knapper learns to read the core and delivers each blow in response to fresh perceptual information gathered in the moment (Nonaka et al 2010).

Haidle (2009) bases her cognigrams on *chaîne opératoire* methodology (Fairlie and Barham 2016 – Appendix 3). She adds the concept of a problem-solution distance to the methodology, and infers increased decision-making and planning ability from increased numbers of action concepts, numbers of objects requiring the tool-maker's attention and increased problem-solution distance. She includes *H. sapiens* hafted tools made with resin-based adhesive in her research, but not hafted tools made by Neanderthals that use birch bark tar or bitumen (Section 1.6.3), (Haidle 2010; Lombard and Haidle 2012). Wragg Sykes (2015) lists the problems presented by the cognigram format in the context of hafted technology. It describes the actions of a single maker that all happen at the same time and place. The reality of hafted tools is that component parts may have been made by a range of people outside of any tool-making framework, without a felt need to solve immediate tool-making problems (Haidle 2010). The full set of hafted tool manufacturing stages in the cognigrams could have taken up to a year to complete depending on the availability of organic components (Hurcombe 2008). For the author (ibid) there is no time-depth to cognigrams. They do not reflect what are likely to have been the daily routines of a group of hafted tool-making Neanderthals, nor the complex group network likely to have been involved (Section 1.6). A more detailed review of existing *chaîne opératoire* methodologies for analysing cognition can be found in Section 5.3.

2.5 Signs of Paradigm Change

While all of the above theories of cognition persist in the literature in some form or another, other kinds of theory have started to appear alongside them. These new theories (apart from aspects of the social brain hypothesis, Section 2.5.1) do not rely on cognitivism. They are not generally explicit about a replacement cognition model, but they are likely to be connected with evolutionary developmental theory and to originate from other academic disciplines, particularly biology. They also have a tendency to explain behavioural change as the product of interactions between different environmental components and thus move closer to some aspects of complexity theory (Section 3.1). Section 2.5.1 discusses the Social Brain Hypothesis in this context even though it still retains some cognitivist aspects. Section 2.5.2 deals with nutrition which potentially forms some kind of modern behaviour theory but is more frequently represented within the following theoretical models as part of an ecological system component. Section 2.5.3 discusses various models connected with ecological and cultural factors which originally had a rather linear content but which have become increasingly complex as they have continued to be tested against the archaeological record. Section 2.5.4 discusses material engagement theory which again looks like a single-factor explanation, but which is explicitly developed to link in with accurate descriptions of the variability of the archaeological record, evolutionary developmental mechanisms of change, neurological biology (Sections 4.2.1, 4.2.2 and 4.2.3), niche construction theory (Section 2.5.5), and perceptual action and dynamic cognition theories (Section 3.2). Finally Section 2.5.5 discusses Niche Construction Theory which provides a framework within which all of these models fit easily together. Niche construction models allow for the consideration of an increasingly complex set of evolutionary components and their multiple interactions, and it is possible for authors from different disiciplines to specialise in particular aspects and add their contribution to the overall model.

2.5.1 The Social Brain Hypothesis

It is not intended to describe this well-known hypothesis expounded by Robin Dunbar (Dunbar 1993; 2003) except to say that it is concerned to explain cognitive evolution as a product of the increasingly complex social environments experienced by hominins living in groups. The main data sets demonstrated a correlation between animal and hominin group-sizes and the average size of members' neocortices. Increased neocortex size was taken as a proxy for increased cognitive capacity. This was an innovative theory because Dunbar insisted that cognition was not driven by technological activity at all and was instead a social or cultural product (Dunbar 2007). The acquisition of cognitive ability was considered gradual, and in a sense emergent from pre-existing primate characteristics. However, the theory relied heavily on a cognitivist-style ToM theory (Section 2.3.4) and took on a teleological aspect with its attempts to explain the appearance of the symbolic behaviour of complex language-use. Its main importance was in focussing research on the social environment in a very real way for the first time, and in allowing space for gradual change from a primate to modern human condition.

Barrett et al (2007) takes issue particularly with the over-reliance on ToM which they describe as a Cartesian model that cannot accommodate an accurate description of gradual change from a primate cognitive state. Charvet and Finlay (2012) comment that multiple theories about the cause of encephalisation have emanated from archaeological, anthropological and palaeontological disciplines, and they select the social brain hypothesis as one of many. They do not believe that it is possible for one causal factor – in this case the ability to manage increasingly complex social situations – to be responsible for all evolutionary change in the hominin brain. Theories concerning the unique evolutionary role of technological activity would probably be equally problematic. For these authors the act of focussing on one causal factor just means that other potential interacting causal factors are ignored.

2.5.2 The Importance of Nutrition

Charvet and Finlay (2012) mention nutritional theories alongside the social brain hypothesis as examples of single-factor theories about encephalisation. These theories can be taken on their own in this way, but are increasingly embedded in more complex commentaries about interrelationships between ecology, climate, hominin culture and cognition. Several recent articles have discussed the presence or absence of docosahexaenoic acid (DHA) in the human diet which is essential for optimal brain development (Crawford et al 2008; Dauncey 2012; Brenna and Carlson 2014), but which is only freely available in the flora and fauna of fresh and salt-water biomes. The DHA needs to be accumulated in newborns' bodies as early as possible. Cunnane and Crawford (2014) comment that its absence is still a global cause of brain under-development and cognitive dysfunction today. Expectant mothers based inland with a varied diet can manufacture DHA in their bodies and deliver it through the placenta or in breast milk. It is suggested by Brenna and Carlson (ibid) that the last 5 weeks of human gestation has evolved to allow DHA absorption through the placenta until critical brain size is reached.

Archaeologists have picked up on a possible link between environmental DHA availability and the positioning of archaeological sites (Brown et al 2013; Archer et al 2014). Herculano-Houzel (2011b; 2012a) clarify that the energy budget of a brain is directly related to the number of neurons present. This means that the brain energy requirements vary according to species with modern humans allocating a huge 20% of their metabolism to 2% of their body mass. The importance to hominins of getting a good diet increases over evolutionary time. The ability to control fire and cook food becomes vital because cooked food is digested more effectively, and the range of available food sources is increased (Wrangham and Carmody 2010; Navarrete et al 2011). The human ability to store body fat for emergencies is also related to brain metabolism requirements (Leonard et al 2007; Navarrete et al 2011).

2.5.3 Ecological, Demographic and Cultural Complexity Models

This section discusses a range of types of models which are new and still undergoing constant change in the way that they are used and defined. While their earlier versions may have been single-factor and over-controlled in terms of the type of information they were prepared to deal with, the tendency is now for them to become more inclusive and dynamic in their depiction of interacting components. Material engagement theory has been developed explicitly as a connecting factor to allow different model components to interact (Section 2.5.4) and to allow for the reentry of archaeological artefacts as valid evidence after the impact of the social brain hypothesis (2.5.1). Niche Construction Theory (Section 2.5.5) is probably the most complete expression of this type of model.

Barham (2010) challenges Dunbar's (2007) assertion that cognitive evolution was only driven by increasing group complexity. He suggests that a good model would chart variable interactions between social factors and technological factors (the sociotechnology of Pfaffenberger 1992). Tools can act as agents in social networks and their manufacture may trigger changes in the makers' cognitive abilities (Malafouris 2013). The act of teaching technological behaviours to the next generation is a social one (Högberg et al 2015), and so is the manufacture of combinatorial tools as it is likely to involve an increase in interactions between group members (Section 1.6; Barham 2013b).

This theme of increasing interactions between group members reappears as various authors argue against the simplicity of the first cultural models. Andersson and Read (2016) argue against the idea that cultural sophistication is lost over time as a result of faulty learning of technologies (Henrich 2004) and can only be maintained in larger groups. For them small groups will only seek to maintain technologies that all members are capable of learning, and more difficult technologies will only appear in larger and more complex groups where specialisation is an option. Grove (2016) adds that rather than analysing group size or density to try and understand technological complexity, it would be more appropriate to understand the 'encounter rate' or interactions between members. This measure allows for long-distance travel between individuals, or in complexity terms (Holland 2014) the spread of skills through small-world community networks. Enquist et al (2011) stress that the development of different cultures is a cumulative and complex process that will express increasing variability as recombinations of component elements become more differentiated over time. Heyes (2012) confirms that human cognition development is linked with cultural evolution through technological social learning (Kendal et al 2011). Laland and Janik (2006) comment on the need to model culture with multiple variables that include ecological components rather than attempting to control for them as older models often did (and see Boesch et al 1994).

Ash and Gallup (2007) describe a link between climate variability and encephalisation. The need to change behaviours became more pressing as resource availability constantly changed due to climate change (and see Barham 2013b on links between climate change and combinatorial technology). In order to rise to the challenge of increasing behavioural variability, genetic change (or more likely epigenetic change – Section 4.2.1) resulted in increased neuronal volume (and see Bateson 2004 on the Baldwin effect and the primacy of behaviour as a driver of evolutionary change). Potts and Faith (2015) continue this theme as does Grove (2011a; 2012; 2014). Grove (2011a) distinguishes between linear climate change which promotes directional selection of particular traits, and climate variability which has to be matched with increased behavioural variability or cognitive plasticity. Grove (2012) shows a correlation between climate variability and encephalisation, and Grove (2014) refers to the changes caused by the new behaviours enabled by encephalisation as a form of niche construction (Section 2.5.5 and see Sol 2009; Sol et al 2008; Grove 2011b).

2.5.4 Material Engagement

Material engagement theory emphasises the effect that objects in the environment and the making of objects, can have on the cognitive abilities of hominins. The theory forms the last link in a circle or feedback-loop between perception action-framed activity (Section 3.2) and the plastic effects of those activities on the actor's neuronal networks. It is an explicitly anti-cognititivist, radically embodied theory of cognition that stands on its own. It can also provide a link for authors who make reference to the cognitive scaffolding effect of activity or to the triggering effect on cognition of constructed niches (Malafouris 2013). The brain is plastic in nature and changes constantly as new learning processes are experienced. This process of continuous change has both an ontogenetic and phylogenetic dimension (Section 4.2) (Malafouris 2008a,b). The main biological driver that Malafouris refers to is brain metaplasticity (Section 4.2.2) which is neurological science material. This new way of understanding the brain makes accessibility to and understanding of material archaeological artefacts essential, and they become unique sources of information for a suite of new evolutionary theories, including evolutionary developmental theory, developmental systems theory and niche construction theory (Malafouris 2010a,b), (and see Iriki and Sakura 2008; Laland and O'Brien 2010; Park and Huang 2010; Hodder 2012). Archaeologists do not need to stand on the sidelines and watch the environmentalists at work. They have important information to contribute through niche construction theory so long as that information is rigorously scientific (Sections 8.4 and 8.5).

2.5.5 Niche Construction Theory

Shea (2012) rejects the causal effects of the innate genetic traits described by evolutionary psychologists and advocates niche construction theory as a replacement theory for evolutionary change (Odling Smee et al 2013). In this model information that supports adaptive behaviours can be transmitted culturally and independently of genetic processes. Sterelny (2007) emphasises that human cognition is the product of an interaction with a niche environment which in itself is the product of both social and ecological interactions and the ways in which the group has responded to them. The niche provides an already elevated level of technological challenge which new individuals can use to scaffold their own cognitive processes through interactions with social structures that enable learning.

Andersson et al (2014) states that the culture of a constructed niche acts through institutions to retain adaptive behaviours and eliminate non-adaptive ones. Tool technology reflects niche variability through time and plays a crucial role in the development of these cultural institutions. Downey and Lende (2012) propose a brain development niche model which incorporates cultural traditions, information transfer, technological skills, development and social skills. They believe that the human brain is primed for strong social interaction and for learning new behaviours. We learn to shape our environment in new ways, and in turn the environment shapes us and our cognitive processes. We are emergent from both our biological and cultural inheritances (Jablonka and Lamb 2006). Many of the original single-cause theories about modern behaviour can be incorporated into niche construction theory alongside data from genetics, palaeoanthropology and comparative neuroscience. Evolution is not about the shaping of a brain full of discrete tools by outside forces – it is much more holistic and interesting than that (Downey and Lende 2012). Sinha (2015) describes artefacts within a niche as both tools and as agents of cognitive change (Laland et al 2000; Kendal et al 2011; MacKinnon and Fuentes 2012; Morgan 2016).

2.6 Conclusion

Gowlett et al (2012) state that palaeoanthropology has not really engaged with evolutionary theory or actively investigated mechanisms of change. It has failed to consider multiple interacting causes or to look at long-term trends and social change. These sentiments are echoed by Steven Mithen during panel session 3 at the Festschrift for Clive Gamble in June 2015. He said that he believed that palaeoanthropology had failed in its attempt to understand or explain cognitive evolution and that ultimately this task would be completed by other academic disciplines.

The content of these first two chapters goes some way to disprove this sentiment. Initial misdirection may have been caused by the presence of a dominant and generally unhelpful cognitive model, but this has affected all disciplines, especially psychology. It is possible that challenging the cognitivist model has been a productive process as it has helped many researchers to clarify their own theories. Ultimately it has not stopped archaeologists doing well what they do best and continuing to supply well-documented and carefully obtained evidence of continuous and variable technological change over time, thus exposing the model's limitations. The references given in Sections 1.5, 2.5 and those that follow illustrate how palaeoanthropology is feeling its way towards something different and opening itself up to work alongside other disciplines just as Gowlett et al (ibid) propose.

2.6.1 Signposts Forwards

Gibson (2007) considers how best to choose between different models of cognitive development. She recommends links with the neurosciences and evolutionary developmental theory, and takes a gradualist approach with great emphasis placed on environmental drivers. She is interested in hierarchically organised cognitive capacities and the break-down of information into small units capable of infinite recombination. She thinks that greater emphasis needs to be given to motor or gestural cognition, and that there has not been enough attention paid to the subconscious ability to produce gestural sequences, and to the non-modular nature of a brain capable of developing such behaviours. Gibson mentions the importance of cognitive plasticity and the way it links great-ape and human behaviours and she acknowledges the importance of combinatorial technology both in humans and Neanderthals.

Stout and Hecht (2014) recommend an integration of neuroscience and archaeology approaches and comment that more interest in this association has so far been shown by archaeologists than by neuroscientists. In fact archaeologists are best placed to provide evidence about emerging behaviours through time as a result of their expertise in dealing with the material record. They just need to change their cognitivist approach to one based on the behavioural model provided by ecological psychology. Niche construction theory will be of great importance as will a dynamical systems approach. It will be particularly necessary to describe how components of higher order behaviours are selected, sequenced and organised (ibid; Sections 4.3.1 and 4.4).

Barham (2013a) suggests that a new paradigm for cognitive theory is in the offing and that it will be a gradualist theory connected with the hierarchical complexity of cognition (Simon 1962; Stout 2011; Section 3.1). Garofoli and Haidle (2014) recommend the establishment of a well-defined and hierarchical set of macro and micro theories to make up a new paradigm. The macro theory will define how lower and more specific subcomponent theories will work, and each subcomponent theory will govern micro theories for particular domains of research.

It is suggested that complex adaptive systems theory (Section 3.1) would be an appropriate macro theory for understanding evolution in general. It has a mathematical basis although this is still in its early stages (Holland 2014) and provides a language and set of concepts that will apply to all subcomponent levels. In terms of the subcomponent level for this enquiry into cognitive evolution, a niche construction model with dynamical qualities (Section 3.2.1) seems appropriate. At a micro level the cognitive organisation of gestural sequences of technological behaviours is best described by a perception action or ecological psychology model (Section 3.2; Beer 2000). Chapter 3 will give a more detailed description of complex adaptive system theory (Section 3.1) and perception action theory (Section 3.2). Chapter 4 will take a closer look at aspects of cognitive science that rarely make an appearance in archaeology literature but that give real support to the theory that cognitive change can take place outside of genetic mutation at both ontogenetic and phylogenetic levels. Chapters 5, 6 and 7 are concerned with the two pilot studies that form the heart of this project. Chapter 8 will summarise this first attempt to analyse the cognitive substrate of sociotechnological gestural sequences, and will also discuss the role of archaeologists in researching cognitive evolution.

Chapter Three

Possible micro and macro theories for a new evolutionary change paradigm

"Distilling spatial and temporal patterns in the stream of experience makes prediction of events and actions possible. Thus the primary goal of development – sensory, motor and, arguably, conceptual – is to learn struture in space in time"
Goldstein et al (2010: The Goal of Development)

"The brain is fundamentally *a pattern-forming, self-organised system governed by nonlinear dynamic laws"*
Kelso (1995:26)

"I suggest…that answers to questions about the structure of early human tools cannot be divorced from a consideration of the actions of the hand and / or arm that embody tool use. More broadly…we also need to consider the evolution of the actions that individuals employ during tool use and how our action capabilities…have shaped the tools of human culture"
Lockman (2000:141)

3. Chapter Summary

Chapter 2 concluded that a new, complete paradigm is needed which would allow a more rigorous and coherent study of phylogenetic and ontogenetic evolutionary and developmental change. Cognitive scientists and psychologists who do not have some kind of connection with cognitivist theory mostly use models from the group represented by complexity theory, dynamic systems theory and perception action theory. As we will see the theories are often linked in the same papers. The language used to describe one theory-type fits well with and echoes the language of the other types. Appropriately they are like nested structures which have developed together in reaction to older models, and provide a range of differently sized frameworks for larger more holistic depictions down to detailed specialist microscopic analyses.

Section 3.1 starts with a basic, verbal discussion of complex adaptive systems theory which is the type of complex system most relevant to evolutionary change. Section 3.2 deals with perception action theory which has grown out of ecological psychology (Gibson 1979) and is the most appropriate model for the analysis of technological gestural sequences. It forms the basis of the methodology set out in Chapters 5, 6 and 7. Sections 3.2.1-3.2.3 pick up on important aspects of this theory which appear repeatedly in different papers.

Dynamic theory is used by authors referenced here as a way of explaining the mechanisms of perception action. Some authors extend the dynamics theory further to a model called dynamic cognition theory and this is touched on briefly on Sections 3.2.1 and 3.2.2, but it is too complex and mathematically-based to discuss fully. It refers particularly to neuronal network complexity and dynamic brain activation, offering a fascinating set of new ways of thinking about thinking (Thelen 1981a; Thelen and Smith 1994; Kelso 1995; Beer 2000; Gibson and Pick 2000; Edelman and Tononi 2001; Thelen et al 2001; Smith and Thelen 2003; Smitsman et al 2005; Baber 2006; Cosmelli et al 2007; Stoerig 2007; Tognoli et al 2007; Kelso 2008; Oullier et al 2008; Miller and Kinsbourne 2012; Nonaka and Bril 2012; Wilson and Golonka 2013; Bryant 2014; Schmidt et al 2014; Smith et al 2014; Stout and Hecht 2014; Baber 2015; Bressler and Kelso 2016; Rouse et al 2016; Tozzi et al 2016).

Section 3.2.2 discusses the still largely unaddressed issue of conceptual thinking within a perception action framework and Section 3.2.3 discusses how perception action processes can themselves be the trigger for evolutionary change.

3.1 Complexity and Complex Adaptive Systems Theory

Bassett and Gazzaniga (2011:Concluding Remarks) state that "neuroscience desperately needs a stronger theoretical framework to solve the problems that it has taken on for itself. Complexity science has been posited as a potentially powerful explanation". They state that neuroscientific research has been carried out using circumscribed and highly controlled laboratory experiments in an attempt to answer small, detailed questions, but no serious attempt has been made to date to amalgamate the results of these multiple experiments. Important aspects of brain function consistent across all research would fit well into a complexity framework, specifically the networked neuronal system architecture with varying numbers of connecting nodes forming small-world networks (Edelman and Tononi 2001; Herculano-Houzel 2012b; Holland 2014). The framework would also explain how new cognitive functions emerge out of recombined older information networks that connect in new ways (Barton 2001; Anderson 2010; Barton 2012). Other aspects of cognitive theory which have been problematic within a cognitivist model would be more easily expressed within this framework, particularly the emergence of consciousness out of other cognitive states grounded at lower levels. For the authors, expressing neuroscience within this framework would allow for direct comparison with other large bodies of theory for which complexity is a workable framework.

Stout (2011) describes the developmental dynamic of reductive tool-making skills as a hierarchical complexity system. He states that the individual elements of tool-making are grouped into nested groups of gestures that become increasingly specialised over time. Higher levels of the hierarchies may have some kind of conceptual content related perhaps to a planned morphology for the tool, and lower levels are formed by interactions between fluctuating task, environmental and agent constraints, and the momentary quality of affordances (Section 3.2). Information can pass either up or down through the system, so that the overall design components can affect the way that the task parameters are handled, while at the same time the overall design can also be affected by the ongoing parameter changes of the task (Section 4.3.3). Learning provides an increasing ability to manage these continual interactions between task levels and nested subsystems. Reed (1996) defines the ability to react with appropriate gestural sequences in the face of continual change as the function of cognition (Section 8.1).

Sambrook and Whiten (1997) summarise the basic structure of a complex system for behavioural and cognitive scientists. They state that the word 'complex' starts to appear in biology and psychology as an intuitive descriptor of a quality in organisms that increases over time. More recently it has started to emerge as a more rigorous theory because complexity has ceased to be considered a simple proxy for biological change, and is now seen as its main cause. Sambrook and Whiten (ibid) state that complexity is fundamentally a way of describing types of information patterns that are neither random (completely unpredictable), or periodic (easy to predict and inflexible) and has a close relationship with the laws of thermodynamics (Simon 1962). Complexity patterns are highly unpredictable with high levels of potential variability, but are capable of description using predictive algorithms by an observer who knows both the rules that govern the system, and the current state of all of its variables. This position half-way between periodicity and randomness allows for the unpredictable emergence of new levels in complex systems. Emergent levels of a complex system are inevitable, and form the basis of hierarchical organisation (Simon 1962). Sambrook and Whiten (ibid) state that the fact that complexity describes both patterns and pattern-organisation has interesting implications for understanding cognitive processes. Unfortunately they do not follow through on what the implications might be. They do note however, that only perceptual information enters the system at its lowest level, and subsequently makes its way up from level to level by recombining with other information patterns. This gives the system depth. Each level also has breadth which varies according to the number of different types of variables interacting together at each stage.

Different organisms have cognitive systems with varying proportions of depth and breadth (and see Byrne et al 2001).

Bassett and Gazzaniga (2011) specifically discuss the application of complexity theory to the human brain. The brain is one of the most complex multicellular structures in biology, formed by a non-linear developmental increase in the ability to process information efficiently. This ability is supported by what some neuroscientists (Edelman and Tononi 2001; Herculano-Houzel 2012b) call the small-world architecture of the brain (the term is also used by complexity theory specialists about complex networks - Holland 2014). Basset and Gazzaniga (ibid) describe it as a network where neuron subpopulations carry out specialist operations but network together with other specialist populations in respect of a particular task. Edelman and Tononi (2001:131) state that high values of complexity in the brain correspond with an "optimal synthesis of functional specialization and functional integration within a system". They go on to specify that this requires arrangements of well-defined neural groups heavily interconnected amongst themselves but with sparse main-line connections with other groups that include a lot of reentrant or two-way feedback routes. These groups build up dynamic relationships between themselves as a result of their history of connecting up for particular functions. Neuronal selection operates on the redundant array of potential alternative networks over time so that the system's ability to match external complexity with internal information recombination evolves with experience (learning).

Simon (1962) is an early and seminal paper on the importance of complexity theory. It was presented to a room of eminent scientists as a non-domain-specific theory deliberately described in abstract terms so that it could be applied to a range of different phenomena. All of these phenomena are described as adaptive systems. A complex system "is one made up of a large number of parts that interact in a nonsimple way…[where] the whole is more than the sum of the parts…in the important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole" (ibid:468). These systems are necessarily hierarchical. Examples of hierarchical complex systems include social systems, biological systems, language and music all of which are given structure by their hierarchical interactions. Interactions can take place within subsystem hierarchies only, or between all levels of the entire system, both upwards and downwards.

Holland (2014) describes complex adaptive systems (CAS) theory. These systems have a hierarchical structure, but significantly they are in a continuous state of change as they constantly adapt in order to match their constantly changing environments. CAS network nodes are described as 'agents' because they have the ability to rate the efficiency of the information strings that pass through their space and to make changes to the strings in order to increase their effectiveness. Change consists of recombining older sub-units of information into more effective sequences. Agents are arranged into small-world networks so that one agent's change directly affects the activity of all connected agents. Adaptive change within the system is unpredictable and emergent. However, it is governed by the system's 'corpus' or set of rules that controls recombination, and so could be predicted by an observer in possession of all relevant information (Sambrook and Whiten 1997) – an ability not yet available to CAS specialists (Holland 2014). One of the ways of trying to understand a CAS is to assign codes to small sub-units of the information strings in the same way as is done for DNA. In this way it is possible to try and work out patterns of units integral to particular strings of information, and to analyse different strings for patterns that they have in common ('motifs'). Motifs are likely to be highly effective units. Combinations of patterns from different agents at one level get chunked together as one agent at the next system level up, and the new recombined string is put together according to the system's corpus.

Holland (ibid) describes the number of connections outward bound (efferent) from a node as the number of edges that go to make its 'fanout'. The human CNS has an average fanout of over a thousand edges within a very small local network. Some of the edges are feedback information loops (reentrant neural connections in Edelman and Tononi 2001) which allow the system to predict virtual future system states without actually performing the relevant interactions. The increased specialisation of these small communities of nodes correlates with increased whole-system complexity. Effective boundaries are formed around the nodes which become more highly specified as complexity increases, or more selective about which information strings can pass through. The appearance of a new boundary signals the presence of a new agent and of emergent change. The author considers it essential that complex adaptive systems in different contexts should be described using a common language so that their similarities and differences can be further analysed. He states that "it is clear that complex systems are still primarily at the stage of collecting and examining examples, much as was the case in the early stages of biology, or the early stages of physics before Newton…we are still a long way from an overarching theory of complexity, but there is strong evidence that such a theory is possible" (ibid:90).

We can only speculate as to how existing evolutionary theories will be able to fit into a CAS structure. There are very clear connections with the sociotechnical systems described in Section 1.6.1, from the increased levels of complexity apparent in technologies through time as a result of recombination, to the increased need for good communication between groups producing specialised technologies and their need to network with other specialised groups. The modern human neuronal network system is already being analysed by the authors referenced here and by others, as a CAS.

Chapter 7 attempts to establish whether the gestural sequences used by tool-makers during different technology sequences amount to information strings whose patterned differences and similarities might yield some kind of meaning (Reed 1996). It is anticipated that CAS boundaries might be usefully interpreted as the spaces between groups of gestures that amount to task stages. The average number of task stages per technology increases over evolutionary time (Section 6.4 and Table 7.1) which already indicates a CAS increase in complexity and rising rates of information recombination. It is also anticipated that the boundaries become more specified as well, and greater amounts of change have to occur each side of them because less task-information will be able pass through. Or in effect each task stage becomes more specialised internally and thus differentiated from other task stages. It is anticipated that specialisation will be particularly clear in hafted tool sequences, as will recombination processes effectively coded by different raw materials from different original technologies. The operation of the human neuronal network has already been described as a CAS, and presumably this means that different hominin species' neuronal network systems will represent alternative stable states of the same system at earlier less complex stages. This should mean that if it can be shown that a technology dynamic can also be described as a CAS it could be regarded as part of the same embedded, distributed and embodied cognitive system (Section 3.2) as the neuronal system itself, and provide useful information about the relationship between hominin cognitive systems and related technological artefacts.

3.2 Perception Action

This Section proposes perception action theory as the new micro-level paradigm component relevant to this particuar project (Section 2.7). A micro-theory should be domain-specific and its concepts and language should deal directly with the specific phenomena being investigated. Any comparison between say a sociotechnological dynamic and the human neuronal network system could not be carried out using perception action theory. However, the relationship between changes in both domains could be established at a subcomponent level using niche construction theory, and directly compared by 'translating' both sets of domain-specific information into macro-theory or complex adaptive system language.

Perception action theory explicitly rejects the internal worlds created by cognitivist theory. It describes instead a cognitive system in a continuous state of change and embodiment in the real world, enabling agents to search out and create meaning from multiple sources of environmental information, by organising the gestures that they perform. The appropriate combining of gestures provides two-way connections and information-flow between the agent and the environment in which she is embedded, and future recombinations of those initial information sequences at different levels by one individual or between individuals, represents both ontogenetic and phylogenetic learning.

For Turvey (2013), perception action theory provides a psychological model for all organisms. It is a scientific exploration of the quality of 'agency' in the organisms who are able to use their perceptive abilities to explore their environment and identify means for bringing about specific results, ('prospectivity' for Turvey and also Gibson and Pick 2000, and 'intention' for Reed 1996). They exhibit flexibility about the particular combination of gestures and objects used at any particular time (Section 3.2.1) and draw on past experiences to inform the present (retrospectivity). The organisms are CAS agents (Section 3.1) who as a result of learning are able to judge how effective gesture / object combinations are likely to be and to adapt or recombine them as appropriate (flexibility or variability). The information that they seek out takes the form of information arrays that betray the presence and configuration of possible 'affordances' or patterns of the environmental substrate which permit particular behaviour sequences. Turvey (ibid:153) defines an affordance as "an invariant combination of properties of surface, substance, and medium taken with reference to an organism and specific to an action performable by the organism". The affordance is an inherent characteristic of the substrate but will only be sought out by organisms with appropriate embodied characteristics and prospectivity (Witt and Riley 2014; Wilson et al 2016a). One bit of substrate may offer more than one affordance depending on which organism is interacting with it at any given time. For Turvey, the job of perception action researchers is to capture the physics and maths structures that can describe how organisms extract semantic content from information arrays without the need for internal mental calculations or representations (Turvey et al 1981; Gibson 1979; Wilson and Golonka 2013; Wilson et al 2016a,b).

Reed (1996) acknowledges this primary need for mathematical models to reinforce the foundations of ecological psychology, but adds that there is also room within the discipline for interpretative methodologies seeking to describe perception action processes at higher levels. The author suggests the concept of 'action units' (or motifs in Section 3.1) which can be identified and then used to break down (or code in Section 3.1) strings of gestural information so that they can be better analysed. He recommends a much closer analysis of the characteristics of affordances, in an attempt to understand why they trigger particular action-unit sequences from the huge potential variability of organism responses. He believes that affordances trigger Darwinian selection processes in organisms trying to use information-search and response gestures in order to maximise the effectiveness of their behavioural sequences (Section 3.2.3). High levels of potential variability require a cognitive system capable of organising short-term, small-scale neuromuscular events (action units) into "ecologically meaningful patterns" (ibid:68). Improved sequences are always recombinations of older action unit sequences. The cognitive system must have dynamic qualities in order to provide optimal responses in such variable circumstances and to perfect them through time – "the effort after meaning is almost always a learning process" (ibid:107).

Eleanor Gibson, the wife of James Gibson (1979), researched the ontogenetic development of modern human infants using a perception action learning model. In Gibson and Pick (2000) the authors state that all child development is founded on the accurate detection of and appropriate responses to new affordance information. Affordances are properties of the environment and include objects, aspects of objects and object layouts, as well as events. Postural control mechanisms mature in tandem with perceptual skills as movement is an integral part of gestural information-search and affordance-response (Section 3.2.3; Reed 1988; Caruso 1993).

Tool-use is extensively covered in perception action literature in relation to child development, skills development and cognitive evolution. However, there has never been any true consensus about the definition of a tool (Bentley-Condit and Smith 2010). A working definition suggested by these authors (ibid:188) is "the external employment of an unattached environmental object to alter more efficiently the form, position, or condition of another object, another organism, or the user itself when the user holds or carries the tool during or just prior to use and is responsible for the proper and effective orientation of the tool". It is suggested that in terms of the perception action model tools are affordances which like all other affordances offer up an array of information which can be sought out and used by organisms with appropriate effector organs and intent. Unlike a lot of affordances though we would expect a tool to be separate from the environmental substrate and capable of retention and mobilisation by the organism's effector organs. These last two features imply that the gestural perceptive and response sequences are likely to be affected by the incorporation of the tool as part of the body of the organism. This should result in an increase in the breadth and depth of the action unit hierarchy and cognitive sequencing load created (Section 3.2.3). If in addition, the tool is not just a separate part of the substrate but is to be modified for use, then the cognitive sequencing load is likely to increase in different ways during the modification process. These issues have not yet been fully addressed directly by perception action theory but are relevant here, especially when we briefly address the issue of how concepts should be described within a perception action framework (Section 3.2.2). At the very least we should be able to say that an affordance that is used as a tool is likely to indicate the presence of more complex action unit recombination patterns and hierarchies than a static affordance.

Lockman (2000) rejects the cognitivist assumption that infants only start to use tools when the appropriate conceptual brain module substrate matures at a particular age. Instead the author uses a perception action framework to identify basic uncombined action units for tool use in young infants by observing their exploration of a range of interesting affordances on separate objects. At 6 months infants have a good level of finger dexterity and a stable sitting posture which allows them to explore objects that they are holding. From about 8 months they are able to grip a handle. When given both soft and hard hammers to play with they are more likely to bang effectively with the hard hammer surface aligned with another hard surface than with the soft hammer, presumably because of the rewarding noise. The author remarks that we need to consider carefully how "how our action capabilities…have shaped the tools of human culture" (ibid:141).

Kahrs and Lockman (2014) confirm that infants use a tool in combination with an appropriate surface for achieving a sensory reward. At 6-10 months infants chose the hard surface of a cube rather than softer ones to elicit noise. When offered a hammer made out of the same cube on the end of a handle they were able to grip the handle but did not pay attention to the distal end or attempt to elicit noise. Older infants showed more efficient and consistent hand trajectories when reaching for the hammer handle and were able to use it to produce noise, indicating that the use of the hafted tool was more difficult than the hand-held object and required increased information recombination to deal with the new biomechanical and perceptual (Section 3.2.3) arrangement. Chappell et al (2013) looked at the ability of young children to innovate a tool design to solve a problem. From the age of 4 they were able to select the right tool for a task and could make a tool successfully after having watched someone else demonstrate. However, they were not able to innovate and the authors speculated that this was because the cognitive process they needed to go through had not been adequately scaffolded for them through previous experience (and see Nielsen et al 2014).

Bril et al (2009) confirm that in a perception action framework it is the effectiveness of the performance that should be assessed and not of hypothesised underlying representations. The authors reference Reed (1996) and observe that task constraints are distributed between the organism, the task itself and environmental factors, and that performance emerges from interactions between these factors. When provided with hammerstones of different weights in order to carry out a nutcracking task, chimpanzees modulated the velocity and amplitude of the arm / tool system in order to adjust for the change in weight of the tool in each case and to access the kernel successfully. The more experienced chimpanzees were able to modify their action parameters more effectively. The authors observe that "movements…express underlying cognitive processes…Indeed, tool use necessitates sequences of movements with objects in ways that places significant challenges on the cognitive-motor system" (ibid:217), (and see Birch 1945). Stout (2005a) proposes that cognitivist models are unable to account for the variability of tool-use performance. Perception action models embed cognition in performance. Cognition represents the ability to detect and use the action possibilities afforded by the environment as effectively as possible, and knapping skill resides in the ability to recognise and use the affordances offered by the stone core (Nonaka et al 2010).

3.2.1 The Uncontrolled Manifold and Dynamic Systems

The uncontrolled manifold or degrees of freedom question first set by Bernstein (1967) is framed as a problem by cognitivists. Bernstein's careful measurements of motor activity in the human body revealed that a single action when repeated numerous times is never made up of the same combinations of muscular and joint movements (hence an 'uncontrolled manifold'). This high level of variability challenges cognitivists who assume that the same representation or mental template applied more than once, must lead to the same stored motor programme being put into action on each occasion. A lot of intellectual energy has been spent trying to explain why this does not happen. For Latash (2012), reframing motor cognition within perception action theory removes the problem. Abundance of degrees of freedom during the sequencing of action units is a vital part of the system. The entire set of system components in which an action is embedded are never the same even where the action required appears to remain stable to an observer. Massive variability in the way that action units are put together allows us to deal with unexpected secondary tasks and peturbations. Motor control is not based on Newtonian physics but on dynamic interactions (and see Turvey 2013). In Byrne et al (2001) the authors calculate a potential 2520 different ways in which basic action stages for thistle-leaf processing can be put together. Most gorillas tended to use only 1-5 possible variations so at some level they were actively selecting which combinations to use. Reed (1996) suggests that the role of cognition in action is actually to sequence each new variable pattern of action units appropriately in the circumstances.

Parry et al (2014) describe tool-use as a learned ability to control the functional dynamics of a task in progress and this requires selecting just one out of a variety of different combinations of action units for each performance. When unskilled knappers were compared with skilled knappers successful performance was not equated with any particular movement pattern. 'Erratic' performance was observed in the unskilled. But the skilled knappers' combinations were constantly reworked in a way that preserved kinetic energy, and there was an acute awareness at some level of how to balance angle of blow, point of percussion and external angle in order to achieve the largest flakes possible. For these authors an increase in the potential variability of the actions provided a good basis for learning and for getting some kind of results even at a novice level.

Thelen and Smith (1994) describe cognition as a dynamic system and use examples from human infant development to illustrate changes through time that correspond with individual maturation. Development is the unique route that each individual takes from an immature to a mature state. It is messy and context-sensitive with no single element having causal primacy. Behaviour emerges from a hierarchical arrangement of subsystems and varies continually around a stable mode or attractor (a term used specifically in connection with dynamic theory to denote a point to which a changing system frequently returns). Variability is not noise, but is part of the process. It is a measure of the stability of the system around its attractor. Thelen et al (2001) is a seminal article which describes the complete deconstruction of the Piagetian-based A not B error assessment, similar to the false belief test for ToM (Section 2.3.4). By reformulating the assessment multiple times the authors were able to show that younger children vary between solving the problem (locating an object in its actual hiding place) or not solving it (looking unsuccessfully for the object in the same hiding place that it has been in throughout previous sessions), depending on how the dynamics of the complete task have unrolled over time. Knowing the location of the object cannot be separated from the acts of perceiving, acting and remembering all of which take their strength or otherwise from the task context. Older children more consistently locate the hidden object correctly because their ability to control perceiving and reaching has improved along with their ability to combine them with all other task parameters. Wilson and Golonka (2013) discuss this paper in detail and remark that even adults can be made to commit the A not B error if the context is sufficiently manipulated.

Roux and Bril (2005) describe a perception action dynamic in full flow and touch on the involvement of concepts in the system which will be explored further in Section 3.2.2. Cognition is "the ability to structure the serial order of the organism's behaviour" (ibid:4). Control of the system is bottom up through the system as all of the parameters of the task are monitored and action units are adjusted in response. Stable action emerges from between this constantly readjusting balance between components and is continuously reframed by past experiences, and by new information as it arises. High levels of degrees of freedom (uncontrolled manifold) provide flexibility and variability. Some kind of top-down planning or concept about the outcome of the task may be present exerting influence on how the flow of information is used, but it will also be subject to bottom-up change if circumstances become unpredictable (Sections 4.3.3 and 4.3.4).

Perception action theory often describes cognition as 'distributed'. The dynamic of action contains interacting components which emanate from a number of different objects, their respective layout or the nature of the space being used. If more than one individual is cooperating during the course of the task then there will be a significant distribution of cognitive control between them. Baber et al (2014) and Baber (2015) use the model to observe a group of jewellers at work in their workshop. Baber (2015) describes the mixed top-down and bottom-up flow of information through the system which is composed of continuous interactions between the tool-user, the tool, the objects being worked on and the environment itself (and see Keller and Keller 1996). He describes the tool-user as having to establish the attractor state of the tool-using activity (sawing copper discs) and how the different task components cause the task dynamic to vary around their maximally effective point of intersection. Through her own actions the jeweller must keep adjusting her own dynamic components so that the complete task stays as close as possible to the point of task stability. Increased experience allows for this adjustment to become completely integrated with the shifting dynamic. The workshop space is managed to provide particular affordances, and movements of tools and objects within the workshop become affordance management or distributed cognition. Thus "cognition becomes an active response to the affordances of the interaction and object in terms of the task goal that the user is seeking to achieve" (Baber et al 2014:Discussion). Experience amounts to some reduction in the variability of performance and better control over expended energy (thermodynamics).

Stout (2002) gives an ethnographic account of a modern adze-making community in Irian Jaya, Indonesia. He uses a perception action model and embeds the tool-making traditions firmly within the social and cultural layers that he was able to observe. Interestingly, the tools which were the subject of this paper were hafted; they were bound adjacent-hafted adzes with a wooden frame. But the only technological processes discussed were those involved in the production of the stone insert by dominant all-male groups. No mention was made of the social groupings or processes involved in the manufacture of the other tool components. For other accounts of embodied and distributed perception action see Varela et al 1993; Keller and Keller 1996; Beer 2000; Barrett et al 2007; Borghi and Pecher 2011; Shapiro 2011; Greenberg et al 2013; Overton 2013; Massen and Rieger 2016.

3.2.2 Non-Episodic or Declarative Information

Brooks (1991) discusses the role of perception action systems in the construction of robots. In his opinion, if a constructed system's most basic level of input is perception data that informs action, then the system can become more complex in a gradual and incremental way. Basic function is established by the connection between perception and action which allows environmentally embedded behaviours to build up. Each new small addition to the system intended to increase the complexity of the behaviours can be made without problem so long as it is interfaced well into the existing system. Higher-level layers can be plugged into lower-level layers. The lower-levels continue to carry out the operations for which they were designed without interruption but the overall pattern of behaviour is changed by the new higher-level recombination of information. The continuity between layers means that however many new layers are added, perception still remains connected to action (Greenberg et al 1999).

This idea that even high-level cognitive processes such as using complex language, solving algorithms or designing space-going vehicles are part of the same perception action process as catching a baseball, is one that perception action theory needs to address in more detail. We should be prepared to find any explanation difficult given that it is likely to involve descriptions of the recombination of perceptual information at levels and in ways that nobody has previously attempted to describe. This potential complexity is almost certainly the reason why cognitivist theory has no real explanation for these behaviours either. In the meantime, as long as this issue remains unaddressed cognitivist theory effectively remains unchallenged.

All environmental data enters an animal's system as memories of information-arrays, and gathering and response gestural sequences (Gibson and Pick 2000; Anderson 2003; Wilson and Golonka 2013; Stout and Hecht 2014). The degree to which that information can subsequently be recombined with other information and start to lose its obvious episodic nature will depend on the breadth and depth of the neuronal network system and distributed cognitive system involved (Section 3.1). We need to be able to explain better the nature of the recombination processes at higher levels, the kind of information that results from them and whether they still ultimately result in some kind of gestural performance. What follows is a range of suggestions from perception action and dynamic cognition authors about how these new levels might be described. All suggestions should be considered as connected and equally important. Some of them have a higher obvious applicability to the changes reported in the stone tool and hafted tool sociotechnological dynamic analysed in Chapters 6 and 7, although ultimately all of them are likely to be applicable. New and rigorous relevant research is eagerly awaited.

Authors dealing with ontological developmental processes report that as an infant starts to store information from large numbers of similar perception action processes they become increasingly aware of the variations and similarities represented by those processes and what might have caused the variability. They start to be able to access information about cause and effect and to be able to establish rules of interactions between different phenomena in different contexts (compare Section 4.4.2). Dynamic cognition theory uses attractors in the dynamic patterns of brain activation to describe this accumulation of episodic information in relatively context-free structures. Complex attractors contain a lot of information that experience has categorised as connected. The attractors are deep and connected with each other in small-world networks. Infants' simple unconnected attractors can only be triggered by an almost equivalent set of events re-occurring. In other words an almost entirely re-created context is required for them to be able to retrieve learned information (Thelen et al 2001). Throughout development retrieving information from attractors become less context-dependent. Increasingly, entire attractors replete with connected and complex concepts can be triggered by a tiny portion of new but connected information entering one small part of the network (Thelen and Smith 1994; Greenberg et al 1999; Gibson and Pick 2000; Anderson 2003; Stout and Hecht 2014). It is tempting to see this increasing liberation from context (or 'release from proximity', Gamble 1998) in all stages of the evolutionary sociotechnological dynamic described in Sections 1.5. It is particularly relevant to the transition to hafting where we start to see the first recombinations of skills and raw materials from older separated and simpler attractor systems.

Our information search skills and the potentially distributed nature of cognition also mean that information can be successfully stored externally and retrieved when we need it. As society becomes more complex cultural insitutions develop which specialise in the gathering and redistribution of specialised bodies of knowledge in conceptual form. If we are embedded in the society we can learn the skills needed to access the information (for example skills involved in using language or learning from others) and to successfully recombine it (Greenberg et al 1999; Anderson 2003). The start of this process is visible in descriptions of hafting activity being located in specialised sites which individuals travel to and from as part of their networked journeys (van Peer et al 2004; Rots and van Peer 2006). It may also be glimpsed in accounts of groups travelling significant distances to obtain raw materials or stache them in a range of places for future use (Potts 1991; Braun et al 2008; Braun et al 2009; Harmand 2009).

Authors trying to place language development and use within perception action frameworks have re-addressed the contentious issue of symbols and suggest that they can be considered as high-level tools or particular arrangements of affordances. Others have suggested that a symbol is in fact a highly-chunked set of different bits of information (Forsythe et al 2015) that have been categorised together (perhaps also describable as a low-level attractor). Wilson and Golonka (2013) suggest that they are a kind of shorthand for fluid and context-dependent processes. All of the information that symbols contain has its origins in perception action processes but has been recombined at multiple different levels since acquisition (Greenberg et al 1999; Gallese and Lakoff 2005; Glenberg 2007; Mirolli and Parisi 2009; Glenberg and Gallese 2012; Wilson and Golonka 2013; Overmann 2016). Mathematical and reading and writing skills require symbol-use today but are also founded in basic perception action processes (Overmann 2013, 2016). Symbols appear to have been decontextualised from their original perception action episodic origins, but can only re-achieve meaning when used within an appropriate new context which allows individuals to interpret what they represent. These meaning-giving contexts need to be socially or culturally agreed (Jablonka and Lamb 2006; Wilson and Golonka 2013), and thus appear to be another example of distributed cognition. It seems likely that a technology such as hafting could not be socially organised without some kind of language and teaching ability being available to the groups concerned (Section 1.6.3).

Goldstein et al (2010) state that the primary goal of sensory, motor and conceptual development is to 'learn structure in space and time' (ibid:The goal of development). We use our perceptual, cognitive and social skills to understand how 'patterns are learned and used over multiple timescales simultaneously' (ibid:no page number). Understanding how information is patterned allows us to isolate re-usable units or motifs (Section 3.1) and predict future events. When learning our native language the undifferentiated stream of speech needs to be parsed into units, compared to unit sequences heard elsewhere and tested for statistical significance (Sections 4.3.1 and 4.4.2) all within different contexts. Socially embedded learning allows us to collect a wide range of examples for comparison and to establish socially mediated contextual cues (see also Ambridge and Lieven 2011).

3.2.3 Affordances as Agents of Natural Selection

We have seen how the combination of complex adaptive system theory and perception action theory provides a sound basis for describing tool-use and manufacture sequences, and links gestural units with the cognitive processes that underlie them. We have also seen how the higher-level cognitive processes that start to appear in these sequences might also fit into the theory, although this level of description remains tentative. Reed (1996) (Section 3.2) suggests that affordances can act as agents of natural selection in relation to the organisms that are dependent on them (Varela et al 1993; West-Eberhard 2003). Selection might act directly on the ability to sequence gesture, but is also important with relation to physiological aspects of the organism.

West-Eberhard (2003:24) states that 'behaviour takes the lead in evolution' and that "genes are followers, not leaders" (ibid:20) (Gottlieb 2002; Bateson 2004). Behavioural adaptive change has two stages. The first is the development of a variable range of behaviours with varying fitness and the second is the selection of the behaviours with the highest fitness quotient. West-Eberhard states that behaviour is by far the most plastic domain in which change can occur as it is the most sensitive to environmental influence. It can provide a good range of variability over short periods of time. Once an organism changes its behaviour then variants of its physiological and developmental attributes may also be subject to selection. She adds that behaviour is highly recombinatorial so it is possible that changes to particular aspects of physiology will be mediated by a need to maximise a range of co-existing behaviours for which that physiology is an effector organ, and to prevent over-specialisation.

Primate hands, and human hands in particular are a perfect example. All evolutionary changes in primate hands that we are able to trace despite the paucity of fossil evidence, are related to behavioural change and perforce to changes in affordances. What follows is a review of some of the recent literature on evolutionary changes relating to both primate hand morphology, and also to an emergent level of gestural sequence organisation (cognition) that we symbolise as 'handedness' or 'manual differentiation'. Finally we will briefly review articles on how primate perceptual systems reorganise as soon as primates grasp a tool with any length.

Marzke (1997) remarks that we have major problems being able to relate the development of hand morphology in hominins to the use of tools and that one of the reasons for this is the lack of fossil evidence (Marzke 2013). Kivell (2015) documents the growing evidence for advanced manual manipulative abilities in pre-*Homo* species which were bipedal but were also at least partially arboreal. She remarks that the mosaic quality of archaic and derived features indicates a morphology capable of serving both manipulative and locomotor functions (Kivell et al 2011). Almecíja et al (2015) find that great apes do not constitute a homogenous group in respect of their hand morphology and physiology. Hand evolution has been mosaic and there is no obvious model in past species for the human hand. Modern human modified finger and thumb morphology in particular allow refined manipulation but the main derived features in the human hand occurred earlier than the current dates for freehand knapping. Tocheri et al (2008) state that only *H. neanderthalensis*, *H. sapiens* and *H. antecessor* benefitted from a derived knapping morphology although a lack of these derivations did not exclude previous species from being able to knap. Williams et al (2014) identify derived human hand attributes that they believe would have enabled a higher velocity of hand movement during knapping and may have protected against damage due to hyperextension, although it should be noted that there is no evidence for restricting the application of these adaptations just to knapping tasks.

We have also seen in Chapter 1 that all hominin species are likely to have been involved in a wide range of manual tasks requiring different attributes such as the ability to manipulate single strands of twine, chop wood, break open bones, pluck plants or caress a baby's face. As Kivell (2015) intimates, it is likely that hand morphology at any given moment represented the maximised biomechanical arrangement to enable different concurrent specialist functions. The modern human hand and upper limb system represents a physiology that maximises variability in grip, power and range of movement. The hand in particular is also supplied with a very large number of sensory receptors. The receptors provide information about the size, shape, position, temperature, texture and weight of any object being touched and enable direct and automatically correct manipulation responses that we use without being conscious of the essential role that they play in our daily lives (Yekutiel 2000). A reduced innervation of these receptors may be a compromise made by species who still used their hands as locomotor effectors, and is likely to result in lower levels of manual dexterity. Yekutiel (2000) describes this effect in stroke patients who loose afferent receptor information due to brain damage. This does not mean that we should presume that early hominins could not knap or process other materials, but their manual accuracy may possibly have been reduced in relation to non-arboreal species. Key and Dunmore (2015) describe the important role played by the non-dominant thumb during Oldowan freehand flake removals. They consider the thumb to have become more derived in non-arboreal species, and that during freehand knapping the non-dominant thumb plays an important role in holding the core in the correct position during blows and repositioning it between blows. Presumably the role of sensory receptors would also be important here. It may be possible to model fossil-based information, hand-span, possible sensory receptor innervation levels, range of upper limb joint movements, behaviours and technological profile to get a better idea of how this kind of dynamic evolved, but no such work has been done as yet.

It is commonly assumed that the way that we differentiate our hand use during daily activity (or our 'handedness') is genetically inherited from our parents. However recent papers reject this assumption. Michel et al (2013) describe the accepted dominant gene theory where a left-hander must have a left-handed gene from both parents and a right-hander can have either two or just one right-handed parents. Only twenty-five percent of the offspring of two left-handed parents turn out to be left-handed. Ten percent of the offspring of two right-handed parents are left-handed. Neither of these two sets of figures would be correct in a dominant-gene arrangement (Byrne and Byrne 1991; Uomini 2009; Mosquera et al 2012). Uomini (2009) describes a growing recognition that our established assumption that modern humans are clearly divided between people who always differentiate as right-handers and those who differentiate as left-handers is not accurate. The way that people differentiate is more variable and no extant hand differentiation assessment procedure is currently able to provide consistent categories of differentiation corresponding to the real-life experience of individuals (Mosquera et al 2012).

Hand differentiation during a task occurs where both hands are used but perform very different types of action units. Nonaka and Bril (2012) call this asymmetrical bimanual coordination. The dominant hand takes on action units related to fine manipulation while the non-dominant tends to stabilise the object being worked on and move it around into new and suitable positions. Nonaka and Bril (ibid) point out that the two sets of actions are nested or coordinated – in effect each hand's moves interact with the moves of the other hand. The role of both hands is equally important to the overall success of the task. This can be seen as a recombination of two originally separated streams of information for each hand. It is an essential way of efficiently reducing the uncontrolled manifold in a two-handed task (Section 3.2.1). The organism does not need to constantly delegate each action unit to one or another hand as each hand has a habitual role. The cognitive system can also take advantage of already-chunked action unit sequences for each hand from multiple past events, and from any learning experiences that have occurred. Byrne (2005:166) comments; "when the two hands need to take distinctively different roles in a single task, it pays not to switch roles between left and right hands".

Hand differentiation at a population level (right-handeness) is unique to *H. sapiens* (Uomini 2009; Mosquera et al 2012). Throughout the course of the day we perform many activities, frequently involving tool-use, which require this kind of differentiation. We all have a settled preference for either left or right handedness during complex tasks, but we also have a species-level preference at about 74 to 96 percent, for right-handedness (Uomini 2009). Preference is likely to be the result of each person's individual developmental dynamic with multiple components including social ones, each having some kind of influence on the outcome (Michel et al 2013). However the probability of right-handedness is high because the right hand has a more direct connection with the motor functions in the left hemisphere relevant to dominant-hand-type activity (Guiard 1987), and because modern humans are usually under some kind of pressure to conform with existing social norms. Uomini (2009) and Mosquera et al (2012) comment that various primate groups have been observed to come close to a population preference when tasks have been complex and involved tool use. Fiore et al (2015) state that Neanderthals had a right-handed population preference at the same level as *Homo sapiens* which indicates that the complexity and tool-involvement levels of daily tasks carried out by both species may have been similar.

An individual's developmental establishment of a preferred differentiation can be quite drawn out and might include various preference-changes at different times. Individual preferences can become marked in chimpanzees (Mosquera et al 2012) although Boesch (1991) comments they can take ten years to stabilise. Byrne and Byrne (1991) state that at 3 years of age 5 out of 6 gorillas have developed a marked differentiation preference due to their complex manual sequencing during feeding. Mosquera et al (2012) draw attention to the need for security of posture in chimps before they can differentiate and Braccini et al (2010) and Holder (2005) note a correlation with increased bipedalism. Corbetta (2005) establishes that during human infant development task complexity, posture and balance skills all affect the degrees of differentiation observed. Pre-locomotor infants with a stable sitting posture develop a preference which is lost and potentially swapped after crawling, and subsequently walking behaviours have stabilised.

Wang and Sainburg (2007) discuss differentiation in terms of arms rather than hands but again concentrate on the roles of control of steady state posture (non-dominant arm), and the efficient coordination of multiple units of a task (dominant arm). They repeat that the two roles are equally important and have both evolutionary and ontogenetic roots. It is important to concentrate on the whole arm when considering how tool-use affects differentiation (Guiard 1997). The handling of multiple objects also triggers change. Kotwica et al (2008) observe that in human infants the skills of handling multiple objects, sometimes holding one in each hand, and then placing them in a place convenient for retrieval is linked with the development of differentiation.

Bril et al (2012) and Bril et al (2015) describe how differentiation in chimpanzee nutcracking is less marked than it is in freehand knapping, because the non-dominant hand in nutcracking merely acts as a stabiliser and does not actively move the nut in combination with movements made by the dominant hand. Nonaka and Bril (2012) suggest that increased differentiation in modern humans knapping stone beads occurred during the more challenging stages of the task and required a greater stability in other component task factors. They thought it likely that the bead-makers benefited from the ability to modulate differentiation between the hands depending on the ever-changing demands of the task (and see Rein et al 2013). Pelegrin (2005) also stresses the high level of control demanded of a knapper producing conchoidal flakes. It is maintained through the differentiation of precise percussive action through the dominant arm and muscular contraction of the non-dominant arm holding the core at exactly the right time and position in space to absorb the blow. These particular knapping action unit sequences develop complexity in the form of differentiation as a direct response to the dynamics of the knapping task and the affordances offered by both the core and the hammer in use at the time. Differentiation must be less complex where the core is not uniquely supported by the non-dominant hand and stabilisation affordances are provided by, for example, an anvil or a thigh. However, it is possible that fine control over flake removal will be lost as a result of using these affordances.

We have seen that affordances offered by tools can result in increased complexity of action unit sequence organisation through hand differentiation. Perceived tool affordances can also cause an immediate change in the organisation of the organism's perception of what does and does not constitute its body parts, and the shape of the immediate space around its body. This occurs so that the tool's gestures can be organised as if the tool itself is part of the organism's body. Additionally peturbations of the tool during use can be interpreted as embodied perceptual information about the ongoing task (Malafouris 2013). This change in self-perception rules is probably only relevant to elongated tools or tools with handles although this is not specified in any of the literature covered here. A tool or object that fits into the palm of the hand may not require a change in perception of body-space in the same way as a hafted tool that projects out from the body – more research is required here. For further information see Berti and Frassinetti (2000); Bonifazi et al (2007); Iriki and Sakura (2008); Cardinali et al (2009); Serino et al (2015).

3.3 Conclusion

We have reviewed how well complex adaptive system theory and perceptual action theory can be used as macro and micro theories in a new comprehensive paradigm for interrelated evolutionary or phylogenetic change and ontogenetic change in hominin species. This change is two-way and involves the effect of cognitive change on environments as well as the effect of environments on cognitive change. The models allow room for well-considered analyses of relevant aspects of evolutionary change, including changes related to sociotechnological changes over time such as the transition to hafting. They would also combine well with a niche construction approach as an intermediate theory (Section 2.5.5). In order to complete as full an explanation of gradual as opposed to stepped evolutionary change as is currently possible, Chapter 4 will address some of the actual biological mechanisms which may be behind the kinds of change described here in Chapter 3.

Chapter four

Mechanisms of phylogenetic and ontogenetic change

"animals are exquisitely sensitive to complex patterns of information"
Reed (1996:66)

"The laws of physics, basic biophysical principles, and the nature of animals' bodies…together constrain animal activity to be 'pulsed' at a very specific environmental grain, usually measurable in parts of meters per second. The law of natural selection has operated to organize and entrain these pulses and make of them functional postures and movements"
Reed (1996:97)

"Implicit learning refers to the process whereby our brains unconsciously recognize patterns and infer the relevant rules that emanate from those patterns during our day-to-day experiences"
Forsythe et al (2015:60)

"As we use technology for practical and social purposes…we draw on a nonverbal form of human cognition whose capabilities clearly form an enormous, but heretofore little recognised, component of our species' everyday intelligence"
Pfaffenberger (1992:508)

4.1 Introduction

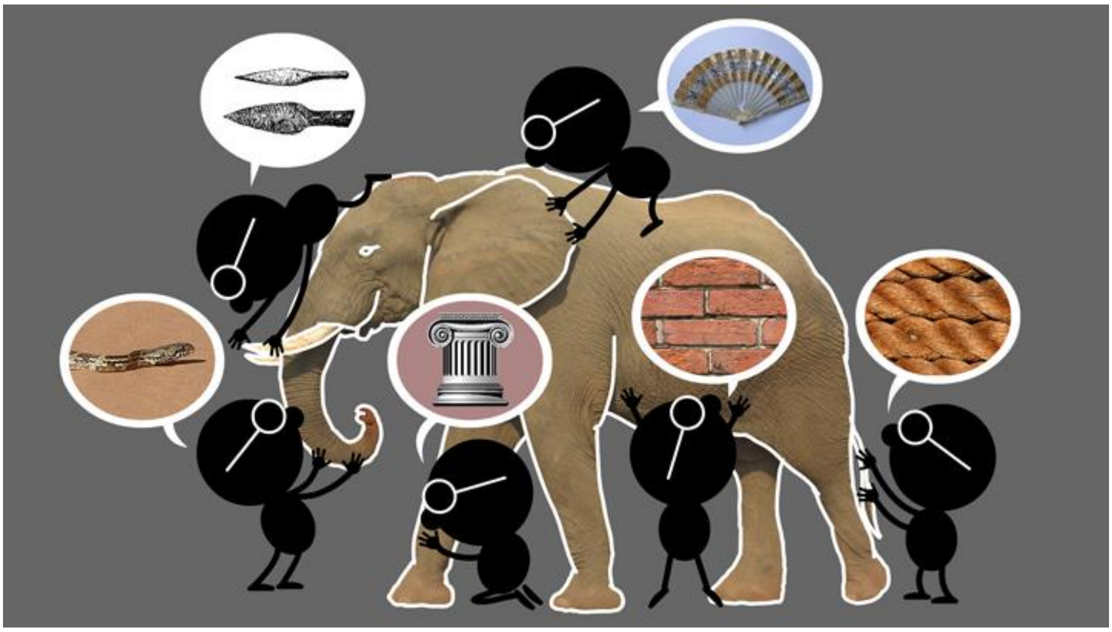

Figure 4.1 Taken from The Blind Men and the Truth of the Elephant – Simon Says: The Random Ramblings of Simon Camilleri

Chapter 3 reviewed the usefulness of complex adaptive systems theory as a meta-theory for a new evolutionary paradigm; of niche construction theory as a mid-range theory, and of perception action theory as domain-specific or micro-theory for understanding the sociotechnological and associated cognitive dynamics of change. The models supported detailed descriptions of cognitive and technical change both in the direction of change caused by organism to environment, and change caused by environment to organism using multiple interactive components. In Chapter 4 we review areas of current cognitive science literature concerning neurological systems. These systems may form the substrate for continuous cumulative cognitive and associated physiological change in component biological systems in accordance with both phylogenetic and ontogenetic time-scales. These systems are discussed specifically in relation to great apes, hominins and modern human tool use and tool manufacture, and general action sequences.

All of the research described has been conducted within a predominantly cognitivist environment. There is an interesting change in emphasis through time in researchers' attempts to make their findings fit into the dominant paradigm. Descriptions of the implicit system (Section 4.4.3) are riven by attempts to differentiate it from what the authors obviously still think of as the 'real' cognitivist thinking process, and to explain why an additional thinking process should even be present. In contrast, despite initial rejection by individual academics, more recent descriptions of epigenetic change (Section 4.2.1) took root in a stable base already provided by the increasing importance of evolutionary developmental and dynamic theory.

Where cognition researchers do not use complexity theory they are still trying to present their findings as individual black-box or Fodorian systems with fixed locations in the brain and specific functions and representations (Downey and Lende 2012). A single adaptive multi-layered system with highly variable outcomes is never considered. Evolutionary perspectives are not applied thus removing any chance of considering increasing complexity through time, or of an existing system starting to function in new ways after adaptation to new environmental pressures (Reber 1993). Just as with the blind men who all examined different and separate parts of the elephant in the room, and identified a series of separate objects (Figure 4.1), every time a new cognitive function is identified it is still assumed to be the product of a new and isolated system, and separate teams of specialists are allocated to work on it who do not integrate with other teams (Bassett and Gazzaniga 2011). An example of this problem is the obvious connections between the implicit learning system research (Section 4.4.3) and perception action learning (Section 3.2). These connections have not been made by researchers belonging to each group. Perception action researchers never mention implicit learning system research and implicit learning system researchers still use cognitivist assumptions and try unsuccessfully to identify relevant representations for their results (Berry and Dienes 1993; Reber 1993).

Research into the modern human visual system offers an exception perhaps because a great deal of information has been gathered by different communicating groups. It is accepted that visual information enters at the bottom level of what is a hierarchical system. The information consists of differences in light wave-lengths, and that information is subsequently recombined at different levels to provide visual depth, the relative positioning and shapes of different objects, their apparent colours and the general surround-screen vision that humans enjoy (Gibson 1979; Varela et al 1993; Damasio 2010). The highest level of recombination occurs in brain area V1 and if damage occurs here the individual concerned reports blindness despite the fact that the eyes and all lower levels of information processing are still working.

However, some of these patients manifest a condition called 'blindsight' (Gregory 1987; Elman et al 1996; Simons et al 2007; Stoerig 2007; Umiltà 2007). When presented with objects and asked to guess between a number of possible object-names, blind-sighted patients frequently choose the correct names on an above-chance frequency even though they experience blindness (Gregory 1987). They are reported as able to move around environments freely, avoiding obstacles in their path. One patient who broadcast recently on Radio 4 (Today Programme April 2017) said that she was more able to rely on her blindsight if she acted quickly and did not think too much about what she was doing, suggesting that lower levels of visual perception are associated with more automatic levels of behaviour (Section 4.4.3; Simons et al 2007; Damasio 2010). It is suggested that this combinatory model of visual brain function could be usefully applied to other functions in an attempt to eliminate the numerous proposed small-scale independent systems which are currently proliferating in theoretical accounts of behavioural cognition (Bassett and Gazzaniga 2011).

Section 4.2 will describe fast-reacting mechanisms which create cumulative change in neurological and physiological systems both within an individual's lifetime and across generations. A brief description of epigenetics is given, a sub-system of genetics which responds to environmental triggers by altering genetic protein production and thus developmental processes from generation to generation (Section 4.2.1). Also included is a description of the plastic nature of neuronal network systems which undergo continuous structural lifetime changes as new information is absorbed and learned. There is some discussion as to how the results of these changes are inherited across generations (Section 4.2.2). Finally some features of encephalisation and brain architecture change are mentioned that are likely to have some genetic as well as epigenetic involvement, including mutations to the gene FOXP2 and its protein products (Sections 4.2.3 and 4.2.4).

Section 4.3 deals with a proposed hierarchy of different patterns of action units starting with the least cognitively loaded system of rhythmical repetitive entrainment (Section 4.3.1), and moving on to more cognitively loaded discrete gestural actions (Section 4.3.2). Self-organized action unit systems of basic (bottom-up) activity follow, and then action sequences framed by strongly marked goal and sub-goal boundaries tht may indicate a degree of conceptual planning (top-down activity), (Section 4.3.3). Section 4.3.4 describes what is known about the combined roles of the cerebellum and the prefrontal cortex in organising mixed-pattern sequences.

Section 4.4 examines various systems proposed for the patterning, chunking, storage, recombination and use of bottom-up information and the capacity of each to incorporate top-down information as well. The examples include expert systems (Section 4.4.1), activity parsing systems (Section 4.4.2), implicit learning and memory systems (Section 4.4.3) and a group of systems that support conscious awareness (Section 4.4.4).

4.2 Mechanisms of Cumulative Change

4.2.1 Epigenetics

Duckworth (2013) discusses the new science of epigenetics. Environmentally-triggered change has long been considered a possibility but it was always assumed to be transient. Only the genome was considered able to provide long-term change. Charney (2012) describes the epigenome as a regulator of how DNA is expressed through RNA replication. The protein output of genes can be altered by epigenetic activity as a response to environmental triggers. Thus Duckworth (2013) can say that the phenotypic effect of an unchanging DNA sequence can be highly variable for each new generation depending on each generation's epigenome. The most likely result of epigenetic change is an increase in variability across the generation which then becomes subject to fast and appropriate natural selection (Bonduriansky et al 2011). Charney (ibid) points out that in modern humans the most significant effects of epigenetic change are found in the brain, increasing effectiveness of perception, memory, cognition, learning, and neural and behavioural plasticity (Section 4.2.3) for all behavioural domains. Entire developmental trajectories can be changed by epigenetic activity continually adjusting the match between organism and niche (Section 3.1 on complex adaptive systems).

Enard et al (2002) point out that modern humans and chimpanzees share 98.7% of their DNA which leaves very little room for genetic change as an explanation of differences between the two species. However, epigenetic change can fill the gap. It is particularly derived in humans in relation to brain development. Cáceres et al (2003) found that all 'up-regulation' in gene expression in modern humans compared with chimpanzees was related to brain function, particularly metabolic requirements and cerebral physiology. Barry and Mattick (2012) relate epigenetic change to human cortex enlargement, specifically the prefrontal area (Section 4.3.4). They also discuss metabolic change and increased numbers of neurons (Section 4.2.3), and an increase in neuronal plasticity (Section 4.2.3) which is an essential part of the hominin ontogenetic ability to learn and remember complex new information. Boffelli and Martin (2012) stress the heritability of epigenetic adjustments to DNA transcription and state that significant epigenetically-caused differences have been found in the germline between chimpanzees and humans. Jablonka and Lamb (2006) emphasise how little effect epigenetic theory has had on palaeoanthropological descriptions of evolution. It provides an essential but as yet missing sub-text of Darwinian theory because it describes how high variability can be maintained, allowing natural selection to act in immediate response to environmental triggers (for example, Darwin's finches). See Johnston and Gottlieb (1990); Greenberg et al (1999); Gerhardt (2004); Breuker (2006); Gilbert and Epel (2009); Brakefield (2011); Keverne (2011); Franks and Hoffmann (2012); Greenberg et al (2013); Harper (2013); Klironomos et al (2013); Ledón-Rettig et al (2013) and also Grove (2011a); Schmidt et al (2013); Grove (2014).

4.2.2 Plasticity and Metaplasticity

Epigenetic effects are particularly linked with an increase in brain plasticity in modern humans, and also presumably, in hominins as well. As the ontogenetic potential to plastically alter neuronal structures increases, the ability to store, recombine and sequence or learn and use information also increases (Barry and Mattick 2012). So cognitive ability might increase cumulatively across generations, firstly because the ontogenetic plastic change is inherited in the germline and perhaps is increased in succeeding generations by further epigenetic processes. Secondly information that one generation learns as a result of its neuronal plasticity can be taught more efficiently and effectively to new generations who may then go on to increase their own cognitive potential as a result of the scaffolded learning that they have received (Malafouris 2013), and to generate more complex stores of information for subsequent generations.

Edelman (1993) describes how human infants are born with few neuronal synaptic connections in place and how each individual builds up neuronal networks and connections as a result of lifetime experience, thus ensuring a maximum fit of neuronal-system to niche. This means that despite the fact that we all share a similar system layout for various processual reasons (Elman et al 1996), when exaimined in detail every single one is unique. This combination of maintained structure and high levels of variability is an important feature of complexity. During the first major episode of plastic change in modern humans, synapses start to be formed and some neurons that do not get included in the new networks die away. But plastic change continues throughout our lifetime as new information is absorbed, recombined and used on different occasions and returns back to the system in a new form as experiential learning (Barry and Mattick 2012). The development of a small-world network in the human brain corresponds to increasing information categories that are accumulated in tightly connected local networks, and also to the reentrant long-range connections that link the local networks or categories together (Edelman 1993; Edelman and Tononi 2001) (Section 3.2.2). Malafouris (2010b) confirms that the continuous process of epigenetic neuronal plastic change means that the human brain can be seen as a dynamic bio-cultural system subject to constant transformation, or even as a cultural artefact in its own right. Hecht et al (2013) claim to have shown plastic change in the brains of their subjects after they acquired in-depth knapping skills over a period of two years. The changes reported were in the fronto-parietal areas (see also Maguire et al 2000; Munte et al 2002; Kelly and Garavan 2005).

The term 'metaplasticity' refers to the control of levels of plastic change over time in the brain. It is regulated so that it does not cause damage (Abraham 2008). There is some evidence that metaplasticity levels can change so that the potential for plastic change can be lowered, or raised by an individual's need to learn new skills over a long time-period (Ragert et al 2004; Rosenkranz et al 2007; Bronfman et al 2014). Schmidt et al (2013) report that metaplasticity levels can affect the length of time between initial neural activity and subsequent plastic changes, and it can also be used as a global descriptor of plasticity. The authors describe 'behavioural plasticity' or the potential for behavioural change resulting from an interaction between environmental change, plasticity, stress, developmental processes and genetic and epigenetic modifications. They provide a useful review of this concept. Plastic change can affect neurophysiological and neuroendocrine structures and sensory and behavioural control. Plasticity and behavioural plasticity effects are generally adversely affected by stress (Schmidt et al 2013) (and see also Zhang and Linden 2003; Aberg and Herzog 2012). It is possible that the effect of lifetime learning can also increase metaplasticity in individuals and the new levels may also be heritable (Bronfman et al 2014).

4.2.3 Encephalisation and Brain Architecture

The subject of encephalisation is complicated and far better expounded by experts. However, we will touch briefly on aspects of encephalisation which have direct relevance to the increasing complexity of neuronal network systems. Shettleworth (2012) stresses the difference between the evolutionary developmental concept of modularity and the cognitivist and Fodorian concept of modular brains. She states that Fodor (Fodor 1983), described the brain as composed of discrete modules with specific components, in geographically identified locations, each responsible for a specific function. There is no mechanism for describing change in these modules. This concept of the brain persists despite mounting evolutionary developmental evidence for modular mammalian brains (Shettleworth 2012). Brains are composed of parts which are semi-independent, but cannot generate behavioural function without networking with other parts within a complex hierarchical system. According to Shettleworth evolution simply is not possible without this structure as local developmental change needs to take place without disrupting the function of the whole. (Although as parts of a complex adaptive system all other modular networks connected to the modular network in question would have to effect corresponding changes, but the global function of the system would not come under stress – and see West Eberhard 2003.)

Aboitiz and Montiel (2012) describe the mammalian brain structure as highly conserved, and even when particular brain areas change in size they do so in accordance with allometric ratios of change common to all mammals. They believe that *H. sapiens'* brain is a standard mammalian brain in this context. Herculano-Houzel (2012b) acknowledges that all clades share allometric scaling rules for brain-size change, but states that they have different rates of density at which individual neurons can be packed into brain space (Herculano-Houzel 2011a). Of all clades tested for neuron density primates have the highest packing rate which means that even if a primate's brain remains the same size as the brain of another clade-member, the primate's brain would contain more neurons. Brain-size correlates more closely to the number of non-neuronal cells (white matter) present. *H. sapiens* retains a standard primate brain in this respect (Herculano-Houzel 2012b; Lefebvre 2012). Modern human cognitive function, as opposed to that of other primates, is due to the increased number of neurons present because of cranium size.

Increase in cortex size usually means an increase in the ratio of white over grey matter as more connective tissue is required. Long connective pathways across larger spaces results in a slow-down in cognitive processes. This means that in larger primate cortices short connective pathways and a small-world network start to develop. Persisting long-distance connections with other parts of the brain specialise in the fast and highly-insulated transmission of signals across the shortest distance possible (and see Herculano-Houzel 2011b, 2012a). Buxhoeveden (2012) discusses some of the potential changes to connective architecture that arise as local neuronal networks start to increase in complexity.

The globular shape of the modern human brain does appear to be unique among all primates and hominins. Bruner (2004) describes dorsal extension and ventral flexion which leads to convolution and globularity. Gunz et al (2010) state that this process happens post-natally but the globular shape does not appear to be present in immature or adult Neanderthals. Recent finds of what are claimed to be early *H. sapiens* fossils at Jebel Irhoud, Morocco, (c300Kya) have brain cases more suited to Neanderthal-like brain-shapes (Section 1.3; Hublin et al 2017; Richter et al 2017), raising the possibility that globularisation occurred post-speciation as a result of developmental or epigenetic change (Sections 4.2.1 and 4.2.2). Bruner (ibid) speculates that this shape-change is part of the process of increasing connectivity. As the proportion of connective white matter in the cortex rises faster than grey neuronal matter as brain size increases, connective tissue starts to take up too much space. It makes sense to increase the number of short-distance connections where possible, and decrease the long-distance connections. Surviving long-distance connections need to be kept as short and well-insulated as possible in order to maintain transmission speed. Travel distances are lowered by reducing the brain's overall length and effectively bringing different parts of the ventral portion of the brain into contact with each other.

Sherwood et al (2012:248) state that differences in the human brain are not the direct result of a difference in brain size. Instead "the human brain phenotype is constructed dynamically in ontogeny through the interaction of uniquely modified genes that regulate neuronal proliferation…, cell migration…, cell adhesion…, and axon guidance…as well as the synthesis and turnover of chemicals involved in signalling and energy utilization". All of these building-blocks of increased connectivity and activity are controlled by epigenetic processes (Section 4.2.1). See also Falk (2012) which provides a summary of recent research on the behavioural consequences of changing neuronal structures.

4.2.4 FOXP2

The story of FOXP2 within the Palaeoanthropological community is illustrative of the problems caused by adherence to a cognitivist model. In the 1990's a story broke about an inherited genetic disorder in the KE family. Members of the family had a 50 percent chance of inheriting a damaged autosomal gene (FOXP2) which was reported as causing an inability to put sentences together grammatically. In addition FOXP2 in its normal modern human form was found to have mutated in recent evolutionary time. For a while this was reported as the missing genetic link that everyone was looking for as it seemed to distinguish modern humans from other hominins. It proved that a modern human genetic mutation that allowed the construction of complex sentences was the cause of our high-level cognitive abilities. Eventually, with the isolation of Neanderthal DNA (Noonan et al 2006) it became clear that *H. sapiens* was not the only hominin with the mutated gene and excitement started to die down. The true significance of FOXP2 was never followed through although more accurate reports about the family disorder started to emerge.

Elman et al (1996) point out that initial reports about the family's disorder were incomplete and did not include full assessments of their condition. The authors reference Vargha-Khadem et al (1995) as a complete report never included in discussions about the evolutionary implications of FOXP2. This report states that previous reports about the family had been highly selective about which deficits were mentioned. The authors believed that the inherited disorder had a broad phenotype which included articulatory impairment, intellectual, linguistic and orofacial praxic function. They emphasised that non-linguistic cognitive functions were significantly affected and that there was no support for FOXP2 as a 'grammar gene'.

Gash and Deane (2015) report that FOXP2 dysfunction produced cognitive *and* motor deficits and that MRI scans of patients reveal low levels of grey matter bilaterally in several major brain areas. They suggest that the gene plays a crucial role in managing the development and neuroplasticity of neural networks underlying both motor learning and language functions. Negwer and Schubert (2017) describe mounting evidence from a number of different disciplines that the brain's motor networks form a crucial substrate or lower level of language function. Retinoic acid which is involved in the family's mutation plays a crucial role in brain development processes that affect both of these functions. All of this serves to reinforce the message of Jablonka and Lamb (2006) that human genes do not mediate human behaviour directly. There is no such thing as a gene which manages the ability to speak. It is possible that the modern human form of FOXP2 is the product of a more general series of epigenetic and genetic changes triggered by an evolutionary need in Neanderthals, Denisovans and modern humans to increase plasticity or learning capacity in the face of increasing cultural complexity and environmental change. This resulted in among other things, both increased complexity in technological action unit sequencing and in verbal signalling sequences (Chabout et al 2016).

4.3 <u>The Emergence of Complex Patterns of Thought</u>

Now that we have looked at mechanisms at the roots of rapid, cumulative and variable brain architecture change, we examine some of the different types of action unit sequencing that might have emerged from such change. We start with simple rhythmic repetitive behaviours (Section 4.3.1), move on to controlled discrete actions (Section 4.3.2) and then look at mixed types of action unit sequences (Section 4.3.3) and the architecture that might support them (Section 4.3.4).

4.3.1 Rhythm and Entrainment of Motor Activity

Rhythmic repetition takes place at multiple levels within biological organisms, for example in relation to brain activation (Section 3 introduction and references to dynamic theory), heart-beat and breathing, speech, singing and walking. We see entrainment of different internal rhythms (or changes in one or both of two internal rhythms so that they correspond with each other) particularly in brain activation. Where rhythms generated by separate areas come into phase, the temporary combination of both areas for information-sharing is indicated (Kelso 1995; Edelman and Tononi 2001; Kelso 2008). Rhythm can also be present in the environment as perceptible external rhythmic repetition. Entrainment between the internal rhythmic repetition of modern humans and external rhythm has been observed, including situations where the external rhythmic repetition is being provided by one or more conspecifics (Kelso 1995; Forsythe et al 2015 as referenced in Section 2.3.4 where entrainment again indicates shared experience of information; Elliott et al 2016).

For Smith et al (2014) no unified inter-disciplinary definition of rhythm exists. Nozaradan (2014:Part 3) gives a neuronally related definition of entrainment as evidence of a “selective enhancement of the neural response at beat and meter frequencies…related to the perceived beat and meter induced by complex rhythms”. The author confirms that the neural system can be entrained by a rhythmic stimulus. Smith et al (ibid) describe the developing work on rhythm across a wide range of behavioural domains including music, poetry, language and language disorders, behaviour and also cognitive studies. Recent work on neural oscillations opens up a huge new perspective, and inter-disciplinary communication is imperative. They describe neural oscillations as hierarchically organized across multiple frequencies so that events linked by different timescales can all be attended to (compare with a hierarchical description of goal and sub-goal temporal organisation Barton 2012). Rhythm, including deviation from rhythm, is always involved in the creating and sharing of meaning. Halder et al (2005) identify plastic change in the cortex resulting from the repetition of a simple movement multiple times. The authors report that the change acts to improve movement preparation, execution and resultant sensory feedback integration.

When Reed (1996:127) describes the way in which human niches are structured in order to enable learning he refers specifically to the use of rhythm with infants. A lot of early interactions with them such as rocking have a "heavy rhythmic feeling including use of syncopation". He refers to Trevarthen (1994) who divides infant play behaviours up into 2-minute sequences each consisting of 20 to 30 action units, with each action unit lasting about 2-3 beats of about 1.5 seconds each. Thelen (1981b) in a detailed study of rhythmical behaviour in infancy states that what she calls rhythmical stereotypies are likely to be phylogenetically old compared with other kinds of behaviours, and represent a state where highly controlled discrete voluntary movements were rarely available. Thelen (1979) states that rhythmic repetitive behaviours form a large part of the behavioural repertoire of insects, birds and fish, and represent an early developmental stage in other animals. In adult mammals, particularly primates and humans, they are less common and may sometimes be pathological. The trial observed 20 human infants during their first year. They displayed a high level of rhythmic movement behaviours. Forty-seven patterns of movement were described. Groups of patterns had characteristic ages of onset, peak performance and decline which correlated well with ongoing motor development (and Thelen 1981a; Lockman 2000). Bouwer et al (2014:7) state that no musical expertise or special attentional effort is needed for humans to understand rhythms with clear accents. For them rhymic entrainment should be "considered a very fundamental human ability".

Honing et al (2014) state that research into music rhythm has recently attracted attention from developmental psychologists, cognitive psychologists and neuroscientists all interested in fundamental cognitive mechanisms. The authors describe beat-perception as a mixed bottom-up and top-down process (Section 4.3.3). First we perceive a beat and set it up internally (bottom-up), and then we construct a listening process around it (top-down). EEG studies show that attentional energy increases in anticipation of each beat (internal entrainment) and other relevant cognitive processes are also refreshed on the beat. Even when subjects just listen to a beat without having to respond to it, a change in event-related responses occurs (EEG-based experimentation), especially when rhythm is violated (also Bidet-Caulet et al 2012; Sanabria and Correa 2013).

Escoffier et al (2015) describe how rhythmic expectations are supported by a reorganisation of neuronal oscillations which serve to maximise any cognitive processing occurring at anticipated time-points. This effect can be triggered across all kinds of rhythmic cues, different perceptual and motor modalities and different frequencies (Zoefel and VanRullen 2017). Entrainment is a generalised and flexible mechanism used by neuronal systems to predict environmental events, and optimise attention and perception. EEG trials indicate a link between the type of external rhythm perceived and the event-related responses. For Escoffier et al (ibid:no page number), "oscillatory phase [is] an important mechanism through which humans exploit natural regularities in the environment…taken together, our research sheds light on the neural underpinnings of rhythmic expectations and elucidates their importance as a fundamental organizing principle of perception and, possibly, thought". Givon (1998:154) states that different complex rhythmic-hierarchical skills may share the same automated neuronal substrates.

McAuley and Fomboluti (2014:Part 5) state that "attentional entrainment occurs across modalities and is important in speech and language processing, namely in helping listeners segment continuous speech signal into meaningful units".

Sentences with unusual syntactical structures were more easily understood when pronounced with rhythmical regularity even though the subjects did not realise that the easier versions *were* more rhythmical (Roncaglia-Denissen and Schmidt-Kassow 2013). They state that children use rhythm to learn speech by breaking up the auditory stream into perceptual units in order to reduce cognitive load. They start coding repeated chunked phonetic units (or motifs as in Section 3.1) in order to identify words. Descriptions of 'motherese', the manner in which human carers speak to their infants, emphasise its repetitiveness and rhythm, as well as its co-production alongside gestural signs (Falk 2004), (see also Ungan et al 2013; Schmidt et al 2014). Sakai et al (2004) describe pigeons repeating the same motor sequence multiple times as able to chunk the sequence to relieve the cognitive load of the task. Honing et al (2014) report that reactions to violated rhythm can be recorded using EEG techniques in some animals including macaques, but not apparently rhesus monkeys. Rouse et al (2016) describe a sea-lion who moves its head to a range of different tempos and complex rhythms, and responds to violations. Hattori et al (2015) state that basic beat perception and entrainment is present in chimpanzees but not in such a complex form as in modern humans (Hattori et al 2013). In Sakai et al (2004) chimpanzees presented with a repeated button-pressing task were slower than humans to chunk the sequence and reduce cognitive load, but ultimately were able to compress the whole task into one comprehensive chunk.

Sakai et al (2004) examine the use of rhythm to structure activity. They equate a learner repeatedly practising a motor sequence with increasing rhythmic content as the learner starts to chunk groups of action units together – each chunk corresponds to one or more full beats. Changes in rhythm over time in a repeated action reflect a restructuring of the sequence. Chunked sequences represent a reduced cognitive load and are controlled by the cerebellum (Section 4.3.4). Parts of the sequence that remain relatively unstructured are managed by the prefrontal cortex and have a higher cognitive load. This suggests that a non-rhythmic sequence-part that becomes structured and rhythmic, changes its position in relation to its control network in a process which reduces the relevant cognitive load (Section 4.3.4; Section 4.4.1). Sakai et al (2004:no page number) state that "control of serial order has long been thought key to understanding a wide range of animal and human behavior including simple movements…complex movements…and logical reasoning. This idea is now shared by many researchers who study the neural mechanisms of sequential movements". Studies where participants repeated a button-pushing series multiple times revealed a consistent tendency to chunk relevant action units connected with particular parts of the series. The more the series was repeated the bigger the chunks became. If the experimenters split an original button-pushing sequence into sections and 'shuffled' the sections into a different order, the new sequence was learned faster if the old chunking boundaries were preserved. Processing within chunk boundaries is implicit or has a low attentional demand; "a stereotyped rhythm is the cardinal feature of automatic sequence performance" (ibid:no page number). Completing a particular chunk, crossing its final boundary and choosing a new chunk (Section 3.1; Section 5.3.4; Section 7.2; Table 7.15) requires mediation by the prefrontal cortex and a higher cognitive load results.

4.3.2 Discrete Motor Actions

Defining a discrete motor action only becomes possible in the context of a perception action framework and the existence of rhythmic repetitive action system, and so has not been considered in cognitivist research. Currently perception action researchers are still trying to piece together the way that their model functions in relation to simple action sequences (Section 3.2.2). Dynamic cognition researchers are still trying to piece together details of rhythmic repetitive sequences. Discrete actions constituting single action units or chunked action units in complex behavioural sequences are not being addressed as yet (but see Prinz et al 2013). However, we know from some perception action analyses (for example Bril et al 2009; Nonaka et al 2010; Bril et al 2012; Nonaka and Bril 2012) that a discrete action is likely to comprise a complex system in its own right, with different components of the action being slightly adjusted each time that it is deployed so as to compensate for changing task constraints. Its cognitive load is likely to be higher than a rhythmic repetitive action that relies for its success on the fact that it can be repeated indefinitely until the task outcome is achieved. A discrete action in a technological context is by its very nature only performed once because the task outcome is delicate and needs to be carefully controlled; just 'bashing away at it' is not going to be successful. This might be said to be true for example in relation to the removal of a prepared flake or the placement of an insert into an adhesive-coated distal cleft (Section 7.5.2).

Bril et al (2015) compares the potential complexity of chimpanzee nutcracking with freehand knapping. One of the differences observed is that a chimpanzee can successfully and efficiently extract a nut kernel using a variable sequence of blows most of which rely on repetition until the outcome is achieved. The sequence can consist of very similar blows delivered in series; different types of blow that change in quality as the outcome is approached; one single hard blow followed by a series of less hard blows, or a single effective blow. Effective expert knapping however requires single successful blows each with its own planned end-goal, sequenced together in order to achieve a valid outcome.

It is hypothesised here that with increased technological task complexity rhythmic repetition ceases to be sufficient for entire tool-making sequences and highly controlled discrete actions start to emerge amongst the rhythmic patterns as a new type of action unit with a new type of cognitive control (Section 7.6.1). Leconte et al (2016) differentiate between discrete and rhythmic (repetitive) actions. They compare the ability of stroke patients with motor dysfunction and normal controls to perform both types of actions using an end-effector robot. They conclude that discrete actions are more affected by stroke damage than rhythmic movements. This is similar to the difference in damage between implicit and explicit cognitive functions (Section 4.4.3) in stroke patients. In fact implicit learning functions generally are more likely to survive than explicit learning functions (Berry and Dienes 1993 Reber 1993, Elman et al 1996).

Schaal et al (2004) suggest that rhythmic movements are phylogenetically older than discrete movements in all species. In fact discrete movements only take on any kind of sophistication in primates, presumably because their main role is to control the complex primate manual effector. The authors used fMRI to examine the different brain areas activated by the two types of movement in modern humans. Both conditions involved flexion and extension of the wrist joint, but one condition required rhythmic repetition of the movement and the other required discrete movements. Rhythmic movement only activated a small number of unilateral primary motor areas including the cerebellum. Discrete movements activated the same areas, but additionally activated contralateral nonprimary motor areas 'with very strong bilateral activity in both the cerebrum and cerebellum' (ibid:1141) (Section 4.3.4). They conclude that discrete actions are a special type of rhythmic repetitive action (or potentially if described according to complexity theory, a new level of action emergent from the rhythmic system), and cannot be carried out without the support of the older system. They involve additional activation from higher action planning areas (Wei et al 2003) or what we might term a top-down process (Section 4.3.3).

4.3.3 Bottom-Up and Top-Down Processes

We have seen that during the process of a complex manual task hominin perceptual gateways will be continuously gathering in fresh information resulting in continuous and complex fine motor adjustments that control the way that the task is carried out (Section 3.2). Basic perceptual information enters at the lowest level of a complex system but still has an important effect on the task outcome. We have also seen that more complex tasks may have some kind of conceptual or top-down information active within the system which also has an effect on the outcome. An example might be frequently re-processed experiences about the best way to arrange the haft of a tool intended to be used as a knife. This is no longer episodic information but has been recombined through successive levels of the system and has become learned declarative information (Section 3.2.2). In this way we can expect a complex manual task to involve mutually interactive bottom-up and top-down information – each type can alter the dominance of the other type of information within the context of the task.

Baber (2015) states that expert jewellers start work with an overall goal in mind which is balanced by the complex interactions of a range of bottom-up processes deployed to deal as effectively as possible with the impact of the task parameters. The initial planning carried out by jewellers before starting the task tends to be very ill-defined (Collins and Koechlin 2012; Fairlie 2013), and the true outcome intentions only clarify as the task progresses and parameters are better understood. Byers and Serences (2012) distinguish between the two processes as 'perceptual learning' and 'top-down attentional control'. Perceptual learning requires repeated exposure but enables a long-lasting and stable learning process that hones sensory processing skills for very specific stimuli. Top-down processing directs attention to the most important of a range of task stimuli, perhaps to increase available response variability by engaging conscious as well as more automatic processes. The authors believe that the two types of processing share neural networks and are co-dependent. A range of variable interactions in a single system means multiple learning routes depending on the particular interaction types present throughout any particular event. Attentional learning can override or reverse perceptual learning, or just modulate the way that otherwise automatic responses to perceptual information are generated. They state (ibid:Part 7) that "even though perceptual learning can occur in the absence of top-down attention, attention may still play a critical role as a 'gatekeeper' to determine how training-induced changes in processing are expressed based on current task demands and behavioral goals".

In the Sections that follow this complex and interactive relationship between two different processes will be explored further through different sets of research. These research areas are rarely discussed as parts of the same system (or elephant) (Bassett and Gazzaniga 2011). Section 4.3.4 will discuss the relationship between the modern human prefrontal cortex and the cerebellum. Section 4.4 sets out several theoretical brain system models concerned with learning. Section 4.4.1 deals with expert behaviour. Section 4.4.2 deals with mirror neuron functions and action sequence parsing. Section 4.4.3 deals with research into the relationship between what are called implicit and explicit learning and memory systems. Section 4.4.4 discusses a model for conscious cognitive processes.

4.3.4 The Prefrontal Cortex and Cerebellum in Modern Humans

For Bril et al (2005:70) expert knapping requires the essential skill of controlling the overall goal and the intermediate or sub-goals of an activity. This means being able to sequence the basic action units of each flake removal so as "to produce a flake with the right characteristics at the right time in the sequence" and to eventually end up with the required tool. Hyeon-Ae (2014) believes that the prefrontal cortex is an essential brain area for hierarchical processing of complex behaviour which provides top-down task-control. The author describes action as a series of consecutive sub-sequences with limited short-term goals built into a multi-layered hierarchy. Units at higher levels are larger with longer time-scales, and control the shorter units at lower levels as in music and language analysis. The prefrontal cortex effectively binds (or chunks) short-term goals into longer units with longer-term goals. Koechlin and Jubault (2006) state that the posterior portion of the prefrontal cortex which includes Broca's area, usually associated with speech, and its right-hemisphere homologue, contain a system that controls the start and end states of nested hierarchical action-plan segments.

Collins and Koechlin (2012) report that the prefrontal area monitors up to three or four concurrent potential behavioural strategies during a task and predicts their likely outcomes. It chooses the strategy with the best potential outcome and subsequently abandons it for another if necessary. This process of constantly switching strategies is the cause of the overall goal ambiguity at the start of a task (Fairlie 2013; Baber 2015) and gives the task an exploratory quality (Koechlin et al 1999; Koechlin et al 2000). Ridderinkhof et al (2004) also describe the prefrontal cortex as responsible for flexible goal-directed behaviour. Alternative courses of action are assessed for future possible outcomes in the area, and subsequently evaluated for learning outcomes after task completion. The prefrontal cortex has a range of functions all of which contribute to dynamic decision-making, goal-directed action selection, appropriate response, performance monitoring and learning (Stout and Chaminade 2007; Stout 2010; Teffer and Semendeferi 2012).

Herculano-Houzel (2011a) and (2012b) touch on the significant communication links between the cortex and the cerebellum which have remained unexplored until very recently (Barton 2012). She states that the two areas scale together in relation to numbers of neurons that they contain in 28 different mammalian species. The evolutionary significance of the connection will be different in all species but is indicated by the degree of neuronal connection between the two areas. Baillieux et al (2008) classes the role of the human cerebellum as the learning and 'automization' of motor sequences and implicit learning (Section 4.4.3).

Barton (2012) states that in great apes the expansion of the cerebellum is greater than that of the neocortex in extractive foragers, suggesting a connection between the strengthened network and organising complex behavioural sequences. The cerebellum is critical for the learning of procedural sequences, and recognition of correct spatial and temporal (or rhythmical - Section 4.3.1) relationships between action units. The authors recommend an end to the distinction between sensory-motor control and cognition as it has become an impediment to understanding function and evolution. The cerebellum is connected to all major cortical regions via independent reentrant connections. It is possible that the cerebellum enables all these areas to continuously update and error-correct responses based on a comparison of actual and predicted perceptual inputs for a wide range of functions. This cerebellar activity is particularly important in relation to technological behaviours as "the cerebellum is involved in the learning of procedural sequences, recognition of correct spatial and temporal relations among behaviourally relevant actions, temporal organization of verbal utterances and planning of speech, and mental rehearsal. It also seems to be involved in processing more abstract sequences" (ibid:Part 7) (and see Barton 2001; Barton and Harvey 2000).

Bril et al (2012) believe that there is a marked continuity between humans and other primates in relation to tool-use brain networks and all include the cerebellum. In humans the cerebellum contains almost half of the entire neuron count for the brain and is involved in all cognitive processes. The lateral cerebellum connects with motor areas to organise skilled manual actions and prefrontal areas in relation to motor sequence learning and the recombination of motor information during the development of expertise (Section 4.3.1 and 4.4.1). Sakai et al (2004) describe the importance of the cerebellum in the chunking and rhythmitisation of automatic and less cognitively loaded gestures. Less chunked information accumulates less rhythmic content and is controlled by the prefrontal cortex. For the authors "a stereotyped rhythm is the cardinal feature of automatic sequence performance" (ibid:no page number). And see Whiting and Barton (2003); Weaver (2005). It may be possible to describe the network between the prefrontal cortex and the cerebellum as a combined top-down (prefrontal cortex) and bottom-up (cerebellum) system with reentrant highly protected communication links between them. The prefrontal cortex deals with processes which may be more apparent to us as conscious decisions, while the cerebellum is carrying out non-conscious operations on more highly chunked or expert information, the outcome of which is supplied to the prefrontal decision-making systems. It is also continuously processing newly learned information by chunking it, giving it rhythmic content and making it accessible for recombination with new top-down input (Forsythe et al 2015).

4.4 <u>Brain Systems That Pattern Different Types of Action Units</u>

4.4.1 Expert Behaviour

By examining the behaviour and brain activations of experts in a particular sensory-motor behaviour we can detect patterns of changes that might be less obvious in non-experts. Ericsson and Charness (1994) take this approach in their study of expertise. They state that being an expert is not the consequence of having innate and special cognitive abilities. It is simply the product of at least ten years of practice acquiring appropriate complex skills and physiological adaptations. This kind of practice allows information to be collected and chunked outside the constraints of working-memory (Paas and Sweller 2012). The authors state that all modern humans have access to this kind of learning. Ericsson and Charness believe that the expert system involves conscious decision-making processes or top-down processes that interact with and are enabled by the heightened skill-levels available from long-term memory (and see Ericsson et al 1993; Ericsson and Lehmann (1996). Forsythe et al (2015) do not refer to experts but simply to the learning process of a normal individual. For them new learning is initially under conscious control but gradually the need for high levels of awareness are reduced and information shifts from its original site in the brain to the cerebellum and basal ganglia network. In this network information can be at least partially controlled without awareness and arranged in complex sequences. This kind of transformation of information use is available to all individuals across a wide range of functions.

Bilalić et al (2011) studied brain activations in chess experts. These experts had a significantly increased perceptual ability in relation to the artefacts of their expertise. They were able to recognise the implications of the relative positions of chess pieces very fast and remember them over long periods of time. The act of recognition in experts differed from non-experts in relation to brain activation. Expert recognition involved bi-lateral as opposed to uni-lateral activation which echoes the difference between repetitive (unilateral activation) and discrete (bilateral activation) in wrist movements (Schaal et al 2004). Russell (2011) followed the structure of the chess player experiments but instead looked at the recognition capacity of experienced knappers as opposed to novices. Expert knappers were more able to recognise knapped flakes that they had previously viewed than were novices. The authors took this effect to be caused by the increased effectiveness of specific perceptual and memory systems developed by the experts as a result of repeated practice.

4.4.2 Parsing Action Sequences

In 1999 Richard Byrne set out to describe the process that he believed juvenile gorillas use to understand and learn the complex and variable manual sequences that they observe adult group members performing in order to obtain food (Byrne 1999). This learning process is bound to fall within an inter-species definition of expert learning as gorillas spend a large part of every day of their life performing this kind of activity. Byrne's minutely observed and analysed behaviours provide a more detailed description of the same learning process as that described for human expert learning. He describes sequence learning, and the cross-analysis of sequence variation which he supposes had to take place outside of conscious awareness. In this respect the 'parsing' skills of gorillas falls directly into another model described in Section 4.4.3 as implicit or sequence learning in modern humans.

Byrne (1999:63) defines the active parsing of the observed behaviour of others as the detection of "recurring patterns in the visible stream of behaviour [which are]…used to build a statistical sketch of the underlying hierarchical structure". The observer watches the repeated behaviours of model conspecifics and as a result is able to break them down into a simpler elements such as action units and event states. After observing multiple sequences, information such as re-occurring motifs or patterns of action units start to stand out, as do interruptions which define structure, or additional modules that correspond with an unusual contextual feature. Reiteration of modules will be observable as will events signalling the beginning and end of the sequence. The author predicts that "the mental apparatus to…cross-correlate among very large numbers of sequences will need to function automatically and efficiently without demands on central capacity" (ibid:66). He states that this kind of analytical capacity is also available to modern humans but at a higher level of operation which presumably involves at least some conscious processes (Section 4.4.3).

Byrne (2003) emphsises that an observer will only be able to learn sequences where all of the separate action units are already within their repertoire. He believes that where this is the case the mirror neuron system will allow a direct and embodied understanding by the observer of the nature and purpose of the action units carried out by the model conspecific (Byrne et al 2001; Barrett et al 2007; Damasio and Meyer 2008; Barton 2012; Suzuki et al 2015). Mirror neurons would not be an appropriate mechanism for the kinds of implicit learning research described in Section 4.4.3 although they may form an additional part of the learning system and it seems likely that gorillas use them. Byrne's observation of the need for the basic action units to be already knowable fits into a perception action framework where the observer already has experience of the basic units of a new action, which are observed and then subsequently recombined experimentally into more complex sequences (Section 3.2).

Jablonka and Lamb (2006) state that we inherit our behaviours within our cultural niche by observing the behaviours of others. Their behaviour constitutes information, and learning that information depends on the observer's ability to categorise, deconstruct and reconstruct behavioural segments. These learned sequences are highly flexible. They vary slightly from user to user and change in response to environmental influences. Initially they form part of the observer's niche, and subsequently they become tools used by the observer in order to take part in niche construction themselves (see also Byrne 2003; Byrne 2005; Stout and Chaminade 2009; Byrne 2016).

4.4.3 The Implicit System

Parsing behavioural sequences can easily be framed as a function of implicit learning. The implicit learning system started to receive researchers' attention in the 1990's and is still discussed in research papers today. There is a sense in the literature of something unresolved in terms of theoretical structure (Clegg et al 1998) which is hardly surprising because the implications of the research are challenging to cognitivist theory to say the least (but not to perception action theory). It has long been treated as a secondary and less important system than human conscious rational thought. There has been a recent and still only partially acknowledged shift from considering the system as inferior or only of use to people or animals who do not have a functional explicit system (Wynn and

Coolidge 2004), to describing it as the main modern human learning system without which there would be no learning at all. The implicit system enables the gorilla manual-sequence learning process (Section 4.4.2), the learning of information that has to be pieced together without being modelled, and also forms the base of a description of neural networks for conscious thought (Section 4.4.4).

Daltrozzo and Conway (2014:Introduction) state that "learning about temporal patterns in our environment, and using this information to make predictions about upcoming events and actions, is arguably of primary importance to humans and other higher-order organisms". They still believe this system is separate from the explicit system although they state that the two systems interact. The implicit system is bottom-up. It develops early and allows infant humans to learn their native language. The explicit system is top-down, deals in abstract concepts (but see Reber 1993) and involves attentional capacity. Berry and Dienes (1993) give much more detail. The implicit system enables humans to learn complex predictive patterns in their environment and use them effectively without even knowing that they have learned anything or being able to express verbally what information they are using. Implicit learning is only demonstrable by a change in the learner's subsequent behaviours. It has a huge capacity, can take place without attentional response, and it is fast in terms of learning and response provision. It is highly context-dependent however, and difficult to amend subsequently. In contrast explicit learning has a limited capacity and requires increased attention, but it can be used across all behavioural domains and subsequently adjusted. In fact, although the perception action model is not explicitly used they describe implict learning as the link between sensory stimuli and unconscious response provision. The authors state that the two systems should be thought of as combined and thus able to provide a range of different learning routes depending on the amount of attention available or required. They suggest that rather than thinking in terms of conscious and unconscious processes it is more profitable to focus on whether a situation requires learned information to be transferable to another domain or not (Section 4.4.4). Transferable knowledge needs to be explicit, implicit processes simply learn and subsequently recognise and complete patterns in context.

Clegg et al (1998) believe that the ability to sequence information of all types is fundamental to human function. They review different trials of this ability and conclude that subjects can learn sequences of different information types without or sometimes with explicit awareness. They describe the basis of the learning as establishing statistical and probabilistic relationships between different elements which are built into a hierarchical structure as they are chunked together. Once subjects become aware of information that they have learned their brain activation networks undergo a clear change as additional networks become active. Implicit learning is mainly associated with motor control networks but can take place in many different brain areas. They add that "awareness might not be the manifest property of any of the sequence learning systems that initially develop sequential knowledge. Rather, the interaction of these systems with other neural areas could cause the emergence of explicit knowledge and explicit strategies" (ibid:Part 5).

Berry and Broadbent (1984) did much work on the relationship between implicit learning and verbal reporting. They found that subjects who had acquired information implicitly were not able to answer questions about the process. Verbal instruction about the task had some effect on their ability to answer questions, but did not affect task performance. Ferdinand et al (2010) found that some of their subjects were able to explicitly recognise the rules of the sequences they were being presented with. They divided their learning groups into verbalisers, partial verbalisers and non-verbalisers. All 3 groups learned the sequences but the verbalisers, and to a lesser extent the partial-verbalisers, had different event-related potential responses (EEG methodology) from the non-verbalisers when asked to identify previously viewed sequences (cf Clegg et al 1998 in the previous paragraph). Rose et al (2010) describe a transition as individuals start to become aware of implicitly learned information and use it to make conscious choices. Event-related potential response monitoring shows a distinct process that initiates the transition before the individual is aware that it has happened. It is named a 'top-down binding signal' and indicates neural coupling (or entrainment, Section 4.3.1) between two cortical areas, presumed to indicate the formation of a new neural network which has access to explicit processes. The authors believe that this transition forms the link with higher cognitive functions and state that the prefrontal cortex is heavily involved.

Lewicki and Czyzewska (1992) describe human conscious processes as relatively slow and inefficient. They state that all psychologists know that nonconscious information acquisition is incomparably faster and structurally more sophisticated. The need to understand the implicit system becomes particularly acute when trying to understand the heuristics of perceptual information. How can such vast amounts of information which are inaccessible to awareness be absorbed without the implicit system? The authors state that we have not understood "the very foundations of the human cognitive system" (ibid:797) if we do not acknowledge its vital role in cognition. It allows us to develop inferential rules and categorise information. "Most of the 'real work' both in the acquisition of cognitive procedures and skills and in the execution of cognitive operations…is being done at the level to which our consciousness has no access. Moreover, even if the access to that level existed, it could not be used in any way, because the formal sophistication of that level and its necessary speed of processing exceed considerably what can even be approached by our consciously controlled thinking" (ibid:801). The authors state that implicit information is always directly involved in high-level cognitive operations.

Forsythe et al (2015) state that implicit sequencing is most clear in motor activity. Motor activity is continuous and is dependent on enormous amounts of perceptual information of which we are not consciously aware and cannot control. Koziol et al (2012) state that the brain evolved in order to organize gesture and behaviour. For them executive brain function is a meaningless concept. Cognitive control should be placed within a model of sensorimotor behavioural interaction with the environment. Behaviour is controlled using both implicit and explicit systems and the role of the cerebellum is critical to both. Conceptual knowledge is grounded in perceptual information which means that the brain acts as an integrated whole. A true understanding of the function of subcortical brain structures and their cortical networks leads to a better understanding of how cognition can operate outside of conscious awareness. Up to 95 percent of our daily activity is routine and performed almost automatically. They argue that introspective thought is emergent from the motor system as an extra planning mechanism to facilitate action. During action sequences automatic behaviours alternate with higher-order decision-making and control, but both types of behaviour share the same basic information. "All thinking, or thought manipulation, includes the eventual participation in action control" (ibid:519). (See also Zhuang et al 1997; Cleeremans et al 1998; Zhuang et al 1998; Lang and Kotchoubey 2000; Turk-Brown et al 2009; Dale et al 2012; Wessel et al 2012; Schuchard and Thompson 2014).

Reber (1993) examines the evolutionary implications of the implicit system. The book title is true to the ambivalence demonstrated by early researchers in this field and does not make the importance of the content clear. The author states that psychologists have ignored Darwin's work when they should have used it as the basic structure of their research. The use of the evolutionary perspective highlights the necessity to explain cognitive abilities in terms of functional adaptability, requires explanation of individual differences or variability, and places the development of cognition at a phylogenetic level (West-Eberhard 2003). The development of implicit learning systems is a fundamental evolutionary process which enables adaptive behaviour. Psychologists have failed to take learning processes seriously because they are far more interested in the representation of knowledge than its acquisition.

For Reber (ibid), if conscious thought and learning are a late evolutionary development then we need to explain how they are generated from non-conscious systems. In other words, we need to describe an accurate implicit starting-point and then formulate suitable mechanisms of change. The implicit system is capable of working with basic perceptual information and also more abstract information, indicating that systemic change in order to incorporate more sophisticated learning may well have occurred. Reber believes that the fact that the implicit system has been found to be far more robust in the face of brain damage, old age or learning difficulties than the explicit system, is evidence of its far greater age in evolutionary terms. In addition, it has a more uniform presentation throughout the population than conscious learning processes, again indicating an older and more established process. Finally, while conscious learning is reliant on implicit processes, the reverse is not true and implicit learning can occur independently. The default learning system is implicit. Researchers into the implicit system have been required to prove their findings according to cognitivist theory, however, it is cognitivist hypotheses about conscious learning that need to carry the burden of proof. Without an implicit learning system we cannot function.

Reber believes that modern human intelligence should be considered as the combined effects of both implicit and explicit systems. He believes that "we need to be careful not to treat implicit and explicit learning as though they were completely separate and independent processes: They should properly be viewed as interactive components or cooperative processes, processes that are engaged in…a 'synergistic' relationship" (ibid:23). He quotes Simon (1962) and suggests that hierarchical complexity is a theory that is relevant to implicit learning and its evolutionary development. He suggests that self-awareness emerges out of more primitive organisms' interactions with the environment, and that consciousness is a late arrival preceded by increasingly sophisticated implicit functions. He dismisses associative learning as insufficient to predict environmental change and proposes instead that learning is effected by chunking information and understanding how sequence chunks vary in different contexts (Section 4.4.2). Interestingly, Reber does not believe that consciousness is required for abstract thought – this is clearly achieved at some level during implicit trials. From a functionalist perspective, and as a researcher into implicit learning, he hypothesises that consciousness allows us to differentiate between ourselves and others, to avoid blanket automatic responses, and to achieve the generalisation of useful information across behavioural domain boundaries. The degree to which a function requires conscious content should indicate its relative position within an evolutionary dynamic of changing behaviours.

4.4.4 Implicit Systems Out of Which Consciousness Emerges

It seems appropriate to finish this chapter with some researchers concerned with establishing the kind of brain system that can support conscious thought. Much of this research is embedded in this and other chapters, but warrants reiteration in summary form. Forsythe et al (2015) state that we are accustomed to thinking of ourselves as consciously aware. However, a major trend in the last ten years has been a new emphasis on how little of our cognitive function we are actually aware of. We get occasional intimations that different processes are at work and trying to get our attention, perhaps when we hesitate or get brief glimpses of buried memories. In fact our subconscious is constantly generating competing action strategies which are usually selected for unconsciously. We can override these strategies consciously but the unconscious mind does the bulk of all decision-making work, particularly categorising incoming information and selecting it out again as required.

Cosmelli et al (2007:744) state that the conscious mode is only necessary for "time-consuming less stereotyped situations that need planning and decision-making". Brain activation networks representing a conscious state are transient and global, and bound together by active attention. There is no particular part of the brain associated with conscious thought, and the conscious networks (or dynamic cores in Edelman and Tononi 2001) constantly change their boundaries. What creates the dynamic core is the small-world arrangement of the neuronal networks (Sections 3.1 and 4.2.3) that allows for differentiated local areas to be bound together temporarily by long-distance connections in order to carry out a particular function. Small world networks, as we have already seen (Section 4.2.3), serve to reduce the average length of neuronal connections, provide high levels of synchronous activity (or rhythmic entrainment between areas, Section 4.3.1), enhanced propagation speed and systemic stability. Cosmelli et al (ibid:749) stress that synchrony is correlated with the integration of different areas in order to carry out multiple important cognitive functions including language production, and is "ubiquitous in virtually all sensory and motor modalities. It has often been found to be related to perception, memory, and motor programming".

Baars and Franklin (2007) (and see also Seth and Baars 2005; Edelman et al 2011) set out a more coherent model for consciousness that is referenced in Cosmelli et al (2007). They state that only one single brain area at a time becomes the focus of conscious thought when it is triggered by conscious attention. This area requests working memory to recruit widespread unconscious contextual information from different systems in order to shape up the conscious content. Conscious processes are very limited in capacity and computation efficiency without this support. Multiple small unconscious networks form coalitions or networks then compete with each other to supply the information (compare prefrontal and cerebellum activity in Section 4.3.4). The winning coalition is broadcast back globally to recruit further resources. Conscious recruiting networks like this are only needed where our unconscious networks cannot deal with a problem. Awareness can rove across environmental or internal features and serve as a look-out for potential problems that require conscious recruitment. The authors state that there is now substantial experimental evidence to support the hypothesis that conscious networks are much more widespread in the brain than unconscious networks (as with discrete as opposed to rhythmic repetitive actions, Section 4.3.2; explicit as opposed to implicit learning, Section 4.3.3; or the production of handaxes as opposed to Oldowan cores and flakes, Stout and Khreisheh 2015).

4.5 Conclusion

We have searched for the elephant that we believed to be in the room, and ended up following a long trail. We started in Chapter 1 with a fresh assessment of the variability of the archaeological record, and the evidence that it provides for substantial information recombination over time in respect of both artefacts and evolutionary change in hominins. In Chapter 3 we assessed complexity theory as a suitable basis for understanding behaviours and neuronal structures, and perception action theory in relation to understanding activity sequences. We discussed the potential of perception action theory to support the integration of more conceptual information, and how an understanding of affordances enabled a more precise description of natural selection. In Chapter Four we have seen how the constantly changing nature of the brain and its increasingly complex architecture enable more sophisticated cognitive processing. In particular we have seen the importance of action unit sequencing processes, how they are parsed both by observers and by agents, and their increasingly varied and complex recombined content, increased task-structure complexity and the accompanying need for enhanced awareness and context-free information transfer. All of these last elements will play an essential role in Chapters 6 and 7 which report on the two pilot studies. However, firstly in Chapter 5 we will review already-existing methodologies concerned with the analysis and comparison of reductive stone tool and hafted tool production sequences, and introduce the new methodologies used in Chapters 6 and 7.

Chapter five

Thinking through a new methodology

"The tool use action itelf may be seen to embody the actor's capacity to perceive [a] relevant stimulus and coordinate an efficient response…As such, functional approaches to the analysis of tool use behavior may provide particularly rich information regarding the cognitive abilities of [the] actor."
Parry et al (2014:Introduction)

"The approach taken in this research…allow[s] us to reduce the complexity of situated cognition and real-world production to a manageable degree by focusing on well-defined, goal-oriented, observable actions…Anthropologists have long

recognized that humans are distinguished in the animal world by their pervasive, effective, and creative use of tools. Yet few contemporary anthropologists interested in knowledge and practice have focused on actual tool use as an entrée to dynamic cognition"
Keller and Keller (1996:19)

5. Introduction

Chapter 5 introduces the two pilot studies constituting the original research content of this Thesis (Chapters 6 and 7). The studies cannot be considered as empirical or quantitative because they do not constitute controlled experiments. Rather than starting with a hypothesis to be proved or disproved the pilot studies represent an inductive process whereby data is gathered and then analysed for recurrent patterns which are of interest to the research questions posed. No single variable is manipulated at the same time as other variables are controlled. There is no full statistical analysis of results, although some basic figures are given in the Second Pilot Study to help identify inherent gestural patterns. The sample size is small in both cases. These studies are therefore presented as qualitative (Thelen and Smith 1994; Green and Thorogood 2014).

Hammell and Carpenter (2000) state that the main thrust of qualitative behavioural research is to describe and interpret data in order to generate new hypotheses and theories in fields where no workable theory exists. Because a non-cognitivist epistemology is preferred (Section 5.1) many existing theories about the relationship between cognition and tool-construction cannot be used here. There is a scarcity of non-cognitivist theories relating to the construction of full, comparable tool-making sequences, particularly in relation to hafted tools (Barham 2013b). Suto (2000) and Carpenter and Hammell (2000) state that in an exploratory qualitative context it is appropriate to use data from a variety of diverse theoretical contexts and 'triangulate' them. The eclectic nature of the epistemology used here represents this kind of approach.

The conclusion (Chapter 8) emerges from a combination of the research results described in Chapters 6 and 7 and the epistemology outlined in Chapters 1-4, and summarised in Section 5.1. The methodologies in relation to both pilot studies are set out in Section 5.2. The method for each pilot study is set out respectively in Chapters 6 and 7. Section 5.3 consitutes a review of existing *chaîne opératoire* methodologies used to analyse tool-making events in order to identify cognitive processes. Section 5.4 will discuss some of the main problems raised by the pilot studies.

5.1 Epistemology

Carter and Little (2007) stress that qualitative researchers should ensure that both methodology and method are well rooted in a corresponding epistemological base. For them the method gives visibility to the epistemology and is in turn constrained by both the epistemology and methodology from which it springs. All three must be internally consistent. The authors describe methodology as "a theory and analysis of how research should proceed" (ibid:1317); it is a second level of theory and does not constitute the actual method used during the research. It is chosen by the researcher because it is in accordance with its epistemic background. Green and Thorogood (2014) stress the importance in inter-disciplinary research and research concerning human behaviour of clarifying the theoretical basis of what is done with an explicit epistemology. They echo Carter and Little (ibid) in describing what they call macro and middle level-theory which need to be made explicit and should be reflected in the research method (cf Section 2.6.1). They state that the macro level is the one at which research questions are framed and the middle level (or methodology) often wrongly remains unclarified and implicit.

5.1.1 Summary of Relevant Theories Discussed in Chapters 1-4

This project is described in Section 1.1 as an attempt to identify and describe the cognitive differences between a group of hominins that only make and use reductive stone tools, and a hominin group whose assemblage includes hafted as well as reductive tools (Sections 1.1-1.3).

Sections 1.4 and 1.5 describe major problems with the existing and often implicit epistemology underlying attempts to use reductive stone tool technology as the main source of evidence for researching the evolution of cognition. These problems include a universal lack of definition of cognition itself, the ways in which it changes over time and the causes of that change (Section 3.2; Chapter 4). In particular the use of existing theories about cognitive processes connected with motor activity are shown to have actively impeded new approaches to research into cognitive evolution and to have supported conclusions that are are at odds with the archaeological record (Sections 1.5; 2.3; 2.4). There has been an over-emphasis on the importance of genetic identity in constructing cognition, and a neglect of the importance of behavioural processes and cultural structures at all levels of change (Sections 1.4; 2.5). The guidelines laid down by Darwin (Jablonka and Lamb 2006; Darwin 2008) that natural selection and thus evolution are the products of variability, and that their effects accumulate gradually through time, have not been adhered to. Cognitivism, the current dominant cognitive model used (usually implicitly) in stone-tool literature is critiqued in section 2.1-2.4. Alternative partial approaches that have not cohered enough as yet, to form such a pervasive model as cognitivism are discussed in Sections 2.5-2.6. Section 1.6 includes a discussion about the problems associated with hafted-tool research which has precluded this technology from being included up until now as evidence for cognitive evolution alongside reductive stone tools.

Chapters 3 and 4 set out a wide range of theoretical sources used to try and describe a new model for cognition. This model represents a flexible pattern-recognition system (Section 4.4; Forsythe et al 2015). More complex versions of the model are capable of learning and can produce expert motor performances (Section 4.4). Performances are constructed as an individual interacts with her environment through a process of information gathering, comparing new with previously experienced information patterns and with past responses. New responses are generated, constrained by the new circumstances encountered and supported by additional information search concerning the current event. Past response information is stored as embodied motor memory rather than symbols and can be accessed directly when triggered by appropriate perceptual information patterns (Gibson 1979). High levels of skilful activity can be carried out without the need for the algorithmic or conceptual processes proposed by cognitivism (Sections 2.1; 4.4). The expert activity is constructed by and through the performance of action units and the way that they are patterned and sequenced (Sections 3.1; 3.2; 4.3). The main function of what we call cognitive process is actually to ensure the interaction between information retrieval, matching with new information, adaptation to new constraints and the accurate performance of motor gestures or action units in a meaningful sequence. It is by organising and performing the gestures themselves that the cognitive process effects the retrieval and matching of information patterns and the attribution of meaning and intended outcome to the physical interaction of the organism with its environment (Section 4.4). It is the ability to organise increasingly complex, flexible and specific networks of information in order to sequence increasingly complex action sequences on a moment by moment basis that appears to emerge from known evolutionary changes to nervous system architecture (Sections 4.2-4.4).

The new model is radically embodied (Sections 3.2-3.3) and represents a complex adaptive system (Section 3.1). The system is fundamentally the same across all mammals but is highly variable in its complexity, the type of information it uses, its ability to change in response to lifetime learning, the number and types of different information sources that it can process together at each horizontal level, the different levels of information recombination that it can provide at vertical levels and the extent of its ability to generate emergent change in relation to its own processes. Inter-species variability depends on the results of interactions between multiple components for every species, including for example their unique phylogenetic histories, their different niche-environment characteristics, their resource requirements and embodied states.

Change in this system happens hierarchically across many different time-scales simultaneously, including ontogenetic, phylogenetic and evolutionary time-scales (Section 3.1). Mechanisms of change at different levels include genetic, epigenetic, developmental and socio-cultural processes, but are always closely associated with some kind of change in behaviour. Chunks or units of old behaviours are recombined with new information in order to respond to new triggers from within the niche-environment. As a result of behavioural change there will also be corresponding changes in physiological, neuronal, developmental, cultural and social structures that enable or constrain the new behaviour, if it increases fitness at an individual and / or group level (Sections 2.5.4; 4.2).

It is speculated that the most complex of these adaptive cognitive systems have evolved so as to be able to recombine information to high systemic levels where the original embodied, perceptual or episodic information context is lost and the processed information becomes conceptual (Section 3.2.2). Some connection with the ability to use complex language as opposed to basic communication systems is implicated at these levels of recombination. A system operating at this level of complexity continues to be totally dependent on its use of perceptual information, but increases its fitness through the additional interactive use of slower but highly flexible attentional systems that recombine conceptual information (Sections 4.4.3; 4.4.4). Such conceptual sub-systems are in turn unlikely to develop outside of a highly-integrated group niche that provides infants with appropriate behaviour models, external information, cognitive scaffolding and practical experiences so that they can learn to use them effectively (Section 3.2). They are generated best through active and physically-based learning as they must be embedded within the more fundamental perception action information systems without which they cannot function. In relation to concepts or symbols that are used at a group level there must be some kind of group consensus about how they are used or are unpacked from situation to situation. They are effectively created by the group as a whole through embodied interaction rather than being retrieved innate, fully-formed and identical from the brains of each individual.

Any individual using this cognitive system in order to construct artefacts does not need as in cognitivist theory, to intellectually generate a full mental template of physical behaviour sequences for the body-slave-system to act out. Some kind of intention or purpose is clearly needed to start the construction process but it does not have to be well-formed (Baber 2015). Reed (1996) states that intentionality is not a derived or highly evolved action quality, but one possessed by all organisms. Without intentionality an organism's gestural sequences would be randomly constructed rather than patterned (Sambrook and Whiten 1997; Gibson and Pick 2000) and it would have no evolutionary fitness. As soon as the organism's body, its effector and perceptual organs and any tools come into contact with the raw materials, information will start to feed back about the current situation, triggering relevant past information input and pattern-matching with the present situation. As a result of the gestural process of interaction with the environment and its substrates the individual starts to form and manipulate sub-sub and sub-goal sequences as necessary (Section 4.3) in order to structure the event-in-process, and to reconcile her orginal intentions with the end-product or goal that is actually achievable in the circumstances.

Sections 5.2.1 and 5.2.2 will set out each of the proposed pilot study methodologies and show clearly how they relate to the project epistemology which is summarised here. Section 5.2.3 will comprise a review of *chaîne opératoire* literature devoted to the analysis of cognitive processes through the analysis of reductive and hafted tool-making processes. Comparisons between the quality of data generated by the literature reviewed and the new methodology used in the Second Pilot Study (Chapter 7) will be made in Section 7.6.5. The review will also illustrate more generally why researchers should clarify and make explicit their own epistemologies and methodologies before designing any type of research method, whether quantitative or qualitative.

Both methodologies used here are observational. In both cases the researcher recruited tool-makers with a certain level of experience that matched as far as possible the experience-levels of hominin tool-makers. And in both cases the tasks that they were asked to carry out were only minimally pre-structured by the researcher so as to avoid effectively providing them with a mental template. The aim was not to control behavioural variables, but rather to watch them change and interact through and between task stages, across tasks and tool-makers and across different technologies. The tasks were filmed and the footage was then worked through by the researcher using the different information-gathering processes detailed in Chapters 6 and 7. The tool-makers were not told beforehand what particular information the researcher was interested in, nor were they asked to try and identify any particular conscious thought processes as they arose during the tasks. The researcher was more interested in changes in the embodied task performance and wanted that performance to stay as 'natural' as possible (Keller and Keller 1996; Stout 2002, 2005a; Baber 2006).

Both methodologies involved an assumption derived from their common epistemology that analysis of the task performances would reveal some kind of patterning of gesture. The main question asked in both cases was whether or not changes in any detected patterning might reflect changes in cognitive strategy. In both pilot studies the researcher attempted to identify patterns and pattern-changes in the gestural sequences although a different method of pattern identification was used in each case.

West-Eberhard (2003) and Byrne (2005) describe behaviour as divided into subunits which are discrete and dissociable and can be reiterated, omitted, chunked together or reorganised depending on constraints and goals. Subunits of behaviours can be categorised at different levels right down to brief muscular contractions. Their organisation always reveals patterns. Bril et al (2009) and Byrne (ibid) emphasise individual gestural interactions between the organism and environment as the units to be analysed. Reed (1988; 1996) states that a unit of behaviour is any single gesture that results in a change in the relationship between an individual and her environment. The unit as defined can always be further subdivided and together with other units always forms a continuous stream of activity. Behaviour is made up out of microscale impermanent units or neuromuscular events which the individual must organise into "ecologically meaningful patterns". The author states that the organisation is carried out by the neural system. This system compares a range of different pattern-options and creates the optimal pattern in the circumstances (Section 3.2.1; Sporns &

Edelman 1993; Kelso 1995; Reed 1996; Bingham 1998; Byrne et al 2001; Edelman & Tononi 2001; Byrne 2003; Roux & Bril 2005; Baber 2006; Cosmelli et al 2007; Latash 2012; Nonaka & Bril 2012; Rein et al 2013; Parry et al 2014; Forsythe et al 2015).

5.2 Methodologies

5.2.1 Methodology of the First Pilot Study

The methodology for the First Pilot Study (Chapter 6; Appendix 3) was selected by the researcher because she was already familiar with it through her work as an occupational therapist. Occupational therapists (OTs) are Allied Health Professionals. They work in interdisciplinary teams in medical settings alongside doctors, nurses, physiotherapists, speech therapists and psychologists. OTs are concerned with the rehabilitation of patients who have suffered any kind of mental or physical illness that has affected their ability to carry out purposeful activity. They are taught to be conscious of their professional epistemology because it is different from that of their colleagues who (with the possible exception of psychologists) all work with medical models. OTs have always been behavioural specialists even when it was difficult to admit to such a thing (Bloch 2012). With the temporary disappearance of behavioural science during the twentieth century (Bloch 2012), they have had to formulate their own theoretical frameworks and models of practice, and even introduce their own academic discipline (Occupational Science). Hocking and Wright-St-Clair (2011:Introduction) define occupation as "self-initiated chunks of activity…that are organized into patterns, routines and roles…have practical or symbolic significance…and promote development"

It is the job of an OT to understand the true complexity (Royeen 2003; Ikiugu 2007) of the individual patient's life as a developmental process which continues post-illness; to isolate the components of the dynamic most likely to alternatively hinder or promote recovery; and to arrange appropriate therapeutic sessions. Therapy always takes the form of activity, as real dynamic change can only be effected by behavioural change. The process of coming to understand individual patients' lives requires a long process of initial investigation using a range of formal and informal quantitative and qualitative assessments. Then a behaviour-based therapy programme can be devised and ongoing quantitative assessment used to monitor and assess change.

Gary Kielhofner (1949-2010) was a prominent occupational scientist. He constructed a model for OTs known as the Model of Human Occupation or MOHO (Kielhofner 2008). It describes the main areas from which OTs should extract information about their patient as volition, habituation, performance capacity and environment. Volition relates to motivation to act and changes as experience is accumulated over time. Habituation refers specifically to accumulated learning and memory, and the role that they play in the present. Performance capacities consist of interacting variables such as biological and cognitive systems and the current state of perceptual and effector organs. Environment includes a wide range of spaces, objects, past family history, institutions, cultural assumptions and educational experiences. The goal of the patient is to achieve 'occupational adaptation' which emerges through time as the interactive variables of volition, habituation, performance capacity, and also group participation self-organise into a more effective dynamic.

The MOHO model provides a good starting point as it corresponds directly with the project epistemology. Its methods are designed to enable OTs to assess a patient's competence in carrying out activities of daily living after some major crisis has occurred. The assessor looks for dysfunction in the behavioural patterns presented. She is trained to observe levels of different interacting behavioural variables that present throughout the behaviour, and to make judgements about which of them can be considered as being present at 'normal' levels. The variables with abnormal levels are the ones causing dysfunction, and become the subject of therapy.

Behavioural variable levels observed during the recreation of Pliocene and Palaeolithic tool-making sequences cannot be defined as dysfunctional.

However, it is possible that observed behavioural variable changes in chronologically ordered tool-making tasks result from increasing cognitive challenges. Using an OT observational method offered a way of identifying which behavioural variables changed during the progressive task reconstructions (Kelso 1995). The method was used across a wide range of tasks and provided the qualitative and observational context required by the epistemology as well as emphasising the importance of cognition-in-action. It produced sufficiently useful results to enable the design of the Second Pilot Study which was based on a coding method.

5.2.2 Methodology of the Second Pilot Study

After scrutinising the results of the First Pilot Study it was felt that more detail should be obtained during the Second Pilot Study (Chapter 7) of the individual gestures that made up each stage of the different tool-making sequences recorded. Coding was identified as the best observational methodology for retrieving this kind of detail.

Bakeman and Quera (2011) recommend the use of behavioural observation methods where the subjects of the research are unable to simply tell us the answers to our questions. They add that observational data collection may also be preferable if the activity involved is non-verbal and not easily described in words. In relation to the Second Pilot Study the original hominin tool-makers are unavailable for questioning, and their modern human stand-ins are likely to be engaged in an implicit activity when tool-making, the intricate details of which are not accessible to their language networks (Sections 4.4.1-4.4.3). Indeed we should question whether it is appropriate or even effective to ask modern humans to use their language networks at all in a context where hominins may not have had access to such a resource (Section 5.4). Bakeman and Quera (ibid) suggest that just observing a series of behaviours allows them to unfold 'naturally' without being artificially controlled. Observation also provides data that relates to change through time. This effect cannot be provided by static empirical experimentation. They state that the use of a coding methodology imparts a systematic quality to what would otherwise be a straightforward qualitative narrative. This quality arises from the act of compiling a code and consistently applying it to particular observed objects and aspects of behaviour in order to provide categorised data. This information can be further analysed and provides a basis for understanding cause and effect processes. Finally, coding is a standard methodology associated with behavioural analysis where it is the behavioural process itself rather than its outcome that is of prime interest.

Coding provides a categorisation system for information extracted from long, continuous or intermittent behavioural sequences. If the coding system is designed appropriately according to a rigorously compiled coding protocol (Bakeman and Quera 2011) the resulting data is collected in a complex adaptive system information format (Section 3.1). It can go on to form the basis for comparison with similar behaviours across different tool-makers, or the same tool-maker behaviours with different parameters operating, thus providing a basis for a better understanding of variability. It can be reliable and totally verifiable even if it is collected manually. It can become the subject of statistical analyses although the codes themselves only represent nominal data.

5.3 A Review of Current Chaîne Opératoire Approaches

Chaîne opératoire (CO) methodology is extremely well established within archaeological and palaeoanthropological disciplines in respect of the analysis of different reductive stone-tool production processes. Without the skills of artefactual analysis and experimentation associated with CO, the high level of expertise within the archaeological community in relation to stone-tool technology would not be possible. Soressi and Geneste (2011) provide a summary of the methodology's history (Section 2.4). It starts with the work of Leroi-Gourhan (1964) whose intentions were that it should be used to establish a theory of human technological skill and cognition within varied socio-cultural cultural settings. Schlanger (1990:20) quotes him as saying that "the tool really exists only with the gesture which renders it technically efficient". Proponents of

CO continued to express the idea that stone tool-making analyses should extend to other interacting non-lithic technologies and socio-cultural contexts (Section 1.5) through the 1990's. Cognition could be addressed because analysis of the tool-making processes ("operational schemes" ibid:337) would involve the isolation of the tool-makers' working concepts. These would become clear because of their "regularities" or constant reappearances which could be used as evidence of the tool-makers' intentionality.

In practice however, Soressi and Geneste (ibid) conclude that CO methodology was mostly used as a tool for lithic technology analysis. Section 1.5 describes how its use in this capacity alongside a cognitivist model frequently (but not always) results in standardisation of the archaeological record rather than in a description of its variability. Soressi and Geneste (ibid) conclude that the CO technological approach has resulted in some major accomplishments, but it has not fulfilled its original intentions of analysing cognition and casting more light on "the relationship between the social and the economic context and the dynamic of technical changes" (ibid:340). They recommend an increased focus on the "phylogeny" of artefacts through time and on the "cognitive and motor skills of the different human species and subspecies throughout human evolution" (ibid:344) – issues which they describe as having been "underestimated" until now. They believe this will involve an increased level of collaboration with evolutionary developmental researchers, cognitive scientists and researchers into comparative (animal) cognition.

This sub-section examines the methodology's limitations in relation to analysing cognition in more detail, and seeks to show how an observational coding methodology used post-CO-analysis might help. CO can be used for a sophisticated analysis of technological procedures but cannot in and of itself provide information about cognition-in-action motor or gestural skills. In particular, as we will see, it has never been used to describe a technological dynamic through time with its connected cultural and social changes. One of the reasons for this is because as it currently stands the methodology can only attempt to analyse the cognitions behind one type of prehistoric technology. The very structure of the CO cognitive analyses is based on the reductive nature of the processes that it is used to describe. It seeks to describe and compare all the products of an original piece of stone as it is broken apart through time using different techniques. It uses the fact that the pieces, including debitage, can theoretically all be fitted back together again, making refitting one of its most effective procedures. The analysis of (hafted) tools that are made by joining together parts derived from widely different raw materials, some of which are the products of induced-change and combinatorial technologies (Section 1.6) rather than reduction technologies, will require a new formulation of the methodology. Up until now this reformulation, and as a result the potential importance of alternative technologies including hafted tools, has been neglected (Sections 1.5 and 1.6).

Figure 5.1 is an illustration taken from Shea (2016) which describes the basic stages involved in the removal of a flake from a stone core, the characteristic marks left on both core and flake by the removal, and by the subsequent retouch of the flake which finalises the intended morphology of the tool. This diagram is drawn according to a set of protocols common within CO methodology which are designed to highlight the features which allow for technological analysis. It is not common practice to use photographs as these carry a great deal of information which would be irrelevant or even distracting, and do not always provide such clear outlines of adjacent, or fitting fracture surfaces.

Figure 5.2 portrays a very similar knapping sequence based on the analysis already provided by Figure 5.1 but using the flow-diagram format which has since become ubiquitous in stone-tool analyses. The box on the left representing the role of mental templates is not usually made explicit but remains an important implicit part of the format.

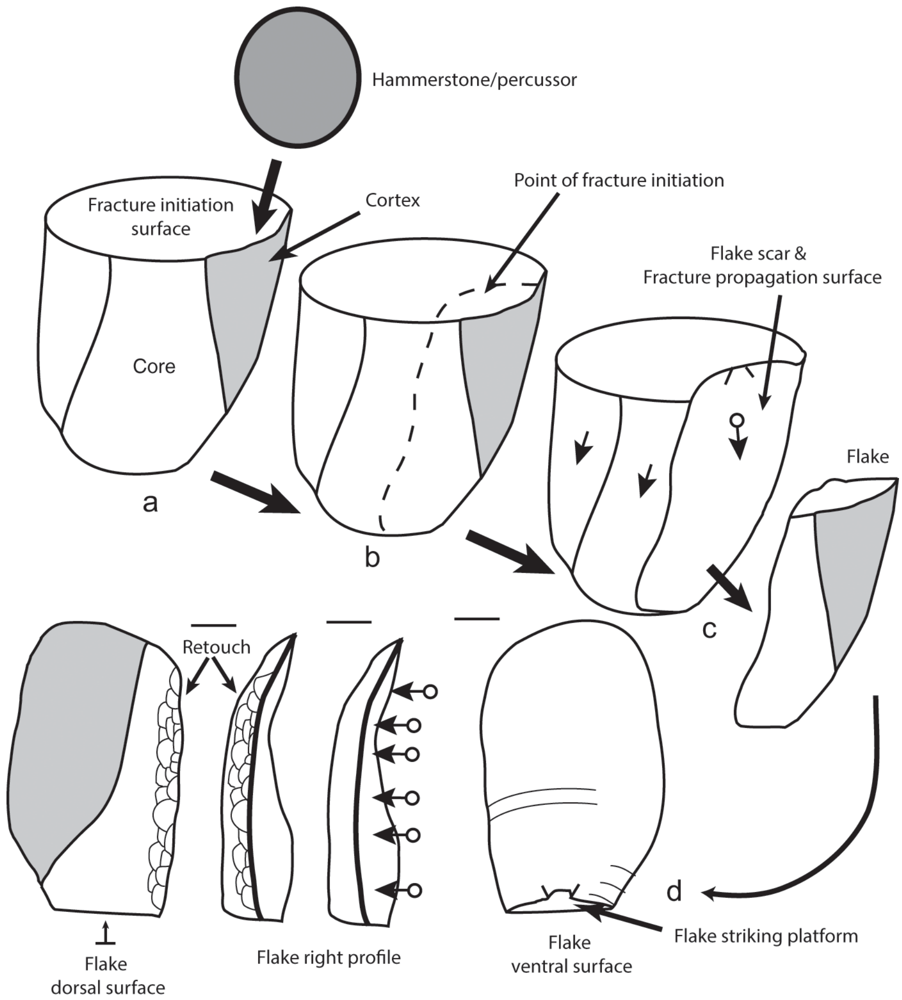

Figure 5.1 *Chaîne opératoire diagram taken from Shea (2016) to illustrate a commonly used technological format which emphasises the processes, techniques and potential refitting of stone reduction at the expense of any other type of available information*

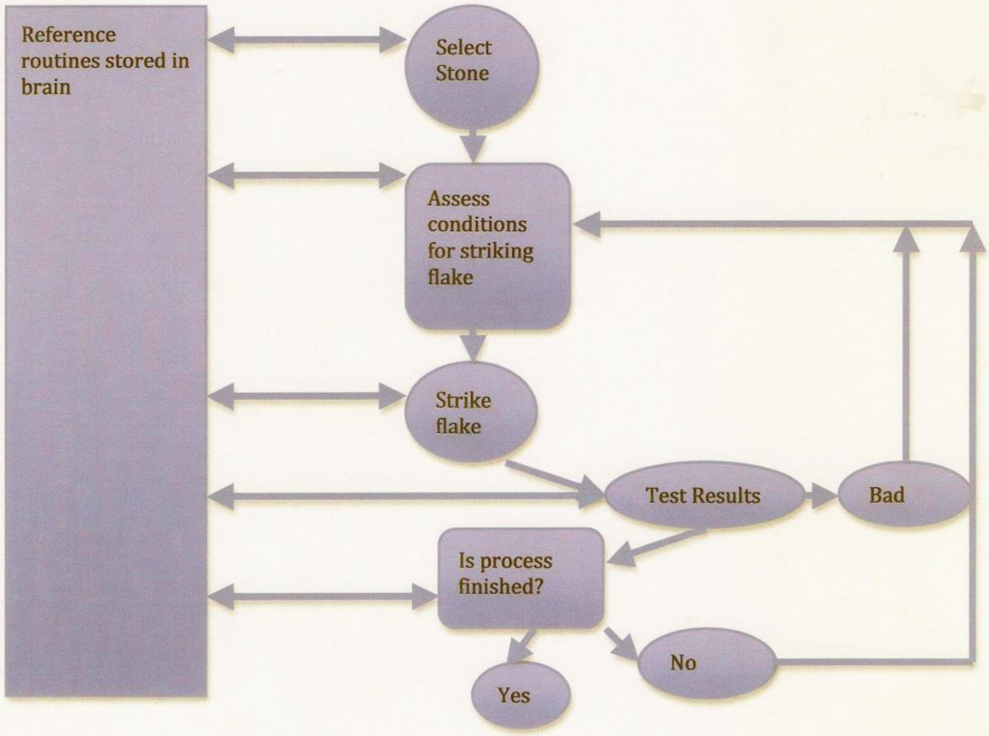

Figure 5.2 *A very early CO flow-diagram adapted from Gowlett (1990) showing the same basic stages as figure 5.1 but also including their theoretical relationship with predetermined cognitivist mental templates (box on left).*

The basic gestural sequences represented in Figure 5.1 are converted by the theoretical presence of mental templates into 'decisions' or the skeleton of a disembodied cognitive process in Figure 5.2. Karlin and Julien (1994) provides a good example of this type of analysis. For them derived modern human cognition is described as different from that of animals because it is based on 'intellectual' activities and the use of algorithms. This new type of thinking is represented during the reductive tool-making process as a series of mental representations which allow a task to be entirely preconceived. Without this planning ability the task process cannot be completed because the gestures that make up the task are "purely motor faculty know-how" (ibid:159), (and see Rogers et al 2016 for an up-to-date equivalent).

It is interesting to note that another paper published in 1994 (Schlanger 1994) represents an opposing view about the best use of CO. This view was eventually silenced by the subsequent popularity of the model exemplified by Karlin and Julien (1994), but may now be enjoying a renaissance. Schlanger describes CO as a practical research tool but as "neither explanatory, nor sufficient" (ibid:143) to explain the relationship between material behaviour and cognition. Concepts such as 'mental template' are "inadequate and impoverishing" (ibid:148). He follows Leroi-Gourhan and Lemmonier in regarding actions or gestures as components in an '*enchaînement*' of stages and sequences that create meaning through transformation. Just as in complex language, gestures are arranged in a syntax of technique which grants both fixity and flexibility to operational sequences.

Although a sense of the importance of embodiment is missing from this account it represents an attempt to describe cognition-in-action, as knowledge is continually accessed, assessed, chosen, applied and generated in a new form throughout the tool-making process. Schlanger's choice of the dual interacting concepts of flexibility and fixity (or specificity here) exactly repeats the main joint qualities that a complex adaptive system bestows on its internally generated information (Holland 2014 and Section 3.1).

We have already given good reasons for regarding the cognitivist model as superseded by modern developments in cognitive, developmental and complexity theory (Chapters 2-4). Additionally, because decisions or concepts are discussed in relation to these diagrams but never defined in terms of a cognitive model of dynamic change over time, the use of the diagrams imply that *all* reductive tool-makers have the same modern-human-like conscious decision-making faculty. Tostevin (2011) criticises this use of CO methodology to construct quasi-cognitive processes and states that just because the modern analyst with a huge reservoir of knowledge about different knapping techniques can perceive potential options about how to proceed with a knapping sequence, it is not right to infer that a hominin knapper ever went through conscious decision-making processes at the same points. Comparing CO flow-diagrams greatly separated by evolutionary and archaeological time (up to about 2.5 million years by now) does not yield information about difference or change in the relevant cognitive processes involved, except potentially that later tools took longer to make (hence reinforcing the popularity of working memory theory – Section 2.3.2).

Another related problem of using the information in the flow diagram in Figure 5.2 to portray a cognitive process is that it is the wrong type of information – it is too domain-specific and only serves to describe stages in a reductive tool-making sequence. Just as nominal data cannot become the subject of statistical analyses, words describing unspecified groups of gestures defined only by their relationship with a standardised knapping sequence cannot be used to describe a cognitive process unless that cognitive process is entirely knapping-specific and suffering from an excess of Fodorian modularity (Fodor 1983). In this study a cognitive system is viewed as a system that recognises patterns in information, irrespective of where that information comes from or what it is going to be used for (Section 5.1.1). The same system is used for hafting tools, collecting fruit or caring for a baby and should be described in terms which can equally apply to all of these and many other behaviours besides.

Garofoli and Haidle (2014) suggest that behaviours and cognitive processes from different behavioural domains cannot be compared without 'translating' the domain-specific information relevant to each behaviour up to a higher common level where they can all be described and compared using the same language (and see Botha 2008). It is suggested here that appropriate translations of domain-specific information can be made into complex adaptive system language if, and only if cognition is framed in perception action terms (Section 2.6.1 and see Glossary at Appendix 4).

Moore (2011b) comments that most archaeologists use CO methods to analyse cognitive processes. For him this means that they are trying to understand gesture organisation in the form of goal-driven concepts, but are not paying any attention to lower-order organisation or the basic units of gestural activity in each reductive technology. These units can be shown to be rearranged across technologies to form increasingly complex hierarchical structures through archaeological time. Moore is explicit about the shared neurological substrate between the cognitive processes that structure motor activity and complex language. He sets out the basic flake unit in Moore (2011b). Basic flake units can be performed in a simple chain during which the knapper carries out an automatic activity without room for any conscious activity that displays intent. It is only when analysis of a reductive artefact shows that the basic flake units have been nested in hierarchical groups in order to adjust a platform angle (complex flake unit), or additionally to grind the striking platform (elaborated flake unit), that he is able to say that the tool-maker shows intentionality or presumably modern human behaviour (Section 2.3.1). For Moore some bifaces may show intentionality but it is only clearly observed in the production of Levallois flakes.

This description begins to reflect the approach taken in the Second Pilot Study here which looks at the way basic gestural units are grouped together at different task levels in order to produce more or less specific results. It puts an appropriate emphasis on the importance of the gestural unit. Moore however, has translated child psychology-specific language (Greenfield 1991) straight into knapping-specific language in order to categorise his flake units. What was really needed was to find a separate language generalisable to both behavioural domains and carry out analyses using that language. The language in Moore (2011b) is still knapping-specific and cannot be used for hafted tools or for any other behavioural domain. It cannot therefore cast any light on an analysis of relevant cognitive processes other than that there is a strong possibility that they all become increasingly hierarchical over time (Section 3.1). His conclusions about the quality of 'mind' associated with the different identified patterns is cognitivist and implies a step-change to modern human behaviour with the introduction of Levallois flakes. Hafted tools, which ought to epitomise the highest level of behaviour described by Greenfield (1991) in terms of prehistoric technologies are not even mentioned.

Interestingly, Hayashi et al (2006) and Hayashi (2015) use Greenfield (1991) to analyse manual gestural routines of great apes and humans, and of primate percussive tool-users respectively. They actually use a coding methodology to do this (and also see Tan et al 2015 who use a sophisticated coding methodology in relation to macaque tool-use behaviour), but while there is no hint in these papers of a search for a step-change in cognition, the descriptions remain domain-specific. The authors believe that the gestures are patterned implicitly (Section 4.4.3), but that there is an increasing cognitive challenge through evolutionary time in formulating "an appropriate combination of actions and objects in an appropriate sequence" (Hayashi 2015:section 5). They find Greenfield's subassembly strategy (or in Moore's categorisation, the elaborated flake unit equated with Levallois manufacture) to be within the capacity of humans, chimpanzees and capuchins (Hayashi 2015:section 4), (and see Givon 1998; Carvalho et al 2008; Leca et al 2011).

Stout (2011) discusses the need for a better method for identifying and describing the variability of different Palaeolithic technologies, focussed on the tool-making process rather than the final artefact. He believes that CO is not able to generate the necessary comparisons between different technologies and cannot directly describe or analyse cognitive processes either. He specifically mentions Moore's work and his use of Greenfield's theory, and goes on to produce a slightly more detailed version of Moore's hierarchical diagrams in order to show increasing hierarchical structure through evolutionary time. He believes that as the hierarchical element of the task increases, the cognitive system becomes increasingly able to form sub-sub and sub-goals in order to be able to maintain control of the flexible sequence of nested gestural groups as they unfold (Section 4.3). He speculates about an increased flexibility of method and specificity of outcome. However, he also uses descriptions which are domain-specific so that just as for Moore his only clear result is that tasks become increasingly hierarchical over time. Stout et al (2014) pursues the same theory but uses handaxes dated from around 500Ka from Boxgrove as evidence that more sophisticated and more finely made tools are the product of extra layers of hierarchical knapping, namely in this example platform preparation and the intermittent use of a soft hammer. Both papers are interesting but they remain knapping-specific and not applicable to hafting. No hard evidence is provided by the diagrams as to how an increasingly hierarchical structure is organised by cognitive processes.

Haidle (2010) describes and illustrates the use of her own type of mental template flow-chart which she calls 'cognigrams'. She extends her analysis from just naming decision-making moments to also considering environmental objects at different stages of the task in her diagram. This is a hesitant first step towards embodied cognition but it results in diagrams which are difficult to understand. She describes her method as being enhanced *chaîne opératoire* (CO). It illustrates what she considers to be single steps in tool-making processes defined as short sequences of activity based on a series of different 'foci' of attention. She states that this method clarifies the importance of the underlying working memory theory taken from Wynn and Coolidge (Haidle 2010), but it is not clear how this works.

Haidle's use of working memory theory is problematic (Section 2.3.2) and its relevance is not made clear by the cognigrams. Haidle claims that the cognigrams allow for comparison between different tool-making events. This would certainly be an asset but no real comparison is presented in this paper that leads to new information about cognition. As with the previous hierarchical methods we are just left with the impression that increasing cognitive load throughout the tasks is represented by increasingly complicated diagrammatic content. However, importantly Haidle is the first theoritician who attempts to use the same diagrammatic method to analyse both reductive and hafted tools.

There is an attempt to compare the cognitive content of three different tasks in Lombard and Haidle (2012); the construction of a wooden spear, a hafted spear and a bow and arrow set. All three tasks are said to require the 'decoupling' of tool from immediate need. The second and third tools require a 'combinatorial' ability. The bow and arrow set alone also requires an ability to conceptualise two tools that act together. The first and third of these supposed cognitive abilities have no basis in reality outside of cognitivist concepts. The second cognitive ability described (combinatorial ability) is a useful idea in line with the cognitive theory used here. However, it needs a great deal more unpacking. A fourth suggested cognitive ability ascribed to the second and third tools is the "modularization of action units" or in other words the ability to sequence hierarchically nested gestural units, reflected by Haidle's increasing use of hierarchical diagrams over cognigrams for more complex tools. Wragg Sykes (2015) discusses how impoverished her cognigram-generated data involving Neanderthal hafted tools are in relation to the rich archaeologically-generated data that she sets out in the article.

Haidle's cognigrams do not relate to specific events but are constructed out of standardised mental templates. Because they do not derive directly from observed events they do not have the explanatory power or the variability that data collected through direct observation are able to contribute to the analytical process. A changing hierarchical structure involving an increasingly flexible and complex arrangement of different nested sub-sequences is a set of characteristics generated by all complex adaptive systems. The hierarchical structure becomes more marked as the system continues to change and adapt through internal emergent change (Section 3.1). By translating observation-derived coded data from different tool-making events up into a CAS language it becomes possible to discuss all of those events in the same terms and to examine their similarities and differences. But it is also necessary to replace the interpreted data from each observed event back into a niche-construction or 'real-life' context so that it can also be described in domain-specific terms. This replacement is likely to assist in providing an explanation for the inter-event differences and similarities.

Muller et al (2017) have produced an observational study of a sequence of reductive stone-tool-making events which they compare quantitatively in an attempt to identify changes in cognition through time. They claim to be using Haidle's work as a model but they only use hierarchical diagrams as opposed to cognigrams. They do describe her 'problem-solution distance' or task duration as one of the quantities to be analysed in respect of each event. This duration is broken down into units which they call 'phases' which represent the sections of the task spent concentrating on one or another of the various 'foci of attention'. This has the effect of starting to create a hierarchy breadth (Section 3.1) as each phase respectively can be broken down again into smaller units. They create vertical depth as well (Section 3.1) by using the number of hierarchical knapping levels relevant to each event as in Stout (2014). Although reference is never made in the paper to complexity theory the way that the data are formatted and used takes on the form of complex adaptive system (CAS) theory. The nature of the results adds to this effect as they show increased numbers of phases per knapping event over time and increased hierarchical depth.

This new appearance of an unacknowledged complex adaptive system in the paper conflicts with brief attempts to justify other aspects of Haidle's work (for example working memory theory – Section 2.3.2) which do not provide support. The authors attempt a description of the cognitive processes involved in a knapping process (ibid:177) which has very little to do with problem-solution distances and mental templates, and a lot more in common with the cognition-in-action of perception action theory. The authors and their work would benefit from the additional structure and methodology available from an explicit use of a perception action cognitive model.

The language used within the diagrams remains knapping-specific as although it takes on a hierarchical format, it still describes a series of task stages. There is a serious confusion in the paper that arises every time these task stage labels are referred to as cognitive processes. The two things are simply not equivalent. Cognitive processes, as has frequently been pointed out in this chapter are behaviour-general and should work for all kinds of evidenced behaviours. A different language is needed to describe them. The CAS generated by this research does not portray a dynamic of cognitive change.

A second problem follows on as Muller et al (ibid) comment repeatedly that there is little or no difference between the performances generated by different knappers. This is contrary to all empirical evidence, both cognitivist and non-cognitivist, generated by the observation of one individual performing the same task repeatedly, and different individuals all performing what appears to be the same task (Section 3.2.1 on the uncontrolled manifold). The evidence shows that while task outcomes remain constant across repetitions, the ways in which they are performed by the body always vary (Latash 2012). This apparent error arises here from the inappropriate use of task stage labels and a lack of interest in embodiment.

The data used to compare performances across tool-makers have been based on whether intellectual task stage concept sequencing is or is not consistent, not embodied gestural performance. CO scholars all share intellectual knowledge of different technology task stage structures in the form of both episodic and non-episodic information and are extremely likely to repeat them exactly when reconstructing particular technologies. They also only study reductive tool-making sequences where the order in which task stages is performed are non-optional (fixed) as opposed to the flexible order of performance in hafted tools which increases the potential for variability. It is possible that the illusion that tool-production requires a capacity to create and store fixed task-stage sequences as concepts has been sustained because only fixed task stage (reductive) tool-making has been analysed. Using data wrongly to try and show that when concept sequences remain consistent so does physical performance, tends to reinforce cognitivist error.

Muller et al (ibid) place their technology-types in order of increasing complexity and identify the Levallois flake sequences as the most hierarchically complex processes. It is suggested that the degree of hierarchical complexity may not be the only source of cognitive load in a tool-making process. There is a difference between making a hierarchically complex tool where the process is still relatively short and reliable, and making a tool with a lesser level of hierarchical complexity that requires constant high levels of attentional control because of a prolonged duration with a high risk of failure caused by fixed task stages. When the researcher asked the tool-maker Karl Lee which reductive and or hafted technology he found most difficult he named lanceolate points which take up to two days to complete and which carry increasingy high costs of failure through the process as a result. These constraints are also applicable to a slightly lesser degree, to thinned hand axes. Again, the assumption that the hierarchical aspect of the process is the only cognitive component of any importance reflects the fact that data are not replaced back into a real-life or niche-construction perspective for interpretation in CO methodologies.

The use by Muller et al (2017) of a Levallois definition (Boëda 1995) (and see Moore 2011b) rather than a prepared-core definition is also problematic because it changes the chronological relationship between all of the technologies examined. The earliest dates for Levallois flakes are given as Middle Stone Age which makes them more recent than hand axes and therefore prompts a conclusion that the cognition behind them should be more evolved. However non-Levallois prepared-cores and flakes (proto-Levallois) can now be dated back to about 545Ka (Barham 2013b) or even 1Ma (Li et al 2017), and are associated with the concurrent early presence of blade technology (Barham 2013b). De la Torre (2016) dates handaxes between 1.7-0.01Ma. Highly thinned hand axes are found at Boxgrove dated at about 500Ka (Roberts and Parfitt 1999) which makes them an additional concurrent technology. Also see Herzlinger et al (2017) which describes a prepared core technology used to shape flake blanks for cleavers at Gesher Benot Ya'aqov at around 780Ka. The tool-types are therefore potentially part of the same assemblages before local variability is taken into account, and rather than replacing each other as brains get better, they all have differentiated and interactive roles to play within dynamic group technological profiles.

This leads onto another problem with all CO analyses of cognition which is that they usually do not include hafted tools which are clearly a vital part of any cognitive evolution dynamic (Section 1.4). This has been partly because of a rather strange voluntary blindness to the existence of this technology (Barham 2013b) reinforced by the difficulty of evidencing its presence in assemblages and recreating its task stages (Section 1.6). It is also likely that analyses of hafted tools have not been carried out because of an over-dependence on CO analytical methods designed and only suitable for reductive tools. Muller et al (ibid) express a desire to analyse hafted tool-making processes but have clearly not done so in this paper because of methodological problems. The hierarchical diagrams can only describe stone reduction processes. Wood reduction would require a different set of labels that would not be comparable. Induced-change and combinatorial processes would not sit in the same format at all. The hierarchical structure of knapping results from the fact that flakes are removed in sequence and each removal affects the next series of removals and is dependent on the previous set of removals in a predictable way. This kind of structure is not present, for example, in the creation of a haft cleft, in the mixing of ingredients to make adhesive or the fitting of a blade into a shaft. The reductive task displayed in a hierarchical format cannot therefore be compared with other types of technology. Combinatorial tasks are hierarchical overall but hierarchy is guaranteed only at the task stage level and not necessarily at the gestural level. This means that the magnification of hierarchically analysed reductive and combinatorial tasks would be different and not directly comparable as a result.

Bril et al (2005) is a difficult paper but it involves a tentative attempt to explore activity sequences as structures with interconnected levels that provide depth and breadth. It is best read in conjunction with Bril (2015) which is a theoretical discussion and provides a clearer account of some of the material contained in the earlier paper. The (2005) paper is presented as one empirical trial but actually contains a range of different sets of trials all run together. Different methods of data collection are used for each of these sub-trials and both methods and the implications of their results are not always clearly described. However, this paper is interesting because the authors attempt to try and analyse two comparable types of observed knapping tasks carried out by two different groups of experienced knappers (bead-makers from Khambat in India), one with more expertise than the other. This is the first paper that makes some attempt to analyse and compare differences in gestural sequencing in order to infer cognitive processes, particularly in relation to the context of the transfer of skills from a well-learned task to a novel one. It is additionally interesting because it uses an explicit perception action rather than a cognitivist model. It sets out to show that the gestural patterns of the two types of task are variable across each knapper for each knapping event, and between task-types. The cause of the variability can be different degrees of expertise or the introduction of an unfamiliar raw material but it is not always identifiable or predictable. In the presence of such variability the authors conclude that the cognitivist assumption of pre-task fixed mental templates is not theoretically viable.

It is also significant that Bril et al (ibid) try to describe the knapping process as having different layers of operation, all of which interact and all of which are grounded in basic gestural sequences (see Nonaka et al 2010 which describes some of the unobservable aspects of single knapping gestures which change over time to improve knapping processes at all levels). Again we have the potential implicit introduction of a CAS, although there are some problems with the description of the different operational layers and their connections with the methods employed to try and record changes within them. The most basic layer of activity is constructed from minimal gestures which are classed as the smallest possible functional action unit available to the knappers. These mostly consist of hammer-blows to the stone or glass bead. The next layer up consists of minimal gestures or hammer-blows which are grouped together to make up single units described as 'sub-goals' but which look like individual task stages. The highest layer consists of the entire task or what is described as the full sequence of sub-goals. This kind of quasi-cognitive description of the top two layers but not of the lowest layer relates straight back to CO methodology and raises all of the same problems of mixed gestural and quasi-cognitive language that we have seen in connection with all of the papers already discussed. If the second layer of activity could be described as groups of gestures with identifiable first and last gestures forming group boundaries, then the top layer could be described as a task-length sequence of groups of gestures. As a result a genuine hierarchy would be created, and the current apparent conflict between the proposed presence of sequenced sub-goals structuring the task levels, and the proposed absence of mental templates would be avoided.

This review identifies a series of recurrent problems with CO-based methodologies used to try and identify changes in the cognitive processes associated with tool-making. With the exception of Bril et al (2005) they make an unevidenced assumption that all tool-makers start their process by accessing a mental template made up of what are variously described as concepts, decision-making points or sub-goals which do not change across all tasks of the same 'type'. All of the real cognitive work is therefore described as either being completed before the sheer automatic labour of making the tool is commenced, or at isolated intervals throughout the task. The gestural 'filling' between points of cognition is not considered worthy of analysis. Any changes in cognitive ability through time is construed as changes in the ability to store more complex mental templates and get them acted out by the body. This assumption becomes so overriding that resulting inconsistencies with the archaeological record, especially in relation to the dating for prepared-core technology, or the unanalysed presence of hafting technology are ignored. Although the biological mechanisms of this type of cognitive change are never described they are somehow associated with the increasingly hierarchical diagrams drawn up in relation to reductive tools. All that the body needs to carry out its menial tasks is information from the mental templates and an increasingly effective 'working memory' as the tasks (and diagrams) get more complex. Changes are presumably deemed to be the result of modular genetic mutations to the brain, although such changes have so far not been evidenced by neuroscientists, including changes proposed by Wynn and Coolidge (2004) to working memory (Section 2.3.2).

This model does not allow for the description of cognition as an interacting series of processes which are domain-general and which work for all behaviours. Cognition is only ever described in terms of knapping. The question of how it should be described in relation to other behaviours is never addressed. No account is taken of the unusually fixed nature of gestural sequencing in stone reduction which perpetuates the idea of static mental templates for all types of behaviours. There is no room for a consideration of the embodied nature of cognition and its relationship with the physiological changes that we know are associated with evolution. There is also no room for the distributed nature of cognition within a niche-construction environment or for the role of social and cultural variables in cognitive change through evolutionary time. In particular the spontaneity, variability, individuality, manual skill and sheer artistry of creative behaviours is completely lost in what becomes a standardising process.

All of these problems are addressed by the observational analysis carried out in the Second Pilot Study. This is done by using gesture as the basic unit of analysis at all operational levels of the event, as opposed to any quasi-cognitive unit. Gestures are comparable across any type of behaviour and fit easily within a coding methodology. They are also interconnected with cognition at all moments when a perception action cognitive model is used (Section 3.2). In the Second Pilot Study (Chapter 7) the patterns made by different levels of gestural sequences are identified and compared across tool-makers, tool-types and technology-types, and across comparable task-stages. Section 7.6.5 summarises the ways in which the new gestural coding methodology overcomes the problems raised here of using CO as a direct method of cognitive analysis.

5.4 Problems With the Observational Methodologies in Chapters 6 and 7

5.4.1 Definition of a Hafted Tool

Although there is now an increasing interest in hafted tools, we do not have a standard set of complete tools from the time period in question to use as the basis of reliable reconstructions. This is partly due to the taphonomic frailty of organic hafted tool components. In addition, hafting technology becomes more variable precisely because of its increased complexity. The hafting technological system is capable of producing a range of more task-specific products out of a wider selection of localised resources. In order to recreate hafted tools for this project it has been necessary to rely heavily on use-wear and trace analyses of stone hafted tool inserts from a range of sites (Rots 2003; Rots 2004; Rots & Williamson 2004; Rots & Van Peer 2006; Rots 2009; Rots 2010; Rots et al 2011; Wilkins et al 2012; Barham 2013b; Hardy et al 2013; Monnier et al 2013; Yaroshevich et al 2013; Lemorini et al 2014; Miller 2014; Morales & Verges 2014; Rots & Plisson 2014; Claud et al 2015; Rots et al 2015; Wadley et al 2015; Wilkins et al 2015) in order to understand which haft engineering techniques were likely to be appropriate for reconstruction. The lived, perceptual-action based experience of the two hafted tool makers involved in the recreations in Chapters 6 and 7, was also essential. They are both professional tool-makers whose livelihood depends on a high standard of reproduction and knowledge about the archaeological record, and both have experimented with different techniques in their own right.

5.4.2 Do Modern Human Brains Work Like Hominin Brains?

When modern humans are used to recreate hominin knapping routines, researchers may be open to the criticism that they are using evolutionarily more modern brain functions than the hominins would have had access to, and that experimental results may be misleading. Chapters 3 and 4 describe modern humans as having primate brains which have increased in size over time in predictable ways in order to accommodate the increasing neuronal volume and connectivity that enables more information recombination and more complex behaviours. This means that when the modern human brain is involved in straightforward motor functions which are demonstrably within the capabilities of hominin tool-makers, original basic neuronal networks are still available as a substrate of the existing modern human neuronal network (Section 4.3.4), and are likely to be the ones employed in the relevant activities (Stout & Chaminade 2007; Stout et al 2008; Stout & Kreisheh 2015; Muller et al 2017). A possible reservation would be that the manual differentiation showed by modern humans recreating these tools might be more marked than that of the earlier hominins involved in stone reduction (Section 3.2.3). There may also be differences in the earlier morphologies of both upper limbs and in perceptual processes, particularly the ability to focus the eyes on close objects and in the distribution-density of manual sensory receptors.

In relation to stone-reduction we need to stick to tool-making sequences that are well-evidenced by *chaîne opératoire* methodology in order to maintain this surety. Introducing language-use into the sequence for example, may well be anachronistic and trigger inappropriate neuronal networks (Section 4.4.3). Correspondingly with wood-reduction, adhesive and twine production we need to use verifiable technologies in order to analyse the processes involved. Exceptions are seen in the use of a gas ring for heating adhesive and metal pans to contain it, by the hafted tool-makers in Chapters 6 and 7. The gestural sequences involved and their associated task stages were not analysed for this project.

5.4.3 Sample Size

One of the reasons for using a qualitative rather than a quantitative methodology for the Second Pilot Study was the small sample size available in terms of modern humans capable of recreating skilful hominin knapping and hafting events. Any empirical study in these circumstances would have had difficulty claiming significance for its results. Although the Second Pilot Study uses some quantification processes to show patterns in the retrieved gestural data, it makes no claim that another tool-maker doing the same tasks would produce exactly the same patterns. Instead, the aim of the Second Pilot Study is to show that gestural sequences *have* patterns at multiple levels and to enquire further into the causes of their similarities and differences as far as is possible within the constraints of the data obtained. Increasing the sample size and number of different technologies analysed would not result in evidence for standardised gestural patterns. Instead it would result in an increased variability of gestural patterns. However, the nature of their combined variability and similarity would provide further information about the combined flexibility and specificity of the underlying cognitive processes.

5.4.4 Guide to Reading Coded Sequences

Due to the innovative use of a coding methodology in order to collect data the way that the results of Pilot Study 2 are set out will present an initial problem as the format will be totally unfamiliar. Figure 5.7 below shows the data or information-string for the haft creation task stage of a thrusing spear (KL4 3d). A brief set of instructions will be given here for reading this coding and as a result, the coding sequences for all other task stages analysed by the Second Pilot Study (Appendix 2).

{(vii)e(vii.07.06 – 07.08shaft) (xvii.07.09 – 07.15)} {(xi)d(xi.07.16point) (xi.07.17shaft) (vi.07.18flint flake) (vi.07.19 – 07.21small quartzite hs)} {(ii)a(ii.07.22 – 07.24retouch flake laterals) (i.07.25)} {(ii)9(ii.07.26 – 07.33) (viii.07.34small quartzite hs) (i.07.35) (vii.07.36shaft)} {(xvi)g(xvi.07.37 – 07.38) (vi.07.39small quartzite hs)} {(ii)8(ii.07.40 – 07.47flake laterals) (viii.07.48 – 07.49small quartzite hs)} {(xvi)a(xvi.07.50 – 08.06tapering cleft prongs) (i.08.07)} {(xvi)a(xvi.08.08 – 08.43) (i.08.44 – 08.47)} {(xvi)g(xvi.08.48 – 08.49) (vi.08.50small quartzite hs)} {(ii)10(ii.08.51 – 09.10flake laterals) (viii.09.11small quartzite hs) (i.09.12)} {(xvi)a(xvi.09.13 – 09.56tapering cleft prongs) (i.09.57 – 09.58)} {(xvi)a(xvi.09.59 – 10.20) (i.10.21 – 10.22)} {(xvi)a(xvi.10.23 – 10.25) (i.10.26)} {(xvi)a(xvi.10.27 – 10.28) (i.10.29 – 10.31)} {(xvi)h(xvi.10.32 – 11.35) (viii.11.36flake) (vii.11.37point)} {(xvii)b(xvii.11.38 – 11.47) (vi.11.48 – 11.50small quartzite hs)} {(ii)a(ii.11.51 – 11.55bulb & butt) (i.11.56)} {(ii)a(ii.11.57 – 12.01) (i.12.02 – 12.03)} {(ii)a(ii.12.04 – 12.06) (i.12.07)} {(ii)a(ii.12.08) (i.12.09)} {(ii)a(ii.12.10) (i.12.11)} {(ii)a(ii.12.12) (i.12.13 – 12.14)} {(ii)a(ii.12.15 – 12.24) (i.12.25 – 12.26)} {(ii)a(ii.12.27) (i.12.28)} {(ii)a(ii.12.29 – 12.33) (i.12.34)} {(ii)a(ii.12.35 – 12.37) (i.12.38 - 12.40)} {(ii)a(ii.12.41) (i.12.42)} {(ii)a(ii.12.43) (i.12.44)} {(ii)11(ii.12.45 – 12.48) (i.12.49) (viii.12.50small quartzite hs) (i.12.51 – 12.52)} {(xvii)(xvii.12.53 – 13.06)}

Figure 5.3 *Coding for the haft creation task stage of the thrusting spear – KL 4(3)d*

The information records two levels of the gestural hierarchy of the task stage. The most basic gestural level recorded by the pilot study was the action sets which are shown between the smooth brackets (see Appendix 4 – Glossary - for a definition of action sets). The action set sequence provides a continuous stream of information that comprises the backbone of the task stage. For quantification purposes the action sets have subsequently been divided up into action set groups (Appendix 4) and these are shown by the curly brackets. When trying to 'read' the coding to understand what happened during the task stage it is best to ignore the action set groups and just read straight through each action set. The curly brackets can be ignored as can the corresponding turquoise codes. A key for all of the different action set group codes can be found in Appendix 1. The key for the action set codes in the smooth brackets (or list of action set types) is shown at Table 5.1 and again at Table 7.2.

Code	Action Description
(i)	Information search
(ii)	Dominant hand flake removal
(iii)	Flake caching for later retrieval
(iv)	Turn object being worked on
(v)	Debris clearage
(vi)	Retrieve / change tool
(vii)	Retrieve / change object
(viii)	Put down tool
(ix)	Non-dominant hand flake removal
(x)	Bi-manual flake removal
(xi)	Put down object
(xii)	Dominant hand sawing wood
(xiii)	Four-way snap of wooden shaft
(xiv)	Hammer wedge into shaft distally
(xv)	Adjust wedge in shaft
(xvi)	Strip wood
(xvii)	Adjust insert in shaft
(xviii)	Bind cleft
(xix)	Trim binding with flake
(xx)	Gouge cleft in wood
(xxi)	Apply adhesive
(xxii)	Press insert into adhesive
(xxiii)	Clear excess adhesive
(xxiv)	Insert lateral wedge into cleft
(xxv)	Remove wedge
(xxvi)	Hammer in lateral wedge
(xxvii)	Dip cleft end into adhesive
(xxviii)	Rock-cut into cleft using flake
(xxix)	Pass part of tool through flame
(xxx)	Manually mould adhesive
(xxxi)	Stir adhesive

Table 5.1 – *Complete list of action set type codes and the actions that they represent – red action sets represent general actions, blue action sets are knapping-specific and purple action sets are hafting-specific*

The roman numeral codes in the smooth brackets (Figure 5.7) are some of the codes listed in the left hand column of Table 5.1. Using the table, the nature of the action set sequence being performed during KL4 3(d) can be established. For this haft creation the first action set represents the retrieval of the wooden shaft and the time taken for that gesture is shown as 3 seconds. The second action set shows the tool-maker trying out the stone insert (knapped in KL4 3c) in the cleft that has already been cut into the shaft (KL4 3b) for 7 seconds. Continuing to read in this way we watch the tool-maker put down the shaft and insert and pick up a small hammerstone and flake, sharpen the flake, pick up the shaft again and then use the flake to strip the wood round the cleft and the cleft prongs to reduce its overall bulk. All the points at which he stops to look closely at what he has done are shown as 'information search' or (i). The inter-nesting of wood reduction with intermittent resharpening of the flake tool is shown clearly using this methodology. Finally the flake tool is put down and the insert is picked up once again and re-tried in the reduced cleft. This is followed by several groups of knapping action sets as the insert is reduced further to improve the haft fit, and then tried for a final time in the cleft to see if the overall haft (Section 1.6) is up to standard. (For a full description of the formation of action set groups see Section 7.4.) KL4 3(e) is a shaft-stripping task stage and the haft completion is coded in KL4 3(f) (Table 7.1).

5.5 Conclusion

This chapter bridges the gap between the epistemological background provided by Chapters 2, 3 and 4, and the methods employed by the two Pilot Studies which follow in Chapters 6 and 7. It describes the fundamental methodology out of which the methods emerge. Chapter 8 will finally reconcile the combined Pilot Study results with the epistemology of chapters 1-4.

Chapter six

The first pilot study – an observational analysis of changes in behavioural variables across a range of reductive stone tool and hafted tool-making events

6.1 Introduction

The First Pilot Study aims to establish the feasibility of observing and analysing behavioural tool-making sequences by identifying and monitoring behavioural variables throughout the sequences that act as foci for technological and associated cognitive change.

Section 5.2.1 discusses methods used by specialist occupational therapists (OTs) when assessing cognitive dysfunction in modern human patients (Turner et al 1996; Hammell & Carpenter 2000; Jongbloed 2000; Royeen 2003; Carter & Little 2007; Ikiugu 2007; Kielhofner 2008; Hocking & Wright-St-Clair 2011; Green & Thorogood 2014). The OT observes the patient carrying out a behavioural sequence familiar to them, in a location where they regularly carried it out before becoming ill. She also observes a range of behavioural variables within the sequence which are common to most modern human behaviours. She compares her patient's behavioural variable levels during the observation with expected or 'normal' levels. This methodology is strictly observational and does not necessarily include the recording of quantitative information during the sequence. However, the variables provide qualitative information for each individual observed, and a base level from which therapies can be planned, and quantifiable assessments used. It was decided that observational analysis was a relevant qualitative model for the First Pilot Study and that it might lead to more quantitative assessments in the Second Pilot Study.

Fairlie & Barham (2016) give full details about the First Pilot Study. It is included in full in Appendix 3, so the description given here will act as a summary.

6.2 Method

Reconstructed tool making events representing different diagnostic tool-types were chosen so as to observe changes in the interactions between behavioural variables over archaeological time. The tool-types consisted of:

a. Oldowan chopper core with one retouched flake made by the reductive tool maker (RTM)
b. Acheulean flake-based biface made by the RTM
c. Prepared core with one retouched prepared flake made by the RTM
d. Hafted end scraper and arrow(a) made by combinatorial tool-maker 1 (CTM1)
e. Arrow(b) and an atlatl spear made by combinatorial tool-maker 2 (CTM2)

The RTM was filmed carrying out the first three tasks which were all reductive stone tool-making tasks (Section 1.1). Two separate hafted tool makers (Section 1.6) referred to here as CTM1 and CTM2, were each asked to make two hafted tools. Only the assembly task stages as opposed to the preparatory stages of the hafted tool-making process were filmed (Section 1.6.3). Section 7.6.4 explains why preparatory stages are not included in the pilot studies. CTM1 made a hafted end scraper and an arrow in parallel. He worked the hafted end scraper to the point at which the insert was bound into its cleft, and then repeated the process in respect of the arrow. This meant that both tools had adhesive applied at the same time which represented a good saving of time and effort. CTM2 made his two tools separately. He did not use adhesive on the atlatl spear as he wished to re-use the point subsequently for another tool.

Each tool-making session was filmed using a hand-held Samsung HMX-F90 camcorder. The footage was run on a Mac Pro laptop DVD player with a resolution of 0.5 of a second, and changes in levels of various behavioural variables were noted and are described below in Section 6.3. The groups of behavioural variables used are shown in Table 6.1.

Behavioural Variable Groups	Example Variables
Postural	Seated, crouched
Mobility	Walking, bending down
Handling	Grip, hand differentiation
Flows and paces	Smooth transition between gestures and performance duration
Tool and object moving	Drag, lift, push, tilt
Muscle synergy	Force of blow, fix / activate muscles
Sequencing	Initiate, continue, terminate
Tool and object choice	Change tool, change object
Tool and object organisation	Fetch more binding, cache good flakes
Appropriate reactions	Repair step fracture, straighten wooden shaft
Information search	Examine core surface, listen to hammer noise

Table 6.1 - *Behavioural variable groups (after Table 1 from Fairlie & Barham 2016)*

Task diagrams were also drawn up (Appendix 3:Tables 2-7) showing proposed divisions between the two different levels of action units designated as 'action sets' and 'task stages'. Tables 6.2 and 6.3 are examples of two hafting task diagrams showing the divisions between these two types of action units. Each block of horizontal divisions on the Table which share the same colour form a task stage, or a separate part of the task. Each separate horizontal division is an action set or series of similar gestures which in series make up the task stage.

The diagrams show the boundaries between different action sets and task stages, and also the relationship between boundaries and behavioural variable change. The definition of relevant reductive task stages was taken from knapping literature (Andrefsky 1998; Odell 2004). For hafted tools no such definitions existed. It was necessary to be guided by CTM1 and CTM2, and by recurrent patterns in their activity over several tool-making events (Roberts & Parfitt

1999; Bril et al 2005; Hallos 2005; Goren-Inbar 2011; Langbroek 2011; Lombard & Haidle 2012; Section 5.4.1).

Each task stage consists of a series of different action sets or groups of actions. Action units comprising individual gestures were not used. Complete task stages are represented by coloured blocks and the action sets are shown by the horizontal divisions within the coloured blocks (Appendix 3:Tables 2-7). The right hand column of the tables shows changes in behavioural variables associated with boundaries between action sets and task stages, including a change in the type of affordance being sought by the tool-makers at those moments (Section 3.2; Reed 1996; Gibson & Pick 2000; Lockman 2000; Roux & Bril 2005; Turvey 2013; Stout & Hecht 2014; Witt & Riley 2014; Baber 2015; Wilson et al 2016a,b).

The main aims of this analysis were to establish:

a. The usefulness of selecting and observing behavioural variables in order to trace change
b. Whether behavioural variable change was gradual or took the form of step-change at the transition between reductive and hafted tools
c. The best basic unit of analysis (for example complete task, task stage or action set) to be used for the second pilot study
d. Whether an analysis of action unit boundaries would assist a description of increasing complexity

6.3 Results

Results are presented here in two different ways. First, changes observed in behavioural variable groups are discussed. Each Section from 6.3.1 to 6.3.11 discusses changes in one of the variable groups listed in Table 6.1 Second, the task stage diagrams are commented on. Sections 6.3.12–17 deal with each of the task diagrams illustrated in Appendix 3 (Fairlie and Barham 2016):Tables 2-7.

Tables 6.2 and 6.3 are based on two of the most important task diagrams and are shown here for convenience.

6.3.1 Postural Variables

Posture changes continually (Reed 1988). Here only major changes such as moving from seated to standing or crouching postures were noted. All reductive stone tool tasks shared similar seated postures. Everything required for the task was fetched to the sitting place before starting. Bending down to the ground whilst still seated was the biggest postural change observed. A seated posture was common during hafted tool events, but it varied more depending on which body parts were in use during particular action sets. For the delicate movements to open a cleft in wood, movement would be concentrated lower down the arm than for knapping, with more muscle fixation in order to provide additional stability. More posture changes were noted during hafted tool events as the tool-makers mobilised to fetch additional objects or tools, or dealt with adhesive. This group was considered to represent a step-change at the transition to hafting.

6.3.2 Mobility Variables

This behavioural variable group varied in the same way as posture (Section 6.3.1). It was considered to represent a step-change at the transition to hafting.

6.3.3 Handling Variables

These variables allow the body to maximise its connection with an object or tool, effect manipulation, and differentiate between different hands (Guiard 1987; Bingham 1988; Boesch 1991; Byrne & Byrne 1991; Guiard 1997; Fagg et al 1998; Berti & Frasinetti 2000; Byrne et al 2001; Corp & Byrne 2002; Byrne 2003; Maravita & Iriki 2004; Byrne 2005; Corbetta 2005; Holder 2005; Pelegrin 2005; Baber 2006; Bonifazi et al 2007; Iriki & Sakura 2008; Cardinali et al 2009; Uomini 2009; Braccini et al 2010; Geribás et al 2010; Bril et al 2012; Osiurak

2012; Rein et al 2013; Williams et al 2014; Almecija et al 2015; Harmand et al 2015; Kivell 2015; Malafouris 2013; Massen & Rieger 2016). Grip variability during reductive tasks was related to the size of the core being held. Additional support for large cores was provided by secondary body parts. Manual differentiation was consistent throughout all tasks. A wider range of grips was employed by the CTMs. Their range of different tool-types was greater, as was the range of basic movements required. This group was considered to have the potential for gradual change with a more marked change evident at the transition to hafting.

6.3.4 Flows and Paces

Retouch during knapping tasks was fast and had an audible rhythmicity. Both pace and rhythmic quality appeared to decrease with the flake-based biface and the preformed core and flake-making as hesitation and information search became more dominant. Rhythmicity and flow were evident in hafted tool reductive action sets involving wood and stone, but were lost during combinatorial actions sets. Fairlie & Barham (2016) (Appendix 3), report that the tool-making durations in the first pilot study increased with each reductive tool event. However, Section 7.5.3 indicates that during the same series of diagnostic technological events carried out by two other knappers, the biface had the longest duration. The reasons for this are discussed in Section 7.6.3. It appears that constraints encountered by RTM when knapping the flake biface in the first pilot study have distorted its duration results. Despite these inconsistencies it is clear that levels of performance pace and flow, which are increased by rhythmic repetition, are indicators of gradual change and show marked change at the hafting transition.

6.3.5 Object Moving Variables

These changes co-varied with choice of tool and object variables (Section 6.3.8) and were not considered separately.

6.3.6 Muscle Synergy Variables

This group of variables are not all directly observable. They consist of interactions between the components of individual gestures such as calibration of a blow, its direction of force and individual muscle synergies (Bril et al 2012; Nonaka et al 2012). The group is important because it represents the next level down of subdivided action units, and provides links with important inter-disciplinary research. It was felt that these unobservable variables must perforce show increased variability at the same time as all observable behavioural variables also increase their variability.

6.3.7 Sequencing Variables

This group contains the important behaviours of initiating action, continuing it and terminating it. These can all be lost after brain damage, making daily living tasks almost impossible (Grieve 1993). Also included is the ability to sequence the individual action units such as action sets or task stages into a meaningful order, so that the desired end product is achieved (Simon 1962; Sakai et al 2004; Bril et al 2005; Delagnes & Roche 2005; Roux & David 2005; Smitsman et al 2005; Baber 2006; Jablonka & Lamb 2006; Koechlin & Jubault 2006; Kotwica et al 2008; Stout et al 2008; Stout & Chaminade 2009; Stout 2011; Bril et al 2012; Lombard & Haidle 2012; Nonaka & Bril 2012; Roncaglia-Denissen et al 2013; Baber et al 2014; Daltrozzo & Conway 2014; Stout et al 2014; Baber 2015; Stout & Khreishe 2015). The ability to sequence implicitly contains the continuous use of initiation, continuation and termination in interlocked mosaic units, as well as a recurrent element of choice between options at some level of consciousness as the task unfolds. This group is considered to be another indicator of gradual change.

6.3.8 Choice of Tool and Object

The first pilot study shows a step change between reductive events and hafted events for this behavioural variable (Appendix 3). However with additional tool-makers involved, the second pilot study showed additional gradual change across reductive tools as well (Sections 7.5.3-7.54).

6.3.9 Organisation of Tools and Objects

This behavioural variable was subsumed into Section 6.3.8.

6.3.10 Appropriate Reaction Variables

In a perception action framework action action units are generated in response to the current layout of affordances (Reed 1996; Gibson & Pick 2000; Lockman 2000; Roux & Bril 2005; Turvey 2013; Stout & Hecht 2014; Witt & Riley 2014; Baber 2015; Wilson et al 2016) and when these layouts change unexpectedly then the agent must change her gestural response in order to adapt to the new situation. Gestural response changes were observed as more frequent in relation to hafted tools. Hafted tool manufacture involves more raw materials, techniques, tools and affordance detection skills than reductive tool manufacture. The potentital for unexpected events becomes higher, requiring a better ability to respond adaptively. However the variable was taken to be capable of gradual change. The RTM had to make significant changes to his original intention when the raw material for the biface turned out to be full of impurities (Fairlie 2013). This adaptation would not have been necessary if the technology had been Oldowan.

6.3.11 Search for Information

A perception action framework postulates that no mental task-template is produced by a tool-maker before commencing her task (Section 3.2). Instead she gathers information through all perceptual gateways throughout the task, allowing her to sequence her gestures in the moment. During the First Pilot Study many of the gestures were identifiable as information search which involved manipulating the object without modifying it in order to gather visual, haptic and aural information. Fairlie & Barham (2016) (Appendix 3), observed that information search increased across all tasks. In the Second Pilot Study the proportion of information search gestures were quantified for all task stages and a straightforward relationship between task complexity and increased search was not proved for reasons discussed in Section 7.6.1. Information search remains a fundamental behavioural variable which allows continuous adaptive behavioural responses to take place and is highly sensitive to changes in activity.

6.3.12 Task Diagram For Oldowan Core and Flake

This diagram is shown in Appendix 3:Table 2. The main unit of action used is the task stages. These are indicated by the coloured blocks. The action sets are shown by the horizontal divisions within the coloured block. The action set type is shown in the left hand column and information in the right hand column is information about behavioural variable changes related to action set boundaries. There is little information available about relevant affordances although the inference is that they are all related to flake removal. Information about the gestures making up the action sets is limited. The diagram shows that the Oldowan task has three task stages and that the two main ones are repetitive. The boundary between the last two task stages is associated with a change of object as the core is discarded and some kind of decision is made about the flake to be used for retouch. The order in which the task stages must be performed in order to achieve a retouched flake is fixed which indicates a lack of flexibility and weak boundaries (Section 3.1).

6.3.13 Task Diagram for Flake-Based Biface

This diagram (Appendix 3:Table 3), shows four task stages as opposed to the three of the Oldowan task. According to academic tradition (Andrefsky 1998; Odell 2004) there are one or two task stages missing as the biface is not thinned and finished. The action set detail does not provide any information about why. The number of tools in use has increased from the Oldowan process, but does not include a soft hammer or abrader as would have been expected. The last three stages are all repetitive and fixed in sequence.

6.3.14 Task Diagram for Prepared Core and Flake

This diagram (Appendix 3:Table 4), demonstrates four task stages for prepared core and retouched prepared flake. It is not possible to use the diagrams to establish why this task took longer than the flake-based biface (Section 6.3.4). Again the task consists of fixed repetitive task stages although there is a new element of recursion here as the knapper alternated between preparing the core and removing prepared flakes.

6.3.15 Task Diagram for Hafted End Scraper and Arrow(a)

Hafted tool task diagrams are more informative. They provide some kind of story-line although information about the action sets themselves is still sparse. Table 6.2 shows CTM2's two tools made in parallel. The hafted scraper has seven task stages while the arrow has nine. They share their adhesive task stages. Changes between tools and objects occur at action set boundaries as well as task stage boundaries, and there are posture changes at task stage level as well. The opening task stages for both tools are not fixed and could have been carried out in different orders.

Parallel Hafted Scraper and Arrow(a) Sequences	**Tools, Objects and Final Affordances**
Mobilise; choose raw material Mobilise; assume seated posture	Blade core Blade core stable
Tilt blade core to search for suitable area	Suitable area located visually
Retrieve soft hammer	Soft hammer Hammer and blade core stable
Prepare striking platform, strike and cache blade Repeat Action Set several times	Several blades detached Put down soft hammer Put down blade core
Retrieve small hammerstone	Small hammerstone Blade and hammerstone stable
Retouch flint blade unifacially from ventral side around perimeter	End scraper completed Put down small hs and end scraper
Retrieve prepared wooden shaft; assess visually and haptically	Wooden shaft Assessed as appropriate for the task
Retrieve debitage blade	Debitage blade

	Wooden shaft and blade stable
Use debitage blade to clear nodules and trim proximally	Area designated is clear
Retrieve soft hammer (bone)	Soft hammer Soft hammer, blade and shaft stable
Insert lateral edge of debitage blade into distal end of shaft and hammer in with soft hammer	Cleft long enough Put down debitage blade and hammer
Retrieve scraper insert	Insert Handle and insert stable
Place insert into cleft. Assess visually and haptically	Scraper blade held in place by cleft
Mobilise; retrieve length of prepared twine	Twine Incomplete tool and twine stable
Bind twine tightly around distal part of cleft	Haft strongly bound Put down incomplete tool
Mobilise; retrieve two unprepared dried flax strips	Flax strips Flax strips stable
Use binding technique to create length of twine	Length of twine completed Put down twine
Retrieve blade debitage and assess visually	Blade debitage Assessed as appropriate for insert
Retrieve small hammerstone	Small hammerstone Blade debitage and hs stable
Retouch debitage unifacially from ventral side along one lateral	Small point completed Put down small point
Retrieve prepared shaft and assess visually and haptically	Wooden shaft Slight deviation from the straight
Bend shaft in opposite direction to deviation and re-assess	Slight deviation persists
Repeat previous action set until end of Stage	Shaft assessed as straight
Retrieve debitage blade	Debitage blade Blade and shaft stable
Strip bark from shaft using dorsal side of debitage blade	Designated area clear
Retrieve soft hammer	Soft hammer Soft hammer, blade and shaft stable
Insert lateral edge of debitage blade into distal end of shaft and hammer in with soft hammer	Cleft created Put down blade and soft hammer
Retrieve point	Insert Insert and shaft stable
Place insert into cleft and assess visually and haptically	Insert held in place by cleft
Mobilise; retrieve length of twine	Twine Twine and incomplete tool stable
Bind twine tightly around cleft	Haft strongly bound Put down incomplete tool

Mobilise; retrieve gas ring and match box	Match Striking surface Gas ring Match, striking surface and gas ring stable
Strike match; apply flame to gas ring	No flame Remove gas cylinder and dead match
Mobilise; replace gas cylinder and re-light repeating Action Set above with new match	New gas cylinder New match Flame
Mobilise; retrieve pan of solid adhesive and place over flame – repeatedly assess visually, haptically and olofactorily	Pan of solid adhesive Adhesive melted
Mobilise; retrieve goose feather and incomplete tool	Goose feather Incomplete tool Feather and incomplete tool stable
Use feather to spread melted adhesive over bound area of scraper	Bound area fully covered Put down goose feather
Assess adhesive coverage visually	Excessive coverage
Retrieve piece of hide	Hide Hide and incomplete scraper stable
Pass incomplete scraper over flame; wipe excess adhesive onto piece of hide	Coverage appropriate Put down complete scraper Put down hide
Mobilise; retrieve goose feather and incomplete arrow	Goose feather and incomplete arrow Feather and incomplete arrow stable
Use feather to spread melted adhesive over bound area of arrow	Coverage appropriate
Use feather to spread melted adhesive between shaft and insert – assess visually	One shoulder of haft protrudes too far Put down goose feather
Retrieve debitage blade	Debitage blade Blade and incomplete arrow stable
Use debitage blade to press shoulder of haft inwards – assess visually and haptically	Aerodynamic shape achieved Put down debitage blade and complete arrow
Mobilise; turn off gas ring	No flame

Table 6.2 – *Task diagram showing parallel production of CTM1's hafted end scraper (blue and green colour block task stages) and arrow(a) (pink and orange colour block task stages) with shared adhesive application in white (after Table 5 from Fairlie & Barham 2016)*

6.3.16 Task Diagram for CTM2's Arrow(b)

Table 6.3 shows that this task has thirteen task stages which is more than for the parallel-worked tools. Again there is an increased flexibility over reductive stone tools, especially in the opening task stages. The high level of tool and object change at action set boundaries continues.

Arrow(b) Sequence	Tools, Objects and Final Affordances
Retrieve existing flint point; assess visually and haptically	Point too large for arrow insert
Retrieve antler tine and hide pad	Antler tine Hide pad Pad, tine and point stable
Pressure flake to create smaller point	Point appropriate size for arrow Put down pad and tine
Tilt point to visually assess	Distal end too wide for hafting
Retrieve antler tine and hide pad	Antler tine Hide pad Tine, point and pad stable
Thin the base	Appropriate size and shape for insert Put down pad, tine and insert
Retrieve debitage flake and shaft	Debitage flake Shaft Flake and shaft stable
Use two hands on flake to scrape bark off entire shaft; remove bud points; visually and haptically assess	Shaft devoid of bark and feels smooth Put down flake
Retrieve sharp piece of flint rubble	Flint rubble Flint rubble and shaft stable
Taper distal end of shaft to encourage aerodynamic shape in haft	Sufficient wood removed Put down flint rubble and shaft
Retrieve debitage flake; assess non-working edge haptically	Debitage flake Debitage flake has non-working edge sharp enough to cut flesh
Retrieve flint rubble	Flint rubble Debitage flake and flint rubble stable
Use flint rubble piece to dull non-working edge of debitage flake; re-assess haptically	Debitage flake backed Put down flint rubble
Retrieve shaft	Shaft Backed flake and shaft stable
Push backed flake into distal end of shaft	Backed flake partially inserted
Retrieve flint rubble	Flint rubble Flint rubble, shaft and backed flake stable
Use rubble to hammer backed flake in further	Cleft created Put down rubble and backed flake
Retrieve insert	Insert Insert and shaft stable
Put insert in cleft; assess visually and	Cleft acts as secure vice but more

haptically	tapering needed Put down insert
Retrieve backed flake	Backed flake Backed flake and shaft stable
Taper distal end of shaft using slow controlled strokes and assess visually	Distal end of shaft tapered further Put down backed flake
Retrieve insert	Insert Insert and shaft stable
Put insert into cleft – assess visually and haptically	Insert being pushed more strongly by one side of haft than by other side Put down insert
Retrieve backed flake	Backed flake Backed flake and shaft stable
Reduce one side of the haft	Both sides of haft appear equal Put down backed flake
Retrieve insert	Insert Insert and shaft stable
Put insert into cleft – assess visually and haptically	Point secure in haft Put down incomplete tool
Mobilise; retrieve gas ring, match and striking surface	Match Striking surface Gas ring Match, striking surface and gas ring stable
Strike match; put lit flame to gas ring	Flame
Mobilise; retrieve pan of solid adhesive; place over flame; assess visually, haptically and olofactorily	Adhesive not melted
Leave adhesive to melt	Flame and pan of adhesive stable
Mobilise; retrieve strips of retted, dried lime bark	Retted lime bark strips Retted bark stable
Split retted bark into narrow bands	Strips completed Put down strips
Mobilise to heating adhesive; retrieve stick	Stick Stick stable
Assess adhesive visually, haptically and olofactorily	Adhesive melted
Retrieve shaft	Stick and shaft stable
Use stick to apply melted adhesive to distal end of shaft	Sufficient adhesive applied Put down stick
Retrieve insert	Insert Shaft and insert stable
Put insert into cleft; apply pressure to close cleft while moulding adhesive around point	Haft tightly closed and covered in sticky adhesive
Mobilise; retrieve wretted bark strips	Wretted bark strips and incomplete arrow stable
Bind over adhesive to tightly constrain haft	Haft stable

Pass bound area of arrow over flame to remove binding hairs	Haft smooth
Retrieve stick	Stick and incomplete arrow stable
Use stick to apply melted adhesive over binding	Adhesive applied evenly over binding Put down stick
Manually shape adhesive aerodynamically – assess visually and haptically	Haft completed Put down arrow
Mobilise to turn off gas ring	No flame

Table 6.3 – *Task diagram showing production of CTM2's arrow(b) (after Table 6 from Fairlie & Barham 2016)*

6.3.17 Task Diagram for CTM2's Bound Atlatl Spear

This task diagram (Appendix 3:Table 7) is not reproduced here because it does not contain an adhesive application task stage and is otherwise very similar to the arrow(b) diagram (Section 6.3.15).

6.4 Discussion

In terms of the original aims of this pilot study (Section 6.2) some behavioural variables were sensitive enough to show graduated differences across all of the reconstructed tool events. The ones that were considered useful enough to be carried forward to the second pilot study were:

a. Flows and paces

   Variations in rhythmicity and repetition stood out during the reconstructed events and it was decided that they should be investigated further as there were potential links with various theory structures (Section 4.3.1). Duration was also a sensitive variable.

b. Sequencing variables

   Particularly in relation to the reductive tools the task diagrams did not provide detail about the internal patterning of action sets. However, the number of task stages rose across all tasks, and their ordering became more flexible during the hafted events. It was decided that better information about action set sequencing was required.

c. Choice of tool and object variables

   The number of tools and objects increased across different tasks. The task diagrams indicated that changes in tool and object use occured at action set or task stage boundaries and that the number of boundary changes appeared to increase overall, indicating a strengthening of boundaries and increasing specialisation within boundaries. Change was gradual across all tools, but increased suddenly at the transition to hafting. Tool and object choice co-varied with grip, tool manipulation and tool organisation, affordance detection skills and muscle synergy variables, and can therefore act as a useful proxy.

d. Search for information

   This variable provides a sensitive measure of change in action set and task stage activity and is an essential component of action perception models. Understanding how it varies is fundamental and further investigation was thought necessary.

The main unit of analysis was the task stage. This resulted in a loss of vital information at the observable gesture end of the scale. It was decided that any further analysis would have to include more detail about individual gestures as well as task stages. Any attempt to analyse whole tasks was considered as without real meaning as their legitimate variability was too high, especially in relation to hafted tools (Appendix 3). Comparison between task stages such as haft creation in hafted tools, or thinning in biface tools would however, yield useful information.

During this pilot study and the planning of the second study it became evident that understanding boundaries between all action unit types was vital (Section 3.1). Despite the lack of academically-defined hafting event task stages, familiarity with the tasks in question, the tool-makers' own behavioural markers, and the shared modern human cognitive capacity for observing and categorising simultaneously or parsing (Section 4.4.2) resolved the issue. In both pilot studies the observed task stages (as opposed to preparatory task stages which were not observed or recorded - Sections 1.6.3 and 7.6.4) contain a flexible and variable sequence of the following types:

a. Knapping of insert
b. Shaft or handle strip and trim
c. Cleft creation
d. Haft creation
e. Haft completion

Increased variability through archaeological time was noted in task duration, number of tools used, objects worked on and affordance utilisation. The number of internal task divisions increased (Lombard & Haidle 2012). Task stage and action set boundaries became more marked indicating increasing specialisation and task specificity (Holland 2014). A rhythmic and highly repetitive quality was observed in earlier reductive sequences which reduced over archaeological time and seemed to vanish completely in some hafting task stages. This suggested that the task-structuring function of rhythmic repetition (Section 4.3.1) gradually became just one out of a range of interacting cognitive strategies. An increasing flexibility of task stage and individual action set sequencing in hafted tools suggested a loss of contextual triggers for appropriate behaviours and increasing ability to identify the next appropriate behaviour by other means. The meaningful organisation of the action set sequences in cleft creation, haft creation and completion stages was sophisticated enough to allow various objects to be co-modified so that they could ultimately be fitted together into one combined object.

Chapter seven

the second pilot study – a coded analysis of the gestural content of a series of reconstructed Pleistocene and Palaeolithic reductive stone-tool and hafted tool-making events

7.1 Introduction, Hypotheses and Predictions

7.1.1 Structure of Chapter 7

This second pilot study is a partial description of a complex technological skills dynamic which develops over time. Because of the original data-capture methods, unfamiliar technical terms, and data re-working at different levels, Chapter 7 has an unusual structure. Section 7.2 describes basic data collection methods but details are not given until they become relevant during the results section (Section 7.3). Section 7.3 compares results for reductive (Section 7.3.1) and hafted tools (Section 7.3.2) at the most basic action set data-processing level, and the duration of each task stage. In Section 7.4 action set data is used to create 'action set group' data. Section 7.5 discusses the different patterns formed by action set group sequencing that may have relevance to different types of cognitive strategies in play (Sections 7.5.1 and 7.5.2). Section 7.5.3 describes how action set group information has been used to give a quantified description of reductive tools, and Section 7.5.4 gives a quantified description of hafted tools. Section 7.6.1 discusses whether hypotheses and predictions set out in Section 7.1.3 are supported by the evidence. Other relevant insights are discussed in Sections 7.6.2, 7.6.3 and 7.6.4. A general discussion about the findings of both pilot studies in the context of theories outlined in Chapters 3 and 4 takes place in Chapter 8.

7.1.2 Relevant Conclusions From the First Pilot Study

The First Pilot Study was run to establish protocols for a second study. Observations appeared consistent with theoretical models and research discussed in Chapters 3 and 4. But they were subjective and not supported by quantitative analysis. There was a lack of detail about action sets. This limited investigation of gestural sequence patterns and their boundaries. Qualities such as repetition and rhythm were discussed as significant, but no direct evidence of their presence or variability was provided.

The Second Pilot Study was designed to build on the findings of the first. It remained observational (Chapter 5). The observed behaviours were filmed and coded as sequences which could be analysed at different levels. The codes enabled collection of information about the content and patterning of action sets, and the formation of action set groups. This made a basic quantitative analysis of each task stage possible. All task stages of the same type by different tool-makers could then be compared (eg. the thinning stage of a biface sequence), as could different task stages making up a single tool-making sequence, and task stages from distinct technologies. As with all qualitative research much information was collected and the clearest patterns had to be distinguished and extracted – a subjective process (Hammell & Carpenter 2000; Jongbloed 2000; Carter & Little 2007; Green & Thorogood 2014). The original coding sequences are available in Appendix 2.

7.1.3 Questions to be Answered

One of the main questions to be answered is whether different prehistoric tool-making technologies formed part of a developmental dynamic or complex adaptive system (Section 3.1). Description of a CAS required a correspondingly complex format. Section 7.3 forms a hierarchical structure of different information processing-levels. Information that describes the basic level of the gestural sequences is re-processed at higher levels to form more complex descriptions of technological systems until some kind of overview of developmental processes is formed.

Information already obtained from relevant literature and the first pilot study allowed for the following predictions:

a) Basic units of action (action sets) will be identifiably present and will become 'chunked' into longer sequences (action set groups). Action sets and action set groups will be identifiable as functional by their repeated appearance in related sequences
b) Types of available action sets will increase as the range of behavioural variables increases (first pilot study), and this will result in a wider range of action set group types as the number of potential action set combinations rises
c) In the hafted tool sequences it will be possible to identify the splicing together of older patterns derived from both non-lithic and lithic technologies
d) Specific reductive wood-working action sets and action set group patterns should be different from specific reductive knapping action sets and action set group patterns, but should also have some similarity

If Reed's description (Reed 1996) of the role of cognition within a perception-action model (Gibson 1979; Turvey et al 1981; Brooks 1991; Caruso 1993; Sporns & Edelman 1993; Thelen & Smith 1994; Reed 1996; Bingham 1998; Clark 1999; Gibson & Pick 2000; Lockman 2000; Thelen et al 2001; Stout 2002; Roux & Bril 2005; Stout 2005a; Baber 2006; Barrett et al 2007; Iriki & Sakura 2008; Goldstein et al 2010; Nonaka et al 2010; Rose et al 2010; Borghi & Pecher 2011; Bloch 2012; Osiurak 2012; Shettleworth 2012; Turvey 2013; Wilson & Golonka 2013; Kahrs & Lockman 2014; Neilsen et al 2014; Stout & Hecht 2014; Witt & Riley 2014; Baber 2015; Wilson et al 2016a,b) as comprising the event-specific selection and fine-tuning of the most successful action unit sequences in relation to each new use of environmental affordances could be shown to be true, cognitive strategies would be needed to control the complexity inherent in this selection.

Rhythmic repetition is an ideal strategy for reducing the cognitive load of reductive sequences (Thelen 1979; Thelen 1981a; Thelen 1981b; Kelso 1995; Reed 1996; Givon 1998; Edelman & Tononi 2001; Wei et al 2003; Sakai et al 2004; Schaal et al 2004; Bril et al 2005; Halder et al 2005; Cosmelli et al 2007; Oullier et al 2008; Bidet-Caulet et al 2012; Nonaka & Bril 2012; Roncaglia-Dennisen et al 2013; Sanabria & Correa 2013; Ungan et al 2013; Bryant 2014; Honing et al 2014; McAuley & Fomboluti 2014; Nozaradan 2014; Schaefer 2014; Wing et al 2014; Bril et al 2015; Escoffier et al 2015; Schmidt et al 2015; Bressler & Kelso 2016; Leconte et al 2016; Tozzi et al 2016).

However, as task duration increases and task content becomes more complex and flexible, an ability to parse and sequence action units (Sections 4.4.2 and 4.4.3) develops, along with neural substrates for managing flexible task-stage and action set group sequencing (Koechlin et al 1999; Koechlin et al 2000; Passingham & Sakai 2004; Ridderinkhof et al 2004; Koechlin & Jubault 2006; Schacter & Addis 2007; Suddendorf & Corballis 2007; Collins & Koechlin 2012; Wessel et al 2012; Hecht et al 2013; Hyeon-Ae 2014; Underwood et al 2015). This should allow for the following predictions:

e) Rhythmic repetition will be more consistent earlier in archaeological time but will become more erratic as a sequence pattern, connected mainly with the reductive modification of objects
f) A reduction in rhythmic repetition during one task stage will correlate with an increase in information search
g) Task stage and action set group sequencing will become more flexible over archaeological time
h) The number of task stage boundaries per task will become greater and more clearly marked
i) Different ways of sequencing action sets and action set groups will result in new forms of sequence patterns as rhythmic repetition reduces

7.2 Method of Data Capture and Analysis

The gestural analysis carried out in the second pilot study was very different from the first and gave rise to completely new data so some footage from the first pilot study was re-used. The knapping task stages carried out by the reductive tool maker (RTM) during the first pilot study (Table 7.1) were re-analysed along with new sequences from JD and KL also shown. New footage was obtained so as to compare the same types of tool-making events by different tool-makers with varied experience. RTM has been knapping for about seven years, averaging about two hours practice a week. JD and KL are both professional tool-makers and teachers, providing replica tools and demonstrations for universities, museums and film-makers. JD has been knapping for about twelve years with five to six hours practice a week. KL has been a tool-maker for twenty-six years and uses his skills on a daily basis.

All three tool-makers knapped one Oldowan chopper and retouched one Oldowan flake. They made a flake-based biface, a prepared core and one retouched prepared flake. JD made two single-stage Oldowan choppers while KL made four (Table 7.1). More hafted tool footage was hard to obtain as the number of experienced professionals with their own workshops in the UK is extremely limited. KL's arrow(b) footage from the first pilot study was re-used. He was also asked to create a further three hafted tools which could have appeared earlier in the archaeological record than arrows. He made a hafted end scraper, a laterally hafted knife and a thrusting spear which are all shown in Table 7.1.

Task Code	Technology	Task Stage	Task Stage	Task Stage	Task Stage	Task Stage	Task Stage
JD 1(1)	Oldowan	(a) Chopper - 131 seconds					
JD 1(2)	Oldowan	(a) Chopper – 181 seconds					
KL 1(1)	Oldowan	(b) Chopper – 39 seconds					
KL 1(2)	Oldowan	(b) Chopper –					

		56 seconds					
KL 1(3)	Oldowan	(b) Chopper – 70 seconds					
KL 1(4)	Oldowan	(b) Chopper – 55 seconds					
RTM 1	Oldowan	(b) Chopper – 195 secs	(c) Retouch – 82 secs				
JD 1(3)	Oldowan	(a) Chopper – 80 secs	(b) Retouch – 76 secs				
KL 1(5)	Oldowan	(b) Chopper – 109 secs	(c) Retouch – 29 secs				
RTM 2	Flake biface	(b) Open boulder – 249 secs	(c) Remove flakes – 244 secs	(d) Shape blank – 257 secs			
JD 2	Flake biface	(a) Remove flakes – 95 secs	(b) Shape blank – 230 secs	(c) Thin & finish – 877 secs			
KL 2	Flake biface	(b) Remove flakes – 348 secs	(c) Shape blank – 280 secs	(d) Thin & finish – 629 secs			
RTM 3	Prepared core and flake	(b) Prepare core – 278 secs	(c) Remove flake – 241 secs	(d) Retouch – 238 secs			
JD 3	Prepared core and flake	(a) Prepare core – 402 secs	(b) Remove flake – 95 secs	(c) Retouch – 186 secs			
KL 3(1)	Prepared core and flake	(b) Prepare core – 155 secs	(c) Remove flake – 155 secs	(d) Retouch – 130 secs			
KL ‘15 1(1)	Non-fletched arrow	(a) Pressure flake point k – 305 secs	(b) Strip & trim shaft – 530 secs	(c) Create haft k – 406 secs	(d) Complete haft – 368 secs		
KL 4(1)	Hafted end scraper	(a)Trim shaft – 73 secs	(b) Create cleft – 60 secs	(c) Knap blades k – 144 secs	(d) Retouch blade k – 145 secs	(e) Create haft k – 177 secs	(f) Complete haft – 139 secs
KL 4(2)	Laterally hafted knife	(a) Trim shaft k – 287 secs	(b) Create cleft k – 358 secs	(c) Create haft – 22 secs	(d) Strip & Trim handle k – 212 secs	(e) Complete haft – 218 secs	

KL 4(3)	Thrusting spear	(a) Trim shaft – 152 secs	(b) Create cleft – 197 secs	(c) Knap blade k – 426 secs	(d) Create haft k – 361 secs	(e) Strip shaft k – 415 secs	(f) Complete haft – 360 secs

Table 7.1 – Tasks and task stages included in the second pilot study – the red k indicates hafting task stages that include at least one knapping sequence

A hand-held Samsung HMX-F90 camcorder was used to obtain footage. It was replayed on a Mac Pro laptop providing a resolution of approximately half a second which was barely sufficient for fast retouch action sets. Data was analysed in task stage units, rather than in whole task units. In relation to reductive knapping tasks, task stage boundaries were simply deemed to occur where the consensus of lithic literature authors put them (Andrefsky 1998; Odell 2004), particularly since this literature and the nature of the boundaries were well-known to the tool-makers themselves. There was no such literary consensus for the hafted tools, but their task stage boundaries were well-signalled. This was partly due to the degree of change that occurred at each boundary (Section 7.5.1 on transit change), and partly because they were verbally signalled by the tool-makers as the end of one task stage, and the beginning of the next. (Table 7.1) shows 51 different task stages each of which was coded as a unit.

Individual gestures were not coded as this would have resulted in unnecessarily long sequences. Instead each 'action set' or group of repeated gestures was coded manually, indicating its 'type' and start and finish time. One coded sequence of action sets was created for each task stage. Gestures included in an action set were not identical to each other as parameters such as grip, posture, force, speed, angle of tool impact and non-dominant hand action changed constantly sometimes resulting in observable differences (Section 3.2.1), but to an observer they remained of the same type and were carried out with the same intention.

Action sets in each task stage were subsequently divided into 'action set groups' by the researcher and given their own set of codes. A new action set group commenced with its own main activity set. This type of grouping is natural in reductive knapping sequences. Figure 7.1 shows the coded sequence for a prepared core reduction. The main activity set is (ii) for 'dominant hand flake removal'. It always appears first in action set groups, followed for example by (iv) for 'turn core', (v) for 'clear debris' or (i) for 'information search'. Information search is one of the most frequent action sets. It can happen concurrently with other action sets, but it occurs on its own when the tool-maker gestures with the object being worked on in order to examine it, usually visually or haptically. On these occasions gestures are executed but no modification to the object takes place, (eg a hammerstone used to tap a core for auditory information about possible flaws) (Reed 1988).

In more complex task stages where many tool and object-changes occur and different types of activity are interspersed it was more difficult to be consistent about divisions between action set groups. This loss of clarity in action set group formation is likely to have caused problems with some of the calculations carried out in section 7.5 and is discussed further where relevant.

Code	Action Description
(i)	Information search
(ii)	Dominant hand flake removal
(iii)	Flake caching for later retrieval
(iv)	Turn object being worked on
(v)	Debris clearage
(vi)	Retrieve / change tool
(vii)	Retrieve / change object
(viii)	Put down tool
(ix)	Non-dominant hand flake removal
(x)	Bi-manual flake removal
(xi)	Put down object
(xii)	Dominant hand sawing wood
(xiii)	Four-way snap of wooden shaft
(xiv)	Hammer wedge into shaft distally
(xv)	Adjust wedge in shaft
(xvi)	Strip wood
(xvii)	Adjust insert in shaft
(xviii)	Bind cleft
(xix)	Trim binding with flake
(xx)	Gouge cleft in wood

(xxi)	Apply adhesive
(xxii)	Press insert into adhesive
(xxiii)	Clear excess adhesive
(xxiv)	Insert lateral wedge into cleft
(xxv)	Remove wedge
(xxvi)	Hammer in lateral wedge
(xxvii)	Dip cleft end into adhesive
(xxviii)	Rock-cut into cleft using flake
(xxix)	Pass part of tool through flame
(xxx)	Manually mould adhesive
(xxxi)	Stir adhesive

Table 7.2 – *Complete list of action set type codes and the actions that they represent – red action sets represent general actions, blue action sets are knapping-specific and purple action sets are hafting-specific*

Figure 7.1 is an example of a fast and efficient task stage and its codes can be read using Table 7.2 and the instructions at Section 5.4.4. It is the core reduction stage of a prepared flake task KL3 1(b). There are only four types of action sets involved, (i), (ii), (iv) and (v). Each action set's code and timing is enclosed by normal brackets. Curly brackets enclose action sets groups and their action set group code appears in turquoise. Each task stage can be quantified by its duration, number of action sets and action set types, and its number of action set groups and action set group types. The task stage shown has a strong rhythmic and repetitive alternation between knapping blow action sets (ii), and information search action sets (i).

{(ii)b(ii.00.00 – 00.01) (v.00.02)} {(ii)b(ii.half) (v.half)} {(ii)b(ii.half) (v.half)} {(ii)a(ii.00.05 – 00.10) (i.00.11)} {(ii)a(ii.00.12 – 00.13) (i.00.14 – 00.15)} {(ii)a(ii.00.16 – 00.20) (i.00.21)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.00.24) (i.00.25 – 00.29)} {(ii)a(ii.00.30) (i.00.31)} {(ii)b(ii.00.32) (v.00.33)} {(ii)b(ii.half) (v.half)} {(ii)d(ii.00.35) (v.00.36) (i.00.37)} {(ii)b(ii.00.38) (v.00.39)} {(ii)b(ii.half) (v.half)} {(ii)a(ii.00.41) (i.00.42)} {(ii)a(ii.043) (i.00.44 – 00.46)} {(ii)b(ii.00.47 – 00.48) (v.00.49)} {(ii)b(ii.00.50) (v.00.51)} {(ii)d(ii.00.52) (v.00.53) (i.00.54 – 00.55)} {(ii)x(ii.00.56) (i.00.57) (iv.00.58 – 00.59)} {(ii)b(ii.01.00) (v.01.01)} {(ii)b(ii.01.02 – 01.05) (v.01.06)} {(ii)b(ii.01.07 – 01.09) (v.01.10)} {(ii)b(ii.half) (v.half)} {(ii)b(ii.half) (v.half)} {(ii)x(ii.01.13 – 01.14) (i.01.15) (iv.01.16)} {(ii)a(ii.01.17 – 01.20) (i.01.21)} {(ii)y(ii.01.22 – 01.23) (iv.01.24) (i.01.25)} {(ii)a(ii.01.26 – 01.27) (i.01.28 – 01.30)} {(ii)d(ii.01.31 – 01.34) (v.01.35) (i.01.36)} {(ii)a(ii.01.37) (i.01.38 – 01.39)} {(ii)a(ii.01.40 – 01.46) (i.01.47)} {(ii)a(ii.01.48) (i.01.49)} {(ii)a(ii.01.50) (i.01.51)} {(ii)a(ii.01.52 – 01.56) (i.01.57 – 01.58)} {(ii)a(ii.01.59) (i.02.00)} {(ii)a(ii.02.01) (i.02.02)} {(ii)a(ii.02.03) (i.02.04)} {(ii)a(ii.02.05) (i.02.06)} {(ii)a(ii.02.07) (i.02.08)} {(ii)b(ii.02.09 – 02.11) (v.02.12)} {(ii)a(ii.02.13 – 02.16) (i.02.17)} {(ii)a(ii.02.18 – 02.19) (i.02.20)} {(ii)a(ii.02.21) (i.02.22)} {(ii)x(ii.02.23 – 02.24) (i.02.25 – 02.32) (iv.02.33 – 02.34)}

Figure 7.1 – Coded sequence for KL3 1(b) – prepared core formation task stage

Coded sequences for every task stage shown in Table 7.1 can be found in Appendix 2.

Further information was also collected from the footage, (Section 7.5.1). It included:

- Whether the sequence of task stages of a single task had to be performed in a fixed order or whether their order was flexible
- The number of different tools used and objects worked on during the task stage
- Major changes in posture. Postural change would have been continuous (Reed 1988) so only changes between seated, and standing and mobilising postures were noted
- The relative speed of the task stage expressed as the average number of seconds each action set took to execute
- The percentage of the task stage duration taken up by information search
- The 'efficiency rating' or percentage of action set groups in a task stage containing four or more action sets
- The 'rhythmic repetition' level or percentage of action set groups consisting of three or less action sets which appear more than once during a task stage
- Whether an identifiable action set group pattern was formed for each task stage

Using this information it was the possible to establish:

- How many variables changed at the boundary between two task stages of the same task, or in other words the strength of the task stage boundary (transit changes)

- Whether the relationship between variables changed in some way across task stages of the same type performed by different tool-makers, reflecting different levels of experience

7.3 Results

7.3.1 Action Sets and Duration

The 51 task stages shown in Table 7.1 produced 31 different action set types listed in Table 7.2.

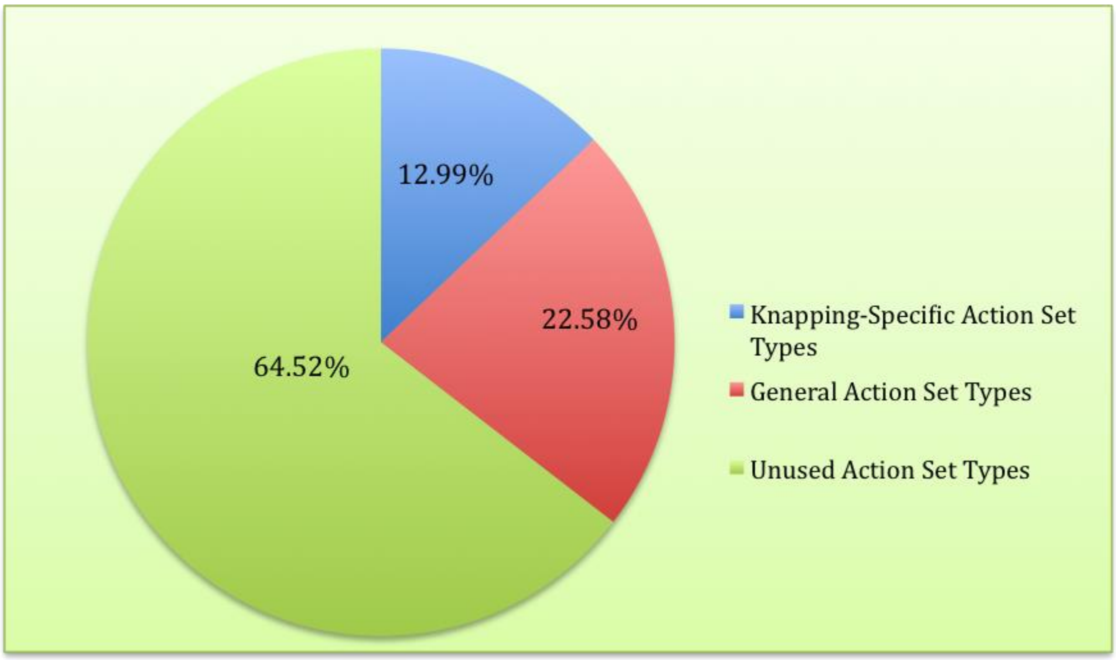

Figure 7.2 – Comparative use of different categories of action set types in reductive tools

Figure 7.2 shows how few of the total available action set types are used during reductive tool tasks (35.48%), while 93.55% (Figure 7.3) are used during hafted tool making. Two knapping-specific action set types are lost during the hafted tool tasks. They were only used in one reductive tool task stage (KL2 1(b) –

Appendix 2) which constituted removing flakes from a very large, dense and immoveable boulder.

7.3.2 Action Sets and Duration – Reductive Tools

The total number of action set types used for each knapping task stage does not show any change through archaeological time. All action set types for reductive knapping (with the exception of (ix) and (x) which only appear in KL2 1b), make consistent appearances throughout reductive tasks. The average number of action set types used by each tool-maker for each task stage is shown in Table 7.3.

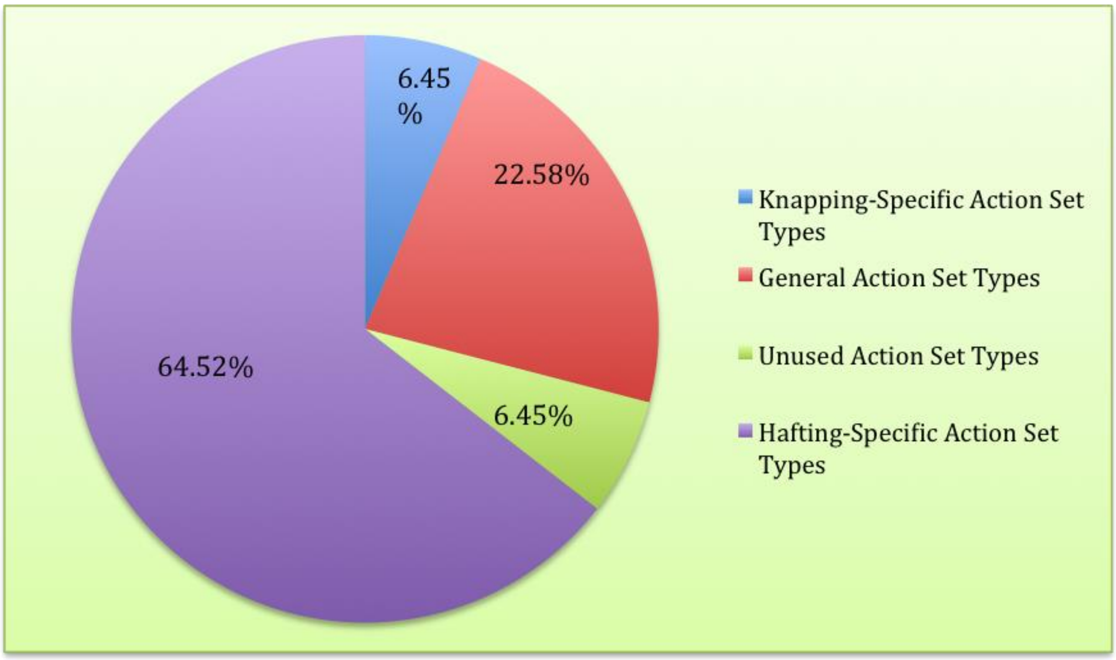

Figure 7.3 – Comparative use of different categories of action set types in hafted tools

RTM (8 task stages)	4.88 action set types on average
JD (10 task stages)	6.4 action set types on average
KL (12 task stages)	5.16 action set types on average

Table 7.3 – Average number of action set types used by each tool-maker across all of their knapping task stages

RTM's average score is lower because he did not change tools as much. He never used a soft hammer or abrader resulting in a reduced number of codes. JD's average score is higher than KL. All of his choppers were bifacial, requiring a code for core-turning. He used a second tool (leather muffler) to protect his arm from vibration and swapped between abrader and soft hammer more frequently. The reductive task stages with the lowest number of action set types (4 on average) are flake retouches (Table 7.15).

Several complete knapping task stages form part of the hafted tool tasks (Table 7.1). These consist of a pressure flaking task stage KL'15 1(1)a with six action set types; a blade removal task stage KL 4(1)c with seven, and a blade retouch task stage KL 4(1)d with six. KL 4(3)c consists of what would have been two separate task stages in a reductive knapping task – the removal of a blade from a core and its shaping into a spear point. In a hafted task these two stages become compressed into one knapping task stage with nine action set types.

Table 7.4 shows the task stage durations of all the different technologies except the one-stage choppers. The times for each tool-maker are given, as well as the average time for each technology so that some conclusion can be drawn about the effects of experience and technology-type. KL 4(3)c where both blade removal and finishing occurred in the same task stage is included, but the times have been separated out here for comparison.

Oldowan	Chopper	Retouch Flake		Total
RTM	195 seconds	82 seconds		277 seconds
JD	80 seconds	76 seconds		156 seconds
KL	109 seconds	29 seconds		138 seconds
Average	128 seconds	62.33 seconds		190.33 secs
Flake biface	Remove flakes	Form blank	Finish	
RTM	493 seconds	257 seconds	Not done	750 seconds
JD	95 seconds	230 seconds	877 seconds	1,202 seconds
KL	348 seconds	280 seconds	629 seconds	1,257 seconds
Average	312 seconds	255.66 secs	753 seconds	1,069.66 secs
Prepared core & flake	Prepare core	Remove flake	Retouch	

RTM	278 seconds	241 seconds	238 seconds	757 seconds
JD	402 seconds	95 seconds	186 seconds	683 seconds
KL	155 seconds	155 seconds	130 seconds	440 seconds
Average	278 seconds	163.66 secs	184.66 secs	626.32 secs
KL 4(3)c		Remove blade	Thin & Finish	
		220 seconds	206 seconds	
Hafted Tool Sequence			Average task stage duration	Average duration
			255 seconds	1,338.75 secs

Table 7.4 – Durations in seconds of tasks and task stages of reductive and hafted tools for each tool-maker

7.3.3 Action Sets and Duration – Hafted Tools

While the reductive tasks only require 35.48% of all available action set types, the hafting tasks require 93.55% (Section 7.3.1). Table 7.4 shows that the average task duration for hafting is longer than for reductive task durations. The average hafting task stage duration is longer than the average Oldowan task stage, shorter than the flake-based biface task stages and comparable with prepared core and blade-based task stage durations.

Figure 7.1 shows the coding for KL's prepared core reduction. This task was observed to be highly rhythmic in terms of the consistent and regular noise from hammer blows being delivered to the core. There is an alternation between delivery of the knapping blow, and information search. Hafting task stages can be similarly structured where the main action set is reductive. Figure 7.4 shows a handle preparation task stage for a hafted scraper which is dominated by alternation between the sawing gesture (xii) and information search (i). Other hafting-specific action set types that can act as a main action set for this alternation are wood stripping (xvi), hammering in a wedge distally (xiv), and gouging out a lateral cleft in wood (xx). This type of pattern is persistent across both tool-types and becomes important during later discussions.

{(vi)a(vi.04.47 – 04.51denticulated flake) (i.04.52 – 04.53)} {(xii)a(xii.04.54 – 04.59) (i.05.00 – 05.01)} {(xii)a(xii.05.02 – 05.05) (i.05.06 – 05.07)} {(xii)a(xii.05.08 – 05.13) (i.05.14 – 05.15)} {(xii)a(xii.05.16 – 05.23) (i.05.24 –

05.25)} {(xii)a(xii.05.26 – 05.33) (i.05.34)} {(xii)b(xii.05.35) (viii.05.36denticulated flake) (i.05.37)} {(xiii)a(xiii.05.38 – 05.53under left foot on ground) (xi.05.54residual hazel) (i.05.55 – 05.59bi-manual)}

Figure 7.4 – Coded sequence for KL 4(1)a showing an alternation or hafted tool rhythmic repetitive pattern in a handle trimming task – action set (xiii) at the end represents the snapping off of the shaft end once sawing is finished

7.4 Action Set Groups in All Technology Types

Once action sets had been identified and coded for they were put togther into action set groups shown by the curly brackets in the coding. For reductive knapping tasks this was straightforward because each new action set group started with the next (ii) or flake removal blow. This method was also used for forming reductive non-knapping action set groups for hafting, although the first action set code varied, mostly between (xii), (xvi), (xiv), (xviii) and (xx) (Table 7.2). This method of forming action set groups did not work for task stages without an identifiable repetitive main action set, particularly for JD 2a, KL'15 1(1)d (Table 7.14), KL2 1(b) (Table 7.8), KL4 1(e) (Table 7.13) & (f) (Table 7.14), KL4 2(c) (Table 7.13) & (e) (Table 7.14), and KL4 3(b) (Table 7.12) & (f) (Table 7.14). The repetitive nature of the gestural sequences in these task stages was reduced and the formation of action set groups became more subjective (or more difficult to parse using observation only).

There are 215 action set groups (Appendix 1). Ninety-six of these groups (44.65%) start with (ii) for knapping blows. Many of them are long and contain between four and nine actions sets. Action set groups of this length never occur in more than two different task stages and appear to be randomly generated when there is some doubt about how to proceed. With the exception of five (ii)-based action set groups, all of the action set groups that appear in three or more different task stages and which can therefore be considered as functional and effective groups, contain a maximum of three action sets with no internal repetition. They are often associated with rhythmic repetition. They occur where rhythmic performance is audibly or visibly strongest and are frequently repeated (Figures 7.1 and 7.4). They represent a strong reductive pattern in both technologies. All of the forms in which they appear are shown in Table 7.5.

There are only 32 of these action set groups, constituting 14.88% of the total number of action set groups recorded (Appendix 1).

Action Set Group Sequence	RTM Frequency of Use	JD Frequency of Use	KL Frequency of Use	Total
Knapping Types				
(ii)(i)	6 task stages	10 task stages	15 task stages	31
(ii)(v)	6 task stages	3 task stages	10 task stages	19
(ii)(v)(i)	6 task stages	4 task stages	8 task stages	18
(ii)(iv)	1 task stage	3 task stages	8 task stages	12
(ii)(i)(iv)	1 task stage	4 task stages	7 task stages	12
(ii)(iv)(i)	1 task stage	3 task stages	6 task stages	10
(ii)(i)(v)	1 task stage	4 task stages	3 task stages	8
(ii)(vi)	1 task stage	3 task stages	3 task stages	7
(i)	1 task stage		5 task stages	6
(ii)(i)(vi)		3 task stages	3 task stages	6
(ii)	1 task stage		4 task stages	5
(ii)(viii)			5 task stages	5
(ii)(iv)(vi)		4 task stages	1 task stage	5
(ii)(v)(iv)		2 task stages	3 task stages	5
(ii)(i)(iv)(i)	1 task stage	2 task stages	1 task stage	4
(i)(vi)		1 task stage	2 task stages	3
(ii)(iii)	1 task stage		2 task stages	3
(ii)(iii)(i)	3 task stages			3
(ii)(vi)(i)	2 task stages		1 task stage	3
(ii)(i)(iv)(vi)		3 task stages		3
(ii)(i)(v)(i)	1 task stage	2 task stages		3
(ii)(v)(i)(iv)	2 task stages	1 task stage		3
(i)(v)(i)(iv)(i)	2 task stages	1 task stage		3
General Types				
(vi)		2 task stages	5 task stages	7
(vi)(i)		1 task stage	5 task stages	6
(xi)			3 task stages	3
(xi)(viii)		2 task stages	1 task stage	3
Wood-Work Types				
(xvi)(i)			6 task stages	6
(xii)(i)			4 task stages	4
(xiv)(i)			3 task stages	3

(xvi)(i)(v)			3 task stages	3
(xvi)(v)(i)			3 task stages	3

Table 7.5 – Action set groups appearing in more than two task stages, by technology type and then frequency of appearance. The tool-makers that used them are also shown

7.5 Task Stage Quantification

7.5.1 Rhythmic Repetition, Efficiency, Speed, Flexibility and Pattern Types

This section describes the methods for quantifying action set groups within task stages. The task stages closest to a straightforward alternation between a main action set group and information search are described as rhythmic repetition patterns and categorised as (a). The same pattern appears in knapping and non-knapping reductive hafting task sequences (Section 7.4 and Figures 7.1 & 7.4). The level of rhythmic repetition for each task stage was calculated by identifying the action set group types used during the task stage with a maximum of three action sets which were used more than once during the task stage (Table 7.5), and then calculating what proportion of all task stage action set groups were represented by these types.

The task stage efficiency rating was calculated using the percentage of action set groups in the task stage consisting of four or more action sets, or in other words the inefficient action set groups (Section 7.4). The greater the proportion of such action set groups, the less efficient the task stage. This method of calculation provides reliable comparators of efficiency between reductive task stages, both knapping and wood-based. However, it became more difficult to identify the boundaries between action set groups where rhythmic repetition was not clearly identifiable (Section 7.4) so the usefulness of this method for non-reductive sequences is questionable.

It was not possible to measure speed with the technology employed here. However, an attempt was made to provide comparators by dividing the task stage duration by its total constituent action sets. This gave the number of seconds taken up by an average-length action set for the given task stage and provided reasonable comparators for reductive task stages. However, the method became more problematic in relation to reductive woodworking, haft creation and haft completion task stages. The coding showed that where speed was slower in non-knapping sequences, what had actually happened was that the action sets had gone on longer than for knapping sequences. This did not mean that the gestural speed had slowed, but rather there had been a reduction in the number of alternations with information search action sets. The percentage of the task stage duration taken up by information search is given as a separate figure for each task stage, and it decreases in many of the task stages where the speed calculations become slower. Non-knapping reductive sequences and haft creation and completion stages are not slower but require less stopping for information-gathering.

The flexibility of the task stage position within the overall sequence is either given as 0 where it is the only task stage, 1 where it can only be carried out in its present position in the sequence, or 2 where its position is more optional and sequencing decisions need to be made. Where the task consists of more than one task stage the 'transit change' is calculated. The calculation adds together the number of tools and objects that are relinquished as the task stage finishes, and the number of tools and objects picked up in preparation for the next task stage. Where a tool or object is retained across the task stage boundary it is not included. Also part of the total are any major changes in posture. These are not so frequent as tool and object changes and tend to involve a transition between standing and mobilising postures, and seated postures.

As well as rhythmic repetition pattern (a), three other types of action set group patterns were identified. The second pattern was classified as a 'slow repetition' pattern (b). Here the alternation between a main action set and information search action sets were still present along with a rhythmic repetition level. But the speed calculation and information search were lower. This pattern is present in JD1 (1) which is a chopper reduction (Table 7.6). The pattern here is likely to be a genuine product of slow working as the cobble was dense and repeated arm-jarring blows were required to produce a flake. It is also present in KL4 3(a) - a strip and trim task stage (Table 7.11), and a cleft creation task stage, KL4 2(b) (Table 7.12). In both these hafted task stages as compared with other task stages of the same type, action sets were long, and independent information search levels were relatively low, while rhythmic repetition levels remained higher.

The third pattern was called 'complex rhythmic repetition' and categorised as (c). Five of the relevant task stages are KL'15 1(1)b, KL4 1(a), KL4 2(a), KL4 2(d) and KL4 3(e) which are all stripping and trimming task stage types (Table 7.11). They have rhythmic repetition action set groups based on more than one main action set type (Section 7.4). Alternative main action set types that are accompanied by information search and other action sets include knapping blows (ii), sawing (xii), hammering wedges (xiv), gouging out wood (xx), and wood-stripping (xvi). They contain either two or three interspersed main action set types in action set groups that are alternated. Without these additional main action set types the task stages might be classed as a (b). A further three (c) task stages are one cleft creation KL4 3(b) (Table 7.12), and two haft creation task stages KL'15 1(1)c and KL4 3(d), (Table 7.13 and Appendix 2).

The fourth pattern was classified as 'narrative' (d). KL2 1(b) (Figure 7.5 & Table 7.8) is one of them, carried out with high levels of constraint. KL2 1(b) is the first task stage in a flake-based biface reductive sequence where the flakes for creating a blank were removed from a boulder. The task stage was problematic because the boulder was large, dense, and of such poor quality that flakes could not be removed in the normal way. KL had to mobilise around the boulder and reach in non-ergonomic postures to try and access parts of the boulder that might yield a flake. Flakes were obtained only after using a lump hammer, and this is the only task stage where codes had to be used for bi-manual and non-dominant-hand knapping (Table 7.2). See also JD 2(a) a narrative knapping task stage (Table 7.8) where the removal of a flake from a core to use for a biface was achieved so quickly that any kind of repetition did not become necessary.

{(vi)(vi.02.58 – 03.24lump hammer)} {(ii)P(ii.03.25 – 03.48bent over) (viii.03.49 – 03.51lump hammer) (iii.03.52 - 03.57) (i.03.58 – 04.00) (vi.04.01medium hs) (i.04.02 – 04.23)} {(ii)W(ii.04.24 – 04.27kneeling) (i.04.28 – 04.36) (vi.04.37 – 04.43 medium hs for new medium hs)} {(ii)W(ii.04.44 – 04.47kneeling) (i.04.48 – 04.56) (vi.04.57 – 05.50medium hs for large hs)} {(x)d(x.05.51 – 06.01kneeling) (viii.06.02large hs) (iii.06.03 – 06.04) (i.06.05 – 06.27) (vi.06.28large hs) (i.06.29 – 06.38)} {(x)c(x.06.39 – 06.42kneeling) (viii.06.43large hs) (iii.06.44 – 06.47) (i.06.48 – 07.04) (vi.07.05 – 07.06medium hs)} {(ix)a(ix.07.07 – 07.13kneeling) (viii.07.14medium hs) (vi.07.15 – 07.18medium hs)} {(ii)R(ii.07.19 – 07.21kneeling) (viii.07.22medium hs) (v.07.23 – 07.24) (i.07.25 – 07.27) (vi.07.28 – 07.31large hs)} {(x)a(x.07.32 – 07.51) (viii.07.52large hs) (i.07.53 -08.22) (vi.08.23 – 08.24large hs)} {(x)b(x.08.25 – 08.29kneeling) (viii.08.30large hs) (iii.08.31 – 08.39) (i.08.40 – 08.45)}

Figure 7.5 – Coded sequence for KL 2(1)b - narrative sequence of a highly constrained flake removal task stage

Two (d) task stages (KL4 1(e) and KL4 2(c)) are haft creation task stages (Table 7.13 and Section 7.5.2), and the remaining four constitute all of the haft completion task stages (KL'15 1(1)d, KL4 1(f), KL4 2(e) and KL4 3(f)), (Table 7.14 and Section 7.5.2). The haft completion task stages and KL4 2(c) show the same pattern of long action sets, low levels of separate information search and no rhythmic repetition. KL4 1(e) has some repetition coupled with information search, but is based on the action set type of manually adjusting the insert which is not regarded elsewhere as an action set type that carries rhythmicity. A small sequence of insert retouch is also included but is not long enough to build up any rhythmic quality.

The number of main action set types rises in haft completion narrative (d) patterns (Table 7.15). The haft creation stages KL4 1(e) and KL4 2(c) have just two and one main action set types respectively (Table 7.13). KL '15 1(1)d, KL4 1(f), KL4 2(e) and KL4 3(f) which are all haft completions (Table 7.14) have eight, three, three and five main action set types respectively. These include combinations of binding the cleft (xviii), trimming the binding (xix), applying adhesive with a stick (xxi), pressing the insert into adhesive (xxii), dipping the cleft in adhesive (xxvii), passing the tool through flame either to trim binding or soften adhesive (xxix), manually moulding the adhesive on the haft (xxx), stirring adhesive (xxxi) and clearing away excess adhesive (xxiii). No action set types support rhythmic repetition, and instead are strung together in sequences of discrete or distinct actions. Rhythmic repetition patterns can be performed without much need for active sequencing (Section 4.3.1). They allow certainty as to what action comes next, and when it will happen. However, if discrete actions or action set groups are not actively sequenced in the correct order (or occur randomly), then no meaningful outcome is achieved. As a result of the sequence being actively organised (or complex) in haft completions, each tool component is mutually adjusted in relation to the other components and individual parts come together into a whole with meaning as a single object or tool.

7.5.2 All Haft Creation and Haft Completion Task Stages

In order to clarify the important difference between (c) and (d)-type patterns and emphasise the unique nature of hafted tool-making, each haft creation and haft completion task stage is described briefly below. These task stage types represent the point at which the full range of processed raw material components are adjusted in relation to each other before being assembled into a single unit. The task stages can be considered as highly constrained or cognitively challenging in terms of deciding 'which bit to act on next and what to do to it', and 'how much to do', all in the context of the task-specific morphology of each tool.

KL'15 1(1)c is the (c) pattern haft creation of an arrow (Table 7.13 and Appendix 2). The form of the distal cleft is finalised with constant reference to the insert that is going to go inside. Depending on how good the fit is initially, various adjustments are necessary, including tapering the cleft prongs or further knapping of the insert. This is particularly important for arrows which require a combined distal shape which is aerodynamic in flight and will enter the prey's body easily (Barham 2013b; personal conversation with KL). KL'15 1(1)c includes a large number of reductive rhythmic repetition action set groups made up from (xvi) and (i) and cannot be classed as narrative. There is also rhythmic repetition from the backing of the flake, opening and shaping the cleft prongs, and deepening the distal cleft using the rock-cut- technique. A narrative (d pattern) is buried within the (c) pattern as the tool-maker changes between different techniques and affordance detection skills to deal with different tool/object pairs.

KL4 1(e) (Table 7.13 and Appendix 2) – endscraper - is the same task stage type but here there is no need to create a tapered haft. Additionally, because the tool is a scraper the insert will quickly need replacing, and so the tool-maker may deliberately refrain from working the haft too much. The task stage has been classed as a narrative or (d). The tool-maker moves quickly through testing the insert in the cleft, briefly stripping back cleft prongs without rhythmic repetition developing, checks the insert again and knaps its proximal laterals, again without rhythmic repetition, and finally adjusts the insert in the cleft to check the final fit.

KL4 2(c) (Table 7.13 and Appendix 2) is the haft creation stage of the laterally hafted knife. It consists only of three non-repeated action set groups. Because the haft is lateral the tool-maker has not been constrained by the energy stored along the length of fresh wood. No gestures concerned with protection from excess splitting were needed, nor checking for the sprung closure of the cleft. The cleft was just gouged out and the blades checked for fit. The task stage is a (d) pattern.

KL4 3(d) (Table 7.13 and Appendix 2) is the same stage in respect of the thrusting spear for which the haft shape is almost as important as for the arrow. We see rhythmic repetition during reduction of the cleft prongs and the butt end of the insert, and the sharpening of the flake tool. There is more movement than in an (a) pattern between different objects being worked on, different affordance detection skills and different techniques. It takes the form of a complex rhythmic repetition (c) pattern.

All the haft completion task stages are (d) patterns (Table 7.14 and Appendix 2). KL'15 1(1)d is the completion stage of the arrow. The open cleft is dipped in heated adhesive, the insert is pressed into the adhesive-covered cleft, the adhesive is manually moulded around it, binding is applied tightly around the cleft and trimmed, and then adhesive is re-applied on top of the binding and manually moulded several times to maximise the haft shape. KL4 1(f) is completion of the hafted scraper. It has a short duration because only binding is used. KL4 2(e) is the knife completion stage. The only repetition present is caused by the fact that the same thing has to be done to two separate inserts. Adhesive is used but no binding as there is no necessity to restrain a sprung distal cleft and the main force during use will push the blades into the cleft. KL4 3(f) is the completion of the thrusting spear. The narrative moves in an identical way to the arrow completion but without manual moulding of adhesive after application, perhaps because aerodynamic requirements are reduced.

7.5.3 Reductive Tools Quantification Tables

Table 7.6 shows quantifications (Section 7.5.1) for the chopper tasks. There is no transit change information for one-stage tasks, nor flexibility in the potential task stage sequencing. The number of action set types follows closely whether or not the chopper had a bifacial edge (unifacials are KL1 1(b), KL1 4(b)), and also reflects JD's use of a leather muffler as a second tool. The task lends itself to speed and rhythmic repetition but information search can also be significant. All of the quantities directly reflect KL's significantly longer experience as a knapper, particularly in terms of speed, information search, efficiency rating and rhythmic repetition.

Task Stage	JD 1(1)	JD 1(2)	KL 1(1)b	KL 1(2)b	KL 1(3)b	KL 1(4)b
Action Sets	26	44	17	41	57	28
Action Set Types	7	7	3	6	4	3
Action Set Groups	8	18	8	14	22	14
A.S.G. Types	7	7	3	7	6	4
No. of Tools	2	2	1	1	1	1
No. of Objects	1	1	1	1	1	1

Worked On						
No. of Postures	1	1	1	1	1	1
Speed in Seconds	5.04	4.11	2.29	1.37	1.23	1.96
Info. Search %	75.57	51.93	51.28	30.36	28.57	56.36
Efficiency Rating	37.5	16.67	0	7.14	4.55	0
Rhythmic Rep. Level	7.69	72.22	87.5	57.14	86.36	85.71
Pattern	(b)	(a)	(a)	(a)	(a)	(a)
Flexibility	0	0	0	0	0	0
Transit Changes	N/A	N/A	N/A	N/A	N/A	N/A

Table 7.6 - Quantification of chopper action set groups

Table 7.7 shows the quantification of the Oldowan core and flake tasks. For two tasks the only transit change is from core to flake as objects, while JD's transit change is higher because he changes tools. All of the speeds are reasonably fast for both task stages and rhythmic repetition is high. The efficiency levels follow according to experience with RTM showing the least efficient use of action set groups and JD showing a slightly less efficient use than KL.

Task Stage	RTM 1(b)	RTM 1(c)	JD 1(3)a	JD 1(3)b	KL 1(5)b	KL 1(5)c
Action Sets	84	58	28	40	90	9
Action Set Types	5	4	7	6	5	4
Action Set Groups	25	28	12	20	36	4
A.S.G. Types	13	2	5	3	9	3
No. of Tools	1	1	2	1	1	1
No. of Objects Worked On	1	1	1	1	1	1
No. of Postures	1	1	1	1	1	1
Speed in Seconds	2.32	1.41	2.86	1.5	2.21	3.22

Info. Search %	48.72	46.34	47.5	30.92	24.77	37.93
Efficiency Rating	36	3.57	8.33	0	5.55	0
Rhythmic Rep. Level	56	96.43	66.66	90	86.11	50
Pattern	(a)	(a)	(a)	(a)	(a)	(a)
Flexibility	1	1	1	1	1	1
Transit Changes	2	N/A	5	N/A	2	N/A

Table 7.7 – Quantification of Oldowan core and flake action set groups

A comparison between average quantifications for the chopper task stage types and Oldowan core and flake task stage types (Table 7.15) shows that the number of action set types and action set group types remains steady as would be expected from two technologies of the same type. The number of tools and objects used, postures employed, and speeds all remain steady. As a result of the Oldowan core and flake groups having a second task stage there was an overall increase in the number of action sets and action set groups, and in duration (Table 7.1). Information search drops by 9.7%, the efficiency score shows a slight improvement from 10.98 to 8.91, and rhythmic repetition increases from 66.1 to 74.2. All these changes are due to the presence of the highly rhythmic repetitive and efficient nature of retouch in all the second task stages.

Table 7.8 shows the three-stage flake-based biface (handaxe) tasks. Each tool-maker has produced some distinct quantities. RTM has a poorly defined boundary between first and second stages. His following task stage only consisted of a blank creation as the biface was not thinned. The first two stages could equally have been treated as a combination of the core reduction and flake removal, and the second stage as the blank creation. If RTM 2(d) is compared with JD 2(b) and KL2 1(c) then his number of activity sets is high, the efficiency rating is not good in comparison with the other two, and the rhythmic repetition is lower. The average efficiency score for the bifaces (Table 7.15) is the lowest out of all the reductive tools and the average rhythmic repetition is at its lowest.

JD and KL's finishing stages are the longest knapping–specific task stage durations coded (Table 7.4). The production of a well-finished handaxe may be the most cognitively challenging and time-consuming of the reductive technologies (7.6.3).

Task Stage	RTM 2(b)	RTM 2(c)	RTM 2(d)	JD 2(a)	JD 2(b)	JD 2(c)	KL 2(1)b	KL 2(1)c	KL 2(1)d
Action Sets	37	64	151	12	102	458	40	101	272
Action Set Types	5	6	6	7	7	6	8	8	6
Action Set Groups	11	15	53	4	40	158	10	44	114
A.S.G. Types	8	11	12	4	14	36	9	9	18
No. of Tools	1	2	1	2	3	3	4	2	2
No. of Objects	1	1	1	1	1	1	1	1	1
No. of Postures	1	1	1	1	1	1	5	1	1
Speed in Seconds	4.95	3.81	1.7	7.92	2.26	1.92	8.7	2.77	2.31
Info. Search %	66.66	57.79	33.27	35.79	27.61	24	37.93	33.21	18.6
Efficiency Rating	27.27	60	22.64	25	15	22.15	60	4.55	8.77
Rhythmic Rep. Level	62.5	40	71.7	0	75	76.58	0	93.18	86.84
Pattern	(a)	(a)	(a)	(d)	(a)	(a)	(d)	(a)	(a)
Flexibility	1	1	1	1	1	1	1	1	1
Transit Changes	0	5	N/A	5	3	N/A	7	2	N/A

Table 7.8 – Quantification of flake-based biface action set groups

Table 7.9 shows the prepared core and flake tasks. There is a straightforward relationship between the three tool-makers based on their relative experience. KL appears to have a particular expertise with a maximised efficiency level for the first and last stages. His speed for the last stage again appears to be slow but on examination of the coded sequence this is because his flake removal action sets are long – his efficiency and rhythmic repetition for this stage are maximal.

Task Stage	RTM	RTM	RTM	JD	JD	JD	KL	KL 3	KL

	3(b)	3(c)	3(d)	3(a)	3(b)	3(c)	3(1)b	(1)c	3(1)d
Action Sets	69	65	153	266	28	108	99	56	20
Action Set Types	4	6	3	6	7	4	4	8	3
Action Set Groups	18	15	76	99	10	47	46	19	10
A.S.G. Types	9	13	3	19	6	9	5	11	2
No. of Tools	1	1	1	3	3	2	1	1	1
No. of Objects	1	1	1	1	1	1	1	1	1
No. of Postures	1	1	1	1	1	1	1	1	1
Speed in Seconds	3.29	3.71	1.55	1.55	3.39	1.72	1.57	2.77	6.5
Info. Search	60.35	63.9	40.76	40.55	49.47	30.38	31.61	50.65	28.46
Efficiency Rating	33.33	53.33	0	14.14	20	6.38	0	26.32	0
Rhythmic Rep. Level	55.55	26.66	97.37	82.83	50	82.98	97.83	63.16	90
Pattern	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
Flexible	1	1	1	1	1	1	1	1	1
Transit Changes	2	2	N/A	2	5	N/A	2	2	N/A

Table 7.9 – Quantification of prepared core and flake action set groups

Comparison between all the reductive technologies so far (Table 7.15) confirms that flake-based bifaces had the longest duration, number of action sets and action set groups; required the largest number of tools, the lowest average speed, the poorest efficiency rating, the lowest rate of rhythmic repetition and also the most marked task stage boundaries (Section 7.6.3). All of this suggests a stronger presence of sequence-organising strategies as opposed to rhythmic repetition strategies. The differences between the three tool-makers suggests that this sequencing skill needs to be learned, and the learning process requires more accumulated experience than rhythmic repetition-based learning. The other three technology groups show a gradual increase in quantification in relation to action set and action set group numbers and the number of tools required. All other quantities remain reasonably level if the biface quantities are not included. All knapping task stages are fixed in the sense that their position within their sequence is not optional. Any new sequencing cognitive strategies at this stage only organise increasingly complex sequences of existing action set types where rhythmic repetition is reduced.

7.5.4 Hafted Tools Quantification Tables

Table 7.10 shows the knapping task stages of hafted tool events. These concern the inserts for each tool except KL4 2 which was knapped during KL4 1. KL'15 1(1)a shows a slow speed but this represents low information search. Gesture was fast and continuous without stops to search for information, the rhythmic repetition and efficiency rating for both task stages are good. During KL4 3(c) KL detached a blade and shaped it into a spear point making the duration much longer than for both KL4 1(c) and (d) together, as the reduction was more complex (Table 7.1). However, the efficiency level and rhythmic repetition of both tasks is comparable (Table 7.15). The obvious difference from the reductive task stages is that all of these task stages are flexible. They could have been executed at other points in the hafting process although they need to have been finished before haft creation and haft completion. They also show a higher average transit change or a clearer task stage boundary than they would if they were part of a reductive task (Table 7.15) because the next task stage may not be knapping and may require completely different objects, tools and posture.

Task Stage	KL '15 1(1)a Pressure Flake	KL 4(1)c Detach Blade	KL 4(1)d Retouch Blade	KL 4(3)c Detach & Shape Blade
Action Sets	50	60	43	214
Action Set Types	6	7	6	9
Action Set Groups	22	28	20	99
A.S.G. Types	7	7	6	18
No. of Tools	3	2	1	2
No. of Objects	1	1	1	2

No. of Postures	1	1	1	1
Speed	6.1	2.4	3.37	1.99
Info. Search %	23.93	25.69	30.35	29.34
Efficiency Rating	0	7.14	0	2.02
Rhythmic Rep. Level	77.27	85.71	85	90.91
Pattern	(a)	(a)	(a)	(a)
Flexible	2	2	2	2
Transit Changes	7	3	2	4

Table 7.10 – Quantification of hafted tool knapping action set groups

Table 7.11 below shows the wood-working task stages which consisted of either or both a stripping and an end-trimming task. Different kinds of debitage were used as tools, including flakes, a sharp-edged chunk of flint and flakes retouched during the task stage, (denticulate or backed). These are all repetitive stages and only one was judged slow enough to have lost rhythm. Where the rhythmic repetition was being used with different tool/object pairs for different purposes the task stages were judged to be complex rhythmic repetition (section 7.5.1). These are more flexible task stages because their position can change easily with any insert preparation task stage. Two were inserted in-between haft creation and completion task stages.

Task Stage	KL'15 1(1)b	KL 4(1)a	KL 4(2)a	KL 4(2)d	KL 4(3)a	KL 4(3)e
Action Sets	98	18	53	38	21	49
Action Set Types	10	6	8	8	7	8
A.S Groups	34	8	20	16	10	24
A.S.G. Types	19	4	7	8	5	9
No. of Tools	2	1	2	2	1	4
No. of	1	1	2	2	1	2

Objects						
No. of Postures	1	2	2	1	1	1
Speed	5.41	4.05	5.42	5.58	7.24	8.47
Info. Search %	22.26	23.29	30.66	14.62	18.42	13.98
Efficiency Rating	23.53	0	20	12.5	0	0
Rhythmic Repetition	52.94	62.5	75	62.5	80	79.17
Pattern	(c)	(c)	(c)	(c)	(b)	(c)
Flexible	2	2	1	2	1	2
Transit Changes	3	4	3	9	4	10

Table 7.11 – Quantification of hafted woodworking strip and trim action set groups

Table 7.15 highlights that these task stages are relatively short with good efficiency ratings. However their action sets are more extended with reduced information search, and their rhythmic repetition levels are slightly reduced. They require slightly raised numbers of tools and objects, and their transit change scores are the highest of the task stage groups so far, indicating strongly marked task stage boundaries.

Table 7.12 shows the quantification of all of the cleft creation task stages apart from KL'15 1(1) where cleft creation is part of the haft creation stage (KL'15 1(1)c). KL4 2(b) is the lateral or gouged-out knife cleft. It has a longer duration (Table 7.1) and higher numbers of action sets and action set groups (7.12). Its rhythmic repetition is higher and its information search lower than the other cleft creations because the tool-maker did not need to keep breaking off to check as he would have done with a sensitive distal cleft. While they are all repetitive these task stages are different enough from rhythmic reductive task stages that one is a slow repetition (b), and one has been classed as a complex rhythmic repetition (c) because of the high variability of action set types and tool / object pairs. Transit change scores remain high. The average scores (Table 7.15) show a common trend with the strip and trim task stage group for slower, shorter task stages with good efficiency, low levels of information search and medium levels of rhythmic repetition.

Task Stage	KL 4(1)b	KL 4(2)b	KL 4(3)b
Action sets	13	51	42
Action Set Types	7	9	10
Action Set Groups	6	22	18
A.S.G. Types	4	8	11
No. of Tools	2	2	3
No. of Objects	1	2	3
No. of Postures	1	1	2
Speed	4.62	7.02	4.69
Info. Search %	26.67	8.1	30.97
Efficiency Rating	0	13.64	16.66
Rhythmic Rep. Level	42.86	77.27	50
Pattern	(a)	(b)	(c)
Flexible	2	1	2
Transit Changes	6	5	8

Table 7.12 – Quantification of hafted tool cleft creation action set groups

Table 7.13 shows all of the haft creation task stages (Section 7.5.2). Two of them (KL'15 1(1)c and KL4 3(d)) are complex rhythmic repetition (c). They involve a tapered haft and have more action sets and action set groups than the other two task stages as well as a higher rhythmic repetition level. The other two are classed as narrative (d). KL4 2(c) is very short as it simply consisted of trying out both blades side by side in the gouged-out lateral cleft. It has a maximised efficiency and no rhythmic repetition at all. The average scores (Table 7.15) reflect a general rise in the complexity compared with the previous wood-working stages, with increased action sets and action set groups, and a higher number of objects worked on. Speed is steady but information search has fallen yet again, indicating that it is being carried out at the same time as the action sets are being performed. Rhythmic repetition is at its lowest to this point while the number of objects worked using different techniques is raised.

Task Stage	KL '15 1(1)c	KL 4(1)e	KL 4(2)c	KL 4(3)d
Action Sets	117	22	6	67
Action Set Types	13	8	4	8
Action Set Groups	53	8	3	67
A.S.G. Types	13	6	3	12
No. of Tools	2	2	0	2
No. of Objects	3	2	3	3
No. of Postures	1	1	1	1
Speed	3.47	8.05	3.66	5.39
Info. Search %	29.31	16.95	22.73	9.97
Efficiency Rating	5.66	12.5	0	10
Rhythmic Rep. Level	83.02	37.5	0	70
Pattern	(c)	(d)	(d)	(c)
Flexible	1	1	2	2
Transit Changes	8	2	5	4

Table 7.13 – Quantification of haft creation action set groups

Table 7.14 shows all the haft completion task stages (Section 7.5.2). They are all narrative patterns. There is no repetition. The pattern is a recursive sequence arranged so as to bring together disparate components into one meaningful or function-specific object. Each haft completion is different because of the different object-combinations being used, and because each intended function is very specific. Task stage sequencing for reductive tools is fixed and its product is a general-purpose tool. However, each hafted tool needs to be sequenced individually at task stage and action set group levels to increase adaptiveness or task-specificity. With the loss of rhythmic repetition the designation of action set groups becomes more difficult (Section 8.3). Separate information search levels are very low, suggesting increased reliability, or in other words more continuous control over the object modification in hand than is present during reductive tasks.

Task Stage	KL '15 1(1)d	KL 4(1)f	KL 4(2)e	KL 4(3)f
Action Sets	36	13	17	16
Action Set Types	13	7	7	9
Action Set Groups	13	4	7	5
A.S.G. Types	12	4	4	5
No. of Tools	4	1	3	4
No. of Objects	4	3	4	5
No. of Postures	1	1	1	1
Speed	10.22	10.69	12.82	22.5
Info. Search%	9.78	18.71	5.51	0.56
Efficiency Rating	30.77	50	0	40
Rhythmic Rep. Level	0	0	0	0
Pattern	(d)	(d)	(d)	(d)
Flexible	1	1	1	1
Transit Changes	N/A	N/A	N/A	N/A

Table 7.14 – Quantification of haft completion action set groups

Table 7.15 gives average quantifications for each type of task stage. It shows that haft completions have the lowest number of action sets out of all task stage types because their duration is short. In stark contrast they have the highest number of action set types indicating that despite the lack of cognitive support that would otherwise have been provided by rhythmic repetition, a uniquely variable range of action set types are being sequenced in an effective way. These task stages also have the highest number of tools and objects connected with them which is consistent with the variability of action set types required. Raised levels of ability to move between different areas of learned experience are indicated, together with expanded affordance detection skills. While there may be some problems with the calculation of speed, and of the efficiency rating because of the lack of action set group definition, the average rhythmic repetition level of zero is reliable and highly significant.

Tech. Type	Chopper	Core / Flake	Biface	Prepared Core / Flake	Insert	Strip & Trim	Cleft Creation	Haft Creation	Haft Completion
Action Sets	35.5	51.5	130.55	96	91.75	46.17	35.33	53	20.5
Action Set Types	5	5.17	6.55	5	7	7.83	8.66	8.25	9
Action Set Groups	14	20.83	49.89	37.77	42.25	18.66	15.33	32.75	7.25
A.S.G. Types	5.66	5.83	13.44	8.55	9.5	8.66	7.66	8.5	6.25
No. of Tools	1.33	1.17	2.22	1.55	2	2	2.33	1.5	3
No. of Objects	1	1	1	1	1	1.5	2	2.75	4
No. of Postures	1	1	1.44	1	1	1.33	1.33	1	1
Speed	2.66	2.25	4.04	2.89	3.47	6.03	5.44	5.14	14.06
Info. Search %	49.01	39.36	37.21	44.01	27.33	20.54	21.91	19.74	8.64
Efficiency Rating	10.98	8.91	27.26	17.06	2.29	9.34	10.1	7.04	30.19
Rhythmic Rep.	66.1	74.2	56.2	71.82	84.72	68.69	56.71	47.63	0

Transit Changes	N/A	3	3.66	2.5	4	5.5	6.33	4.75	N/A

Table 7.15 – Average quantifications for each technology type

7.6 Conclusion

7.6.1 Questions and Predictions Evaluated

The predictions (a-i) set out in Section 7.1.3 are assessed, and implications for future research discussed. Section 7.6.2 - 7.6.4 will focus on findings not necessarily relevant to the predictions which also have implications for future research.

(a) Basic units of action (action sets) will be identifiably present and will become 'chunked' into longer sequences (action set groups). Action sets and action set groups will be identifiable as functional by their repeated appearance in related sequences

And

(b) Types of available action sets will increase as the range of behavioural variables increases (First Pilot Study), and this will result in a wider range of action set group types as the number of potential action set combinations rises

Action sets were identifiable in all task stages. The gestures that made up each action set were not individually recorded and differed slightly from each other while still belonging to the same gesture type (Section 3.2.1; Sporns & Edelman 1993; Kelso 1995; Reed 1996; Bingham 1998; Byrne et al 2001; Edelman & Tononi 2001; Byrne 2003; Roux & Bril 2005; Baber 2006; Latash 2012; Nonaka & Bril 2012; Rein et al 2013; Parry et al 2014). The description of action sets and action set types was found to be useful. But it is acknowledged that analysis by single gesture may be necessary in future projects in order to record accurate speeds, the level of rhythmic repetition and to deal more accurately with non-repetitive rhythmical patterns. Higher levels of technological support will be required (Bakeman & Quera 2011).

Fifty-one different task stages were coded (Table 7.1) with flake-based bifaces providing the highest average count of action sets in one task stage at 130.55 (Table 7.15). Excluding bifaces there is a rise in action set numbers from choppers through all knapping tasks, and then a drop again through the non-knapping hafted tool task stages with haft completion task stages showing the lowest figures (Table 7.15). The number of used action set types remains at thirty-one across all task stages. Knapping tasks used 35.48% of available action set types, while hafted tool tasks used 93.55%, despite the fact that the figure for total action sets used per task stage decreases at the transition from reductive to hafted tools. This indicates a much higher propensity for knappers to repeat the same action sets over and over, and for hafted tool-makers to carry out shorter sequences of discrete action set types.

Action sets could be divided up into action set groups in relation to reductive and hafted tool task stages where objects were being reduced in some way. The beginning of a new action set group could be easily defined by the appearance of the next main action set. Divisions between action set groups were less clear in non-reductive task stages – particularly where different tool components were being combined. In future non-reductive task stages could perhaps be treated as one single action set group, or action set group boundaries might be triggered by tool / object changes.

Appendix 1 shows a high variability in the way action sets can be potentially chunked into action set groups. Two hundred and fifteen action set group types were recorded across all task stages. Just under half of them (44.65%) had knapping blows as their main action. This suggests that while knapping tasks do not require a wide variety of action set types, they can achieve variability through action set group formation (Delagnes & Roche 2005; Andersson et al 2014). For hafting the variability is to be found at a lower or action set level, and long action set groups are not required (Appendix 1).

Only 32 of the 215 action set groups (14.88%) are used in three or more task stages. Twenty-seven of these re-used groups (84.38%), have a maximum of three action sets. This indicates the self-organisation of action units into short effective chunks which are frequently re-used. These units (Table 7.5) are all associated with particularly fast, effective retouch task stages. Less effective longer reductive action set groups form almost randomly at highly constrained moments of uncertainty during more complex knapping task stages and are hardly ever re-used. Byrne (2016) describes the same pattern of great apes learning communicative gestures, starting with long random chains of gestures which over time they learn to reduce down to their most effective format (Section 3.2.1).

The first prediction is therefore correct. Action sets can be identified in their own right, and chunked into action set groups some of which appear to be more effective and more re-used than others. The second prediction is more problematic. The rate of increase in action set types across all tasks is surprisingly steady, (from 5-7 on average for knapping task stages and 7-9 on average for hafted task stages, Table 7.14). There is a corresponding steady increase in the average number of action set groups and action set group types through the knapping task stages. This implies that as archaeological time progressed the tasks became more challenging and required an increase in the types of actions performed and in the ability to arrange them into different types of groups depending on circumstances. But action set group numbers fall for all non-knapping hafted task stages (Table 7.14). This may be partly a product of the loss of clear action set group boundaries. But it may also indicate a new cognitive strategy for producing variability – the use of a larger number of discrete action set types in one task stage.

(c) In the hafted tool sequences it will be possible to identify the splicing together of older patterns derived from both non-lithic and lithic technologies

Within each hafting task there is a mosaic of different nested technology types. Knapping skills are used to prepare stone inserts. Woodworking skills are used in the strip and trim and cleft creation stages. Adhesive and binding technology do not dominate whole task stages as their preparatory stages were not coded, but appear at the next level down, combined into a mosaic with other technologies during haft completion task stages (Section 7.6.4). All woodworking task stages can include knapping technology at the task stage level. This is mainly in relation to the creation and maintenance of the debitage-based tools used to reduce wood. Even if the tool is already denticulated or backed for example, it may still need sharpening during the course of the task stage. Haft creation and completion stages contain knapping sequences for the same reasons, but also require finely tuned last-moment changes to the insert. Haft completion task stages include adhesive and/or binding sequences which can be alternated (Section 7.6.4). This prediction is correct, and leads to the conclusion that hafted tool-makers are able to move more easily and quickly than reductive tool-makers between different skill types and modes of affordance detection within a single task, and to sequence correctly so as to ensure that the variability has a complex, meaningful outcome and does not become random.

(d) Specific reductive wood-working action sets and action set group patterns should be different from specific reductive knapping action sets and action set group patterns, but should also have some similarity

Wood-working action set groups are reductive and this is reflected in the fact that where the main action set in a group is wood stripping, sawing, gouging or snapping, the action set group is frequently short, effective and rhythmically repetitive (Table 7.5). Table 7.15 shows that while speed remains consistent for reductive knapping tasks, it slows down through all of the reductive hafting task stages which are mostly wood-working action set groups. Section 7.5.1 concludes that it may be more accurate to describe wood-working action sets as longer and less interrupted by information search than the knapping action sets. They are more continuous, with partial ongoing visual feedback, haptic feedback from contact with the tool in use, from skin surfaces, and from muscular tension, none of which can be maintained during knapping. It is possible that knapping is less controlled and should be described as more risky than wood-working. Table 7.15 confirms that the percentage duration taken up by information search during non-knapping hafted tool task stages decreases from strip and trim onwards, while rhythmic repetition levels only start to fall in relation to haft creation and completion task stages. The prediction is accurate and also allows an illustration of how behavioural variables interact and co-vary over time. Wood as opposed to stone can be worked with more continuous control, allowing reduction to achieve more specificity, and causing a new selection for cognitive strategies involving more continuous multi-modal information feedback.

(e) Rhythmic repetition will be more consistent earlier in archaeological time but will become more erratic as a sequence pattern, connected mainly with the reductive modification of objects

Table 7.15 shows a range between 56 to 85 for knapping rhythmic repetition levels. The lowest level (56.20) is for the flake-based bifaces which seem to have carried the highest cognitive load or constraint level out of all of these types (Section 7.6.3). Without the bifaces the range would be 66 to 85. The hafted tool knapping task stage averages are high at 84.72, possibly because they were all performed by the most experienced tool-maker, and because he chose to use less complex technologies appropriate for hafting (Section 7.6.3). Individual strip and trim task stages (average rhythmic repetition level of 68.69) and individual cleft creation stages (average level of 56.71) were also counted as reductive. The average rhythmic repetition level for all types of reductive task stages is 67.79, while that for an average non-reductive task stage is 23.82. All of the haft completions score 0 for rhythmic repetition. One of the cleft creation task stages is a (c) pattern with a rhythmic repetition level of 50. Two out of the four haft creation task stages are also (c) patterns with high knapping-like levels of 83.02 and 70. The other two are (d) patterns with levels of 37.5 and 0. The prediction is accurate but begs the question of how the loss of such a useful cognitive strategy is compensated for.

(f) A reduction in rhythmic repetition during one task stage will correlate with an increase in information search

Two non-retouch reductive knapping task stages show this replacement of rhythmic repetition with increased information search (JD 1(1) and KL2 1(b)). These task stages appear to involve high levels of constraints which have to be dealt with by increasing information levels. However, in most cases as well as a drop in rhythmic repetition there is also a drop in information search across the same task stages. This prediction is not fully correct and increased information search does not provide an alternative cognitive strategy for the loss of rhythmic repetition.

(g) Task stage and action set group sequencing will become more flexible over archaeological time

All reductive knapping task stages need to be performed in a fixed sequence in order to achieve the expected tool outcome. The knapping task stages of hafted tools however, are often more flexible in terms of sequencing as they are more self-contained. Strip and trim task stages and cleft creation task stages are all flexible and are shown occurring in slightly different sequences (Table 7.1). Haft completion task stages have to come last but a strip and trim task stage intervened between haft creation and completion on two occasions. Flexibility allows the tool-maker more leeway to deal with local constraints or mistakes, and for the creation of a more task-specific tool. This prediction is accurate. Cognitive strategies must include a new ability to perceive and react to a range of constraints and affordances and actively organise sequences at all levels.

The contents of this section confirm the increasing importance of actively sequencing internal action set groups and action sets in an order that will result in a functional tool. Strict rhythmic repetition implies no option about what action set comes next or when it is going to happen. The further away a sequence is from being rhythmically repetitive, the more active cognitive sequencing strategies must be. Where task stage sequences are flexible the new sequencing cognitive strategy needs to be present during every task stage. A new responsivity to very small changes in task conditions is required in order to identify the approaching end of every action set and action set group, as well as the way to commence succeeding action sets and action set groups, and the associated tools and objects required.

(h) The number of task stage boundaries per task will become greater and more clearly marked

Numbers of task stages per task increases through all reductive knapping tasks. Their boundaries were described according to academic tradition but most were also marked by tool changes and pauses in activity on the part of the tool-makers. Section 7.5.3 mentions the 0 score for the transit change between RTM 2(b) and (c). This boundary should be regarded as an artefact of the pilot study as the tool-maker worked right through it. Transit change scores for all reductive knapping tasks were mainly changes in tools, and a change from core to flake. Scores ranged between 2.5 – 3.66 (Table 7.14). The highest score was for the flake-based biface. The transit change scores for the hafted knapping task stages were higher (an average of 4 per transit) because the next task stage required a completely different set of tools and objects. The wood-working task stages for strip and trim and cleft creation averaged a transit change score of 5.5 and 6.33 points. The haft creation task stages showed a reduced transit change score presumably because some of the task stages required the retention of a lot of the objects for re-use in the subsequent task stage. The prediction is accurate.

This kind of detailed change from one kind of task stage to another needs to be capable of self-organisation. Relevant general action sets concerning tool and object change (Table 7.2) need to be included in the action set sequences being formed. The changes are signposts that allow tool-makers and observers to interpret a point in the action sequence as a boundary and to parse the whole event (Sections 4.4.2 and 4.4.3). Boundaries can only become real and have functional importance if they are communally agreed on. We are aware of archaeological sites where communal acknowledgement of these task stage boundaries is evident in respect of reductive tools and allows for a change-over from one tool-maker to another (Roberts & Parfitt 1999; Hallos 2005; Goren-Inbar 2011). Alternative tool-makers or different component part processors, are particularly necessary for hafted tools. Hafted task durations extend well beyond those shown here if all resource acquisition, binding and adhesive production processes (preparatory task stages) are taken into account (Sections 1.6 and 7.6.4). Multiple tool-makers are even more likely to be involved in respect of hafted tools. A communal agreement on how to infer task stage boundaries is also likely to be essential for accurate learning processes (Sections 4.4.2 and 4.4.3). The possible presence of multiple tool-makers suggests a need for high-level cognitive strategies for patterning and parsing both gesture and verbal phonemes, and using parsed verbal description arranged so as to produce a specific meaning (Wragg Sykes 2015) .

(i) Different ways of sequencing action sets and action set groups will result in new forms of sequence patterns as rhythmic repetition reduces

Section 7.5.1 describes four main types of sequencing patterns highlighted by the coding making this an accurate prediction. The first (a) is rhythmic repetition which at its most unadulterated in knapping tasks is associated with fast, efficient, reductive working with low information search. As the reductive tools become more complex the information search increases and efficiency levels become less consistent. This pattern is associated with fixed sequences of task stages and action set groups. It extends into the wood-work action set groups of hafted tools but wood-work action sets are less punctuated by information search. A loss of need to continuously check progress implies that wood reduction is less risky than stone reduction and probably less energy-consuming and stressful. Some reductive sequencing patterns lose rhythm completely and while they remain repetitive are no longer rhythmic. These task stages have been designated as slow repetition (b). (a) and (b) pattern hafted tool task stages can be flexible and carry high transit change scores.

JD and KL's biface and prepared core task stages involve frequent alternation between different tools although the objects don't change. This pattern appears to be a knapping precursor to the third sequencing pattern (c) identified here – complex rhythmic repetition. This pattern is only observed during hafted tool task stages where a range of different objects are worked on during the same task stage, requiring regular tool/object pair changes, and the use of different skill sets in short-duration sequences. Each individual component of a (c) pattern is reductive and so rhythmic repetition and efficiency levels remain elevated. The task stages can be flexible and their transit change scores are high. Rhythmic repetition is layered on top of an underlying narrative (d) pattern.

Narrative consists of short durations with low numbers of action sets but disproportionately high numbers of action set types. Repetition is very low and each action set type is almost unique within the sequence. The tool-maker needs the cognitive ability to move quickly between differentiated action set groups concerned with different tool/object pairings. (d) patterns have close to zero rhythmic repetition levels and the relevant actions are 'discrete' or only performed once. This implies cognitive control and high levels of manual dexterity in delicate situations such as the creation of a sprung cleft, or the preservation of pressure around an insert while binding takes place. It also implies a highly developed ability to sequence each set of discrete gestures in the right order (or the ability to pattern and parse mentioned above). Without correct order the sequence cannot achieve the intended goal or 'meaning', and remains random as opposed to complex.

7.6.2 The Differences Between Reductive Tool-Makers

All three tool-makers made use of nearly all of the knapping-specific and general action set types indicating that differences in performance levels were not caused by the time needed to acquire basic techniques. Differences in performance could be partly accounted for by differences in gestural control that were not considered accessible using an observational analysis methodology (Section 5.2.2; Nonaka et al 2010; Bril et al 2012; Parry et al 2014; Wilson 2016a). Increased knapping-specific motor control must lead to an increase in predictability of flake removals during knapping, which in turn must mean a reduction of the need to repeat unsuccessful sequences or correct mistakes, and a shortening of durations and compression of action set groups as seen here (Table 7.5). Increased control results from unobservable changes in gesture or expert perception action learning. The ability to sequence more complex action set groups effectively must also improve with experience, and this ability must mutually interact with the manual control-learning to increase overall ability.

7.6.3 Flake-Based Handaxes

Figure 7.6 – KL's ovate handaxe - KL 2(1)

Figure 7.7- JD's handaxe – JD 2

The results suggest that sophisticated flake-based handaxes, highly thinned and regularly shaped with a complete contour of sharpened edge, represent a big investment in time and cognitive load (Section 7.5.3 & Figures 7.6 & 7.7). Stone reduction is not so controllable as wood reduction (Section 7.6.1). Handaxe manufacture is risky with a high failure-cost if the tool is spoiled near the end of the fixed process. Bifaces, including handaxes, are the only reductive tools that disappear from the archaeological record. The disappearance is often linked with the emergence of hafting technologies (Section 1.5). Handaxes comprise both a handle and attached sharp edge, but because the tools are reductive both edges and handle are formed from the same piece of stone. Their widely recurrent morphologies may be partially the consequence of the natural qualities of flaked stone (Moore 2011a,b) and partially of the need felt by the tool-maker to maximise different potential combinations of the mutual positioning of handle and edge in one tool. Once hafting technology becomes available this generalist or maximising approach is no longer necessary. Each individual haft can be manufactured so that the tool has a handle and edge combination that is task-specific (Barham 2013b). A hafted task duration can exceed that of a flake-based biface duration (Tables 7.1 and 7.4). But the risk of task failure is greatly reduced, partly because less of the tool manufacture involves working stone, and partly because failure during the course of one flexible task stage only requires the repetition of a single stage, rather than a whole sequence of fixed reductive stages. As the size of the insert blank does not need to encompass a handle a less demanding knapping technique such as prepared core or blade technology as in KL4 3 can be used, except potentially when the specific tool required must be heavy as in Sai Island core axes for mining (Rots and Van Peer 2006; Timberlake and Craddock 2013; Timberlake 2014) or wood-cutting axes (Claud et al 2015).

7.6.4 Adhesive, Binding and Wood-Working Technologies

The Second Pilot Study coded wood and stone modification (assembly) task stages, and some of those task stages included the use of adhesive and binding. No preparatory task stages concerning the sourcing of raw materials, or their transport to the place of manufacture were coded. Neither were any preparatory task stages concerning the processing of adhesive or binding.

There were several different reasons for this. First, it was not considered practical to include sourcing and transport of raw material. The analysis of modern tool-makers' stone acquisition methods would not have been appropriate, although the wood was foraged for in both pilot studies. Second, archaeologically relevant resource acquisition task stages are likely to have been highly varied from site to site and often remain unevidenced. We have very little detail about this variability and reconstruction would not necessarily have been accurate or applicable across technology types. It would however, be appropriate if an observational analysis was used in relation to particular site artefacts to code these task stages where local information was available.

Adding on adhesive production task stages would have also have been problematic. Again they are likely to have been highly varied across sites (Clark 1954; Boeda et al 1996; Barham 1998; Beck et al 1999; Hollander & Schwartz 2000; Jerardino 2001; Koller et al 2001; Barham 2002; Grunberg 2002; Van Peer et al 2004; Wadley 2005; Lombard 2006; Mazza et al 2006; Boeda et al 2008a; Boeda et al 2008b; Wadley et al 2009; Wadley 2010; Henshilwood et al 2011;

Pawlik & Thissen 2011; Rots et al 2011; Carciumaru et al 2012; Barham 2013b; Charrie-Duhaut et al 2013; Monnier et al 2013; Matheson & McCollum 2014; Zipkin 2014; Bigga et al 2015; Claud et al 2015; Wadley et al 2015; Wragg-Sykes 2015). It is not even clear that adhesive manufacturing processes should be considered as part of a hafted tool-making event. Adhesive production could be treated as a separate technology with its own experts, variable task stages and typologies. It is likely that once developed adhesives had multiple uses which included hafting tools. It would be possible to make different types of adhesive the subject of the same kind of comparative study as has been carried out here in relation to reductive and hafted tools.

Plant-based products such as bark and tree resin can only be collected at certain times of year (Hardy 2008; Hurcombe 2008), again indicating a bulk production process not necessarily aligned with the rhythms of tool production, (Clark 1954 – stored birch bark rolls). Both JL from the First Pilot Study and KL made their adhesive in bulk and stored it in a pan in-between sessions. It is likely that they bought their wax although JL reported foraging for pine resin. Both tool-makers foraged for their binding raw materials - flax and lime-bark respectively. These raw materials had to be collected annually in bulk and then dried and stored. The lime-bark also had to be retted in order to remove the soft flesh from the bark, exposing the long, tough, flattened fibres used as binding. Once dried the flax needed to be twisted in a particular way in order to turn it into twine. Binding made from animal products may have been more continuously available but processing before use was still necessary again suggesting bulk production and storage. The same issues about variability from site to site apply in respect of binding manufacture as they do in respect of adhesive manufacture.

It is clear from the information presented here that the stripping and trimming of tree branches represents less of a cognitive challenge than knapping stone although its basic gestural pattern is similar (Sections 7.5.2 and 7.5.3), (Pruetz & Bertolani 2007; Sanz et al 2010; Gowlett 2013). It is therefore likely to have been a concurrent technology. We have very little archaeological evidence of this except for relevant use-wear evidence on stone tools (Rots 2003; Rots 2004;

Rots & Williamson 2004; Rots & Van Peer 2006; Rots 2009; Rots 2010a; Rots et al 2011; Wilkins et al 2012; Barham 2013b; Hardy et al 2013; Monnier et al 2013; Yaroshevich et al 2013; Lemorini et al 2014; Miller 2014; Morales & Verges 2014; Rots & Plisson 2014; Claud et al 2015; Rots et al 2015; Wadley et al 2015; Wilkins et al 2015), but the early use of branches to make simple tools or temporary wooden constructions such as wind breaks is not cognitively problematic.

The production of distal clefts in wooden shafts is shown here as more challenging (Section 7.5.2) but it may have been performed with a lesser degree of expertise prior to the appearance of hafted tools, thus bringing together sharp flakes and wood into the same context at an early stage. Any wood stripping and trimming would also include the use of sharp stone flakes. Knapping events would have occurred during wood-working sequences as the flake tools would have needed retouching (Clark 1958; Clark 2001; Wadley 2005; Nadel et al 2006; Rots & Van Peer 2006; Sanz & Morgan 2006; Hernandez-Aguilar et al 2007; Pruetz & Bertolani 2007; Rots 2009; Sanz et al 2010; Pawlik & Thissen 2011; Rots et al 2011; Barham 2013b; Gowlett 2013; Hardy et al 2013; Igreja & Porraz 2013; Rots 2013; Timberlake & Craddock 2013; Lemorini et al 2014; Morales & Verges 2014; Timberlake 2014; Bigga et al 2015; Claud et al 2015; Rots et al 2015; Schoch et al 2015; Van Kolfschoten et al 2015; Table 7.1).

Even if adhesive was not available before the arrival of hafting (Clark 2001; Rots 2009; Rots et al 2011; Barham 2013b; Rots 2013), binding seems likely to be linked with the manufacture of wooden structures from an early date (Wadley 2005; Nadel et al 2006; Rots & Van Peer 2006; Hardy 2008; Hurcombe 2008; Rots 2009; Pawlik & Thissen 2011; Rots et al 2011; Mohapi 2012; Igreja & Porraz 2013; Rots 2013; Timberlake & Craddock 2013; Miller 2014; Timberlake 2014; Hayden 2015; Rots et al 2015). Finally the results here show that any hominin that worked with fresh branches of wood must have developed the relevant expertise to deal with the unpredictable stored energy that they contain. Straightening trimmed branches for use as a shaft or handle, creating a distal cleft, or binding together sprung fresh branches must have involved learning and passing on to others expertise relevant to the later development of projectile machines and wooden traps.

7.6.5. Summary

The process of technological change indicated by the analysis carried out here appears to be gradual. A greater range of knowledge bases becomes necessary for hafted tools, but many of these skills may have already been available to groups within separate behavioural domains. What changes with hafting is the need to combine the skills and to alternate quickly and appropriately between different skill sets in order to achieve a more task-specific and unique product. These changes rest on cognitive strategies which become increasingly less reliant on repetition and rhythm for providing information about what comes next and when. As stone reduction becomes less dominant in tool-making tasks, greater continuous perceptual control is gained over the tool-making process and it can be adjusted as necessary through an increase in flexible goal and sub-goal sequencing skills. In addition we see hints of an increasing specialisation amongst group members. There is a need for cooperative interaction between them which requires consensus about how internal task stage boundaries of the shared task are perceived and defined, and a clear requirement for language skills. In Chapter 8 the full significance of these results are discussed in the context of the cognitive theories discussed in Chapters 3 and 4.

The results of the Second Pilot Study demonstrate that an observational gestural coding methodology provides more relevant information about changes in cognitive tool-making strategies through time than data obtained using the CO methodologies reviewed in Section 5.3. Differences between CO and observational coding results will be briefly reviewed here.

Section 5.3 showed that CO methodologies make a priori assumptions about how cognition works before collecting evidence for analysis, and these assumptions subsequently bias the interpretation of evidence so as to maintain the status quo. The format of the CO methodology has been developed over time to analyse reductive stone tool technologies. The methodology (excepting Haidle 2010, and Lombard and Haidle 2012) is only used on one technology and knapping-specific language is used wrongly to describe what amount to quasi-cognitive theories. Comparisons cannot be made with other types of reductive technologies, nor with induced-change and combinatorial technologies thus precluding any accurate mapping of change through time. This means that the nature of cognition as a domain-general behavioural organiser is never established, and the inflexible characteristics of stone reduction are attributed unquestioningly to other technologies and behaviours. The presence of fixed mental templates prior to task initiation remains unquestioned. There is no perceived need for any kind of description of cognitive mechanisms of change except for an increase in the ability to pay attention as the length of the mental template increases through time. Because the mental templates are fixed there is a perpetual tendency to seek to standardise them and variability is not looked for. This means that any proposed gradual-change mechanisms based on variability cannot be documented.

In this non-variable environment, change cannot be complex and must be described in linear terms. It is necessary to line up all comparable reductive stone technologies in a chronological sequence and find that the most recent technology in time is the most complex and thus the most cognitively derived. This process has only been made possible by a mis-interpretation of prepared-core technology dates (Section 5.3) so as to show the preferred 'Levallois' technology (Boëda 1995) as more derived than thinned flake handaxes when analysing hierarchical knapping structures. The results of the Second Pilot Study show that the cognitive load of the handaxe manufacture far exceeds that of prepared-core and flake production in relation to all types of data quantification carried out (Section 7.5). Using prepared-core and flake dates (Section 5.3) as opposed to Levallois dates, it becomes possible to view prepared-core, blade and handaxe technologies as overlapping in time, jointly representing a flourishing of variability and increased control over knapping sequences. It could be speculated that bifaces (sometimes generated by prepared-core technology – Section 5.3) were manufactured in preference to prepared-core flakes and blades when a heavier tool with a handle-option was required, up until the point where more task-specific hafting technologies became available (Section 7.6.3).

The use of gesture as the basic action unit at all levels of task analysis allows for the coding of any behaviour from any domain and their comparison in a common language. This new freedom to compare immediately highlights the difference in the flexibility of task-stage sequencing between reductive stone-tool technology and hafting technology. The difference must have been reflected in variable socio-cultural arrangements associated with external information storage, learning processes and inter-individual interactions for each technology. In turn the increased variability of hafted tool construction, and the range of different raw materials that can be included in tool fabrication allow hafted tools to respond more specifically, or to adapt, to changes in the socio-ecological environment as predicted by niche-construction theory (Section 2.5.5). Further observational analysis of gestural sequences should increase our knowledge about the variability between comparable technologies, illustrating how rates of change vary across temporal and geographical locations controlled by different local interacting niche-dynamics.

The importance of replacing observational data back into a niche-construction context to allow for interpretation of similarity and difference is illustrated by the Second Pilot Study results. For example, findings of a narrative (d) pattern in a flake-removal task stage for a handaxe was highly unexpected but easily explained by the camcorder footage. The boulder from which flakes were to be removed was the only one available but it was far too heavy to move from its dark corner in the workshop. It was a dense flint with a mucky but smooth cortex and in order to apply blows the knapper had to lean at unergonomic angles over it, even trying to use his non-dominant hand to wield the hammer. Different hammers were tried out and no rhythmic repetition could be generated, all of which led to a narrative (d) pattern rather than an (a), (b) or (c) pattern. Another example was the reduced speed and information search levels that emerged from the hafted-tool woodworking task stage analyses. The results prompted considerations about the role of perception in a woodworking as opposed to a stone-reduction context and a better understanding of the differences in gestural patterns across the two technologies. They indicated that working wood did not require the tool-maker to stop modification gestures in order to turn the object and assess progress as in knapping, and that woodworking therefore carried less of a cognitive load and was more easily controlled. This example also illustrates the ability of a gestural coding methodology to analyse the role played by information search in tool-making sequences. If such an analysis was required by a CO user, the current methodologies would not be able to support it.

A third example of this kind of interpretation of data concerns the variable presence in all knapping sequences of action set groups containing more than three action sets which were classed as inefficient when calculating efficiency levels of task stages. On investigation they tended to be particularly prevalent where the task was highly constrained such as during handaxe manufacture or the difficult flake removal task stage described above. As such they were associated with an increase in need for attentional monitoring, information search and conscious decisions. They also appeared to be associated with learning processes as their numbers and length appeared to decrease in relation to the increase in number of years' experience of each knapper. This kind of information about what happens in the spaces between successful flake-removals is simply not available using CO methodology. But it relates directly to changes in the cognitive processes involved in tool-making tasks including ontogenetic learning processes. Given the relationship of these action set group types with handaxes in particular, they may offer a more accurate measurement of cognitive load than that provided by CO hierarchy diagrams.

Ideas about the nature of cognition were formed by the researcher before the Second Pilot Study was commenced in as much as a perception action cognitive model was already in use. In practice the use of the model made it possible to regard gesture as important because of its inseparable relationship with cognition, to consider behaviour as a self-organised process that is enacted through gesture rather than through concept formation, and to acknowledge the importance of coding information-retrieval gestures as well as object-modification gestures. Otherwise the methodology simply allowed for the gathering of as much data as possible and for conclusions to be reached from subsequently identified patterns.

The gestural patterns showed a gradual change from task-structures based on rhythmic repetitions generated by single tool-object pairs, through complex rhythmic repetition patterns based on multiple tool-object pairs with a hidden narrative, through to open narrative patterns of discrete gestures. This pattern-change implies an increasing importance of top-down cognitive task structuring processes and precludes the option of denying the need for task planning at any level. However, the need for this new type of task-structuring is shown by the Pilot Study results to increase gradually through all of the coded tasks as rhythmic repetition levels decrease. It emerges out of the increasing complexity of the tasks and task stages. Rigid, predetermined stage-by-stage planning is not the sine qua non of any tool-making processes as cognitivist theory would have us believe. What *is* required is a level of intentionality available to all organisms (Reed 1996) and the expert ability (Section 4.3) to generate appropriate activity structures based on moment-by-moment considerations, continuously modifying them as required. This ability is present in all technologies analysed in the Second Pilot Study. It is the way that activity structures are generated that changes as complexity increases. The continued essential presence of the implicit rhythmic repetitive task-structuring sequences is demonstrated by the Pilot Study Results. More complex task structures are shown to be the product of their increasing tendency to combine with isolated discrete-gesture sequences which have no rhythmic repetition structure providing cues about 'when' to do 'what'. It is suggested that these gestures are cued instead by a derived ability to select and manipulate sub-goals concurrently with or as a result of the actual production of gestures (Sections 4.3-4.4 and Baber 2015). There is no sign of the sudden complete replacement of one task-structuring strategy with another as Modern Behaviour theorists would expect (Section 2.3.1).

Chaîne opératoire methodologies are essential resources for the analysis and greater understanding of all tool-making technologies and without them the Second Pilot Study would not have been possible. However, they do not provide direct access to descriptions of underlying cognitive processes. The Second Pilot Study results confirm that comparative cognitive analyses should be based on a reconstructive, observational and coded analysis of gestural sequences. The gestural analysis needs to be embedded in a perception action cognitive model and interpreted in niche-construction terms.

Chapter eight

conclusion

"without movement or action, there is no need for thought"
Koziol et al (2012:507)

"Cognition is not an abstract and individualized mental process; it is a concrete and collective process in which individuals participate to varying degrees. Thinking is the ability to plan, organize, and assess patterns of ordinary activity and experience, not some sort of internal manipulation of mental things"
Reed (1996:141)

"kinematic patterns in energy arrays are all we ever have access to. The job of the learning organism is to detect these patterns, and come to learn what they mean by using that information to do something."
Wilson and Golonka (2013:Language)

Figure 8.1 *Three of KL's hafted tools – from the bottom up the hafted end scraper, the laterally hafted knife and the thrusting spear*

8. Chapter Summary

This is the final chapter and aims to summarise the contents of all preceding chapters. A very brief summary of the suggested mechanisms of change behind cognitive evolution is given in Section 8.1 (see also Section 5.1). Specific cognitive changes relating to the development of a reductive hand held tool-making dynamic will be described (Section 8.2). Then, as an answer to the main question being posed by this project, cognitive changes relating to the transition between reductive hand-held stone tools and combinatorial or hafted tools will be examined (Section 8.3). A more inclusive summary will be given by Section 8.4. Finally there will be discussion about how archaeologists within the proposed new paradigm for evolutionary change might deal with issues about cognition, and hafted tools in particular (Sections 8.5 and 8.6).

8.1 Thought-in-Action

Cognition is both embodied and distributed. It is embodied because frequently both information collection and appropriate gestural responses can be located at effector sites or relevant body locations outside of the brain without more centrally-based awareness. Responses are constructed from local learning derived from multiple similar past experiences (Sections 4.4.3 and 4.4.4; Gibson 1979; Thelen and Smith 1994; Kelso 1995; Gibson and Pick 2000; Wilson and

Golonka 2013). The processes can also be described as 'distributed'. Their final form will depend on objects, object lay-outs, events, and physical and cultural characteristics of the niche which either constrain gestural sequences, or enable increased effectiveness and specificity of outcome. Objects and conspecifics within the niche can act as behavioural prompts, models or provide cognitive structures for learning purposes (Thelen and Smith 1994; Reed 1996; Gibson and Pick 2000; Jablonka and Lamb 2006; Nonaka et al 2010; Malafouris 2013; Baber 2015; Bril et al 2015). Tool-making processes will also be the result of increasing interactions between different individuals in the niche between whom different parts of the overall task can be distributed (Section 7.6.4).

Environmental information always enters the cognitive system through perceptual gateways but its variability in terms of its past dynamics of recombination can be enormous. An unfamiliar object can be perceived simply in terms of light wavelength information. A familiar quotation from a favourite author will be read using the same type of perceptual array but ontogenetically acquired reading skills will also be involved in the process as will stored experiences of past encounters with the quotation and relevant emotional responses. This information, however recombined it has become at the moment that we perceive it, has started out its dynamic as simple perceptual information in the cognitive system of an individual. It is possible that our ability to understand someone else's highly recombined information is grounded in the similar workings of our own embodied cognitive system (Section 3.2.2; Gallese and Lakoff 2005; Gallese 2007; Glenberg 2007; Glenberg and Gallese 2012) and our shared bio-cultural processes for parsing information and creating meaning (Sections 4.3.1; Section 4.4.2).

Section 4.4.3 describes a system of learning (the implicit system) which in modern humans can provide a highly variable set of different learning and response routes along a sliding scale. At one end of the scale (implicit) we have very fast but context-bound processes with no need for awareness. At the other end of the scale (explicit) we have slower learning processes with a high level of awareness. Information is partly generated in conceptual form and can be used in a range of different contexts. Some authors have shown evidence of learning processes that start out as implicit but which become explicit as they are used repeatedly (Section 4.4.3). In these cases changes in neuronal processes have been identified as the information involved becomes more widely networked and slower to use, but more adaptable to different contexts as a result. Section 4.4.4 illustrates how this kind of highly flexible neuronal system can be described as one out of which conscious thought can emerge when it is supported by a complex implicit learning process.

We have seen in Section 4.2 that by changing behaviour and experimenting with new resources as a result of changes in environmental constraints and affordances, individuals also cause plastic change to their own neuronal systems. Any process of learning causes such change. It appears that the more learning we are obliged to undertake in our particular niche, or by having to move to a new niche, the more likely it is that our plasticity levels will be set higher so that learning becomes easier and quicker for us. The more active learning that we carry out during our lifetime the more likely we are to also require changes in our brain metabolism and the lay-out of our neuronal networks. All of these structural changes can be brought about by alterations to our epigenome and these epigenetic adjustments are likely to be heritable. Intergenerationally hominins may well have passed on an increasing level of metaplasticity through biological systems (Section 4.2.2) and new developmental pathways for neuronal structures (Section 4.2.3). They have also passed on their own skills to new generations by acting as models of behaviour or through actively teaching. Externally stored or cultural information and the cultural institutions that control it also become an increasingly important non-biological learning route (2.5.5).

Sections 8.2, 8.3 and 8.4 will reconcile the findings of the Second Pilot Study with the theoretical frameworks discussed in Chapters 3 and 4. Finally in Sections 8.5 and 8.6 the role of archaeologists in supporting research into the evolution of cognition will be discussed.

8.2 Reductive Stone Tool Dynamics

Various reductive hand-held stone tool sequences were recorded and coded in the Second Pilot Study, and corresponding sequences from the First Pilot Study were re-used in the second Study but analysed in a completely different way the second time round. In total the combined pilot studies produced 6 chopper creation sequences and three chopper plus retouched flake sequences representing Oldowan technology. Some of the choppers had flakes removed from two planes and were referred to as bifacial, while some choppers remained unifacial. Three flake-based bifaces (handaxes), and three prepared-core and retouched prepared flake sequences were also recorded referencing Acheulean technology (Table 7.1). The handaxes were intended to represent a later more refined style (Clark 2001) involving substantial thinning and a more defined morphology, although due to raw material impurities only 2 of the 3 tools reached this standard. Also included in Table 7.1 is the removal and retouch of a blade from a blade core (KL4 3c) during the making of a hafted tool. This process can represent a stand-alone knapping sequence of a hand-held tool although in this instance the product became an insert.

The various quantified changes between reductive hand-held tool making technologies demonstrated a gradually increasing complexity in the way that the tasks were constructed through evolutionary time. Simple chopper production without retouched flakes had an average duration of 89 seconds (Table 7.1), whilst choppers and retouched flakes averaged 190.33 seconds (approximately double the duration of a chopper only). The two thinned flake-based handaxes averaged 1,229.5 seconds, and prepared-core and retouched prepared flakes averaged 626.32 seconds. The duration recorded for the blade removal and retouch during a hafting task was 426 seconds. What is shown here is an increase in the duration of all reductive tasks across the Oldowan-Acheulean transition. The more surprising element is the substantially longer duration of the thinned flake-based handaxe compared with the other Acheulean technology tasks. Other quantifications also illustrate how refined handaxes are likely to have represented a heavier manufacturing cost than other comparable tool-types in terms of time and cognitive effort. This is discussed at more length in Section 7.6.3 where it is suggested that this heavy load was the main reason for the disappearance of bifaces from the archaeological record, once they could be replaced by more efficient and more task-specific hafted tools.

The number of task stages starts at 1 for choppers, goes up to 2 for choppers and retouched flake and to 3 for flake-based bifaces. If the blade had been made from raw material rather than removed from an existing core then it would also have had 3 task stages. This generic archaeological sequence represents a slow increase in complexity in general terms. It also means that where task stage boundaries occur, some kind of break in the rhythmic nature of the activity is also likely, together with some changes to the balance of unobservable components that make up the flake-removal synergies. This corresponds to the notion of the rhythmic content of action unit chunking in Section 4.3.1 and requires some ability to assess the moment at which to stop one kind of task and to proceed with another. Otherwise rhythmic repetitive activity negates the need to decide what to do next or when. It also acts in synchrony with other neuronal-based processes that refresh attention and motor accuracy at each recurrent beat in the rhythmic process (Section 4.3.1).

The average number of action sets in each task stage shows a gradual increase which corresponds with duration. Choppers as tools in their own right average 35.5 action sets per task stage. Chopper and flakes average 51.5 action sets. Flake-based handaxes average 130.5 action sets, and prepared cores and flakes average 96 action sets. Again we see the relatively heavy load represented by the handaxes. Interestingly the number of different types of action sets (action set types) remains steady across all tool-types with a slight elevation for handaxes. The average number of action set types per task stage is 5 for choppers, 5.17 for choppers and flake, 6.55 for the handaxes and 5 for the prepared cores and flake. Across both the coded reductive and hafted tool sequences a total of 31 different action set types were identified (Table 7.2). Out of this full range of reductive tools only used 35.48% of available types (Figure 7.2). Again this implies that while changes in unobservable gestural components were probably taking place over evolutionary time to improve affordance detection, manual dexterity and flake-removal control in relation to the tasks in question, the techniques involved remained contextually bound to stone reduction and were not transferable to other activities.

The average number of action set groups in each task stage shows a gradual increase across all reductive technologies. Again handaxes have the highest score. The scores are an average of 14 action set groups per task stage for choppers, 20.83 for choppers and retouched flakes, 49.89 for handaxes and 37.77 for prepared cores and flakes (Table 7.15). The average number of action set group types for each technology also goes up across reductive technologies, peaking with handaxes. In this instance the increase only happens in relation to handaxes and prepared cores and flakes. It might be caused by the presence of the long and rather random sequences identified in Section 7.4 connected with indecision about how to proceed, and a loss of the supportive rhythmic repetition which would otherwise have removed the need for such decisions.

Table 7.5 shows that with increasing knapping experience action set groups tend to become shorter (chunked) and repeated more often by the tool-maker across different technologies. As action set groups become shorter rhythmic repetition increases along with the cognitive support that it provides. This phenomenon appears to correspond with the rhythmic chunking process described by Sakai et al (2004) (Section 4.3.1) whereby rhythmically chunked action sequences become building blocks in their own right which can be re-used in new tasks with a similar context. It implies that later reductive knapping sequences are harder to learn than earlier ones, and increasingly challenge the implicit system's job of reducing the uncontrolled manifold of variable potential courses of action (Section 3.2.1). This will also mean that in the past, where behaviour challenged neuronal networks, the neuronal networks themselves changed in order to increase behavioural efficiency. The reductive knapping evolutionary dynamic is likely to be one of the interacting causes for increasing epigenetic plastic change potential (metaplasticity) for ontogenetic learning, and developmental increases in neuronal network complexity (Section 4.2). Finally, this pattern indicates that due to the restricted nature of stone reduction, variability and ultimately new technology has to be generated through an increase in length and complexity of action set groups rather than through the addition of new action set types (Section 7.6.1; Delagnes and Roche 2005; Andersson et al 2014).

In terms of numbers of tools used all reductive technologies involved here are pretty steady, with the exception of handaxes. The average number of tools used per task stage is at 1.33 for Oldowan choppers without retouched flakes, 1.17 for choppers and flake, 2.22 for handaxes and 1.55 for prepared cores and flake (Table 7.15). These results are likely to be related to the lack of change in action set types, with the exception of two of the handaxes where the knappers used both a bone and stone hammer or abrader at the thinning task stage. The use of two different types of tools alternately indicates that non-observable variables of flake removal are likely to be distinct for the two different tools, representing a steeper learning gradient, more breaks in rhythmic repetition, and more moments of decision about when to change tools and technique mid-task stage. Again the thinned handaxe represents a higher cognitive load than the other technologies. The average number of objects worked on per task stage for stone reduction is consistent across all task stages and stands at 1. This reflects the relatively invariable nature of stone reduction, but is also controlled by the fact that task stage boundaries are not so well marked, and particularly in relation to earlier technologies a change of object becomes a good task stage boundary-marker both for hominins and modern humans. Most of these tools do involve working on both a core and a flake at different times, but the object change takes place at the task stage boundary and gets counted as a 'transit change' (Sections 3.1 on boundaries; 7.2 and 7.5.1).

Transit changes were calculated by counting the number of tool, object and posture changes that took place at the boundary between task stages. Where the same tool, object or posture was used across the boundary then nothing was counted, but where one of these variables was lost one side of the boundary or arose at the other side it was counted as a change. Transit changes only applied to tasks with more than one task stage, and did not apply to any final task stage. The average transit changes for each reductive technology task stage were 3 for choppers and flake, 3.66 for handaxes and 2.5 for prepared cores and flakes. Again the handaxe score is the odd-one out, showing a slightly higher differentiation of tool-use across task stage boundaries. The boundaries between task stages have been interpreted here as the boundaries described by Holland (2014) within a complex adaptive system (CAS). Boundaries surround each agent in the CAS. As a new agent appears it starts to effect its own changes to the information passing through its boundaries. This results in increased differentiation of information across boundaries as only increasingly specified information can cross for further processing. Increased numbers of agents in the system is equivalent to increased complexity and an increased possibility of new emergent levels developing (Holland 2014).

A quantification described as ‘speed’ was used in the second pilot study but as Section 7.5.1 explains this is not an accurate description of what was actually measured. The duration of each task stage was divided by its total number of action sets thus giving a time in seconds for the average length of each action set. The speed variable provided what appeared to be a useful comparator for reductive stone tools, but became more problematic for hafted tools. Across reductive tools the figures remained steady, apart for handaxes where the quasi-speed slowed to half of the pace of the other technologies, possibly reflecting an increased cognitive load and the use of neuronal networks requiring awareness (Sections 4.3.3 and 4.3.4). Choppers without retouched flakes averaged 2.66 per task stage, choppers and retouched flake averaged 2.25, handaxes averaged 4.04 and prepared cores and flakes averaged 2.89 (Table 7.15).

Information search was hypothesised as being something that would increase with complexity (Section 7.1.3). However, this was one of the few predictions that was not supported (Section 7.6.1). The percentage of task stages given over to information search remained relatively steady across all technologies. The figures show 49.01 percent of task stage duration is information search for choppers. For choppers and retouched flake it is 39.36 percent (the reduction is probably caused by low information search requirements for simple retouch), for handaxes it is 37.21 percent and for prepared cores and flakes it is 44.01 (Table 7.15). Information search remains an important part of a perception action tool-manufacturing process and increased information must be necessary for more complex outcomes.

We know as humans that it is possible to search for information while carrying out other activities at the same time. This means that the long, random action set groups in the more complex reductive tools may mask increased information search taking place at the same time as other non-flake-removal gestures. It follows that as the knapper becomes more experienced and her long, random action set groups become shorter and more effective, she has less need for information search as she is increasingly able to rely on her accurate flake-removal skills in a range of situations. This is a particularly important development in knapping where the effect of the hammer blow is out of sight, or in other words there is a lack of visual information at the moment that the blow is delivered. This may limit the utility of information search when making reductive tools, and force the reductive tool-maker to rely instead on slowly acquired ontogenetic expert haptic and aural learning using the implicit learning system (Section 4.4.1). It is also the basis of the strong alternation in knapping between delivering blows and searching for information that structures rhythmic repetition.

A quantification of rhythmic repetitive action was arrived at by calculating the proportion of action set group types in one task stage that were a maximum of three action sets in length and were repeated more than once during the task stage. The average rhythmic content score for all task stages is 66.1 percent for choppers, 74.2 percent for choppers and flake, 56.2 percent for handaxes and 71.82 percent for prepared cores and flakes (Table 7.15). This represents a consistent reliance on rhythmic patterns for task construction across all reductive technologies (Section 4.3.1). The rhythmic content of the choppers was adversely affected by JD's raw material consisting of dense quartzite cobbles which only yielded flakes reluctantly, so the level is lowest for this particular set of trials but may well have been higher if all tool-makers had used flint. All simple flake retouch tasks showed very high levels of rhythmic repetition as the actions were minimised by the small size of the object being worked, the blows were light with short trajectories, and there was no possibility of damaging a highly-worked piece.

In this context the drop in rhythmic repetition in relation to the handaxes makes sense. We have already seen that these tools probably represent a high cognitive load and certainly represent a significant investment of energy and time. For both of these reasons, even a highly experienced knapper such as KL appears to loose rhythmic repetition during a handaxe sequence, suggesting that other task structuring strategies are coming in to play such as more marked goal and sub-goal sequencing (Sections 4.3.3 and 4.3.4). These strategies require derived prefrontal networking activity (Section 4.3.4) to manage the goal sequences, aligned with the more marked task stage boundaries that designate the beginnings and ends of sub-goal performances, significant unobservable differences between different flake removal techniques, and swapping between different tools. Rhythmic repetition rates recover again in relation to the prepared-cores and flakes but this is in line with other quantifications reported here which confirm that prepared-core technology does not present such a heavy cognitive load as do handaxes.

So in summary what we may be seeing in terms of cognitive change through the reductive dynamic is gradual but significant. What emerges is a variability in different sequence types. Action set numbers increase as does duration, implying an increasing ability to maintain attention and an increasingly specific set of changing outcome requirements indicating increased categorisation facilities (Thelen and Smith 1994). Action set group types increase over this period as part of the process of learning how to increase the variability and reliability of flake-removal techniques. Task stage boundaries become more marked as the content of each task stage starts to become more differentiated from other task stages. In other words, the variability of chunked units increases even though the potential for re-ordering them remains restricted in relation to reductive stone tools which have fixed sequences. The chunked units still appear to be generated by an implicit system that relies heavily on context-bound rhythmic repetitive strategies. High levels of awareness may not be required but the strategies are very fast and reliable. However, we see a possible change in this regard in relation to handaxes where the process slows and may draw more on derived awareness-based systems that start to sequence goals and sub-goals (Sections 4.3.3 and 4.3.4; Stout and Khreisheh 2015).

It is suggested that the learning process for these tools remains mainly an implicit or expert process that relies on extensive rehearsal within a variety of different constraints. The sophisticated differences in flake-removal techniques in the later tools cannot be learned by observation alone. They have to be built into the implicit system through direct experiential learning (Keller and Keller 1996). This kind of implicit learning cannot be transferred into language systems for learning or teaching purposes (Section 4.4.3). Complex language did not form a major part of the learning experiences of the tool-makers who participated in this project or of knapping classes attended by the author. It is more likely that pronounced rhythmic entrainment (Section 4.3.1) of movement (Section 2.3.4 and 4.3.1; Kelso 1995) and sound (Sections 2.3.4 and 4.3.1) is the mainstay of group teaching sessions although this hypothesis requires further exploration. The gorillas' use of observational parsing (Section 4.4.2) would not serve them well for learning to knap. When we consider language in these situations we have to consider how hungry modern humans are for its use in learning situations where our ancestors may not have been. This cultural bias may affect research projects that use modern humans to research the use of language during the learning of knapping skills. We want to get our information from textbooks, powerpoint slides or experts. We tend to ignore the implicit learning abilities that we have access to and do not take account of how much they can do for us. Without these learning abilities we would not have learned to use complex language in the first place (Sections 4.4.3 and 4.4.4).

8.3 Changes in Cognition Implied by a Transition to Hafting

Table 7.1 shows the four different types of hafted tools coded for the second pilot study. They were all made by KL and consist of a non-fletched arrow, a hafted end scraper, a laterally hafted knife and a thrusting spear (Figure 8.1). Section 1.6.1 describes hafted tool making as a hierarchical combinatorial technology and this refers to the two-stage process of preparing a range of different tool components (preparatory task stages) and then assembling them together to make a single tool (assembly task stages) (Section 1.6.3). The preparatory stages of each component (in this study consisting of a knapped flint insert, a straight, stripped and trimmed wooden shaft or handle, plant-based induced-change binding and a combinatorial adhesive) constitute different hierarchical sequences that all combine together at the top level of the dynamic when haft completion takes place. There is no fixed order in which preparatory stages need to be carried out so long as all prepared components are ready for use for assembly stages. Not all of these preparatory stages were filmed and coded for practical reasons (Section 7.6.4) and this must be taken into account when comparing hafted with reductive quantifications.

It is clear from Table 7.1 that even approaching the assembly stage, hafted task stage sequencing is less fixed than it is for reductive stone tool sequences. Various types of task stages were identifiable in relation to the observed sequences carried out by KL. Woodworking stages appear in each task consisting of some combination of stripping and trimming a wooden handle or shaft. There is frequently a knapping stage involving the preparation of a stone insert although on this occasion KL carried out two knapping stages together producing inserts for both KL4 1 and KL4 2 during KL4 1. There is a cleft creation stage where the wooden shaft is prepared to receive an insert. There is a haft creation stage (Section 7.5.2) where the insert and cleft are recursively adjusted together to ensure an effective haft in terms of aerodynamic shape and secure fit. Finally there is a haft completion stage (Section 7.5.2) where all tool components are built into a single object using appropriate fastening methods.

This new sense of flexibility has profound cognitive implications and is highly adaptive. Its most immediate result is that each task stage boundary becomes much more marked, creating small independent task units complete in themselves. These task units can be allocated amongst different individuals with different skill sets, or can be carried out with long periods of time intervening between them during which items might be stored for future use. All of this implies a higher level of awareness in terms of goal and sub-goal sequencing, planning and problem-solving than we saw for reductive tools (Sections 4.3.3, 4.3.4 and 4.4.4). There is also a possibility that sharing out component tasks amongst a group involves high-level inter-individual communication skills likely to consist of language. Both complex motor activity construction and language construction rely on the same set of hierarchical motor sequencing skills (Koechlin and Jubault 2006; Anderson 2010; Barton 2012; Fairlie and Barham 2016; Gash and Deane 2015; Negwer and Schubert 2017). In addition we will see that verbal teaching methods may be more useful for passing on combinatorial tool-making skills than for reductive tools, so the co-development of complex language and hafting skills seems a reasonable hypothesis at this stage.

The durations of the hafted tool assembly stages shown here were 1609 seconds for the non-fletched arrow, 738 seconds for the hafted end scraper, 1097 seconds for the laterally hafted knife and 1911 for the thrusting spear (Table 7.1) (averaging overall 1338.75 seconds – Table 7.4). All of these times are substantially longer than any of the reductive tools except for the thinned handaxes which actually averaged out as the longest duration of all of the tools (2229.5 seconds – Table 7.1). If we take into account that not all of the relevant task stages are included in the hafted sequences then we should assume that the hafted tool durations could be even further removed from the reductive tools than these figures suggest. If the entire hafted tool-making process is considered as continuous and carried out by one tool-maker then the full preparatory and assembly stages would represent a considerable load on attentional and planning capacity. Sharing the task with others may have been a good strategy for reducing that load.

The number of task stages for the hafted tools ranges between 4 (the non-fletched arrow), 5 (the laterally hafted knife) and 6 (the hafted end scraper and the thrusting spear). This is partly the effect of the knife blades being knapped during the making of the hafted end scraper, and partly the effect of the way that the tool-maker ran two potential task stages together during the making of the arrow. This lack of fixed structure illustrates the variability of this technology and still amounts to a higher total of task stages compared with the reductive tools. Because of the high level of flexibility and the long durations there is a need for increased attentional ability together with greater sequencing skills as a momentary response to ongoing constraints. Problems are more likely to arise during hafted tool-making as there is simply more to go wrong and more time during which things can unravel. Isolating and responding appropriately to problems is related to an increased level of ongoing awareness and access to top-down planning (Sections 4.3.3, 4.3.4 and 4.4.4).

In terms of the average number of action sets per task stage (Table 7.15) these can be seen to vary. The action set average for knapping the insert corresponds to the reductive figures. The woodworking action set figures for strip and trim task stages and cleft creation task stages are slightly lower although they both involve reductive activities (the wood of the shaft and cleft, and the stone of the insert and the wood-shaving tool). This is almost certainly the result of a reduction in the need for dedicated information search action set types during woodworking as the tool-maker maintains visual and haptic contact throughout more of the process. A certain amount of rhythmic alternation between reduction and information search action sets is therefore lost as compared with stone reduction tasks. During haft creations action set numbers rise again and this is likely to be the result of the wider range of different processes that need to be carried out at this stage. Both the insert and the cleft may need to be retouched (reduced) recursively, and the wood reduction flake frequently needs resharpening as well during this stage (Section 7.5.2). Action set numbers fall dramatically for haft completions and this is likely to be caused by the marked change in action set patterns at this stage as discussed in the next paragraph (Section 7.5.2 and 7.6.1).

Average numbers of action set types per task stage go up in number for all of the non-knapping hafted tool stages (Table 7.15) even though there is a tendency for action set numbers to fall. This indicates that repetition rates are falling in hafted tool task stages and each new hafting action set is more likely to be a different type from the preceding action set than was the case for stone reduction. What this represents is an increase in the number of discrete actions that are being sequenced one after the other, especially in the haft completion stages. This implies the development of a derived and more recent evolutionary form of motor control, goal and sub-goal sequencing, requiring more complex neuronal networks and an increased need for high levels of awareness (Sections 4.3.2 and 4.4.4). It also implies yet further increased sequencing skill where decisions about what to do next are becoming far less spaced apart than they were for highly repetitive sequences (Section 4.3.1). In support of this change Figures 7.2 and 7.3 show that while reductive stone tools use only 35.48 percent of all available action set types, the hafted tool sequences use 93.55 percent even though average action set numbers are lower than for reductive stone tools. In comparison with reductive stone tool technology which was contextually restricted and could only increase in complexity by generating longer action set groups, hafting technology can increase in complexity at a more basic level by increasing the number of action set types in use during each task stage so long as corresponding sequencing skills are available.

Average action set group numbers (Table 7.15) are shown as reducing across non-knapping hafted tool task stages. The implications of these figures are not clear. The act of deciding how to put action sets into groups became far less clear for hafting task stages as rhythmic repetition levels began to fall. The important fact here is that the loss of rhythm is probably affecting the ease with which the tool-maker can chunk action units using implicit learning processes (Section 4.3.1), and some other kind of chunking process may be being used instead. We can speculate that the tool-maker is now chunking his activity completely around relevant goals and sub-goals organised by the prefrontal cortex (4.3.4). This would correspond with starting and ending chunks when tools and worked objects are changed over, but this hypothesis requires further testing. Action set group numbers will also be affected by the fall in action set numbers.

There is a rise in the average number of tools used per hafted tool task stage, which echoes the increasing variability of action set types within the task stage boundaries and differentiation between task stages. The average number of objects worked on during hafting task stages also rises for the same reasons in stark contrast to reductive stone tools where the figure was a consistent 1 across all technologies (Table 7.15). Again these changes point towards the need for increasing awareness levels and decision-making points as very different action set types are needed in such short periods of time. Higher variability in skill sets associated with different tools and objects are also required, and increased categorisation ability. Transit changes for hafting task stages increase as the differentiation between them also increases (Table 7.15).

The speed calculations show a marked decrease across all non-knapping hafted task stages. This quantification is explained in Section 8.2. It is clearly affected by the reduction in the need for information search action sets during wood reduction and other action set types used here, all of which afford continous visual and haptic information as the activity is carried out. This has had the effect of lengthening the average duration of each action set in a task stage. It also means that the alternation between hammer-blows and search action set types seen in knapping task stages is lost, and it is this alternation which underlies rhythmic repetition patterns. As confirmation we can see that average information search figures for the same sets of hafting task stages (Table 7.15) are greatly reduced.

Sections 7.5.1 and 7.6.1 describe four different rhythmic repetition patterns that have been identified as a result of the coding process (Tables 7.1-7.14). The first two described are (a) rhythmic repetition and (b) slow repetition where rhythm reduces as a result of the loss of alternation between hammer-blows and search described above. Rhythmic repetition is basic to all stone tool reduction sequences but slow repetition does occur in some of the more difficult stone tool reduction task stages (Section 7.5.1). The third pattern is (c) complex rhythmic repetition and is caused by the need to change between different worked objects/tool pairings within a task stage. The reductive and thus basically rhythmic repetitive nature of the pattern is maintained but the pattern varies slightly depending on the tool-object combination in use at the time. This pattern is seen mainly in haft creation task stages (Sections 7.5.1 and 7.5.2). The fourth pattern is (d) narrative. Here the rhythmic repetitive nature of the task is lost and the new emerging pattern of varied but accurately sequenced discrete action sets is seen instead. It is most common in haft completion stages (Sections 7.5.1 and 7.5.2). The changes between these patterns provides some evidence of a gradual change between task-structuring strategies which are totally reliant on rhythmic entrainment (Section 4.3.1) and more derived discrete motor actions requiring longer ontogenetic learning processes, more complex neuronal networking (Section 4.3.2) and a possible connection with more derived and awareness-based sub-goal and goal sequencing systems (Sections 4.3.3, 4.3.4, 4.4.3 and 4.4.4).

8.4 Final Summary

A particular aspect of the local appearance of hafted tools in the archaeological record marks one of the most clearly delineated cognitive changes that we can ever expect to see recorded by artefacts. In addition to all of the changes discussed above, one of the characteristics of hafted tools that authors often pick up on is that they are combinatorial. They are made up a variable selection of different raw materials all of which have their own associated skills, techniques and tools. These raw materials are individually processed and then put together in a specific manner at the tool haft. With the possible exception of adhesives (Section 1.6.2) it seems likely that all of the different techniques involved have a long shared history (Section 1.5). For a very long period of time (c.2.5 million years using currently available dates) these techniques remained contextually separated. Information in less developed perceptual action systems remained episodic, grounded in perceptual arrays and not capable of transfer into new contexts (Sections 3.2, 3.2.1 and 3.2.2).

Ultimately, as the perception action system became more complex and information was recombined at higher levels (Sections 3.1 and 3.2.2) it could be transferred usefully between contexts. This development is echoed in the ontogenetic development of modern humans' increasingly flexible use of recombined perceptual information as they mature (Sections 3.2, 3.2.1 and 3.2.2). The presence of hafted tools in the archaeological record is a clear-cut indication that some kind of milestone in context-free information recombination has been reached by local hominins. It is unlikely to represent a step-change but more probably developed gradually through time for example in relation to the use of twine to bind other objects together, or the joint use of stone flakes and wooden branches in some tasks (Section 7.6.4).

Another important factor about hafted tools is the way in which the engineering of the haft (Section 1.6.3; Barham 2013b) must be specific to the task for which the tool is intended, and relevant to the particular set of components involved in each individual tool-making process. The presence of a pre-activity plan of some sort that was not required by reductive stone tools is indicated. It is not being claimed that hafted tool manufacture requires cognitivist representations or a ready-made mental template related to the technology in question (Section 2.1). But there is a very real possibility haft manufacture does require some kind of initial conceptual process even if it is not definatory (Section 3.2.2 and Baber 2015), an increased involvement of prefrontal goal and sub-goal processes as the task proceeds (Section 4.3.4), and higher levels of awareness (Sections 4.4.3 and 4.4.4).

In terms of the learning processes involved in acquiring hafted tool-making skills implicit perceptual action learning processes (Section 4.4.3) remain essential. However, because of the high level of observable differentiation during the process, observational parsing (Section 4.4.2) would be an extremely useful extra source of data for the implicit system. Because awareness levels are increased for hafted tools, existing language systems could also be networked into the learning process (Section 4.4.3), allowing for the setting of and answering of questions and the giving of instructions. Many of the actions and gestures involved in hafting are capable of verbal description in a way that the delicate adjustment of a hammer blow in relation to a range of implicitly observed factors is not. The availability of these newer learning systems, together with the sharing out of different parts of the task between individuals with specialist skills, may well have helped to control the increased cognitive load of these tasks and improved their efficiency over time as cultural institutions and external information storage became more involved (Section 2.5.5).

8.5 Archaeologists' Role in Understanding Cognitive Evolution?

In Section 2.6 Steven Mithen's statement at the Festschrift for Clive Gamble in 2015 was mentioned. Mithen said that he believed that palaeoanthropologists had failed to describe cognitive evolution correctly and that this was a task that would now be completed by other disciplines. However, palaeoanthropology is changing its approach and starting to open up to the new theoretical models discussed in Chapters 2 and 3 to try and understand cognition better (Section 2.6.1). Malafouris (2010 a,b) emphasises the unique and essential nature of the contribution that archaeologists have to offer. They actually retrieve and identify artefacts which are the end-products of the different types of technological sequences that have been analysed here. They have been the people who have painstakingly reconstructed the skills that went into stone tool reduction and kept records of that variability over time. They have been the people who have challenged cognitivist assumptions about human evolution because they clashed with the integrity of the archaeological record itself (Section 2.3).

Malafouris (ibid) believes that archaeologists have an essential contribution to make, and should do it within a niche construction theory framework (Section 2.6.1). Niche construction theory postulates that any new ecological niche inhabited by an organism very quickly becomes the product of that organism's constructive activity, and the degree to which construction is useful depends on the cognitive capacity of the organism. New generations of the same organism are born within the constructed niche and their plastic neuronal network is moulded by the nature of the constructed niche and the affordances it contains (Reed 1996; Jablonka and Lamb 2006). Their perceptual learning experiences and cognitive abilities are shaped by the niche and enable their subsequent behaviours that modify the niche still further. Their own cognitive processes are thus changed yet again as a result of their own activity, as are the cognitive processes of future generations (Laland et al 2000; Kendal et al 2011; MacKinnon and Fuentes 2012; Odling-Smee et al 2013; Sinha 2015; Morgan 2016). By providing evidence of some of the tools, flora and fauna preserved from prehistoric niches, archaeologists provide vital evidence of the very early stages of a highly recursive and complex process which still continues today.

8.6 How Should the New Paradigm Affect Archaeologists' Work?

Any paradigm change that is predicted here is still in its very early stages. If it occurs in the way suggested then the most obvious difference is going to be that change will be described as gradual and sometimes emergent, rather than the result of genetic mutatory speciation events. This will mean that at any given moment in prehistoric time the potential for future change will be dependent on the amount of variability currently present in the system under examination. This makes it essential that an accurate description of any kind of site cannot be made by categorising it together in a single class with other sites. Instead the site should be treated as an individual interaction between a range of different local factors that make it unique, and the individuality of the site should be the object of description. Neither should any assumptions about the cognitive abilities of group-members related to the site be made based on their species, the type of artefacts found at the site, or the date given to the site. Cognitive ability is a complex emergent product of a wide range of interacting factors. It is better to make a good effort to describe the evidence available for as wide a range as possible of those interacting factors before then trying to establish some kind of opinion about cognitive ability that is contextualised within the site information. Any opinion given will be more sound if some kind of dynamic of change before and after the site date can be shown, and potential interactions with other local sites be discussed.

This project has indicated that the presence of hafted tools in an assemblage may provide significant evidence of an elevated rate of cognitive ability and group interaction in relation to the tool-makers. It might also indicate an increased collaboration within the group and with other local groups. In order to establish whether or not hafted tools are present it would seem imperative to carry out microscopic use-wear analyses of a significant proportion of artefacts recovered, and not to restrict those analyses to points or other items connected with what appear to be hunting tools, or even to retouched tools. Hafted stone-flake inserts with minimal retouch used for woodworking have now been identified (Rots 2013), and their presence indicates a well-embedded hafting culture as opposed to a tentative new one (Section 1.6.2), and thus also a more advanced cognitive profile. Microanalysis will also also give hints as to a full technological profile of the group in terms of what they were using their tools for. The more variability in tool-use that can be shown, the more developed cognitive ability is likely to be. Microanalysis may also provide other more generalised information about the ecological niche as it was originally (Section 1.5). It is possible that the microanalysis process itself will need to undergo changes to make it quicker and simpler to carry out (conversation with L. Barham 2017). Additionally, as a result of this project it has become obvious that sophisticated hafted tools do not get made without the use of a wide range of unretouched, unhafted flake tools (Appendix 2). The presence of a lot of this tool-type does not have to mean a low-grade cognitive profile. It may indicate the presence of an active wood-shaping industry for example and possibly of hafted-tool making (Section 1.6.2). The presence of bone fragments used for resharpening may also be relevant (1.6.2) as woodworking blunts stone flakes very quickly (Timberlake 2014; Van Kolfschoten et al 2015).

Whether or not any archaeologist wants to carry out the extra work that would be involved in getting up to speed with current cognitive science research or the perception action cognitive model is clearly a decision that only they can make. Such knowledge is not an essential component of the skills-package of a good archaeologist. However, what is likely to be increasingly necessary is the awareness that this kind of knowledge is indispensable for anyone who does set out to analyse the evolution of human cognition or any part of it, and cooperation with people that possess it when appropriate can only be a good thing. In contrast, a thorough understanding of niche construction theory would seem to be indispensable to all archaeologists and should be actively provided (Section 2.5.5).

References

Aberg, K.C., Herzog, M.H., (2012). About similar characteristics of visual perceptual learning and LTP. *Vision Research* 61, 100-6

Aboitiz, F., Montiel, J.F., 2012. From tetrapods to primates: Conserved developmental mechanisms in diverging ecological adaptations, in *Evolution of the Primate Brain: From Neuron to Behavior*, eds. M.A. Hofman, D. Falk. Progress in Brain Research 195, Elsevier B.V. 3-24

Abraham, W.C., 2008. Metaplasticity: Tuning synapses and networks for plasticity. *Nature Reviews Neuroscience* 9(5), 387-400

Aiello, L.C., Wheeler, P., 1995. The expensive-tissue hypothesis: The brain and the digestive system in human and primate evolution. *Current Anthropology* 36(2), 199-221

Almecíja, S., Smaers, J.B., Jungers, W.L., 2015. The evolution of human and ape hand proportions. *Nature Communications* 6, Article Number 7717. Doi: 10.1038/ncomms8717

Alperson-Afil, N., Goren-Inbar, N., 2016. Acheulian hafting: Proximal modification of small flint flakes at Gesher Benot Ya'aqov, Israel. *Quaternary International* 411, 34-43

Ambridge, B., Lieven, E.V.M., 2011. *Child Language Acquistion: Contrasting Theoretical Approaches*. Cambridge: Cambridge University Press

Ambrose, S.H., 2010. Coevolution of composite-tool technology, constructive memory, and language: Implications for the Evolution of Modern Human Behavior. *Current Anthropology* 51(1), S135-47

Anderson, M.L., 2003. Embodied cognition: A field guide. *Artificial Intelligence* 149, 91-130

Anderson, M.L., 2010. Neural reuse: A fundamental organizational principle of the brain. *Behavioral and Brain Sciences* 33, 245-313

Andersson, C., Read, D., 2016. The evolution of cultural complexity: Not by the treadmill alone. *Current Anthropology*, 57(3) 261-286

Andersson, C., Tornberg, A., Tornberg, P., 2014. An evolutionary developmental approach to cultural evolution. *Current Anthropology* 55(2), 154-74

Andrefsky, W., 1998. *Macroscopic approaches to lithic analysis*. Cambridge: CUP
Archer, W., Braun, D.R., Harris, J.W.K., McCoy, J.T., Richmond, B.G., 2014. Early Pleistocene aquatic resource use in the Turkana Basin. *Journal of Human Evolution* 77, 74-87

Arthur, W.B., 2009. *The Nature of Technology*. London: Allen Lane

Arthur, W.B., Polak, W., 2006. The evolution of technology within a simple computer model. *Complexity* 11, 5-31

Ash, J., Gallup, G.G., 2007. Paleoclimatic variation and brain expansion during human evolution. *Human Nature* 18, 109-24

Baars, B.J., Franklin, S., 2007. An architectural model of conscious and unconscious brain functions: Global workspace theory and IDA. *Neural Networks* 20(9), 955-61

Baber, C., 2006. Cognitive aspects of tool use. *Applied Ergonomics* 37(1), 3-15

Baber, C. 2015. Thinking through tools: What can tool-use tell us about distributed cognition? *Studies in Logic, Grammar & Rhetoric*, 41(1), 25-40

Baber, C., Parekh, Cengiz, T.G., 2014. Tool use as a distributed cognition: How tools help, hinder and define manual skill. *Frontiers in Psychology: Cognition* doi:org.liverpool.idm.oclc.org/10/3389/fpsyg.2014.00116

Baddeley, A.D., Hitch, G., 1974. Working memory. In *The Psychology of Learning and Motivation*, G.H. Bower (ed). London: Academic Press, Vol. 8, 48-79

Baillieux, H., De Smet, H.J., Paquier, P.F., De Deyn, P.P., Marien, P., 2008. Cerebellar neurocognition: Insights into the bottom of the brain. *Clinical Neurology and Neurosurgery* 110(8), 763-73

Bakeman, R., Quera, V., 2011. *Sequential Analysis and Observational Methods for the Behavioral Sciences*. New York: Cambridge University Press

Barham, L.S., 1998. Possible early pigment use in south-central Africa. *Current Anthropology* 39(5)

Barham, L., 2002. Systematic pigment use in the Middle Pleistocene of South Central Africa. *Current Anthropology* 43(1), 181-190

Barham, L., 2010. A technological fix for ‘Dunbar’s Dilemma’?, in *Social Brain, Distributed Mind*, eds. R. Dunbar, C. Gamble, J. Gowlett. Oxford: Oxford University Press, 367-89

Barham, L., 2013a. Beyond Modernity, in *The Oxford Handbook of African Archaeology*, eds. P. Mitchell, P. Lane. Oxford: Oxford University Press, 341-5

Barham, L., 2013b. *From Hand to Handle: The First Industrial Revolution*. Oxford: Oxford University Press

Barrett, L., Henzi, P., Rendall, D., 2007. Social brains, simple minds: Does social complexity really require cognitive complexity? *Philosophical Transactions of the Royal Society B* 362, 561-75

Barry, G., Mattick, J.S., 2012. The role of regulatory RNA in cognitive evolution. *Trends in Cognitive Sciences* 16(10), 497-503

Barsky, D., 2009. An overview of some African and Eurasian Oldowan sites: Evaluation of hominin cognition levels, technological advancement and adaptive skills, in *Interdisciplinary Approaches to the Oldowan*, eds. E. Hovers, D. R. Braun. Dordrecht: Springer, 39-47

Barton, R.A., 2001. The coordinated structure of mosaic brain evolution. *The Behavioral and Brain Sciences* 24, 281-2

Barton, R.A., 2012. Embodied cognitive evolution and the cerebellum. *Philosophical Transactions of the Royal Society B* 367, 2097-107

Barton, R.A., Harvey, P.H., 2000. Mosaic evolution of brain structure in mammals. *Nature* 405, 1055-58

Bar-Yosef, O., Van Peer, P., 2009. The chaine operatoire approach in middle Palaeolithic archaeology. *Current Anthropology* 50(1), 103-31

Bassett, D.S., Gazzaniga, M.S., 2011. Understanding complexity in the human brain. *Trends in Cognitive Sciences* 15(5), 200-9

Bateson, P.P.G., 2004. The active role of behaviour in evolution. *Biology and Philosophy* 19, 283-98

Beaman, C.P., 2007. Modern cognition in the absence of working memory: Does the working memory account of Neandertal cognition work? *Journal of Human Evolution*, 52(6), 702-706

Beaman, P., 2010. Working memory and working attention: What could possibly evolve? *Current Anthropology* 51(S1), S27-S38

Beck, C.W., Stout, E.C., Bingham, J., Lucas, J., Purohit, V., 1999. Central European Pine Tar Technologies. *Ancient Biomolecules* 2, 281-93

Bednarik, R., 1995. Concept-mediated marking in the lower Palaeolithic. *Current Anthropology* 36(4) 605-634

Bednarik, R., 2003. A figurine from the African Acheulean. *Current Anthropology* 44(3) 405-413

Beer, R.D., 2000. Dynamical approaches to cognitive science. *Trends in Cognitive Sciences* 4(3), 91-9

Bentley-Condit, V.K., Smith, E.O., 2010. Animal tool use: Current definitions and an updated comprehensive catalog. *Behaviour* 147, 185-221

Berger, L.R., Hawks, J., de Ruiter, D.J., Churchill, S.E., Schmid, P., Delezene, L.K., Kivell, T.L., Garvin, H.M., Williams, S.A., DeSilva, J.M., Kinner, M.M., Musiba, C.M., Cameron, N., Holliday, T.W., Harcourt-Smith, W., Ackermann, R.R., Bastir, M., Bogin, B., Bolter, D., Brophy, J., Cofran, Z.D., Congdon, K.A., Deane, A.S., Dembo, M., cDrapeau, M., Elliott, M.C., Feuerriegel, E.M., Garcia-Martinez, D., Green, D.J., Gurtov, A., Irish, J.D., Kruger, A., Laird, M.F., Marchi, D., Meyer, M.R., Nalla, S., Negash, E.W., Orr, C.M., Radovcic, D., Schroeder, L., Scott, J.E., Throckmorton, Z., Tocheri, M.W., VanSickle, C., Walker, C.S., Wei, P., Zipfel, B., 2015. *Homo naledi*, a new species of the genus *Homo* from the Dinaledi Chamber, South Africa. Elifesciences doi: 10.7554/eLife.09560

Bernstein, N.A., 1967. *The co-ordination and regulation of movements*. Pergamon Press: Oxford

Berry, D.C., Broadbent, D.E., 1984. On the relationship between task performance and associated verbalizable knowledge. The *Quarterly Journal of Experimental Psychology A: Human Experimental Psychology* 36(2), 209-31

Berry, D.C., Dienes, Z., 1993. *Implicit Learning*. Hillsdale USA: Lawrence Erlbaum Associates

Berti, A., Frassinetti, F., 2000. When far becomes near: Remapping of space by tool use. *Journal of Cognitive Neuroscience* 12, 415-20

Bidet-Caulet, A., Barbe, P-G., Roux S., Viswanath, H., Barhelemy, C., Bruneau, N., Knight, R.T., Bonnet-Brilhault F., 2012. Dynamics of anticipatory mechanisms during predictive context processing. *European Journal of Neuroscience* 36, 2996-3004

Bigga, G., Schoch, W.H., Urban, B., 2015. Paleoenvironment and possibilities of plant exploitation in the Middle Pleistocene of Schoningen (Germany). Insights from botanical macro-remains and pollen. *Journal of Human Evolution* 89, 92-104

Bilalić, M., Kiesel, A., Pohl, C., Erb, M., Grodd, W., 2011. It takes two – skilled recognition of objects engages lateral areas in both hemispheres. *Plos One* 6(1) e16202

Bingham, G.P., 1988. Task-specific devices and the perceptual bottleneck. *Human Movement Science* 7, 225-264

Birch, H.G., 1945. The relation of previous experience to insightful problem-solving. *Journal of Comparative Psychology* 38(6), 367-83

Blasco, R., Rosell, J., Cuartero, F., Peris, J.F., Gopher, A., Barkai, R., 2013. Using bones to shape stones: MiS 9 bone retouchers at both edges of the Mediterranean Sea. *Plos One* 8(10) e76780

Bleed, P., 2011. Loosening our chaînes: Cognitive insights for the archaeological application of sequence models. Special Issue: Reduction Sequence, *Chaîne Opératoire,* and Other Methods: The Epistemologies of Different Approaches to Lithic Analysis. *PaleoAnthropology*, 297-304

Bloch, M., 2012. *Anthropology and the Cognitive Challenge*. Cambridge: Cambridge University Press

Boëda, E., 1995. Levallois: A volumetric construction, methods, a technique. In H.L. Dibble, O. Bar-Yosef (eds), *The Definition and Interpretation of Levallois Technology*. Prehistory Press: Wisconsin, 41-8

Boëda, E., Bonilauri, S., Connan, J., Jarvie, D., Mercier, N., Tobey, M., Valladas, H., al Sakhel, H., Muhesen, S., 2008a. Middle Palaeolithic bitumen use at Umm el Tiel around 70,000 BP. *Antiquity* 82, 853-61

Boëda, E., Connan, J., Dessort, D., Mehesen, S., Mercier, N., Valladas, H., Tisnerat, N., 1996. Bitumen as hafting material on Middle Paleolithic artefacts. *Nature* 380, 336-38

Boëda, E., Bonilauri, S., Connan, J., Jarvie, D., Mercier, N., Tobey, M., Valladas, H., Al Sakhel, H., 2008b. New evidence for significant use of bitumen in Middle Palaeolithic technical systems at Umm el Tlel (Syria) around 70,000BP. *Paleorient* 34, 67-83

Boesch, C., 1991. Handedness in wild chimpanzees. *International Journal of Primatology* 12(6) 541-58

Boesch, C., Marchesi, P., Marchesi, N., Fruth, B., Joulian, F., 1994. Is nut cracking in wild chimpanzees a cultural behaviour? *Journal of Human Evolution* 26, 325-38

Boffelli, D., Martin, D.I.K., 2012. Epigenetic inheritance: A contributor to species differentiation? *DNA and Cell Biology* 31(S1), S11-S16

Bonduriansky, R., Crean, A.J., Day, T., 2011. The implications of nongenetic inheritance for evolution in changing environments. *Evolutionary Applications* 5(2), 192-201

Bonifazi, S., Farne, A., Rinaldesi, L., Ladavas, E., 2007. Dynamic size-change of peri-hand space through tool-use: Spatial extension of shift of the multi-sensory area. *Journal of Neuropsychology* 1, 101-14

Bordes, J-G., 1961. Typologie du Paléolithique Ancien et Moyen. Delmes, Publications de l'Institut de Préhistoire de l'Université de Bourdeaux, Mémoire no. 1 (1961) réédition CNRS 1988

Borghi, A.M., Pecher, D., 2011. Introduction to the special topic embodied and grounded cognition. *Frontiers in Psychology* 2, 187

Botha, R., 2008. Prehistoric shell beads as a window on language evolution. *Language and Communication*, 28(3), 197-212

Bouwer, F.L., Van Zuijen, T.L., Honing, H., 2014. Beat processing is pre-attentive for metrically simple rhythms with clear accents: An ERP study. *Plos One* 9(5), e97467

Braccini, S., Lambeth, S., Schapiro, S., Fitch, W.T., 2010. Bipedal tool use strengthens chimpanzee hand preferences. *Journal of Human Evolution* 58(3), 234-41

Brakefield, P.M., 2011. Evo-devo and accounting for Darwin's endless forms. *Phil. Trans. R. Soc. B* 366, 2069-75

Braun, D.R., Hovers, E., 2009. Introduction: Current issues in Oldowan Research. In *Interdisciplinary Approaches to the Oldowan*, eds E. Hovers, D.R. Braun. Dordrecht: Springer 1-14

Braun, D.R., Plummer, T., Ditchfield, P., Ferraro, J.V., Maina, D., Bishop, L.C., Potts, R., 2008. Oldowan behavior and raw material transport: Perspectives from the Kanjera Formation. *Journal of Archaeological Science* 35(8), 2329-45

Brenna, J.T., Carlson, S.E., 2014. Docosahexaenoic acid and human brain development: Evidence that a dietary supply is needed for optimal development. *Journal of Human Evolution*, 77, 99-106

Bressler, S.L., Kelso, J.A.S., 2016. Coordination dynamics in cognitive neuroscience. *Frontiers in Neuroscience*, doi: 10.3389/fnins.2016.00397

Breuker, C.J., Debat, V., Klingenherg, C.P. 2006. Functional evo-devo. *Trends Ecol. Evol*. 21, 488-92

Bril, B., 2015. Learning to use tools: A functional approach to action. In L. Filletaz, S. Billet (eds), *Francophone Perspectives of Learning Through Work: Professional and Practice-Based Learning*. Springer International Publishing: Switzerland, 95-118

Bril, B., Dietrich, G., Foucart, J., Fuwa, K., Hirata, S., 2009. Tool use as a way to assess cognition: How do captive chimpanzees handle the weight of the hammer when cracking a nut? *Animal Cognition* 12(2), 217-35

Bril, B., Parry, R., Dietrich, G., 2015. How similar are nut-cracking and stone-flaking? A functional approach to percussive technology. *Philosophical Transactions B* 370. Doi: org/10.1098/rstb.2014.0355

Bril, B., Roux, V., Dietrich, G., 2005. Stone knapping: Khambat (India), a unique opportunity? In *Stone Knapping: The Necessary Coniditions for a Uniquely Hominin Behaviour*, eds V. Roux, B. Bril. McDonald Institute for Archaeological Research, 53-71

Bril, B., Smaers, J., Steele, J., Rein, R., Nonaka, T., Dietrich, G., Biryukova, E., Roux, V., 2012. Functional mastery of 'percussive technology' in nut-cracking and stone-flaking actions: Experimental comparison of the tasks and the implications for the evolution of the brain. *Phil. Trans. of the Royal Soc. London B Biol. Sci.* 367(1585), 59-74

Bronfman, Z.Z., Ginsburg, S., Jablonka, E., 2014. Shaping the learning curve: Epigenetic dynamics in neural plasticity. *Frontiers in Integr. Neuroscience* doi: 10.3389/fnint.2014.00055

Brooks, R.A., 1991. Intelligence without representation. *Artificial Intelligence* 47, 139-59

Brown, A.G., Basell, L.S., Robinson, S., Burdge, G.C., 2013. Site distribution at the edge of the Palaeolithic World: A nutritional niche approach. *Plos One* 8(12), e81476

Brown, K. S., Marean, C. W., Herries, A.I.R., Jacobs, Z., Tribolo, C., Braun, D., Roberts, D. L., Meyer, M. C., Bernatchez, J., 2009. Fire as an engineering tool of Early Modern Humans. *Science* 325(5942), 859-62

Brumm, A., van den Bergh, G.D., Storey, M., Kurniawan, I., Alloway, R.S., Setiyabudi, E., Grun, R., Moore, M.W., Yurnaldi, D., Puspaningrum, M.R., Wibowo, U.P., Insani, H., Sutisna, I., Westgate, J.A., Pearce, N.J.G., Duval, M., Meijer, H.J.M., Aziz, F., Sutikna, T., van der Kaars, S., Flude, S., Morwood, M.J., 2016. Age and context of the oldest known hominin fossils from Flores. *Nature* 534(7606), 249-253

Bruner, E., 2004. Geometric morphometrics and paleoneurology: Brain shape evolution in the genus *Homo*. *Journal of Human Evolution* 47(5), 279-303

Bryant, G.A., 2014. The evolution of coordinated vocalizations before language. *Behavioral and Brain Sciences* 37(6) 549-550, doi: 10.1017/S0140525X1300397X

Burdukiewicz, J. M., 2014. The origin of symbolic behavior of Middle Palaeolithic humans: Recent controversies. *Quaternary International*, 326-327, 398-405

Buxhoeveden, D.P., 2012. Minicolumn size and human cortex in *Evolution of the Primate Brain: From Neuron to Behavior*, eds. M.A. Hofman, D. Falk. Progress in Brain Research Vol. 195 Elsevier B. V., 219-35

Byers, A., Serences, J.T., 2012. Exploring the relationship between perceptual learning and top-down attentional control. *Vision Research* 74, Vol. I, 30-9

Byrne, R., 1999. Imitation without intentionality. Using string parsing to copy the organization of behaviour. *Animal Cognition* 2(2), 63-72

Byrne, R., 2003. Imitation as behaviour parsing. *Philosophical Transactions of the Royal Society B* 358(1431), 529-36

Byrne, R.W., 2005. The maker not the tool: The cognitive significance of great ape manual skills. In *Stone Knapping: The Necessary Conditions for a Uniquely Hominin Behaviour*, eds. V. Roux, B. Bril. McDonald Insitute for Archaeological Research 159-69

Byrne, R.W., 2016. *Evolving Insight*. New York: Oxford University Press

Byrne, R.W., Byrne, J.M., 1991. Hand preferences in the skilled gathering tasks of mountain gorillas (*Gorilla g. berengei*). *Cortex* 27(4), 521-46

Byrne, R.W., Corp, N., Byrne, J.M.E., 2001. Estimating the complexity of animal behaviour: How mountain gorillas eat thistles. *Behaviour* 138, 525-57

Byrne, R.W., Whiten, A., 1988. *Machiavellian Intelligence: Social Complexity and the Evolution of Intellect in Monkeys, Apes and Humans*. Oxford UK: OUP

Cáceres, M., Lachuer, J., Zapala, M.A., Redmond, J.C., Kudo, L., Geschwind, D.H., Lockhart, D.J., Preuss, T.M., Barlow, C., 2003. Elevated gene expression levels distinguish human from non-human primate brains. *PNAS* 100, 13,030-35

Carbonell, E., Sala, R., Barsky, D., Celiberti, V., 2009. From homogeneity to multiplicity: A new approach to the study of archaic stone tools, in *Interdisciplinary Approaches to the Oldowan*, eds. E. Hovers, D. R. Braun. Dordrecht: Springer, 25-37

Carciumaru, M., Ion, R-M., Nitu, E-C., Stefanescu, R., 2012. New evidence of adhesive as hafting material on Middle and Upper Palaeolithic artefacts from Gura Cheii-Rasnov Cave (Romania). *Journal of Archaeological Science* 39(7), 1942-50

Cardinali L., Brozzoli C., Roy A. C., Urquizar C., Farne, A., 2009. Tool-use induces morphological updating of the body schema. *Current Biology* 12, R478-9

Carpenter, C., Hammell, K., 2000. Evaluating qualitative research. In K. W. Hammell, C. Carpenter, I. Dyck (eds) *Using Qualitative Research: A Practical Introduction for Occupational and Physical Therapists*. Churchill Livingstone: Harcourt Publishers 107-119

Carter, S.M., Little, M., 2007. Justifying knowledge, justifying method, taking action: Epistemologies, methodologies, and methods in qualitatitive research. *Qualitative Health Research* 17(10), 1316-1328

Caruso, D.A., 1993. Dimensions of quality in infants' exploratory behavior: Relationships to problem-solving activity. *Infant Behavior and Development* 16, 441-54

Carvalho, S., Biro, D., McGrew, W.C., Matsuzawa, T., 2009. Tool-composite reuse in wild chimpanzees (*Pan troglodytes*): Archaeologically invisible steps in the technological evolution of early hominins? *Animal Cognition* 12(1) S103-S114

Carvalho, S., Cunha, E., Sousa, C., Matsuzawa, T., 2008. Chaînes opératoires and resource-exploitation strategies in chimpanzee (*Pan troglodytes*) nut cracking. *Journal of Human Evolution*, 55(1) 148-63

Chabout, J., Sarkar, A., Patel, S.R., Radden, T., Dunson, D.B., Fisher, S.E., Jarvis, E.D., 2016. A FoxP2 mutation implicated in human speech deficits alters sequencing of ultrasonic vocalizations in adult male mice. *Frontiers in Behavioral Neuroscience* doi: 10.3389/fnbeh.2016.00197

Chappell, J., Cutting, N., Apperly, I.A., Beck, S.R., 2013. The development of tool manufacture in humans: What helps young children make innovative tools? *Philosophical Transactions of the Royal Society B* 368(1630) doi:10.1098/rstb.2012.0409

Charney, E., 2012. Behavior genetics and postgenomics. *Behavioral and Brain Sciences* 35, 331-58

Charrie-Duhaut, A., Porraz, G., Cartwright, C.R., Igreja, M., Connan, J., Poggenpoel, C., Texier, P-J., 2013. First molecular identification of a hafting adhesive in the Late Howiesons Poort at Diepkloof Rock Shelter (Western Cape, South Africa). *Journal of Archaeological Science* 40(9), 3506-18

Charvet, C.J., Finlay, B.L. 2012. Embracing covariation in brain evolution: Large brains, extended development, and flexible primate social systems, in *Evolution of the Primate Brain: From Neuron to Behavior*, eds. M.A. Hofman, D. Falk. Progress in Brain Research 195, Elsevier B.V., 71-87

Clark, G., 1969. *World Prehistory: A New Synthesis.* Cambridge: Cambridge University Press

Clark, A., 1997. The dynamical challenge. Cognitive Science 21(4), 461-81

Clark, A., 1999. An embodied cognitive science? *Trends in Cognitive Sciences* 3(9), 345-51

Clark, D., 2001. Variability in primary and secondary technologies of the Later Acheulian in Africa. In S. Milliken, J. Cook eds. A Very Remote Period Indeed: Papers on the Palaeolithic Presented to Derek Roe. Oxford: Oxbow Books, 1-18

Clark, J.D., 1954. *Excavations at Star Carr: An Early Mesolithic Site at Seamer Near Scarborough, Yorkshire*. Cambridge: Cambridge University Press

Clark, J.D. 1958. Stone age woodworking tools in Southern Africa. *South African Archaeological Bulletin* 13, 144-152

Claud, E., Deschamps, M., Colonge, D., Mourre, V., Thiebaut, C., 2015. Experimental and functional analysis of late Middle Paleolithic flake cleavers from Southwestern Europe (France and Spain). Journal of Archaeological Science 62, 105-27

Cleeremans, A., Destrebecqz, A., Boyer, M., 1998. Implicit learning: News from the front. *Trends in Cognitive Sciences* 2(10), 406-16

Clegg, B.A., DiGirolamo, G.J., Keele, S.W., 1998. Sequence Learning. *Trends in Cognitive Sciences* 2(8), 275-81

Coe, D., 2015. Testing the 'efficiency hypothesis' of hafted tool technology: A pilot experimental Study. Unpublished MSc Dissertation, University of Liverpool

Collins, A., Koechlin, E., 2012. Reasoning, learning, and creativity: Frontal lobe function and human decision-making. *PLOS Biology* 10(3), e1001293

Corbetta, D., 2005. Dynamic interactions between posture, handedness, and bimanual coordination in human infants: Why stone knapping might be a uniquely hominin behaviour. In *Stone Knapping: The Necessary Conditions for a Uniquely Hominin Behaviour*, eds. V. Roux, B. Bril. McDonald Insitute for Archaeological Research, 187-204

Corp, N., Byrne, R.W., 2002. The ontogeny of manual skill in wild chimpanzees: Evidence from feeding on the fruit of *Saba florida*. *Behaviour* 139, 137-68

Cosmelli, D., Lachaux, J-P., Thompson, E., 2007. Neurodynamical approaches to consciousness. In The Cambridge Handbook of Consciousness, P.D. Zelazo, M. Moscovitch, E. Thompson eds. Cambridge: Cambridge University Press, 731-772

Cottingham, J., Stoothoff, R., Kenny, A., Murdoch, D., 1988. *The Philosophical Writings of Descartes* (Vols. I, II & III). Cambridge: Cambridge University Press

Craddock, B.R., Cartwright, C.R., Craddock, P.T., Wray, W.B., 2003. Hafted stone mining hammer from Chuquicamata, Chile, in *Mining and Metal Production Through the Ages*, eds. P. Craddock, J. Lang. London: The British Museum Press 52-68

Crawford, M.A., Broadhurst, C.L., Galli, C., Ghebremeskel, K., Holmsen, H., Saugstad, L. F., Schmidt, W.F., Sinclair, A.J., Cunnane, S.C., 2008. The role of docosahexaenoic and arachidonic acids as determinants of evolution and hominid brain development. *Fisheries for Global Welfare and Environment, 5th World Fisheries Congress 2008* 57-76

Dale, R., Duran, N.D., Morehead, J.R., 2012. Prediction during statistical learning, and implications for the implicit-explicit divide. *Advances in Cognitive Psychology* 8, 196-209

Daltrozzo, J., Conway, C.M., 2014. Neurocognitive mechanisms of statistical-sequential learning: What do event-related potentials tell us? *Frontiers in Human Neuroscience*, doi: org.ezproxy.liv.ac.uk/10.3389/fnhum.2014.00437

Damasio, A., 2010. *Self Comes to Mind: Constructing the Conscious Brain*. London William Heinemann

Damasio, A., Meyer, K., 2008. Behind the looking glass. *Nature* 454, 167-8

Darwin, C., 2008. *On the Origin of Species.* Oxford: Oxford University Press

Dauncey, M.J., 2012. Recent advances in nutrition, genes and brain health. *Proceedings of the Nutrition Society* 71, 581-91

Delagnes, A., Roche, H., 2005. Late Pliocene hominid knapping skills: The case of Lokalalei 2C, West Turkana, Kenya. *Journal of Human Evolution* 48, 435-472

de la Torre, I., 2010. Insights on the technical competence of the Early Oldowan, in *Stone Tools and the Evolution of Human Cognition*, eds. A. Nowell, I. Davidson. Boulder (Co): The University Press of Colorado, 45-65

de la Torre, I., 2014. Acheulean technological behaviour in the Middle Pleistocene landscape of Mieso (East-Central Ethiopia). *Journal of Human Evolution* 76, 1-25

de la Torre, I., 2016. The origins of the Acheulean: Past and present perspectives on a major transition in human evolution. *Philosophical Transactions of the Royal Society B* 371, 20150245

de la Torre, I., Mora, R., 2009. Remarks on the current theoretical and methodological approaches to the study of early technological strategies in Eastern Africa. In *Interdisciplinary Approaches to the Oldowan*, eds E. Hovers, D.R. Braun. Dordrecht: Springer, 15-24

de la Torre, I., Mora, R., Dominguez-Rodrigo, M., de Luque, L., Alcala, L., 2003. The Oldowan industry of Peninj and its bearing on the reconstruction of the technological skills of lower Pleistocene hominids. *Journal of Human Evolution* 44, 203-24

d'Errico, F., Stringer, C.B., 2011. Evolution, revolution or saltation scenario for the emergence of modern cultures? *Philosophical Transactions of the Royal Society B* 366, 1060-9

Dirks, P.H.G.M, Roberts, E.M., Hilbert-Wolf, H.H., Kramers, J.D., Hawks, J., Dosseto, A., Duval, M., Elliott, M., Evans, M., Grun, R., Hellstrom, J., Herriesl, A.I.R., Joannes-Boyau, R., Makhubela, T.V., Placzek, C.J., Robbins, J., Spandler, C., Wiersma, J., Woodhead, J., Berger, L.R., 2017. The age of *Homo naledi* and associated sediments in the Rising Star Cave, South Africa. *eLife* 6:e24231, doi:10.7554/eLife.24231

Dominguez-Rodrigo, M., Pickering, T.R., Bunn, H.T., 2012. Experimental study of cut marks made with rocks unmodified by human flaking and its bearing on claims of ~3.4-million-year-old butchery evidence from Dikika, Ethiopia. *Journal of Archaeological Science* 39(2), 205-14

Dominguez-Rodrigo, M.,J. Serrallonga, J., Juan-Tresserras, J., Alcala, L., Luque, L. 2001. Woodworking activities by early humans: A plant residue analysis on Acheulian stone tools from Peninj (Tanzania). *Journal of Human Evolution* 40 289-299

Downey, G., Lende, D.H., 2012. Evolution and the brain, in *Encultured Brain: An Introduction to Neuroanthropology*, eds. D.H. Lende, G. Downey. Cambridge (MA): MIT Press, 103-40

Duckworth, R.A., 2013. Epigenetic inheritance systems act as a bridge between ecological and evolutionary timescales. *Behavioral Ecology* 24(2), 327-28

Dunbar, R.I.M., 1993. Coevolution of neocortical size, group size and language in humans. *Behavioral and Brain Sciences* 16, 681-94

Dunbar, R.I.M., 1998. The social brain hypothesis. *Evolutionary Anthropology* 6, 178-90

Dunbar, R.I.M., 2003. The social brain: Mind, language, and society in evolutionary perspective. *Annual Review of Anthropology* 32, 163-81

Dunbar, R.I.M., 2007. The social brain and the cultural explosion of the human revolution. In *Rethinking the Human Revolution*, P. Mellars, K. Boyle, O. Bar-Yosef, C. Stringer eds. Cambridge: McDonald Institute Monographs, 91-8

Edelman, G.M., 1993. Neural Darwinism: Selection and reentrant signaling in higher brain function. *Neuron* 10, 115-25

Edelman, G.M., Gally J.A., Baars B.J., 2011. Biology of consciousness. *Frontiers in Psychology* 2(4). Doi:10.3389/fpsyg.2011.00004

Edelman, G.M., Tononi, G., 2001. *Consciousness: How Matter Becomes Imagination*. London: Penguin

Elliott, M.T., Chua, W.L., Wing, A.M., 2016. Modelling single-person and multi-person event-based synchronisation. *Current Opinion in Behavioral Sciences* 8, 167-74

Elman, J.L., Bates, E.A., Johnson, M.H., Karmiloff-Smith, A., Parisi, D., Plunkett, K., 1996. *Rethinking Innateness: A Connectionist Perspective on Development.* Cambridge (MA): MIT Press

Emery, N., N. Clayton, C. Frith, eds., 2008. *Social Intelligence: From Brain to Culture*. Oxford: Oxford University Press

Enard, W., Khaitovich, P., Klose, J., Zollner, S., Heissig, F., Giavalisco, P., Nieselt-Struwe, K., Muchmore, E., Varki, A., Ravid, R., Doxiadis, G., Bontrop, R.E., Paabo, S., 2002. Intra and interspecific variation in primate gene expression patterns. *Science* 296, 185-208

Enquist, M., Ghirlanda, S., Eriksson, K., 2011. Modelling the evolution and diversity of cumulative culture. *Philosophical Transactions of the Royal Society B* 366(1563) 412-23

Eren M. I. (2012). Were unifacial tools regularly hafted by clovis foragers in the North American Lower Great Lakes Region? An empirical test of edge class richness and attributed frequency among distal, proximal, and lateral tool-sections. *Journal of Ohio Archaeology* 2 1-15

Eren, M.I., Lycett, S.J., 2012. Why Levallois? A morphometric comparison of experimental 'preferential' Levallois flakes versus debitage flakes. *Plos One* 7(1), 1-10

Ericsson, K.A., Charness, N., 1994. Expert performance – its structure and acquisition. *American Psychologist* 49(8), 725-47

Ericsson, K.A., Krampe, R.T., Teschromer, C., 1993. The role of deliberate practice in the acquisition of expert performance. *Psychological Review* 100(3), 363-406

Ericsson, K.A., Lehmann, A.C., 1996. Expert and exceptional performance: Evidence of maximal adaptation to task constraints. *Annual Review of Psychology* 47, 273-305

Escoffier, N., Herrmann, C.S., Schermer, A., 2015. Auditory rhythms entrain visual processes in the human brain: Evidence from evoked oscillations and event-related potentials. *NeuroImage* 111, 267-76

Fagg, A.H., Arbib, M.A., 1998. Modelling parietal-premotor interactions in primate control of grasping. *Neural Networks* 11(7-8), 1277-130

Fairlie, J.E., 2013. *The Shape in the Stone: HMap or reconstructing the cognitive complexity of Palaeolithic stone tools* (unpublished MSc dissertation)

Fairlie, J.E., Barham, L.S., 2016. From chaine operatoire to observational analysis: A pilot study of a new methodology for analysing changes in cognitive task-structuring strategies across different hominin tool-making events. *Cambridge Archaeological Journal* 26(4), 643-664

Falk, D., 2004. Prelinguistic evolution in early hominins: Whence motherese? *Behavioral and Brain Sciences* 27, 491-541

Falk, D., 2012. Hominin paleoneurology: Where are we now?, in *Evolution of the Primate Brain: From Neuron to Behavior*, eds. M. A. Hofman, D. Falk. San Francisco (CA): Progress in Brain Research Vol. 195 Elsevier B. V. 255-72

Ferdinand, N.K., Runger, D., Frensch, P.A., Mecklinger, A., 2010. Event-related potential correlates of declarative and non-declarative sequence knowledge. *Neuropsychologia* 48(9), 2665-74

Fiore, I., Bondioli, L., Radovčić, J., Frayer, D.W., 2015. Handedness in the Krapina Neandertals: A Re-evaluation. *PaleoAnthropology*, 19-36, doi: 10.4207/PA.2015.ART93

Fitch, W.T., Hauser, M.D., Chomsky, N., 2005. The evolution of the language faculty: Clarifications and implications. *Cognition* 97(2), 179-210

Fodor, J., 1983. *The Modularity of Mind: An Essay on Faculty Psychology*. MIT Press (US)

Foley, R.A., 2016. Mosaic evolution and the pattern of transitions in the hominin lineage. *Philosophical Transactions of the Royal Society B* 371(1698), doi: 10.1098/rstb.2015.0244

Forsythe, C., Liao, H., Trumbo, M., Cardona-Rivera, R.E., 2015. *Cognitive Neuroscience of Human Systems: Work and Everyday Life*. Florida: CRC Press

Franks, S.J., Hoffmann, A.A., 2012. Genetics of climate change adaptation. *Annual Review of Genetics* 46, 185-208

Gallese, V., 2007. Before and below 'theory of mind': Embodied simulation and the neural correlates of social cognition. *Philosophical Transactions of the Royal Society B* 362(1480), 659-69

Gallese, V., Lakoff, G.F. 2005. The brain's concepts: The role of the sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology* 22, 455-79

Gamble, C., 1998. Palaeolithic society and the release from proximity: A network approach to intimate relations. *World Archaeology* 29(3), 426-449

Garofoli, D., 2016. Cognitive archaeology without behavioral modernity: An eliminativist attempt. *Quaternary International*, 405(A), 125-35

Garofoli, D., Haidle, M.N., 2014. Epistemological problems in Cognitive Archaeology: An anti-relativistic proposal towards methodological uniformity. *Journal of Anthropological Sciences* 92, 7-41

Gash, D.M., Deane, A.S., 2015. Neuron-based heredity and human evolution. *Frontiers in Neuroscience*. Doi: org/10.3389/fnins.2015.00209

Gerhardt, S., 2004. *Why Love Matters: How Affection Shapes a Baby's Brain*. London and New York: Routledge

Geribàs, N., Mosquera, M., Vergès, J.M., 2010. What novice knappers have to learn to become expert stone toolmakers. *Journal of Archaeological Science* 37, 2857-70

Gibson, J J., 1979. *The Ecological Approach to Visual Perception*. Boston (MA): Houghton-Mifflin

Gibson, K.R., 2007. Putting it all together: A constructionist approach to the evolution of human mental capacities, in *Rethinking the Human Revolution*, eds.

P. Mellars, K. Boyle, O. Bar-Yosef, C. Stringer. Cambridge: McDonald Institute Monographs 67-77

Gibson, E.J., Pick, A.D., 2000. *An Ecological Approach to Perceptual Learning and Development.* New York: OUP

Gilbert, S.F., Epel, D., 2009. *Ecological Developmental Biology: Integrating Epigenetics, Medicine, and Evolution*. Massachusetts: Sinauer Assoc. Inc.

Givon, T., 1998. Toward a neurology of grammar. Commentary on Patricia M. Greenfield (1991). Language, tools and brain: The ontogeny and phylogeny of hierarchically organized sequential behavior. *Behavioral and Brain Sciences* 21(1), 154-5

Glenberg, A.M., 2007. Language and action: Creating sensible combinations of ideas. In M.G. Gaskell ed., *The Oxford Handbook of Psycholinguistics*. Oxford: OUP, 361-370

Glenberg, A.M., Gallese, V., 2012. Action-based language: A theory of language acquisition, comprehension, and production. *Cortex* 48, 905-922

Godfrey-Smith, D.I., Ilani, S., 2004. Past thermal history of goethite and hematite fragments from Qafzeh Cave deduced from thermal activation characteristics of the 110 degree C. TL peak of enclosed quartz grains. *Revue d'Archeometrie* 28, 185-90

Goldman-Neuman, T., Hovers, E., 2012. Raw material selectivity in Late Pliocene Oldowan sites in the Makaamitalu Basin, Hadar, Ethiopia. *Journal of Human Evolution* 62, 353-66

Goldstein, M.H., Waterfall, H.R., Lotem, A., Halpern, J.Y., Schwade, J.A., Onnis, L., Edelman S., 2010. General cognitive principles for learning structure in time and space. *Trends in Cognitive Science* 14, 249-258, doi:10.1016/j.tics.2010.02.004

Goren-Inbar, N., 2011. Culture and cognition in the Acheulian industry: A case study from Gesher Benot Ya'aqov. *Philosophical Transactions of the Royal Society B* 366, 1038-49

Gottlieb, G., 2002. Developmental-behavioural initiation of evolutionary change. *Psychological Review* 109(2), 211-18

Gowlett, J.A.J., 1990. Technology, skill and the psychological sector in the long term of human evolution. *Archaeological Review From Cambridge* 9(1), 82-103

Gowlett, J.A., 1992. *Ascent to Civilization: The Archaeology of Early Humans*. New York: McGraw-Hill

Gowlett, J.A., 2013. Elongation as a factor in artefacts of humans and other animals: An Acheulean example in a comparative context. *Philosophical Transactions of the Royal Society B* 368, 1630

Gowlett, J., Gamble, C., Dunbar, R., 2012. Human evolution and the archaeology of the Social Brain. *Current Anthropology* 53(6), 693-722

Green, J., Thorogood, N., 2014. *Qualitative Methods for Health Research*. Los Angeles & London: Sage

Greenberg, G., Partridge, T., Weiss, E., 1999. Integrative levels, the brain, and the emergence of complex behavior. *Review of General Psychology* 3, 168-87

Greenberg, G., Schmid Callina, K., Mueller M.K., 2013. Emergence, self-organisation and developmental science. In *Advances in Child Development and Behavior: Embodiment and Epigenesis: Theoretical and Methodological Issues in Understanding the Role of Biology Within the Relational Developmental System*, Part A, Vol. 44: Philosophical, Theoretical, and Biological Dimensions, eds R.M. Lerner, J.B. Benson. Elsevier, 95-126

Greenfield, P.M., 1991. Language, tools and brain: The ontogeny and phylogeny of hierarchically organized sequential behavior. *Behavioral and Brain Sciences* 14, 531-95

Gregory, R.L., 1987. *The Oxford Companion to the Mind*. Oxford: Oxford University Press

Grieve, J., 1993. *Neuropsychology for Occupational Therapists*. Oxford: Blackwell Science

Grove, M., 2011a. Change and variability in Plio-Pleistocene climates: Modelling the hominin response. *Journal of Archaeological Science* 38, 3038-47

Grove, M., 2011b. Speciation, diversity, and mode 1 technologies: The impact of variability selection. *Journal of Human Evolution* 61, 306-19

Grove, M., 2012. Orbital dynamics, environmental heterogeneity, and the evolution of the human brain. *Intelligence* 40(5), 404-18

Grove, M., 2014. Evolution and dispersal under climatic instability: A simple evolutionary algorithm. *Adaptive Behavior* 22(4), 235-254

Grove, M., 2016. Population density, mobility, and cultural transmission*. Journal of Archaeological Science* 74, 75-84

Grunberg, J.M. 2002. Middle Palaeolithic birch-bark pitch. *Antiquity* 76, 15-16

Guiard, Y., 1987. Asymmetric division of labor in human skilled bimanual action: The kinematic chain as a model. *Journal of Motor Behavior* 19(4), 486-517

Guiard, Y., 1997. The distal-to-proximal increase of link length along the human kinematic chain: An exponential progression of work-space extension. *Annales des Sciences Naturelles, Zoologie* 13(18), 151-6

Gunz, P., Neubauer, S., Maureille, B., Hublin, J-J., 2010. Brain development after birth differs between Neanderthals and modern humans. *Current Biology* 20(21), R921-2

Haidle, M.N., 2009. How to think a simple spear, in *Cognitive Archaeology and Human Evolution*, eds. S. de Beaune, F. L. Coolidge, T. Wynn. Cambridge: Cambridge University Press, 57-73

Haidle, M.N. 2010. Working-memory capacity and the evolution of modern cognitive potential: Implications from animal and early human tool use. *Current Anthropology* 51(1), S149-S166

Halder, P., Sterr, A., Brem, S., 2005. Electrophysiological evidence for cortical plasticity with movement repetition. *European Journal of Neuroscience* 21(8), 2271-77

Hallos, J., 2005. '15 minutes of fame': Exploring the temporal dimension of Middle Pleistocene lithic technology. *Journal of Human Evolution* 49(2), 155-79

Hammell, K., Carpenter, C., 2000. Introduction to qualitative research in occupational therapy and physical therapy. In *Using Qualitative Research: A Practical Introduction for Occupational and Physical Therapists*, K.W. Hammell, C. Carpenter, eds. Churchill Livingstone: Harcourt Publishers, 1-12

Hardy, B.L., Garufi, G.T., 1998. Identification of woodworking on stone tools through residue and use-wear analyses: Experimental results. *Journal of Archaeological Science* 25(2), 177-84

Hardy, B., Kay, M., Marks, E., Monigal, K., 2001. Stone tool function at the Paleolithic sites of Starosele and Buran Kaya III, Crimea: Behavioral implications. *PNAS* 98(19) 10972-1097

Hardy, B.L., Moncel, M-H., 2011. Neanderthal use of fish, mammals, birds, starchy plants and wood 125-250,000 years ago. *Plos One* doi: 10.1371/journal.pone.0023768

Hardy, B.L., Moncel, M-H., Daujeard, C., Fernandes, P., Bearez, P., Desclaux, E., Navarro, M.G.C., Puaud, S., Gallotti, R., 2013. Impossible Neanderthals? Making string, throwing projectiles and catching small game during Marine Isotope Stage 4 (Abri du Maras, France). *Quaternary Science Reviews* 82 23-40

Hardy, K., 2008. Prehistoric string theory. How twisted fibres helped to shape the world. *Antiquity* 82(316) 271-280

Harmand, S., 2009. Variability in raw material selectivity at the Late Pliocene sites of Lokalalei, West Turkana, Kenya, in *Interdisciplinary Approaches to the Oldowan*, eds. E. Hovers, D.R. Braun. Dordrecht: Springer, 85-97

Harmand, S., Lewis, J.E., Feibel, C.S., Lepre, C.J., Prat, S., Lenoble, A., Boës, X., Quinn, R.L., Brenet, M., Arroyo, A., Taylor, N., Clément, S., Daver, G., Brugal, J-P., Leakey, L., Mortlock, R.A., Wright, J.D., Lokorodi, S., Kirwa, C., Kent, D.V., Roche, H., 2015. 3.3-million-year-old stone tools from Lomekwi 3, West Turkana, Kenya. *Nature* 521, 310-315

Harper, L.V., 2013. Pathways by which the interplay of organismic and environmental factors lead to phenotypic variation within and across generations. In *Advances in Child Development and Behavior: Embodiment and Epigenesis: Theoretical and Methodological Issues in Understanding the Role of Biology Within the Relational Developmental System*, Part A, Vol. 44: Philosophical, Theoretical, and Biological Dimensions, eds R.M. Lerner, J.B. Benson. Elsevier

Haslam, M., 2012. Towards a prehistory of primates. *Antiquity* 86, 299-315

Haslam, M., 2014. On the tool use behavior of the bonobo-chimpanzee last common ancestor, and the origins of hominin stone tool use. *American Journal of Primatology* 76(10), 910-18

Hasson, U., Frith, C.D., 2016. Mirroring and beyond: Coupled dynamics as a generalized framework for modeling social interactions. *Philosophical Transactions of the Royal Society B*, doi:10.1098/rstb.2015.0366

Hattori, Y., Tomonaga, M., Matsuzawa, T., 2013. Spontaneous synchronized tapping to an auditory rhythm in a chimpanzee. *Scientific Reports* 3 (1566), doi: 10/1038/srep01566

Hattori, Y., Tomonaga, M., Matsuzawa, T., 2015. Distractor effect of auditory rhythms on self-paced tapping in chimpanzees and humans. *PlosOne* doi: 10.1371/journal.pone.0130682

Hawkes, K., O'Connell, J.F., Blurton Jones, N.G., Alvarez, H., Charnov, E.L., 1998. Grandmothering, menopause, and the evolution of human life histories. *Proceedings of the National Academy of Sciences (USA)* 95 1336-1339

Hawks, J., Elliott, M., Schmid, P., Churchill, S.E., de Ruiter, D.J., Roberts, E.M., Hilbert-Wolf, H., Garvin, H.M., Williams, S.A., Delezene, L.K., Feuerriegel, E.M., Randolph-Quinney, P., Kivell, T.L., Laird, M.F., Tawane, G., DeSilva, J.M., Bailey, S.E., Brophy, J.K., Meyer, M.R., Skinner, M.M., Tocheri, M.W., VanSickle, C., Walker, C., Campbell, T.L., Kuhn, B., Kruger, A., Tucker, S., Gurtov, A., Hlophe, N., Hunter, R., Morris, H., Peixotto, B., Ramalepa, M., van Rooyen, D., Tsikoane, M., Boshoff, P., Dirks, P.H.G.M., Berger, L.R., 2017. New fossil remains of Homo naledi from the Lesedi Chamber, South Africa. eLife, 6:e24232, doi:10.7554/3Life.24232

Hayashi, M., 2015. Perspectives on object manipulation and action grammar for percussive actions in primates. *Trans of the Royal Society B*, doi: 10.1098/rstb.2014.0350

Hayashi, M., Takeshita, H., Matsuzawa, T., 2006. Cognitive development in apes and humans assessed by object manipulation. In *Cognitive Development in Chimpanzees*, T. Matsuzawa, M. Tomonaga, M.Tanaka (eds), 395-410. Tokyo: Springer

Hayden, B., 2015. Insights into early lithic technologies from ethnography. Phil. Trans. of the Royal Society B, doi:10.1098/rstb.2014.0356

Hecht, E.E., Gutman, D.A., Khreisheh, N., Taylor, S.V., Kilner, J., Faisal, A.A., Bradley B., Chaminade, T., Stout, D., 2013. Acquisition of Paleolithic toolmaking abilities involves structural remodelling to inferior frontoparietal regions. *Brain Structure and Function* 220, 2315-31, doi: 10.1007/s00429-014-0789-6

Henrich, J., 2004. Demography and cultural evolution: How adaptive cultural processes can produce maladaptive losses: The Tasmanian case. *American Antiquity* 69(2), 197-214

Henshilwood, C., d'Errico, F., Niekerk, K.L. 2011. A 100,000 year old ochre processing workshop at Blombos, South Africa. *Science* 334, 219-22

Henshilwood, C.S., Marean, C.W., 2003. The origin of modern human behavior. *Current Anthropology* 44(5), 627-51

Herculano-Houzel, S., 2011a. Not all brains are made the same: New views on brain scaling in evolution. *Brain, Behavior and Evolution* 78(1), 22-36

Herculano-Houzel, S., 2011b. Scaling of brain metabolism with a fixed energy budget per neuron: Implications for neuronal activity, plasticity and evolution. *PLos ONE* 6(3), e17514

Herculano-Houzel, S., 2012a. Neuronal scaling rules for primate brains: The primate advantage, in *Evolution of the Primate Brain: From Neuron to Behavior*, M.A. Hofman, D. Falk (eds). Progress in Brain Research Vol. 195, Amsterdam: Elsevier B.V., 325-40

Herculano-Houzel, S., 2012b. The remarkable, yet not extraordinary, human brain as a scaled-up primate brain and its associated cost. *PNAS* 109(1), 10661-8

Hernandez-Aguilar R.A., Moore, J., Pickering, T.R., 2007. Savanna chimpanzees use tools to harvest the underground storage organs of plants. *Proceedings of the National Academy of Sciences* 104, 19210-3

Herzlinger, G., Wynn, T., Goren-Inbar, N., 2017. Expert cognition in the production sequence of Acheulian cleavers at Gesher Benot Ya'aqov, Israel: A lithic and cognitive analysis. *PlosOne* doi:10.1371/journal.pone.0188337

Heyes, C., 2012. New thinking: The evolution of human cognition. *Philosophical Transactions of the Royal Society B*. DOI: 10.1098/rstb.2012.0111

Hocking, G., Wright-St-Clair, V., 2011. Occupational Science: Adding value to occupational therapy. *New Zealand Journal of Occupational Therapy* 58(1) 29-35

Hodder, I., 2012. *Entangled: An Archaeology of the Relationships Between Humans and Things*. Wiley

Högberg, A., Gardenfors, P., Larsson, L., 2015. Knowing, learning and teaching – how *Homo* became *docens*. *Cambridge Archaeological Journal* 25(4), 847-58

Högberg, A., Lombard, M., 2016. Still Bay point-production strategies at Hollow Rock Shelter and Umhlatuzana Rock Shelter and knowledge-transfer systems in Southern Africa at about 80-70 thousand years ago. *PloS One* 11(12) doi: 10.1371/journal.pone.0168012

Holder, M.K., 2005. Investigating manual specialization in extant and extinct hominins. In *Stone Knapping: The Necessary Conditions for a Uniquely Hominin Behaviour*, eds. V. Roux, B. Bril. McDonald Insitute for Archaeological Research 205-16

Holland, J.H., 2014. *Complexity: A Very Short Introduction*. Hampshire: OUP

Hollander, M., Schwartz, M., 2000. Annealing, distilling, reheating and recycling: Bitumen processing in the Ancient Near East. *Paleorient* 26(2), 83-91

Honing, H., Bouwer, F.L., Haden, G.P., 2014. Perceiving temporal regularity in music: The role of auditory event-related potentials (ERPs) in probing beat perception. In *Neurobiology of Interval Timing* H. Merchant, V. de Lafuente (eds), Vol. 829, 305-323

Hublin, J-J., Ben-Ncer, A., Bailey, S.E., Freidline, S.E., Neubauer, S., Skinner, M.M., Bergmann, I., Le Cabec, A., Benazzi, S., Harvati, K., Gunz, P., 2017. New fossils from Jebel Irhoud, Morocco and the pan-African origin of *Homo sapiens*. *Nature* 546, 289-92, doi: 10.1038/nature22336

Hurcombe, L.M., 2008. Organics from inorganics: Using experimental archaeology as a research tool for studying perishable material culture. *World Archaeology* 40(1), 83-115

Hyeon-Ae, J., 2014. Hierarchical processing in the prefrontal cortex in a variety of cognitive domains. *Fron. Syst. Neurosci.*, 8, 223 Doi: 10.3389/fnsys.2014.00223

Igreja, M., Porraz, G., 2013. Functional insights into the innovative Early Howiesons Poort technology at Diepkloof Rock Shelter (Western Cape, South Africa). *Journal of Archaeological Science* 40(9), 3475-91

Ikiugu, M.N., 2007. *Psychosocial Conceptual Practice Models in Occupational Therapy: Building Adaptive Capability*. Elsevier Inc.

Iriki, A., Sakura, O., 2008. The neuroscience of primate intellectual evolution: Natural selection and passive intentional niche construction. *Philosophical Transactions of the Royal Society of London B* 363, 2229-41

Jablonka, E., Lamb, M., 2006. *Evolution in Four Dimensions: Genetic, Epigenetic, Behavioral and Symbolic Variation in the History of Life*. Cambridge MA: MIT Press

Jerardino, A., 2001. Diversity in mastic-mounted stone adzes and the use of mastic in pre-colonial South Africa: Evidence from Steenbokfontein Cave. *Antiquity* 75, 859-66

Johnson, C.R., McBrearty, S., 2010. 500,000 year old blades from the Kapthurin Formation, Kenya. *Journal of Human Evolution* 58(2), 193-200

Johnston, T.D., Gottlieb, G., 1990. Neophenogenesis: A developmental theory of phenotypic evolution. *Journal of Theoretical Biology* 147(4), 471-95

Jongbloed, L., 2000. Choosing the methodology to explore the research. In *Using Qualitative Research: A Practical Introduction for Occupational and Physical Therapists*, K.W. Hammell, C. Carpenter, eds. Churchill Livingstone: Harcourt Publishers, 13-21

Kahrs, B.A., Lockman, J.J., 2014. Building tool use from object manipulation: A perception-action perspective. *Ecological Psychology* 26, 88-97

Kano, F., Krupenye, C., Hirata, S., Call, J., 2017. Eye tracking uncovered great apes' ability to anticipate that other individuals will act according to false beliefs. *Communicative and Integrative Biology* 10(2), e1299836

Karlin, C., Julien, M., 1994. Prehistoric technology, a cognitive science? In C. Renfrew, E. Zubrow (eds), *The Ancient Mind: Elements of a Cognitive Archaeology*. Cambridge University Press, 152-64

Keeley, L.H., 1982. Hafting and retooling: Effects on the archaeological record. *American Antiquity* 47, 798-809

Keller, C.M., Keller, J.D., 1996. *Cognition and Tool Use: The Blacksmith at Work*. Cambridge: Cambridge University Press

Kelly, A.M.C., Garavan, H., 2005. Human functional neuroimaging of brain changes associated with practice. *Cerebral Cortex* 15, 1089-102

Kelso, J.A.S., 1995. Dynamic Patterns: *The Self-Organization of Brain and Behavior*. Massachusetts: MIT Press

Kelso, J.A.S., 2008. An essay on understanding the mind. *Ecological Psychology* 20 180-208

Kendal, J., Tehrani, J.,J., Odling-Smee, J., 2011. Human niche construction in interdisciplinary focus. *Philosophical Transactions of the Royal Society B* 366(1566) 785-92

Keverne, E.B., 2011. Epigenetics and brain evolution. *Epigenomics* 3(2), 183-91

Key, A.J.M., Dunmore, C.J., 2015. The evolution of the hominin thumb and the influence exerted by the non-dominant hand during stone tool production. *Journal of Human Evolution* 78, 60-9

Kielhofner, G., 2008. *Model of Human Occupation: Theory and Application.* Philadelphia: Lippincott Williams & Wilkins

Kivell, T.L., 2015. Evidence in hand: Recent discoveries and the early evolution of human manual manipulation. Phil. Trans. of the Royal Society B, doi: 10.1098/rstb.2015.0105

Kivell, T.L., Kibii, J.M., Churchill, S.E., Schmid, P., Berger, L.R. 2011. *Australopithecus sediba* hand demonstrates mosaic evolution of locomotor and manipulative abilities. *Science* 333, 1411-17

Klein, R.G., 2009. *The Human Career: Human Biological and Cultural Origins*. Chicago & London: The University of Chicago Press

Klironomos, F.D., Berg, J., Collins, S., 2013. How epigenetic mutations can affect genetic evolution: Model and mechanism. *Bioessays* 35, 571-8

Koechlin, E., Basso, G., Pietrini, P., Panzer, S., Grafman, J., 1999. The role of the anterior prefrontal cortex in human cognition. *Nature* 399, 148-51

Koechlin, E., Corrado, G., Pietrini, P., Grafman, J., 2000. Dissociating the role of the medial and lateral anterior prefrontal cortex in human planning. *Proceedings of the National Academy of Sciences of the USA* 97(13), 7651-6

Koechlin, E., Jubault, T., 2006. Broca's area and the hierarchical organization of human behavior. *Neuron* 50(6), 963-74

Koller, J., Baumer, U., Mania, D., 2001. High-tech in the Middle Palaeolithic: Neandertal-manufactured pitch identified. *European Journal of Archaeology* 4(3), 385-97

Kotwica, K.A., Ferre, C.L., Michel, G.F., 2008. Relation of stable hand-use preferences to the development of skill for managing multiple objects from 7 to 13 months of age. *Developmental Psychobiology* 50, 519-29

Koziol, L.F., Budding, D.E., Chidekel, D., 2012. From movement to thought: Executive function, embodied cogntion, and the cerebellum. *Cerebellum* 11(2), 505-25

Kruger, A., Randolph-Quinney, P., Elliott, M., 2016. Multimodal spatial mapping and visualisation of Dinaledi Chamber and Rising Star Cave. *South African Journal of Science* 112 5/6, 103-13

Kuhn, S.L., Stiner, M.C., 2007. Paleolithic ornaments: Implications for cognition, demography and identity. *Diogenes* 54, 40-8

Laland, K.N., Janik, V.M., 2006. The animal cultures debate. *Trends in Ecology and Evolution* 21(10), 542-7

Laland, K.,N., O'Brien, M.,J., 2010. Niche construction theory and archaeology. *Journal of Archaeological Method and Theory* 17(4), 303-22

Laland, K.N., Odling-Smee, J., Feldman, M.W., 2000. Niche construction, biological evolution, and cultural change. *Behavioral and Brain Sciences* 23 131-146

Lang, S., Kotchoubey, B., 2000. Learning effects on event-related brain potentials. *Neuroreport* 11(15), 3327-31

Langbroek, M., 2011. Trees and ladders: A critique of the theory of human cognitive and behavioural evolution in Palaeolithic archaeology. *Quaternary International* 270, 4-14

Langley, M.C., Clarkson, C., Ulm, S., 2008. Behavioural complexity in Eurasian Neanderthal populations: A chronological examination of the Archaeological evidence. *Cambridge Archaeological Journal* 18(3), 289-307

Latash, M.L., 2012. The bliss (not the problem) of motor abundance (not redundancy). Experimental Brain Research 217(1), 1-5

Leca, J-B, Gunst, N., Huffman, M., 2011. Complexity in object manipulation by Japanese Macaques (*Macaca fuscata*): A cross-sectional analysis of manual coordination in stone handling patterns. *Journal of Comparative Psychology* 125(1), 61-71

Leconte, P., Orban de Xivry, J-J., Stoquart, G., Lejeune, T., Ronsse, R., 2016. Rhythmic arm movements are less affected than discrete ones after a stroke. Experimental Brain Research 234(6), 1403-17

Ledón-Rettig, C.C., Richards, C.L., Martin, L.B. 2013. Epigenetics for behavioral ecologists. Behavioral Ecology 24(2), 311-24

Lefebvre, L., 2012. Primate encephalization, in *Evolution of the Primate Brain: From Neuron to Behavior*, eds. M.A. Hofman, D. Falk. Progress in Brain Research 195 Elsevier B.V., 393-412

Lemorini, C., Plummer, T.W., Braun, D.R., Crittenden, A.N., Ditchfield, P.W., Bishop, L.C., Hertel, F., Oliver, J.S., Marlowe, F.W., Schoeninger, M.J., Potts, R., 2014. Old stones' song: Use-wear experiments and analysis of the Oldowan quartz and quartzite assemblage from Kanjera South (Kenya). *Journal of Human Evolution* 72 10-25 doi: org/10.1016/jhevol.2014.03.002

Leroi-Gourhan, A., 1964 [1993 trans. A.B. Berger]. *Gesture and Speech*. London: Massachusetts Institute of Technology

Lewicki, P., Hill, T., Czyzewska, M., 1992. Nonconscious acquisition of information. *American Psychologist* 47(6) 769-801

Lewis, J.E., Harmand, S., 2016. An earlier origin for stone tool making: Implications for cognitive evolution and the transition to *Homo*. *Philosophical Transactions of the Royal Society B* 371(1698) Discussion Meeting Issue

Li, H., Kuman, K., Lotter, M.G., Leader, G.M., Gibbon, R.J., 2017. The Victoria West: Earliest prepared core technology in the Acheulean at Canteen Kopje and implications for the cognitive evolution of early hominids. *Royal Society Open Science*: doi:10.1098/rsos.170288

Lockman, J.J., 2000. A perception-action perspective on tool use development. *Child Development* 71(1), 137-44

Lombard, M., 2006. Direct evidence for the use of ochre in the hafting technology of Middle Stone Age tools from Sibudu Cave. *Southern African Humanities* 18(1), 57-67

Lombard, M., 2012. Thinking through the Middle Stone Age of sub-Saharan Africa. *Quaternary International* 270(23), 140-55

Lombard, M., Haidle, M.N. 2012. Thinking a bow-and-arrow set: Cognitive implications of Middle Stone Age bow and stone-tipped arrow technology. *Cambridge Archaeological Journal* 22(2), 237-64

Lubbock, J., 1865. *Pre-historic Times*. Williams & Norgate: London

MacKinnon, K.C., Fuentes, A., 2012. Primate social cognition, human evolution, and niche construction: A core context for neuroanthropology, in *Encultured Brain: An Introduction to Neuroanthropology*, eds. D.H. Lende, G. Downey. Cambridge (MA): MIT Press, 67-102

Maguire, E.A., Gadian, D.G., Johnsrude, I.S., Good, C.D., Ashburner, J., Frackowiak, R.S. J., Frith, C.D., 2000. Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences (USA)* 97, 4398-403

Malafouris, L., 2008a. Between brains, bodies and things: Tectonoetic awareness and the extended self. *Philosophical Transactions of the Royal Society of London Series B* 363, 1993-2002

Malafouris, L., 2008b. Beads for a plastic mind: The 'blind man's stick' (BMS) hypothesis and the active nature of material culture. *Cambridge Archaeological Journal* 18(3), 401-14

Malafouris, L., 2010a. The brain-artefact interface (BAI): A challenge for archaeology and cultural neuroscience. *Social Cognitive and Affective Neuroscience* 5, 264-73

Malafouris, L., 2010b. Metaplasticity and the human becoming: Principles of neuroarchaeology. *Journal of Anthropological Sciences* 88, 49-72

Malafouris, L., 2013. *How Things Shape the Mind: A Theory of Material Engagement*. Cambridge (MA): MIT Press

Maravita, A., Iriki, A., 2004. Tools for the body (schema). *Trends in Cognitive Sciences* 8(2), 79-86

Martín-Loeches, M., 2010. Uses and abuses of the enhanced-working-memory hypothesis in explaining modern thinking. *Current Anthropology* 51 (S1), S67-S75

Marzke, M.W., 1997. Precision grips, hand morphology and tools. *American Journal of Physical Anthropology* 102, 91-110

Marzke, M.W., 2013. Tool making, hand morphology and fossil hominins. *Phil Trans Royal Soc B* 368(1630), 1-8

Massen, C., Rieger, M., 2016. Cognitive and motor aspects of human tool use. Zeitschrift für Psychologie, 220(1)

Matheson, C.D., McCollum, A.J., 2014. Characterising native plant resins from Australian Aboriginal artefacts using ATR-FTIR and CG/MS. *Journal of Archaeological Science* 52, 116-28

Matskevich, Z., Goren-Inbar, N., Gaudzinski, S., 2001. A newly identified Acheulian handaxe type at Tabun Cave: The Faustkeilblatter. In S. Milliken, J. Cook eds. A Very Remote Period Indeed: Papers on the Palaeolithic Presented to Derek Roe. Oxford: Oxbow Books, 120-132

Mazza, P.P.A., Martini, F., Sala, B., Magi, M., Colombini, M. P., Giachi, G., Landucci, F., Lemorini, C., Modugno, F., Ribechini, E., 2006. A new Palaeolithic discovery: Tar-hafted stone tools in a European Mid-Pleistocene bone-bearing bed. *Journal of Archaeological Science* 33(9), 1310-18

McAuley, J.D., Fomboluti, E.K., 2014. Attentional entrainment and perceived event duration. *Philosophical Transactions of the Royal Society B*, 269(1658)

McBrearty, S., 2001. The Middle Pleistocene of East Africa, in L. Barham, K. Robson-Brown (eds), *Human Roots: Africa and Asia in the Middle Pleistocene*. Bristol: Western Academic & Specialist Press, 81-98

McBrearty, S., 2007. Down with the revolution, in P. Mellars, K. Boyle, O. Bar-Yosef, C. Stringer eds., *Rethinking the Human Revolution*. Cambridge: McDonald Institute for Archaeological Research, 133-151

McBrearty, S., Brooks, A.S., 2000. The revolution that wasn't: A new interpretation of the origin of modern human behaviour. *Journal of Human Evolution* 39, 453-563

McPherron, S.P., Alemseged, Z., Marean, C.W., Wynn, J.G., Reed, D., Geraads, D., Bobe, R., Bearat, H.A., 2010. Evidence for stone-tool-assisted consumption of animal tissues before 3.39 million years ago at Dikika, Ethiopia. *Nature* 466 857-60

Mellars, P., 1989. Major issues in the emergence of modern humans. *Current Anthropology* 39(3), 349-85

Michel, G.F., Nelson, E.L., Babik, I., Campbell, J.M., Marcinowski, E.C., 2013. Multiple trajectories in the developmental psychobiology of human handedness. In *Advances in Child Development and Behavior: Embodiment and Epigenesis: Theoretical and Methodological Issues in Understanding the Role of Biology within the Relational Developmental System. Part B: Ontogenetic Dimensions Vol. 45*, eds. R.M. Lerner, J.B. Benson. Elsevier 227-60

Miller, G.L., 2014. Lithic microwear analysis as a means to infer production of perishable technology: A case from the Great Lakes. *Journal of Archaeological Science* 49, 292-301

Miller, J.G., Kinsbourne, M., 2012. Culture and neuroscience in developmental psychology: Contributions and challenges. *Child Development Perspectives* 6(1), 35-41

Mirolli, M., Parisi, D., 2009. Language as a cognitive tool. *Minds and Machines* 19(4), 517-28

Mohapi, M., 2012. Point morphology and the Middle Stone Age cultural sequence of Sibudu Cave, Kwazulu-Natal, South Africa. *South African Archaeological Bulletin* 67(195) 5-15

Monnier, G.F., Hauck, T.C., Feinberg, J.M., Luo, B.,J-M., Le Tensorer, al Sakhel H., 2013. A multi-analytical methodology of lithic residue analysis applied to Paleolithic tools from Hummal, Syria. *Journal of Archaeological Science* 40(10) 3722-39

Moore, M.W., 2011a. The design space of stone flaking: Implications for cognitive evolution. *World Archaeology* 43(4), 702-15

Moore, M.W., 2011b. 'Grammars of action' and stone flaking design space. In *Stone Tools and the Evolution of Human Cognition*, eds. A. Nowell, I. Davidson. Boulder (Co): The University Press of Colorado, 13-43

Moore, M.W., Brumm, A., 2009. *Homo floriensis* and the African Oldowan. In *Interdisciplinary Approaches to the Oldowan*, eds E. Hovers, D.R. Braun. Dordrecht: Springer, 61-69

Morales, J.I., Verges, J M., 2014. Technological behaviors in Paleolithic foragers. Testing the role of resharpening in the assemblage organization. *Journal of Archaeological Science* 49, 302-16

Morgan, T.J.H., 2016. Testing the cognitive and cultural niche theories of human evolution. *Current Anthropology* 57(3), 370-377 doi:org.ezproxy.liv.ac.uk /10.3389/fnhum.2015.00389

Mosquera, M., Geribas, N., Bargallo, A., Llorente, M., Riba, D., 2012. Complex tasks force hand laterality and technological behaviour in naturalistically housed chimpanzees: Inferences in hominin evolution. *The Scientific World Journal* 514809, doi:10.1100/2012/514809

Muller, A., Clarkson, C., Shipton, C., 2017. Measuring behavioural and cognitive complexity in lithic technology throughout human evolution. *Journal of Anthropological Archaeology* 48, 166-80

Munte, T.F., Altenmuller, E., Jancke, L., 2002. The musician's brain as a model of neuroplasticity. *Nature Reviews Neuroscience* 3, 473-8

Nadel, D., Grinberg, U., Boaretto, E., Werker, E., 2006. Wooden objects from Ohalo II (23,000 cal BP), Jordan Valley, Israel. *Journal of Human Evolution* 50 644-662

Navarrete, A., van Schaik, C.P., Isler, K., 2011. Energetics and the evolution of human brain size. *Nature* 480 91-3

Negwer, M., Schubert, D., 2017. Talking convergence: Growing evidence links FOXP2 and retinoic acid in shaping speech-related motor circuitry. Frontiers in Neuroscience, doi.org/10.3389/fnis.2017.00019

Nielsen M., Tomaselli K., Mushin I., Whiten, A., 2014. Exploring tool innovation: A comparison of Western and Bushman children. *Journal of Experimental Child Psychology* 126, 384-394

Nonaka, T., Bril, B., 2012. Nesting of asymmetric functions in skilled bimanual action: Dynamics of hammering behavior of bead craftsmen. *Human Movement Science* 31(1), 55-77

Nonaka, T., Bril, B., Rein, R., 2010. How do stone knappers predict and control the outcome of flaking? Implications for understanding early stone tool technology. *Journal of Human Evolution* 59, 155-67

Noonan, J.P., Coop, G., Kuduaravalli, S., Smith, D., Krause, J., Alessi, J., Chen, F., Platt, D., Paabo, S., Pritchard, J.K., Rubin, E.M., 2006. Sequencing and analysis of Neanderthal genomic DNA. *Science* 314(5802), 1113-8

Nowell, A., 2010. Defining behavioural modernity in the context of Neandertal and Anatomically Modern Human populations. *Annual Review of Anthropology* 39, 437-52

Nozaradan, S., 2014. Exploring how musical rhythm entrains brain activity with electroencephalogram frequency-tagging. *Philosophical Transactions of the Royal Society B*, 369(1658)

Odell, G.H., 2004. *Lithic Analysis*. London: Kluwer

Odling-Smee, J., Erwin, D.H., Palkovacs, E.P., Feldman, M.W., Laland, K.N., 2013. Niche construction theory: A practical guide for ecologists. *Quarterly Review of Biology* 88(1), 3-28

Osiurak, F., Morgado, N., Paluel-Germain, R., 2012. Tool use and perceived distance: when unreachable becomes spontaneously reachable. *Exp Brain Res* 218, 331-9

Oullier, O., de Guzman, G.C., Jantzen, K. J., Lagarde, J., Kelso, J.A.S., 2008. Social coordination dynamics: Measuring human bonding. *Social Neuroscience* 3(2), 178-92

Overmann, K.A., 2013. Material scaffolds in numbers and time. *Cambridge Archaeological Journal* 23(1), 19-39

Overmann, K.A., 2016. Beyond writing: The development of literacy in the Ancient Near East. *Cambridge Archaeological Journal*, 26(2) 285-303

Overton, W.F., 2013. Relationism and relational developmental systems: A paradigm for developmental science in the post-Cartesian era. In *Advances in Child Development and Behavior: Embodiment and Epigenesis: Theoretical and Methodological Issues in Understanding the Role of Biology Within the Relational Developmental System*, Part A, Vol. 44: Philosophical, Theoretical, and Biological Dimensions, eds R.M. Lerner, J.B. Benson. Elsevier, 21-64

Paas, F., Sweller, J., 2012. An evolutionary upgrade of Cognitive Load Theory: Using the human motor system and collaboration to support the learning of complex cognitive tasks. *Educational Psychology Review* 24, 27-45

Panger, M.A., Brooks, A.S., Richmond, B.G., Wood, B., 2002. Older than the Oldowan? Rethinking the emergence of hominin tool use. Evolutionary Anthropology 11 235-45

Park, D.C., Huang, C-M., 2010. Culture wires the brain: A cognitive neuroscience perspective. *Perspectives on Psychological Science* 5, 391-400

Parry, R., Dietrich, G., Bril, B., 2014. Tool use ability depends on understanding of functional dynamics and not specific joint contribution profiles. *Frontiers in Psychology*, doi: 10.3389/fpsyg.2014.00306

Passingham, D., Sakai, K., 2004. The prefrontal cortex and working memory: Physiology and brain imaging. *Current Opinion in Neurobiology* 14(2), 163-8

Pawlik, A. F., Thissen, J. P., 2011. Hafted armatures and multi-component tool design at the Micoquian site of Inden-Altdorf, Germany. *Journal of Archaeological Science* 38(7), 1699-708

Pelegrin, J., 2005. Remarks about archaeological techniques and methods of knapping: Elements of a cognitive approach to stone knapping. In In *Stone Knapping: The Necessary Conditions for a Uniquely Hominin Behaviour*, V. Roux, B. Bril eds. Cambridge: McDonald Institute for Archaeological Research, 23-33

Perreault, C., Brantingham, P.J., Kuhn, S.L., Wurz, S., Gao, X., 2013. Measuring the complexity of lithic technology. *Current Anthropology* 54(8), S397-S406

Pfaffenberger, B., 1992. Social anthropology of technology. *Annual Review of Anthropology* 21, 491-516

Pomies, M-P., Menu, M., Vignaud, C., 1999. Red Palaeolithic pigments: Natural hematite or heated goethite? *Archaeometry* 41(2), 275-85

Potts, R., 1991. Why the Oldowan? Plio-Pleistocene toolmaking and the transport of resources. *Journal of Anthropological Research* 47(2), 153-76

Potts, R., Faith, J.T., 2015. Alternating high and low climate variability: The context of natural selection and speciation in Plio-Pleistocene hominin evolution. *Journal of Human Evolution* 87, 5-20

Powell, A., Shennan, S., Thomas, M.G., 2009. Late Pleistocene demography and the appearance of Modern Human Behavior. *Science* 324 1298

Prinz, W., M. Beisert, A. Herwig, eds, 2013. Action Science: *Foundations of an Emerging Discipline*. Cambridge (MA): MIT Press

Pruetz, J.D., Bertolani, P., 2007. Savanna chimpanzees, *Pan troglodytes* verus, hunt with tools. *Current Biology* 17(5), 412-17

Ragert, P., Schmidt, A., Altenmuller, E., Dinse, H.R., 2004. Superior tactile performance and learning in professional pianists: Evidence for metaplasticity in musicians. *European Journal of Neuroscience* 19, 473-478

Reber, A.S., 1993. Implicit Learning and Tacit Knowledge: An Essay on the Cognitive Unconscious. New York: OUP, Oxford Psychology Series No. 19

Reddy, V., 2008. Getting back to the rough ground: Deception and 'social living'. *Philosophical Transactions of the Royal Society* B 362, 621-37

Reed, E.S., 1988. Applying the theory of action systems to the study of motor skills. In *Complex Movement Behaviour: The Motor-Action Controversy*, O.G. Meijer, K. Roth eds. Elsevier: Amerstam, 45-86

Reed, E.S., 1996. *Encountering the World: Toward an Ecological Psychology*. New York: Oxford University Press

Rein, R., Bril, B., Nonaka, T., 2013. Coordination strategies used in stone knapping. *American Journal of Physical Anthropology* 150(4), 539-50

Richter, D., Grün, R., Joannes-Boyau, R., Steele, T.E., Amani, F., Rué, M., Fernandes, P., Raynal, J-P., Geraads, D., Ben-Ncer, A., Hublin, J-J., McPherron, S.P., 2017. The age of the hominin fossils from Jebel Irhoud, Morocco, and the origins of the Middle Stone Age. *Nature* 546, 293-6, doi: 10.1038/nature22335

Ridderinkhof, K.R., van den Wildenberg, W.P.M., Segalowitz, S.J., Carter, C.S., 2004. Neurocognitive mechanisms of cognitive control: The role of prefrontal cortex in action selection, response inhibition, performance monitoring, and reward-based learning. *Brain and Cognition* 56(2), 129-40

Roberts, M.B., Parfitt, S.A., 1999. *A Middle Pleistocene Hominid Site at Eartham Quarry, Boxgrove, West Sussex*. English Heritage Archaeological Report 17

Roche, H., Delagnes, A., Brugal, J-P., Feibel, C., Kubunjia, M., Mourre, V., Texier, P-J., 1999. Early hominid stone tool production and technical skill 2.34Myr ago in West Turkana, Kenya. *Nature* 399, 57-60

Roebroeks, W., Bakels, C.C., 2015. 'Forest furniture' or 'forest managers'? On the Neanderthal presence in the last interglacial environments. In *Settlement, Society and Cognition in Human Evolution: Landscapes in Mind* F., eds. F. Coward, R. Hosfield, M. Pope, F. Wenban-Smith. Cambridge: CUP 174-88

Rogers, N., Killcross, S., Curnoe, D., 2016. Hunting for evidence of cognitive planning: Archaeological signatures versus psychological realities. *Journal of Archaeological Science: Reports* 5, 225-39

Roncaglia-Denissen, M.P., Schmidt-Kassow, M., Kotz, S.A., 2013. Speech rhythm facilitates syntactic ambiguity resolution: ERP evidence. *Plos One* 8(2), e56000

Rose, M., Haider H., Buechel, C., 2010. The emergence of explicit memory during learning. *Cerebral Cortex* 20(12), 2787-97

Rosenkranz, K., Williamon, A., Rothwell, J.C., 2007. Motocortical excitability and synaptic plasticity is enhanced in professional musicians. *Journal of Neuroscience* 27(19), 5200-6

Rots, V., 2003. Towards an understanding of hafting: The macro- and microscopic evidence. *Antiquity* 77(298), 805-15

Rots, V., 2004. Prehensile wear on flint tools. *Lithic Technology* 29, 7-32

Rots, V., 2009. The functional analysis of the Mousterian and Micoquian assemblages of Sesselfelsgrotte, Germany. Tool use and hafting in the European Late Middle Paleolithic. *Quartar* 56, 37-66

Rots, V., 2010. *Prehension and Hafting Wear on Flint Tools: A Methodology*. Leuven: University Press

Rots, V., 2013. Insights into Early Middle Palaeolithic tool use and hafting in Western Europe: The functional analysis of Level IIa of the Early Middle Palaeolithic site of Biache-Saint-Vaast (France). *Journal of Archaeological Science* 40(1), 497-506

Rots, V., Hardy, B.L., Serangali, J., Conard, N.J., 2015. Residue and microwear analysis of the stone artifacts from Schoningen. *Journal of Human Evolution* 89, 298-308

Rots, V., Plisson, H., 2014. Projectiles and the abuse of the use-wear method in a search for impact. *Journal of Archaeological Science* 48, 154-65

Rots, V., Van Peer, P., 2006. Early evidence of complexity in lithic economy: Core-axe production, hafting and use at Late Middle Pleistocene site 8-B-11, Sai Island (Sudan). *Journal of Archaeological Science* 33, 360-71

Rots, V., Van Peer, P., Vermeersch, P. M., 2011. Aspects of tool production, use, and hafting in Palaeolithic assemblages from Northeast Africa. *Journal of Human Evolution* 60(5), 637-64

Rots, V., Williamson, B.S., 2004. Microwear and residue analyses in perspective: The contribution of ethnoarchaeological evidence. *Journal of Archaeological Science* 40(1), 497-506

Rouse, A.A., Cook, P.F., Large, E.W., Reichmuth C., 2016. Beat keeping in a sea lion as coupled oscillation: Implications for comparative understanding of human rhythm. *Frontiers in Neuroscience*, doi:org/10.3389/fnins.2016.00257

Roux, V., Bril, B., 2005. General introduction: A dynamic systems framework for studying a uniquely hominin innovation. In *Stone Knapping: The Necessary Conditions for a Uniquely Hominin Behaviour*, V. Roux, B. Bril eds. Cambridge: McDonald Institute for Archaeological Research, 1-18

Roux, V., David, E., 2005. Planning abilities as a dynamic perceptual-motor skill: An actualist study of different levels of expertise involved in stone knapping. In *Stone Knapping: The Necessary Conditions for a Uniquely Hominin Behaviour*, eds. V. Roux, B. Bril. McDonald Institute for Archaeological Research 91-108

Royeen, C.B., 2003. Chaotic Occupational Therapy: Collective wisdom for a complex profession. *American Journal of Occupational Therapy* 57, 609-24 doi:10.5014/ajot.57.6.609

Russell, Y.I., 2011. Prehistoric stone tools, chess expertise, and cognitive evolution: An experiment about recognizing features in flint debitage. *Journal of Evolutionary Psychology*, 249-269

Russon, A.E., Compost, A., Kuncoro, P., Ferisa, A., 2014. Orangutan fish eating, primate aquatic fauna eating, and their implications for the origins of ancestral hominin fish eating. *Journal of Human Evolution* 77, 50-63

Sakai, K., Hikosaka, O., Nakamura, K., 2004. Emergence of rhythm during motor learning. *Trends in Cognitive Sciences* 8(12) 547-53

Sambrook, T., Whiten, A., 1997. On the nature of complexity in cognitive and behavioural science. *Theory and Psychology* 7(2), 191-213

Sanabria, D., Correa, A., 2013. Electrophysiological evidence of temporal preparation driven by rhythms in audition. *Biological Psychology* 92(2), 98-105

Sanz, C.M., Morgan, D.B., 2006. Chimpanzee tool technology in the Goualougo Triangle. *Journal of Human Evolution* 52(4), 420-33

Sanz, C.M., Schöning, C., Morgan, D.B., 2010. Chimpanzees prey on army ants with specialized tool set. *American Journal of Primatology* 72, 17-24

Saxe, R., 2006. Uniquely human social cognition. *Current Opinion in Neurobiology* 16, 235-9

Scerri, E., 2013. On the spatial and technological organisation of hafting modifications in the North African Middle Stone Age. *Journal of Archaeological Science* 40, 4234-48

Scerri, E., Blinkhorn, J., Groucutt, H., Niang, K., 2016. The Middle Stone Age archaeology of the Senegal River Valley. Quaternary International, 408(B) 16-32

Schaal, S., Sternad, D., Osu, R., Kawato, M., 2004. Rhythmic arm movement is not discrete. *Nature Neuroscience* 7(10), 1137-44

Schacter, D.L., Addis, D.R., 2007. The cognitive neuroscience of constructive memory: Remembering the past and imagining the future. *Philosophical Transactions of The Royal Society* B 362(1481), 773-86

Schaefer, R.S., 2014. Auditory rhythmic cueing in movement rehabilitation: Findings and possible mechanisms. *Philosophical Transactions of the Royal Society B* 369(1658), doi; org./10.1098/rstb.2013.0402

Schick, K.D., Toth, N., 1993. *Making Silent Stones Speak*. London: Orion Books

Schlanger, N., 1990. Techniques as human action – two perspectives. *Archaeological Review From Cambridge* 9(1), 18-26

Schlanger, N., 1994. Mindful technology: Unleashing the *chaîne opératoire* for an archaeology of mind. In C. Renfrew, E. Zubrow (eds), *The Ancient Mind: Elements of a Cognitive Archaeology*. Cambridge University Press, 143-51

Schmidt, M.V., Abraham, W.C., Maroun, M., Stork, O., Richter-Levin, G., 2013. Stress-induced metaplasticity: From synapses to behavior. *Neuroscience* 250, 112-20

Schmidt, P., Porraz, G., Bellot-Gurlet, L., February, E., Ligouis, B., Paris, C., Texier, P-J., Parkington, J.E., Miller, C.E., Nickel, K.G., Conard, J., 2015. A previously undescribed organic residue sheds light on heat treatment in the Middle Stone Age. *Journal of Human Evolution* 85, 22-34

Schmidt, R.C., Nie, L., Franco, A., Richardson, M.J., 2014. Bodily synchronization underlying joke telling. Frontiers of Human Neuroscience doi: 10.3389/fnhum.2014.00633

Schoch, W.H., Bigga, G., Bohner, U., Richter, P., Terberger, T., 2015. New insights on the wooden weapons from the Paleolithic site of Schoningen. *Journal of Human Evolution* 89, 214-25

Schuchard, J., Thompson, C.K., 2014. Implicit and explicit learning in individuals with agrammatic aphasia. *Journal of Psycholinguistic Research* 43, 209-24

Scott, R.M., Zijing, H., Baillargeon, R., Cummins, D., 2012. False-belief understanding in 2.5-year-olds: Evidence from two novel verbal spontaneous-response tasks. Developmental Science 15(2), 181-93

Semaw, S., 2000. The world's oldest stone artefacts from Gona, Ethiopia: Their implications for understanding stone technology and patterns of human evolution between 2.6-1.5 million years ago. *Journal of Archaeological Science* 27, 1197-1214

Serino, A., Canzoneri, E., Marzolla, M., di Pellegrino, G., Magosso, E., 2015. Extending peripersonal space representation without tool-use: Evidence from a combined behavioral-computational approach. *Frontiers in Behavioral Neuroscience* doi: 10.3389/fnbeh.2015.00004

Seth, A.K., Baars, B.J., 2005. Neural Darwinism and consciousness. *Consciousness and Cognition* 14, 140-68

Shapiro, L., 2011. *Embodied Cognition*. London & New York: Routledge

Shea, J.J., 2011. *Homo sapiens* is as *Homo sapiens* was: Behavioral variability versus 'behavioral modernity' in Palaeolithic archaeology. *Current Anthropology* 52(1), 1-35

Shea, J.J., 2014. Sink the Mousterian? Named stone tool industries (NASTIES) as obstacles to investigating hominin evolutionary relationships in Later Middle Paleolithic Levant. *Quaternary International* 350, 169-179

Shea, N., 2012. New thinking, innateness and inherited representation. *Philosophical Transactions of the Royal Society B* 367(1599), 2234-44

Shea, J., 2016. *Stone Tools in Human Evolution*. Cambridge University Press, Chapter 3

Sherwood, C.C., Bauernfeind, A.L., Bianchi, S., Raghanti, M.A., Hof, P.R. 2012. Human brain evolution writ large and small, in *Evolution of the Primate Brain: From Neuron to Behavior*, eds. M.A. Hofman, D. Falk. Progress in Brain Research Vol. 195 Elsevier B. V., 237-54

Shettleworth, S.J., 2012. Modularity, comparative cognition and human uniqueness. *Philosophical Transactions of the Royal Society B* 367(1603), 2794-802 doi:10.1098/rstb.2012.0211

Simon, H.A., 1962. The architecture of complexity. *Proceedings of the American Philosophical Society* 106(6), 467-82

Simons, D.J., Hannula, D.E., Warren, D.E., Day, S.W., 2007. Behavioral, neuroimaging, and neuropsychological approaches to implicit perception, in *The Cambridge Handbook of Consciousness*, P.D. Zelazo, M. Moscovitch, E. Thompson eds. New York: Cambridge University Press, 207-250

Sinha, C., 2015. Language and other artifacts: Socio-cultural dynamics of niche construction. *Frontiers in Psychology: Hypothesis and Theory* doi: 10.3389/fpsyg.2015.01601

Smith, L.B., Thelen, E., 2003. Development as a dynamic system. *Trends in Cognitive Sciences* 7(8) 343-348

Smith, R., Rathcke, T., Cummins, F., Overy, K., Scott, S., 2014. Communicative rhythms in brain and behaviour. Philosophical Transactions B 369(1658)

Smitsman, A.W., Cox, R.F.A., Bongers, R.M., 2005. Action dynamics in tool use. In *Stone Knapping: The Necessary Coniditions for a Uniquely Hominin Behaviour*, eds V. Roux, B. Bril. McDonald Institute for Archaeological Research, 129-144

Sol, D., 2009. Revisiting the cognitive buffer hypothesis for the evolution of large brains. *Biology Letters* 5, 130-3

Sol, D., Bacher, S., Reader, S.M., Lefebvre, L., 2008. Brain size predicts the success of mammal species introduced into novel environments. The American Naturalist 172, S63-S71

Soressi, M., Geneste, J-M., 2011. The history and efficacy of the *Chaîne Opératoire* approach to lithic analysis: Studying techniques to reveal past societies in an evolutionary perspective. Special Issue: Reduction Sequence, *Chaîne Opératoire,* and Other Methods: The Epistemologies of Different Approaches to Lithic Analysis. *PaleoAnthropology*, 334-50

Sporns, O., Edelman, G.M., 1993. Solving Bernstein's problem: A proposal for the development of coordinated movement by selection. *Child Development* 64, 960-81

Sterelny, K., 2007. Social intelligence, human intelligence and niche construction. *Philosophical Transactions of the Royal Society B* 362(1480), 719-30

Stoerig, P., 2007. Hunting the Ghost: Toward a neuroscience of consciousness. In *The Cambridge Handbook of Consciousness*, P.D. Zelazo, M. Moscovitch, E. Thompson eds. New York: Cambridge University Press, 707-730

Stout, D., 2002. Skill and cognition in stone tool production: An ethnographic case study from Irian Jaya. *Current Anthropology* 43(5), 693-722

Stout, D., 2005a. Neural foundations of perception and action in stone knapping. In *Stone Knapping: The Necessary Conditions for a Uniquely Hominin Behaviour*, eds. V. Roux, B. Bril. McDonald Insitute for Archaeological Research, 273-286

Stout, D., 2010. The evolution of cognitive control. *Topics in Cognitive Science* 2 614-30

Stout, D., 2011. Stone toolmaking and the evolution of human culture and cognition. *Philosophical Transactions of the Royal Society B* 366, 1050-9. Doi: 10.1111/j.1756-8765.2009.01078.x

Stout, D., Apel, J., Commander, J., Roberts, M., 2014. Late Acheulean technology and cognition at Boxgrove, UK. *Journal of Archaeological Science* 41, 576-90

Stout, D., Chaminade, T., 2007. The evolutionary neuroscience of tool making. *Neuropsychologia* 45(5), 1091-100

Stout, D., Chaminade, T., 2009. Making tools and making sense: Complex, intentional behaviour in human evolution. *Cambridge Archaeological Journal* 19, 85-96

Stout, D., Hecht, E., 2014. Neuroarchaeology. In *Human Paleoneurology*, E. Bruner ed. Springer, 145-175

Stout, D., Khreisheh, N., 2015. Skill learning and human brain evolution: An experimental approach. *Cambridge Archaeological Journal* 25(4), 867-75

Stout, D., Passingham, R., Frith, C., Apel, J., Chaminade, T., 2011. Technology, expertise and social cognition in human evolution. *European Journal of Neuroscience 33, 1328-38*

Stout, D., Semaw, S., Rogers, M.J., Cauche, D., 2010. Technological variation in the earliest Oldowan from Gona, Afar, Ethiopia. Journal of Human Evolution 58(6), 474-91

Stout, D., Toth, N., Schick, K.D., Chaminade, T., 2008. Neural correlates of early stone age tool-making: Technology, language and cognition in human evolution. *Philosophical Transactions of the Royal Society B* 363, 1939-49

Stringer, C., 2011. *The Origin of Our Species*. Milton Keynes: Allen Lane

Suddendorf, T., Corballis, M.C., 2007. The evolution of foresight: What is mental time travel, and is it unique to humans? *Behavioral and Brain Sciences* 30, 299-351

Suto, M., 2000. Issues related to data collection. In K. W. Hammell, C. Carpenter, I. Dyck (eds) *Using Qualitative Research: A Practical Introduction for Occupational and Physical Therapists*. Churchill Livingstone: Harcourt Publishers 35-46

Suzuki, W., Banno, T., Miyakawa, N., Abe, H., Goda, N., Ichinohe, N., 2015. Mirror neurons in a new world monkey, common marmoset. *Frontiers in Neuroscience*, http://dix.doi.org/10.3389/fnins.2015.00459

Tan, A., Tan, S.H., Vyas, D., Malaivijitnond, S., Gumert M.D., 2015. There is more than one way to crack an oyster: Identifying variation in burmese long-tailed macaque (*Macaca fascicularis aurea*) stone-tool use. *Plos One* 10(5), e0124733

Teffer, K., Semendeferi, K., 2012. Human prefrontal cortex: Evolution, development, and pathology. In *Evolution of the Primate Brain: From Neuron to Behavior*, eds. M.A. Hofman, D. Falk. Progress in Brain Research Vol. 195 Elsevier B. V., 191-218

Tennie, C., Call, J., Tomasello, M., 2009. Ratcheting up the ratchet: On the evolution of cumulative culture. *Philosophical Transactions of the Royal Society B* 364, 2405-15

Thelen, E., 1979. Rhythmical stereotypies in normal human infants. *Animal Behaviour* 27(3), 699-715

Thelen, E., 1981a. Kicking, rocking, and waving: Contextual analysis of rhythmical stereotypies in normal human infants. *Animal Behaviour* 29, 3-11

Thelen, E., 1981b. Rhythmical behavior in infancy: An ethological perspective. *Developmental Psychology* 17(3), 237-57

Thelen, E., Schöner, G., Scheier, C., Smith, L.B., 2001. The dynamics of embodiment: A field theory of infant perseverative reaching. *Behavioral and Brain Sciences* 24, 1-86

Thelen, E., Smith, L.B., 1994. *A Dynamic Systems Approach to the Development of Cognition and Action.* Cambridge Ma: MIT Press

Thieme, H., 2003. The Lower Palaeolithic sites at Schöningen, Lower Saxony, Germany. In *Lower Palaeolithic Small Tools in Europe and the Levant*, eds J.M. Burdukiewicz, A. Ronen. Oxford: British Archaeological Reports, International Series 1115, 9-28

Thornton, C., 2012. Renewing the link between cognitive archaeology and cognitive science. *Journal of Archaeological Science* 39, 2036-41

Timberlake, S., 2014. The study of cobble stone, bone, antler and wooden mining tools in prehistoric metal mining: New evidence from the British Isles and beyond. IES Yearbook 27-55

Timberlake, S., Craddock, B., 2013. Prehistoric metal mining in Britain: The study of cobble stone mining tools based on artefact study, enthnography and experimentation. *Revista de Antropologia Chilena* 45(1) 33-59

Tocheri, M.W., Orr, C.M., Jacofsky, M.C., Marzke, M.W., 2008. The evolutionary history of the hominin hand since the last common ancestor of *Pan* and *Homo*. *Journal of Anatomy* 212, 544-62

Tognoli, E., Lagarde, J., DeGuzman, G.C., Kelso, J.A.S., 2007. The phi complex as a neuromarker of human social coordination. *Proceedings of the National Academy of Sciences of the United States of America* 104(19), 8190-95 doi: 10.1073/pnas.0611453104

Tostevin, G.B., 2011. Levels of theory and social practice in the reduction sequence and *Chaîne Opératoire* methods of lithic analysis. Special Issue: Reduction Sequence, *Chaîne Opératoire,* and Other Methods: The Epistemologies of Different Approaches to Lithic Analysis. *PaleoAnthropology*, 351-75

Toth, N., 1985. The Oldowan reassessed: A close look at early stone artifacts. *Journal of Archaeological Science* 12, 101-20

Tozzi, A., Zare, M., Benasich, A.A., 2016. New perspectives on spontaneous brain ativity: Dynamic networks and energy matter. *Frontiers in Human Neuroscience*, doi:org/10.3389/fnhum.2016.00247

Trevarthen, C., (1994). The self born in intersubjectivity: The psychology of an infant communicating. In U. Neisser ed. *The Perceived Self: Ecological and Interpersonal Sources of Self-Knowledge*. New York: Cambridge University Press

Turk-Brown, N.B., Scholl, B.J., Chun, M.M., Johnson M.K., 2009. Neural evidence of statistical learning: Efficient detection of visual regularities without awareness. *Journal of Cognitive Neuroscience* 21, 1934-45. Doi: 10.1162/jocn.2009.21131

Turner, A., Foster, M., Johnson, S.E., 1996. *Occupational Therapy and Physical Dysfunction: Principles, Skills and Practice*. Harcourt Brace & Co. Ltd: Churchill Livingstone

Turvey, M.T., 2013. Ecological perspective on perception-action. What kind of science does it entail? In Action Science: Foundations of an Emerging Discipline, W. Prinz, M. Beisert, A. Herwig eds. Cambridge (MA): MIT Press, 139-170

Turvey, M.T., Shaw, R.E., Reed, E.S., Mace, W.M., 1981. Ecological laws of perceiving and acting: In reply to Fodor and Plyshyn. *Cognition* 9, 237-304

Umiltà, C.A., 2007. Consciousness and control of action. In *The Cambridge Handbook of Consciousness*, P.D. Zelazo, M. Moscovitch, E. Thompson eds, Cambridge: Cambridge Universtiy Press, 327-51

Underwood, A.G., Guynn, M.J., Cohen, A-L., 2015. The future orientation of past memory: The role of BA10 in prospective and retrospective retrieval modes. *Frontiers in Human Neuroscience*, doi: org/10.3389/fnhum.2015.00668

Ungan, P., Berki, T., Erbil, N., Yagcioglu, S., Yuksel, M., Utkucal, R., 2013. Event-related potentials to changes of rhythmic unit: Differences between musicians and nonmusicians. *Neurological Science* 34, 25-39

Uomini, N.T., 2009. The prehistory of handedness: Archaeological data and comparative ethology. *Journal of Human Evolution* 57, 411-19

Vanhaeren, M., d'Errico, F., van Niekerk, K.L., Henshilwood, C.S., Erasmus, R.M., 2013. Thinking strings: Additional evidence for personal ornament use in the Middle Stone Age at Blombos Cave, South Africa. *Journal of Human Evolution*, 64(6), 500-17

Van Kolfschoten, T., Parfitt, S.A., Serangeli, J., Bello, S.M., 2015. Lower Paleolithic bone tools from the 'spear horizon' at Schoningen (Germany). *Journal of Human Evolution* 89, 226-63

Van Peer, P., Rots, V., Vroomans, J-M., 2004. A story of colourful diggers and grinders: The Sangoan and Lupemban at site 8-B-11, Sai Island, Northern Sudan. *Before Farming* 2004(3), Article 1

Varela, F.J., Thompson, E., Rosch E., 1993. *The Embodied Mind: Cognitive Science and Human Experience*. Cambridge MA MIT Press

Vargha-Khadem, F., Watkins, K., Alcock, K., Fletcher, P., Passingham, R., 1995. Praxic and nonverbal cognitive deficits in a large family with a genetically transmitted speech and language disorder. *PNAS* 92, 930 -3

Vernot, B., Tucci, S., Kelso, J., Schraiber, J.G., Wolf, A.B., Gittelman, R.M., Dannemann, M., Grote, S., McCoy, R.C., Norton, H., Scheinfeldt, L.B., Merriwether, D.A., Koki, G., Friedlaender, J.S., Wakefield, J., Paabo, J., Akey, J.M., 2016. Excavating Neandertal and Denisovan DNA from the genomes of Melanesian individuals. *Science* 352(6282), 235-9

Wadley, L., 2005. Putting ochre to the test: Replication studies of adhesives that may have been used for hafting tools in the Middle Stone Age. *Journal of Human Evolution* 49, 587-601

Wadley, L., 2010. Compound-adhesive manufacture as a behavioral proxy for complex cognition in the Middle Stone Age. *Current Anthropology* 51(1), S111-S119

Wadley, L., Hodgskiss, T., Grant, M., 2009. Implications for complex cognition from the hafting of tools with compound adhesives in the Middle Stone Age, South Africa. *Proceedings of the National Academy of Sciences (USA)* 106(24), 9590-4

Wadley, L., Prinsloo, L.C., 2014. Experimental heat treatment of silcrete implies analogical reasoning in the Middle Stone Age. *Journal of Human Evolution* 70 49-60 doi: org/10.1016/j.jhevol.2013.11003

Wadley, L., Trower, G., Backwell, L., d'Errico, F., 2015. Traditional glue, adhesive and poison used for composite weapons by Ju/'hoan San in Nyae Nyae, Namibia. Implications for the evolution of hunting equipment in prehistory. PLoS ONE 10(10): e0149269. Doi:10.1371/journal.pone.0140269

Waguespack, N.M., Surovell, T.A., Denoyer, A., Dallow, A., Savage, A., Hyneman, J., Tapster, D., 2009. Making a point: Wood- *versus* stone-tipped projectiles. *Antiquity* 83, 786-800

Wang, J., Sainburg R.L., 2007. The dominant and nondominant arms are specialized for stabilizing different features of task performance. *Experimental Brain Research* 178(4) 565-570

Weaver, A.H., 2005. Reciprocal evolution of the cerebellum and neocortex in fossil humans. *Proceedings of the National Academy of Sciences of the United States of America* 102(10), 3576-80

Wei, K., Wertman, G., Sternad, D., 2003. Interactions between rhythmic and discrete components in a bimanual task. *Motor Control* 7, 134-54

Wereha, T.J., Racine, T.P., 2012. Evolution, development, and human social cognition. *Review of Philosophy and Psychology* 3(4), 559-79

Wessel, J.R., Haider, H., Rose, M., 2012. The transition from implicit to explicit representations in incidental learning situations: More evidence from high-frequency EEG coupling. *Experimental Brain Research* 217(1), 153-62

West-Eberhard, M.J., 2003. *Developmental Plasticity and Evolution*. Oxford: OUP

Whiting, B.A., Barton, R.A., 2003. The evolution of the cortico-cerebellar complex in primates: Anatomical connections predict patterns of correlated evolution. *Journal of Human Evolution* 44, 3-12

Wilkins, J., Schoville, B.J., Brown, K.S., Chazan, M., 2012. Evidence for early hafted hunting technology. *Science* 338(1609), 942-6

Wilkins, J., Schoville, B.J., Brown, K.S., Chazan, M., 2015. Kathu Pan 1 points and the assemblage-scale. Probabilistic approach: A response to Rots and Plisson, "Projectiles and the abuse of the use-wear method in a search for impact". *Journal of Archaeological Science* 54, 294-9

Williams, E.M., Gordon, A.D., Richmond, B.G., 2014. Biomechanical strategies for accuracy and force generation during stone tool production. *Journal of Human Evolution* 72, 52-63 doi: 10.1016/j.jhevol.2014.03.004

Wilson, A.D., Golonka, S., 2013. Embodied cognition is not what you think it is. *Frontiers in Psychology* doi: 10.3389/fpsyg.2013.00058

Wilson, A.D., Weightman, A., Bingham, G.P., Zhu, Q., 2016a. Using task dynamics to quantify the affordances of throwing for long distance and accuracy. *Journal of Experimental Psychology, Human Perception and Performance* 2016, 42(7), 965-81

Wilson, A.D., Zhu, Q., Barham, L., Stanistreet, I., Bingham, G.P., 2016b. A dynamical analysis of the suitability of prehistoric spheroids from the Cave of Hearths as thrown projectiles. *Scientific Reports* 6(30614), doi:10.1038/srep30614

Wilson, A.E., Smith, M.D., Ross, H.S. 2003. The nature and effects of young children's lies. *Social Development* 12, 21-45

Wing, A.M., Endo, S., Bradbury, A., Vorberg, D., 2014. Optimal feedback correction in string quartet synchronization. *Journal of the Royal Society Interface* 11(93)

Witt, J.K., Riley, M.A., 2014. Discovering your inner Gibson: Reconciling action-specific and ecological approaches to perception-action. *Psychonomic Bulletin Review* 21(6) 1353-70

Wragg Sykes, R.M., 2015. To see a world in a hafted tool: Birch pitch composite technology, cognition and memory in Neanderthals. In *Settlement, Society and Cognition in Human Evolution: Landscapes in Mind*, F. Coward, R. Hosfield, M. Pope, F. Wenban-Smith eds. CUP, 117-137

Wrangham, R., Carmody, R., 2010. Human adaptation to the control of fire. *Evolutionary Anthropology* 19(5), 187-99

Wynn, T. 2009. Whither evolutionary cognitive archaeology? In S.A. de Beaune, F.L.Coolidge, T. Wynn eds, Cognitive Archaeology and Human Evolution. New York: Cambridge University Press, 145-149

Wynn, T., Coolidge, F.L., 2004. The expert Neandertal mind. *Journal of Human Evolution* 46(4), 467-87

Wynn T., Coolidge, F.L., 2009. Implications of a strict standard for recognizing modern cognition in prehistory. In S.A. de Beaune, F.L.Coolidge, T. Wynn eds, Cognitive Archaeology and Human Evolution. New York: Cambridge University Press, 117-127

Wynn, T., Coolidge, F.L., 2016. Archaeological insights into hominin cognitive evolution. *Evolutionary Anthropology* 25, 200-213 doi: 10.1002/evan/21496

Wynn, T., Coolidge, F.L., 2017. The expert cognition model in human evolutionary studies, in *Cognitive Models in Palaeolithic Archaeology* T. Wynn, F.L. Coolidge eds. New York: Oxford University Press, 21-43

Wynn, T., Overmann, K.A., Coolidge, F.L., 2016. The false dichotomy: A refutation of the Neandertal indistinguishability claim. Journal of Anthropological Sciences 94, 1-22

Yaroshevich, A., Nadel, D., Tsatskin, A., 2013. Composite projectiles and hafting technologies at Ohalo II (23 ka, Israel): Analyses of impact fractures, morphometric characteristics and adhesive remains on microlithic tools. *Journal of Archaeological Science* 40(11), 4009-23

Yekutiel, M., 2000. *Sensory Re-Education of the Hand After Stroke*. London: Whurr Publishers

Zhang, W., Linden, D., 2003. The other side of the engram: Experience driven changes in neuronal intrinsic excitability. *Nature Reviews Neuroscience* 4, 885-900

Zhuang, P., Dang, N., Warzeri, A., Gerloff, C., Cohen, L.G., Hallett, M., 1998. Implicit and explicit learning in an auditory serial reaction time task. *Acta Neurologica Sandinavica* 97, 131-7

Zhuang, P., Toro, C., Grafman, J., Manganotti, P., Leocani, L., Hallett, M., 1997. Event-related desynchonization (ERD) in the alpha frequency during development of implicit and explicit learning. *Electroncephalography and Clinical Neurophysiology* 102(4), 374-81

Zijing, H., Bolz, M., Baillargeon, R., 2011. False-belief understanding in 2.5-year-olds: Evidence from violation-of-expectation change-of-location and unexpected-contents tasks. *Developmental Science* 14(2), 292-305

Zilhao, J., Angelucci, D.E., Badal-García E., d'Errico, F., Daniel, F., Dayet, L., Douka, K., Higham, T.F.G., Martínez-Sanchez, M.J., Montes-Bernardez, R., Murcia-Mascaros, S., Perez-Sirvent, C., Roldan-Garcia, C., Vanhaeren, M., Villaverde, V., Wood, R., Zapata, J., 2010. Symbolic use of marine shells and mineral pigments by Iberian Neandertals. *Proceedings of the National Academy of Sciences*. 107(3), 1023-1028

Zipkin, A.M., Wagner, M., McGrath, K., Brooks, A.S., Lucas, P.W., 2014. An experimental study of hafting adhesives and the implications for compound tool technology. *Plos One*. Doi: 10.1371/journal.pone.0112560

Zoefel, B., VanRullen, R., 2017. Oscillatory mechanisms of stimulus processing and selection in the visual and auditory systems: State-of-the-art, speculations and suggestions. *Frontiers in Neuroscience*, doi: 10.3389/fnins.2017.00296

appendices

Appendix 1

The table in Appendix 1 shows the complete set of action set group types made up out of the sequences of action sets from all coded task stages. Section 7.4 describes how the action set groups were made up. The action set groups were easily formed in relation to repetitive reductive action sets and more difficult in task stages where rhythmic repetition levels were low. The longest action set groups are associated with task stages with low levels of efficiency and are probably generated as a result of indecision about how to proceed, and by prolonged information search gestures. Task stage efficiency levels are calculated by differentiating between efficient action set group types of up to 3 action sets in length which are used more than once in the task stage, and all relatively inefficient action set group types of more than 3 action sets in length (Section 7.5). Efficiency levels appear to improve along with the increased knapping experience of each of the three knappers across knapping tasks, and particularly with the presence of rhythmic repetition pattern (a), (Section 7.5). Table 7.5 shows action set group types used in more than one task stage. Most of them are only up to 3 action sets in length. There are 32 of them. They represent an efficient chunking of gestures in relation to the task in hand which have merged into a single unit and are re-used as such by the knappers. The complete list of action set group types displayed here numbers 216 out of which 184 are not used more than once. The longest, (ii)C, contains 9 action sets.

Action Set Group Key	Action Set Groups
(i)	(i)
(i)g	(i)(i)
(i)a	(i)(v)
(i)c	(i)(vi)
(i)h	(i)(xi)
(i)e	(i)(xxiii)
(i)b	(i)(vi)(i)
(ii)	(ii)
(ii)a	(ii)(i)
(ii)I	(ii)(iii)
(ii)t	(ii)(iv)
(ii)b	(ii)(v)
(ii)J	(ii)(vi)
(ii)8	(ii)(viii)
(ii)48	(ii)(xvii)
(ii)x	(ii)(i)(iv)
(ii)u	(ii)(i)(v)
(ii)W	(ii)(i)(vi)
(ii)7	(ii)(i)(viii)
(ii)c	(ii)(iii)(i)
(ii)y	(ii)(iv)(i)
(ii)M	(ii)(iv)(v)
(ii)S	(ii)(iv)(vi)
(ii)d	(ii)(v)(i)
(ii)K	(ii)(v)(iv)
(ii)O	(ii)(vi)(i)
(ii)28	(ii)(vi)(iv)

(ii)10	(ii)(viii)(i)
(ii)14	(ii)(viii)(iii)
(ii)F	(ii)(i)(iv)(i)
(ii)16	(ii)(i)(iv)(vi)
(ii)e	(ii)(i)(v)(i)
(ii)18	(ii)(i)(v)(iv)
(ii)17	(ii)(i)(v)(vi)
(ii)27	(ii)(i)(vi)(i)
(ii)24	(ii)(i)(vi)(vi)
(ii)11	(ii)(i)(viii)(i)
(ii)p	(ii)(iii)(i)(v)
(ii)5	(ii)(iii)(i)(vi)
(ii)f	(ii)(iii)(v)(i)
(ii)44	(ii)(iv)(i)(vi)
(ii)Y	(ii)(iv)(vi)(i)
(ii)15	(ii)(iv)(vi)(vi)
(ii)v	(ii)(v)(i)(iv)
(ii)g	(ii)(v)(i)(v)
(ii)26	(ii)(v)(i)(vi)
(ii)L	(ii)(v)(iv)(i)
(ii)N	(ii)(v)(iv)(v)
(ii)1	(ii)(v)(iv)(vi)
(ii)6	(ii)(v)(xi)(viii)
(ii)V	(ii)(vi)(i)(iv)
(ii)U	(ii)(vi)(iv)(i)
(ii)2	(ii)(viii)(i)(iii)
(ii)T	(ii)(viii)(i)(vi)
(ii)9	(ii)(viii)(i)(vii)
(ii)12	(ii)(viii)(i)(xi)
(ii)13	(ii)(viii)(v)(i)
(ii)47	(ii)(viii)(vii)(i)
(ii)45	(ii)(i)(iv)(vi)(i)
(ii)19	(ii)(i)(iv)(viii)(vi)
(ii)42	(ii)(i)(v)(i)(iv)
(ii)3	(ii)(i)(v)(i)(v)
(ii)w	(ii)(i)(v)(iv)(i)
(ii)34	(ii)(i)(v)(iv)(vi)
(ii)36	(ii)(i)(v)(vi)(iv)
(ii)46	(ii)(i)(vi)(i)(iv
(ii)h	(ii)(iii)(i)(v)(i)
(ii)q	(ii)(iii)(v)(i)(v)
(ii)32	(ii)(iv)(vi)(i)(iv)
(ii)i	(ii)(v)(i)(iv)(i)
(ii)20	(ii)(v)(i)(iv)(vi)
(ii)j	(ii)(v)(i)(v)(i)

(ii)31	(ii)(v)(iv)(vi)(i)
(ii)4	(ii)(viii)(i)(vii)(i)
(ii)R	(ii)(viii)(v)(i)(vi)
(ii)33	(ii)(i)(iv)(vi)(i)(iv)
(ii)29	(ii)(i)(iv)(vi)(iv)(i)
(ii)22	(ii)(i)(iv)(vi)(viii)(i)
(ii)32	(ii)(i)(iv)(viii)(vi)(i)
(ii)E	(ii)(i)(v)(i)(v)(i)
(ii)43	(ii)(i)(v)(i)(viii)(i)
(ii)25	(ii)(i)(v)(viii)(iv)(vi)
(ii)G	(ii)(iii)(v)(i)(v)(i)
(ii)A	(ii)(v)(i)(iv)(i)(v)
(ii)k	(ii)(v)(i)(iv)(v)(i)
(ii)21	(ii)(v)(i)(iv)(vi)(i)
(ii)l	(ii)(v)(i)(v)(iv)(i)
(ii)23	(ii)(v)(i)(viii)(iv)(vi)
(ii)m	(ii)(v)(viii)(i)(vi)(i)
(ii)P	(ii)(viii)(iii)(i)(vi)(i)
(ii)n	(ii)(viii)(v)(i)(vi)(i)
(ii)37	(ii)(i)(iv)(vi)(i)(vi)(iv)
(ii)30	(ii)(i)(v)(iv)(vi)(i)(iv)
(ii)38	(ii)(i)(viii)(i)(v)(iv)(vi)
(ii)D	(ii)(iii)(i)(v)(i)(v)(i)
(ii)o	(ii)(v)(i)(viii)(i)(vi)(i)
(ii)z	(ii)(v)(i)(iv)(i)(iv)(i)
(ii)B	(ii)(v)(i)(v)(i)(iv)(i)
(ii)H	(ii)(v)(i)(v)(i)(v)(i)
(ii)r	(ii)(viii)(iii)(v)(i)(vi)(i)
(ii)s	(ii)(viii)(v)(iii)(i)(vi)(i)
(ii)X	(ii)(i)(vi)(i)(iv)(vi)(iv)(i)
(ii)C	(ii)(v)(i)(iv)(i)(iv)(i)(iv)(i)
(v)a	(v)(vi)
(v)c	(v)(i)(viii)
(v)b	(v)(xv)(vi)
(v)d	(v)(i)(viii)(i)
(vi)	(vi)
(vi)a	(vi)(i)
(vi)b	(vi)(vii)
(vi)q	(vi)(xxxi)
(vi)k	(vi)(i)(vi)
(vi)o	(vi)(vi)(vii)

(vi)j	(vi)(vii)(i)
(vi)r	(vi)(vii)(vi)
(vi)d	(vi)(i)(iv)(vi)
(vi)l	(vi)(vi)(vii)(i)
(vi)e	(vi)(xix)(viii)(i)
(vi)n	(vi)(xxi)(viii)(i)
(vi)s	(vi)(vii)(i)(vi)(i)
(vii)c	(vii)(i)
(vii)h	(vii)(vi)
(vii)e	(vii)(xvii)
(vii)o	(vii)(xviii)
(vii)j	(vii)(i)(iii)
(vii)l	(vii)(i)(vi)
(vii)a	(vii)(vi)(i)
(vii)m	(vii)(vii)(vii)
(vii)g	(vii)(xvii)(i)
(vii)q	(vii)(xvii)(vi)
(vii)f	(vii)(xviii)(i)
(vii)g	(vii)(xxii)(vi)
(vii)k	(vii)(i)(iii)(i)
(vii)b	(vii)(i)(vi)(i)
(vii)i	(vii)(i)(xi)(vi)
(vii)n	(vii)(v)(xi)(vi)
(vii)d	(vii)(xvii) (i)(xi)
(vii)p	(vii)(xvii)(i)(xi)(vi)
(viii)g	(viii)(i)
(viii)k	(viii)(vi)
(viii)i	(viii)(vii)
(viii)f	(viii)(xi)
(viii)j	(viii)(viii)(vi)
(viii)l	(viii)(xi)(vi)(vi)
(viii)h	(viii)(xi)(vi)(vii)(i)
(viii)a	(viii)(v)(iii)(i)(vi)(i)
(ix)a	(ix)(viii)(vi)
(x)a	(x)(viii)(i)(vi)
(x)b	(x)(viii)(iii)(i)
(x)c	(x)(viii)(iii)(i)(vi)
(x)d	(x)(viii)(iii)(i)(vi)(i)
(xi)	(xi)
(xi)c	(xi)(viii)
(xi)e	(xi)(vi)(vi)

(xi)b	(xi)(vii)(vi)
(xi)d	(xi)(xi)(vi)(vi)
(xii)a	(xii)(i)
(xii)c	(xii)(viii)
(xii)b	(xii)(viii)(i)
(xii)e	(xii)(viii)(xiii)(vi) (i)
(xii)g	(xii)(viii)(xiii)(xi)(i)
(xii)d	(xii)(viii)(xiii)(xi)(vi)
(xii)f	(xii)(viii)(xiii)(i)(vi)(i)
(xiii)a	(xiii)(xi)(i)
(xiii)b	(xiii)(xi)(vi)
(xiv)a	(xiv)(i)
(xiv)b	(xiv)(xv)
(xiv)c	(xiv)(xxv)(viii)(i)
(xv)b	(xv)(i)
(xv)a	(xv)(xi)(viii)
(xvi)a	(xvi)(i)
(xvi)b	(xvi)(iv)
(xvi)i	(xvi)(v)
(xvi)g	(xvi)(vi)
(xvi)r	(xvi)(viii)
(xvi)d	(xvi)(i)(v)
(xvi)m	(xvi)(iv)(i)
(xvi)c	(xvi)(v)(i)
(xvi)j	(xvi)(v)(iv)
(xvi)q	(xvi)(viii)(i)
(xvi)h	(xvi)(viii)(vii)
(xvi)e	(xvi)(i)(v)(i)
(xvi)l	(xvi)(v)(i)(iv)
(xvi)k	(xvi)(v)(i)(v)
(xvi)f	(xvi)(viii)(i)(xi)
(xvi)s	(xvi)(xvi)(viii)(i)
(xvi)p	(xvi)(vii)(i)(vi)(iv)
(xvi)n	(xvi)(i)(iv)(i)(iv)(i)
(xvi)o	(xvi)(viii)(i)(v)(i)(v)(vi)
(xvii)	(xvii)
(xvii)a	(xvii)(i)
(xvii)b	(xvii)(vi)
(xvii)c	(xvii)(i)(xi)(vi)
(xviii)b	(xviii)(xix)(vii)

(xviii)c	(xviii)(vi)(xix)(viii)
(xviii)a	(xviii)(vii)(xviii)(i)
(xix)a	(xix)(xxix)
(xx)b	(xx)(i)
(xx)a	(xx)(v)
(xx)c	(xx)(v)(i)
(xx)d	(xx)(v)(viii)(i)
(xxi)a	(xxi)(viii)
(xxi)d	(xxi)(viii)(xxx)(i)
(xxi)b	(xxi)(viii)(xxx)(vi)
(xxi)c	(xxi)(viii)(xxx)(i)(vi)
(xxiv)a	(xxiv)(xxvi)(viii)(i)
(xxv)a	(xxv)(i)
(xxvii)a	(xxvii)(xvii)
(xxvii)b	(xxvii)(xxii)(xxx)
(xxviii)b	(xxviii)(i)(vi)
(xxviii)a	(xxviii)(xxv)(i)
(xxviii)d	(xxviii)(i)(xxv)(vii)
(xxix)a	(xxix)(xxx)
(xxix)b	(xxix)(xxx)(i)
(xxx)a	(xxx)(i)

Table Showing All Action Set Group Types Identified in the Second Pilot Study With Their Individual Codes

Appendix 2
Task Stage Coded Sequences

RTM 1 – Chopper and Retouched Flake

RTM 1(b) – flake removals from chopper core

{(i)a(i.00.003 – 00.07) (v.00.08)} {(ii)b(ii.00.09 – 00.11) (v.00.12)} {(ii)b(ii.00.13 – 00.14) (v.00.15)} {(ii)h(ii.00.16 – 00.17) (iii.00.18 – 00.20) (i.00.21) (v.00.22 – 00.23) (i.00.24 – 00.32)} {(ii)g(ii.00.33 – 00.35) (v.00.36 – 00.37) (i.00.38 –

00.39) (v.00.40 – 00.43)} {(ii)a(ii.00.44 – 00.46) (i.00.47 – 00.50)} {(ii)d(ii.00.51 – 00.52) (v.00.53 – 00.54) (i.00.55)} {(ii)d(ii.00.56 – 00.57) (v.00.58) (i.0.59 - 01.00)} {(ii)e(ii.01.01) (i.01.02 – 01.06) (v.01.07) (i.01.08 – 01.09)} {(ii)d(ii.01.10 – 01.12) (v.01.13 – 01.14) (i.01.15 – 01.24)} {(ii)d(ii.01.25 – 01.27) (v.01.28) (i.01.29 – 01.30)} {(ii)a(ii.01.31) (i.01.32 - 01.34)} {(ii)d(ii.01.35) (v.01.36) (i.01.37 – 01.38)} {(ii)b(ii.01.39 – 01.41) (v.01.42)} {(ii)f(ii.01.43) (iii.01.44 – 01.45) (v.01.46) (i.01.47 – 01.49)} {(ii)h(ii.01.50 01.51) (iii.01.52 – 01.56) (i.01.57 – 02.00) (v.02.01) (i.02.02 – 02.03)} {(ii)c(ii.02.04 – 02.05) (iii.02.06 – 02.07) (i.02.08 – 02.11)} {(ii)l(ii.02.12 – 02.14) (v.02.15) (i.02.16 – 02.17) (v.02.18 – 02.19) (iv.02.20) (i.02.21 – 02.23)} {(ii)i(ii.02.24) (v.02.25) (i.02.26 – 02.29) (v.02.30) (i.02.31)} {(ii)k(ii.02.32 – 02.34) (v.02.35) (i.02.36) (iv.02.37) (v.02.38) (i.02.39 – 02.40)} {(ii)d(ii.02.41) (v.02.42) (i.02.43)} {(ii)a(ii.02.44 – 02.45) (i.02.46)} {(ii)a(ii.02.47 – 02.51) (i.2.52)} {(ii)j(ii.02.53) (v.02.54 – 02.55) (i.02.56 – 02.58) (iv. 02.59) (i.03.00 – 03.02)} {(ii)d(ii.03.03) (v.03.04 – 03.05) (i.03.06 – 03.17)}

RTM 1(c) – retouch one flake

{(vii)a(vii.03.18 – 03.19) (i.03.20 – 03.21) (vi.03.22 – 03.25small hs changed) (i.03.26)} {(ii)a(ii.03.27) (i.03.28)} {(ii)a(ii.03.29) (i.03.30)} {(ii)a(ii.03.31) (i.half)} {(ii)a(ii.half) (i.03.33 – 03.34)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.03.36 – 03.37) (i.03.38)} {(ii)a(ii.03.39) (i.03.40)} {(ii)a(ii.03.41 – 03.43) (i.03.44)} {(ii)a(ii.03.45) (i.03.46)} {(ii)a(ii.03.47) (i.03.48)} {(ii)a(ii.03.49) (i.03.50)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.03.52) (i.03.53 – 3.55)} {(ii)a(ii.03.56) (i.03.57)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.03.59) (i.04.00)} {(ii)a(ii.04.01 – 04.02) (i.04.03)} {(ii)a(ii.04.04) (i.04.05)} {(ii)a(ii.04.06 – 04.08) (i.04.09)} {(ii)a(ii.04.10 – 04.12) (i.04.13)} {(ii)a(ii.04.14) (i.04.15)} {(ii)a(ii.04.16 – 04.17) (i.04.18)} {(ii)a(ii.04.19) (i.04.20)} {(ii)a(ii.04.21 – 04.23) (i.04.24 – 04.25)} {(ii)a(ii.04.26) (i.04.27 – 04.28)} {(ii)a(ii.04.29 – 04.30) (i.04.31)} {(ii)a(ii.04.32 – 04.33) (i.04.34 – 04.39)}

RTM 2 – Flake-Based Handaxe

RTM 2(b) – open boulder

{(i)b(i.01.06 – 01.40) (vi.01.41 – 01.43large hs) (i.01.44 – 01.48)} {(ii)m(ii.01.49 – 01.52) (v.01.53) (viii.01.54 – 01.55large hs) (i.01.56 – 02.07) (vi.02.08 – 02.09large hs) (i.02.10 – 02.14)} {(ii)o(ii.02.15 – 02.24) (v.02.25) (i.02.26 – 02.27) (viii.02.28 – 02.29large hs) (i.02.30 – 02.33) (vi.02.34large hs) (i.02.35 – 02.36)} {(ii)n(ii.02.37 – 02.41) (viii.02.42large hs) (v.02.43 – 02.44) (i.02.45 – 03.06) (vi.03.07 – 03.08large hs) (i.03.09 - 03.10)} {(ii)a(ii.03.11 – 03.19) (i.03.20 – 03.36)} {(ii)d(ii.03.37 – 03.40) (v.03.41) (i.03.42 – 03.49)} {(ii)b(ii.03.50 – 03.51) (v.03.52)} {(ii)a(ii.03.53 – 03.55) (i.03.56 – 03.57)} {(ii)d(ii.03.58 – 03.59) (v.04.00) (i.04.01)} {(ii)a(ii.04.02) (i.04.03 – 04.07)} {(ii)(ii.04.08)}

RTM 2(c) – remove flakes from core

{(viii)a(viii.04.09 – 04.14) (v.04.15) (iii.04.16 – 04.17) (i.04.18 – 04.23) (vi.04.24 – 04.25large hs) (i.04.26)} {(ii)b(ii.04.27 – 04.29) (v.04.30)} {(ii)r(ii.04.31) (viii.04.32 – 04.34large hs) (iii.04.35 – 04.39) (v.04.40) (i.04.41 – 04.54) (vi.04.55 – 04.56medium hs) (i.04.57 – 04.59)} {(ii)d(ii.05.00 – 05.01) (v.05.02) (i.05.03 – 05.14)} {(ii)s(ii.05.15 – 05.16) (viii.05.17 – 05.18medium hs) (v.05.19) (iii.05.20 – 05.23) (i.05.24 – 05.26) (vi.05.27 – 05.28medium hs) (i.05.29 – 05.36)} {(ii)q(ii.05.37 – 05.39) (iii.05.40 – 05.43) (v.05.44) (i.05.45 – 05.46) (v.05.47)} {(ii)j(ii.05.48) (v.05.49) (i.05.50 – 05.53) (v.05.54) (i.05.55 – 06.12)} {(ii)p(ii.06.13 – 06.16) (iii.06.17 – 06.21) (i.06.22 – 06.23) (v.06.24)} {(ii)c(ii.06.25 – 06.26) (iii.06.27 – 06.30) (i.06.31 – 06.50)} {(ii)h(ii.06.51 – 06.55) (iii.06.56 – 07.01) (i.07.02 – 07.10) (v.07.11) (i.07.12 – 07.15)} {(ii)c(ii.07.16) (iii.07.17 – 07.22) (i.07.23 – 07.32)} {(ii)g(ii.07.33 – 07.37) (v.07.38) (i.07.39 – 07.42) (v.07.43)} {(ii)d(ii.07.44 – 07.45) (v.07.46 – 07.47) (i.07.48 – 07.55)} {(ii)b(ii.07.56) (v.07.57)} {(ii)j(ii.half) (v.half) (i.07.59 – 08.06) (v.08.07) (i.08.08 – 08.12)}

RTM 2(d) – handaxe blank

{(vii)a(vii.08.13 – 08.25change flake) (vi.08.26small hs) (i.08.27 – 08.33)} {(ii)u(ii.08.34) (i.08.35 – 08.38) (v.08.39)} {(ii)i(ii.08.40) (v.08.41) (i.08.42 – 08.43) (iv.08.44) (i.08.45)} {(ii)d(ii.08.46) (v.08.47) (i.08.48)} {(ii)k(ii.08.49) (v.08.50) (i.08.51 – 08.52) (iv.08.53) (v.08.54) (i.08.55)} {(ii)d(ii.08.56) (v.08.57) (i.08.58)} {(ii)b(ii.half) (v.half)} {(ii)b(ii.09.00) (v.09.01)} {(ii)d(ii.half) (v.half) (i.09.03)} {(ii)i(ii.09.04) (v.09.05) (i.half) (iv.half) (i.09.07)} {(ii)b(ii.09.08) (v.09.09)} {(ii)v(ii.09.10) (v.09.11) (i.09.12 – 09.13) (iv.09.14)} {(ii)i(ii.half) (v.half) (i.09.16) (iv.09.17) (i.09.18)} {(ii)b(ii.09.19) (v.09.20)} {(ii)v(ii.half) (v.half) (i.09.22 – 09.23) (iv.09.24)} {(ii)v(ii.half) (v.half) (i.09.26) (iv.09.27)} {(ii)d(ii.09.28) (v.09.29) (i.09.30 – 09.31)} {(ii)v(ii.09.32) (v.09.33) (i.09.34 – 09.36) (iv.09.37)} {(ii)v(ii.09.38) (v.09.39) (i.09.40 – 09.42) (iv.09.43)} {(ii)d(ii.09.44) (v.09.45) (i.09.46)} {(ii)k(ii.half) (v.half) (i.09.48) (iv.half) (v.half) (i.09.50 – 09.52)} {(ii)d(ii.09.53 – 09.56) (v.09.57) (i.09.58 – 10.01)} {(ii)a(ii.10.02) (i.10.03 – 10.06)} {(ii)i(ii.10.07) (v.10.08) (i.10.09 – 10.11) (iv.10.12) (i.10.13)} {(ii)a(ii.10.14 – 10.15) (i.10.16)} {(ii)a(ii.10.17 – 10.19) (i.10.20 – 10.21)} {(ii)w(ii.10.22 – 10.24) (i.10.25) (v.half) (iv.half) (i.10.27)} {(ii)a(ii.10.28 – 10.29) (i.10.30)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.10.32) (i.half)} {(ii)x(ii.half) (i.10.34) (iv.10.35)} {(ii)a(ii.10.36 – 10.37) (i.10.38)} {(ii)d(ii.10.39 – 10.40) (v.10.41) (i.10.42)} {(ii)a(ii.10.43) (i.10.44 – 10.47)} {(ii)t(ii.10.48 – 10.51) (iv.10.52)} {(ii)b(ii.half) (v.half)} {(ii)a(ii.10.54 – 10.55) (i.10.56)} {(ii)a(ii.10.57) (i.10.58)} {(ii)a(ii.10.59) (i.11.00)} {(ii)t(ii.11.01) (iv.11.02)} {(ii)a(ii.11.03 – 11.04) (i.11.05)} {(ii)y(ii.11.06 – 11.09) (iv.11.10) (i.11.11 – 11.12)} {(ii)y(ii.11.13 – 11.24) (iv.11.25) (i.11.26)} {(iia)(ii.11.27 – 11.33) (i.11.34 – 11.35)} {(ii)a(ii.11.36 – 11.48) (i.11.49 – 11.50)} {(ii)b(ii.11.51) (v.11.52)} {(ii)t(ii.11.53 – 11.54) (iv.11.55)} {(ii)a(ii.11.56 – 12.10) (i.12.11)} {(ii)t(ii.12.12 – 12.13) (iv.12.14)} {(ii)a(ii.12.15 – 12.16) (i.12.17)} {(ii)a(ii.12.18) (i.12.19)} {(ii)a(ii.12.20 – 12.22) (i.12.23)} {(ii)a(ii.12.24 – 12.26) (i.12.27 – 12.29)}

RTM 3 – Prepared core and prepared and retouched flake

RTM 3(b) – prepare core

{(i)(i.00.51 - 00.56)} {(ii)z(ii.00.57) (v.00.58 – 01.00) (i.01.01 – 01.05) (iv.01.06) (i.01.07) (iv.01.08) (i.01.09)} {(ii)A(ii.01.10 – 01.14) (v.01.15 – 01.18) (i.01.19 – 01.26) (iv.01.27) (i.01.28 – 01.29) (v.01.30)} {(ii)B(ii.01.31 – 01.33) (v.01.34 – 01.36) (i.01.37 – 01.38) (v.01.39) (i.01.40 – 01.41) (iv.01.42) (i.01.43 – 01.44)} {(ii)B(ii.01.45 – 01.46) (v.01.47 – 01.49) (i.1.50 – 01.51) (v.01.52) (i.01.53 – 01.56) (iv.01.57) (i.01.58 – 02.00)} {(ii)d(ii.02.01 – 02.02) (v.02.03) (i.02.04)} {(ii)d(ii.02.05 – 02.08) (v.02.09 – 02.13) (i.02.14 – 02.21)} {(ii)d(ii.02.22 – 02.27) (v.02.28) (i.02.29 – 02.32)} {(ii)d(ii.02.33) (v.02.34 – 02.38) (i.02.39 – 02.53)} {(ii)a(ii.02.54 – 03.01) (i.03.02 – 03.03)} {(ii)a(ii.03.04) (i.03.05)} {(ii)a(ii.03.06– 03.09) (i.03.10 – 03.13)} {(ii)a(ii.03.14 – 03.15) (i.03.16)} {(ii)b(ii.03.17 – 03.18) (v.03.19 – 03.22)} {(ii)v(ii.03.23) (v.03.24) (i.03.25 – 03.26) (iv.03.27)} {(ii)d(ii.03.28) (v.03.29) (i.03.30 – 03.31)} {(ii)C(ii.03.32) (v.03.33) (i.03.34 – 03.37) (iv.03.38) (i.03.39 – 03.47) (iv.03.48) (i.03.49 – 03.57) (iv.03.58) (i.03.59)} {(ii)d(ii.04.00) (v.04.01) (i.04.02 – 04.37)}

RTM 3(c) – remove prepared flakes

{(i)b(i.04.38 – 04.40) (vi.4.41 – 04.43medium to small hs) (i.04.44)} {(ii)c(ii.04.45 – 04.48) (iii.04.49 – 04.59) (i.05.00 – 05.04)} {(ii)b(ii.05.05) (v.05.06)} {(ii)D(ii.05.07) (iii.05.08 – 05.10) (i.05.11 – 05.14) (v.05.15) (i.05.16 – 05.21) (v.05.22) (i.05.23 – 05.27)} {(ii)E(ii.05.28 – 05.33)/ (i.06.48 – 06.51) (v.06.52) (i.06.53 – 06.54) (v.06.55) (i.06.56)} {(ii)F(ii.06.57 – 06.59) (i.07.00 – 07.24) (iv.07.25) (i.07.26 – 07.27)} {(ii)G(ii.07.28) (iii.07.29 – 07.33) (v.07.34) (i.07.35) (v.07.36) (i.07.37 – 07.40)} {(ii)b(ii.07.41 – 07.42) (v.07.43)} {(ii)h(ii.07.44) (iii.07.45 – 07.50) (i.07.51 – 07.53) (v.07.54) (i.07.55 – 08.10)} {(ii)c(ii.08.11 – 08.12) (iii.08.13 – 08.18) (i.08.19 – 08.28)} {(ii)j(ii.08.29) (v.08.30) (i.08.31 – 08.46) (v.08.47) (i.08.48)} {(ii)B(ii.08.49 – 08.50) (v.08.51) (i.08.52 – 09.01) (v.09.02) (i.09.03 – 09.05) (iv.09.06) (i.09.07 – 09.16)} {(ii)d(ii.09.17 – 09.18) (v.09.19) (i.09.20 – 09.33)} {(ii)H(ii.09.34 – 09.36) (v.09.37) (i.09.38 – 09.41) (v.09.42) (i.09.43 – 09.44) (v.09.45) (i.09.46 – 09.47)} {(ii)I(ii.09.48) (iii.09.49 – 09.52)}

RTM 3(d) – retouch prepared flake into a point

{(i)b(i.10.53 – 10.54) (vi.10.55 – 10.57small hs) (i.10.58 – 11.06)} {(ii)a(ii.11.07) (i.11.08)} {(ii)a(ii.11.09) (i.11.10)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.11.13) (i.11.14} {(ii)a(ii.11.15) (i.11.16)} {(ii)a(ii.11.17 -11.18) (i.half)} {(ii)a(ii.half) (i.11.20)} {(ii)a(ii.11.21) (i.11.22)} {(ii)a(ii.11.23 – 11.27) (i.11.28)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.11.30) (i.11.31)} {(ii)a(ii.11.32) (i.11.33)} {(ii)a(ii.11.34) (i.11.35)} {(ii)a(ii.11.36) (i.11.37)} {(ii)a(ii.11.38) (i.11.39)} {(ii)a(ii.11.40 – 11.41) (i.11.42)} {(ii)a(ii.11.43 – 11.46) (i.11.47)} {(ii)a(ii.11.48) (i.11.49)} {(ii)a(ii.11.50 – 11.51) (i.11.52)} {(ii)a(ii.11.53 – 11.54) (i.11.55)} {(ii)a(ii.11.56) (i.11.57)} {(ii)a(ii.11.58) (i.11.59)} {(ii)a(ii.12.00) (i.12.01)} {(ii)a(ii.12.02) (i.12.03)} {(ii)a(ii.12.04 – 12.06) (i.12.07)} {(ii)a(ii.12.08) (i.12.09 – 12.10)} {(ii)a(ii.12.11 – 12.12) (i.12.13)} {(ii)a(ii.12.14 – 12.15) (i.12.16 – 12.17)} {(ii)a(ii.12.18) (i.12.19)} {(ii)a(ii.12.20 – 12.21) (i.12.22)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.12.25 – 12.27) (i.12.28)} {(ii)a(ii.12.29 –

12.31) (i.12.32} {(ii)a(ii.12.33 – 13.35) (i.12.36 – 12.37)} {(ii)a(ii.12.38 – 12.47) (i.12.48)} {(ii)a(ii.12.49) (i.12.50)} {(ii)a(ii.12.51) (i.12.52 – 12.53)} {(ii)a(ii.12.54) (i.12.55)} {(ii)a(ii.12.56 – 12.57) (i.12.58)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.13.00) (i.half)} {(ii)a(ii.half) (i.13.02)} {(ii)a(ii.13.03) (i.13.04)} {(ii)a(ii.13.05 – 13.07) (i.13.08 – 13.09)} {(ii)a(ii.13.10) (i.13.11)} {(ii)a(ii.13.12) (i.13.13)} {(ii)a(ii.13.14 – 13.15) (i.13.16)} {(ii)a(ii.13.17 – 13.19) (i.13.20)} {(ii)a(ii.13.21) (i.13.22)} {(ii)a(ii.13.23 – 13.25) (i.13.26 – 13.27)} {(ii)a(ii.13.28 – 13.29) (i.13.30)} {(ii)a(ii.13.31) (i.13.32)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.13.34 – 13.35) (i.13.36)} {(ii)a(ii.13.37) (i.13.38 – 13.39)} {(ii)a(ii.13.40 – 13.43) (i.13.44)} {(ii)a(ii.13.45 – 13.46) (i.13.47)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.13.49 – 13.50) (i.13.51 – 13.52)} {(ii)a(ii.13.53 – 13.54) (i.13.55)} {(ii)a(ii.13.56) (i.13.57 – 14.00)} {(ii)a(ii.14.01) (i.14.02)} {(ii)J(ii.14.03 – 14.04) (vi.14.05 – 14.09change small hs)} {(ii)a(ii.14.10) (i.14.11)} {(ii)a(ii.14.12 – 14.13) (i.14.14)} {(ii)a(ii.14.15 – 14.17) (i.14.18)} {(ii)a(ii.14.19 – 14.22) (i.14.23)} {(ii)a(ii.14.24 – 14.27) (i.14.28 – 14.31)} {(ii)a(ii.14.32) (i.14.33)} {(ii)a(ii.14.34) (i.14.35)} {(ii)a(ii.14.36 – 14.37) (i.14.38)} {(ii)a(ii.14.39 – 14.42) (i.14.43)} {(ii)a(ii.14.44 – 14.46) (i.14.47 – 14.50)}

JD 1(1) - Chopper

JD 1(1)a – remove flakes

{(vi)l(vi.00.00medium micro-granite hs) (vi.00.01leather muffler) (vii.00.02large quartzite pebble) (i.00.03 – 00.59)} {(ii)d(ii.01.00 – 01.02) (v.01.03) (i.01.04 – 01.10)} {(ii)L(ii.01.11 – 01.15) (v.01.16) (iv.01.17 – 01.20) (i.01.21 – 01.26)} {(ii)d(ii.01.27 – 01.28) (v.01.29) (i.01.30 – 01.37)} {(ii)i(ii.01.38) (v.01.39) (i.01.40 – 01.47) (iv.01.48) (i.01.49 – 01.51)} {(ii)y(ii.01.52 – 01.55) (iv.01.56) (i.01.57 – 01.58)} {(ii)a(ii.01.59 – 02.01) (i.02.02)} {(viii)g(viii.02.03leather muffler) (i.02.04 – 02.10)}

JD 1(2) - Chopper

JD 1(2)a – remove flakes

{(vi)l(vi.00.00medium micro-granite hs) (vi.00.01leather muffler) (vii.00.02quartzite pebble) (i.00.03 – 00.06)} {(vi)a(vi.00.07 – 00.15medium micro-granite hs for large micro-granite hs) (i.00.16 – 00.24)} {(ii)a(ii.00.25 – 00.35) (i.00.36 – 00.40)} {(ii)a(ii.00.41 – 00.50) (i.00.51 – 01.00)} {(ii)a(ii.01.01 – 01.13) (i.01.14 – 01.15)} {(ii)a(ii.01.16 – 01.21) (i.01.22 – 01.23)} {(ii)a(ii.01.24 – 01.25) (i.01.26)} {(ii)T(ii.01.27 – 01.28) (viii.01.29large micro-granite hs) (i.01.30 – 01.31) (vi.01.32large micro-granite hs)} {(ii)13(ii.01.33 – 01.34) (viii.01.35large micro-granite hs) (v.01.36 – 01.37) (i.01.38 – 01.57)} {(vi)a(vi.01.58medium micro-granite hs) (i.01.59)} {(ii)K(ii.02.00 – 02.03) (v.02.04) (iv.02.05)} {(ii)a(ii.02.06 – 02.09) (i.02.10 – 02.14)} {(ii)a(ii.02.15 – 02.18) (i.02.19)} {(ii)a(ii.02.20 – 02.21) (i.02.22 – 02.24)} {(ii)a(ii.02.25) (i.02.26 – 02.29)} {(ii)a(ii.02.30) (i.02.31 – 02.37)} {(ii)a(ii.02.38) (i.02.39 – 02.48)} {(ii)d(ii.02.49 – 02.51) (v.02.52) (i.02.53 – 03.00)}

JD 1(3) – Chopper and Retouched Flake

JD 1(3)a – remove flakes

{(vi)r(vi.03.23leather muffler) (vii.03.24 – 03.32quartzite pebble) (vi.03.33 – 03.36medium micro-granite hs)} {(ii)a(ii.03.37 – 03.38) // (i.04.21)} {(ii)a(ii.04.22 – 04.25) (i.04.26 – 04.30)} {(ii)a(ii.04.31) (i.04.32 – 04.36)} {(ii)a(ii.04.37 – 04.41) (i.04.42)} {(ii)a(ii.04.43) (i.04.44 – 04.50)} {(ii)F(ii.04.51 – 04.52) (i.04.53 – 04.54) (iv.04.55 – 04.56) (i.04.57)} {(ii)a(ii.04.58) (i.04.59 – 05.02)} {(ii)a(ii.05.03) (i.05.04 – 05.06)} {(ii)7(ii.05.07 – 05.09) (i.05.10 – 05.11) (viii.05.12leather muffler)} {(ii)a(ii.05.13 – 05.14) (i.05.15 – 05.21)} {(xi)c(xi.05.22Oldowan quartzite chopper) (viii.05.23 – 05.24medium micro-granite hs)}

JD 1(3)b - retouch

{(vii)h(vii.05.27 – 05.34quartzite flake) (vi.05.35 – 05.40small micro-granite hs)} {(ii)a(ii.05.41 – 05.44) (i.05.45)} {(ii)a(ii.05.46 – 05.47) (i.05.48)} {(ii)a(ii.05.49 – 05.50) (i.05.51)} {(ii)a(ii.05.52) (i.05.53)} {(ii)a(ii.05.54) (i.05.55)} {(ii)a(ii.05.56 – 05.57) (i.05.58)} {(ii)a(ii.05.59 – 06.04) (i.06.05)} {(ii)a(ii.06.06 – 06.09) (i.06.10)} {(ii)a(ii.06.11 – 06.12) (i.06.13)} {(ii)a(ii.06.14) (i.06.15)} {(ii)a(ii.06.16 – 06.17) (i.06.18)} {(ii)a(ii.06.19 – 06.20) (i.06.21 – 06.22)} {(ii)a(ii.06.23 – 06.25) (i.06.26)} {(ii)a(ii.06.27) (i.half)} {(ii)a(ii.half) (i.06.29 – 06.31)} {(ii)a(ii.06.32) (i.06.33)} {(ii)a(ii.06.34) (i.06.35)} {(ii)a(ii.06.36) (i.06.37 – 06.40)} {(xi)c(xi.06.41retouched flake) (viii.06.42small micro-granite hs)}

JD 2 – Flake-Based Handaxe

JD 2a – remove flakes from core

{(vi)s(vi.00.00 – 00.01leather muffler) (vii.00.02 – 00.03flint boulder) (i.00.04 – 00.19) (vi.00.20 – 00.54large quartzite pebble) (i.00.55 – 01.02)} {(ii)a(ii.01.03 – 01.10) (i.01.11)} {(ii)14(ii.01.12 – 01.13) (viii.01.14large quartzite pebble) (iii.01.15 – 01.23)} {(i)h(i.01.24 – 01.32) (xi.01.33 – 01.34flint boulder)}

JD 2b – create blank

{(vii)l(vii.01.35 – 01.36flake) (i.01.37 – 01.41) (vi.01.42 – 01.43medium micro-granite hs)} {(ii)x(ii.01.44) (i.01.45) (iv.01.46 – 01.48)} {(ii)t(ii.01.49 – 01.54) (iv.01.55 – 01.56)} {(ii)t(ii.01.57) (iv.01.58 – 01.59)} {(viii)k(viii.02.00leather muffler) (vi.02.01 – 02.03medium micro-granite hs for sandstone abrader)} {(ii)a(ii.02.04 – 02.09) (i.02.10)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.02.12) (i.02.13)} {(ii)a(ii.02.14 – 02.18) (i.02.19 – 02.21)} {(ii)a(ii.02.22 – 02.23) (i.02.24 – 02.26)} {(ii)b(ii.02.27 – 02.28) (v.02.29)} {(ii)u(ii.02.30 – 02.31) (i.02.32) (v.02.33)} {(ii)a(ii.02.34 – 02.35) (i.02.36 – 02.38)} {(ii)a(ii.02.39 – 02.40) (i.02.41)} {(ii)15(ii.02.42) (iv.02.43 – 02.44) (vi.02.45 – 02.47leather muffler) (vi.02.48sandstone abrader for medium micro-granite hs)} {(ii)16(ii.02.49 – 02.52) (i.02.53) (iv.02.54) (vi.02.55 – 02.56medium micro-granite hs for sandstone abrader)} {(ii)S(ii.02.57 – 03.01) (iv.03.02 – 03.03) (vi.03.04 – 03.05sandstone abrader for medium micro-granite hs)} {(ii)t(ii.03.06) (iv.03.07

– 03.08)} {(ii)17(ii.03.09 – 03.14) (i.03.15) (v.03.16) (vi.03.17 – 03.18medium micro-granite hs for sandstone abrader)} {(ii)16(ii.03.19 – 03.20) (i.03.21 – 03.28) (iv.03.29 – 03.30) (vi.03.31 – 03.33sandstone abrader for medium micro-granite hs)} {(ii)x(ii.03.34 – 03.35) (i.03.36 – 03.45) (iv.03.46)} {(ii)t(ii.03.47) (iv.03.48)} {(ii)S(ii.03.49) (iv.03.50) (vi.03.51medium micro-granite hs for sandstone abrader)} {(ii)a(ii.03.52 – 03.53) (i.03.54)} {(ii)S(ii.03.55 – 04.01) (iv.04.02 – 04.03) (vi.04.04 – 04.05sandstone abrader for medium micro-granite hs)} {(ii)a(ii.04.06) (i.04.07 – 04.10)} {(ii)18(ii.04.11 – 04.12) (i.04.13 – 04.14) (v.04.15) (iv.04.16)} {(ii)a(ii.04.17 – 04.18) (i.04.19)} {(ii)t(ii.half) (iv.half)} {(ii)x(ii.04.21) (i.04.22 – 04.28) (iv.04.29 – 04.30)} {(ii)t(ii.04.31) (iv.04.32 – 04.33) {(ii)a(ii.04.34) (i.04.35)} {(ii)19(ii.04.36 – 04.39) (i.04.40 – 04.42) (iv.04.43 – 04.44) (viii.04.45leather muffler) (vi.04.46 – 04.47medium micro-granite hs for sandstone abrader)} {(ii)S(ii.04.48 – 04.51) (iv.04.52) (vi.04.53sandstone abrader for medium micro-granite hs)} {(ii)a(ii.04.54 – 04.56) (i.04.57 – 04.59)} {(ii)a(ii.05.00) (i.05.01)} {(ii)J(ii.05.02 – 05.03) (vi.05.04 – 05.07medium micro-granite hs for sandstone abrader)} {(ii)a(ii.05.08 – 05.10) (i.05.11)} {(ii)J(ii.05.12 – 05.17) (vi.05.18 – 05.19leather muffler)} {(ii)t(ii.05.20 – 05.22) (iv.05.23 – 05.24)}

JD 2c – thin and shape

{(vi)(vi.05.25 – 05.27sandstone abrader for antler h)} {(ii)a(ii.05.28 – 05.29) (i.05.30 – 05.32)} {(ii)d(ii.05.33 – 05.35) (v.05.36 – 05.37) (i.05.38 – 05.46)} {(ii)a(ii.05.47 – 05.48) (i.05.49)} {(ii)16(ii.05.50) (i.05.51 – 05.52) (iv.05.53 – 05.54) (vi.05.55antler h for sandstone abrader)} {(ii)16(ii.05.56 – 06.02) (i.06.03) (iv.06.04) (vi.06.05sandstone abrader for antler h)} {(ii)a(ii.06.06) (i.06.07 – 06.08)} {(ii)20(ii.06.09 – 06.10) (v.06.11) (i.06.12) (iv.06.13) (vi.06.14antler h for sandstone abrader)} {(ii)16(ii.06.15 – 06.21) (i.06.22) (iv.06.23) (vi.06.24 – 06.26sandstone abrader for antler h)} {(ii)Y(ii.06.27) (iv.06.28) (vi.06.29antler h for sandstone abrader) (i.06.30 – 06.31)} {(ii)a(ii.06.32 – 06.33) (i.06.34 – 06.37)} {(ii)a(ii.06.38 – 06.40) (i.06.41)} {(ii)a(ii.06.42 – 06.44) (i.06.45)} {(ii)S(ii.06.46 – 06.47) (iv.06.48) (vi.06.49 – 06.51sandstone abrader for antler h)} {(ii)21(ii.06.52 – 06.57) (v.06.58) (i.06.59) (iv.07.00) (vi.07.01 – 07.03antler h for sandstone abrader) (i.07.04 – 07.05)} {(ii)a(ii.07.06) (i.07.07)} {(ii)16(ii.07.08 – 07.10) (i.07.11) (iv.07.12 – 07.13) (vi.07.14 – 07.15sandstone abrader for antler h)} {(ii)16(ii.07.16 – 07.17) (i.07.18 – 07.20) (iv.07.21 – 07.22) (vi.07.23 – 07.25antler h for sandstone abrader)} {(ii)y(ii.07.26 – 07.28) (iv.07.29 – 07.30) (i.07.31)} {(ii)a(ii.07.32 – 07.34) (i.07.35)} {(ii)a(ii.07.36 – 07.39) (i.07.40)} {(ii)S(ii.07.41 – 07.42) (iv.07.43 – 07.44) (vi.07.45 – 07.46sandstone abrader for antler h)} {(ii)u(ii.07.47) (i.07.48 – 07.49) (v.07.50)} {(ii)a(ii.07.51 – 07.53) (i.07.54 – 07.55)} {(ii)22(ii.07.56) (i.07.57) (iv.07.58 – 07.59) (vi.08.00 – 08.02antler h for sandstone abrader) (viii.08.03leather muffler) (i.08.04 – 08.05)} {(ii)a(ii.08.06 – 08.10) (i.08.11)} {(ii)15(ii.08.12) (iv.08.13) (vi.08.14leather muffler) (vi.08.15 – 08.16sandstone abrader for antler h)} {(ii)23(ii.08.17 – 08.18) (v.08.19 – 08.21) (i.08.22 – 08.25) (viii.08.26leather muffler) (iv.08.27) (vi.08.28antler h for sandstone abrader)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.08.30 – 08.31) (i.08.32)} {(ii)a(ii.08.33 – 08.36) (i.08.37 – 08.39)} {(ii)a(ii.08.40 – 08.41) (i.08.42)} {(ii)24(ii.08.43 – 08.45) (i.08.46 – 08.47) (vi.08.48 – 08.49leather muffler) (vi.08.50 – 08.51sandstone abrader for antler h)} {(ii)a(ii.08.52) (i.08.53)} {(ii)b(ii.08.54 – 08.55) (v.08.56)} {(ii)Y(ii.08.57 – 08.59) (iv.09.00) (vi.09.01 – 09.02antler h for sandstone abrader) (i.09.03 – 09.10)} {(ii)a(ii.09.11 – 09.15) (i.09.16)} {(ii)y(ii.09.17 – 09.20) (iv.09.21) (i.09.22)} {(ii)J(ii.09.23) (vi.09.24 – 09.25sandstone abrader for antler h)} {(ii)25(ii.09.26) (i.09.27) (v.09.28) (viii.09.29leather muffler) (iv.09.30) (vi.09.31antler h for sandstone abrader)} {(ii)S(ii.09.32 – 09.35) (iv.09.36) (vi.09.37sandstone abrader for antler h)} {(ii)a(ii.09.38 – 09.39) (i.09.40)} {(ii)a(ii.09.41) (i.09.42 – 09.44)} {(ii)a(ii.half) (i.half)} {(ii)S(ii.09.46) (iv.09.47) (vi.09.48 – 09.50antler h for sandstone abrader)} {(ii)a(ii.09.51 – 09.53) (i.09.54)} {(ii)a(ii.09.55 – 10.00) (i.10.01)} {(ii)S(ii.10.02 – 10.03) (iv.10.04) (vi.10.05 – 10.06sandstone abrader for antler h)} {(ii)a(ii.10.07 – 10.09) (i.10.10)} {(ii)u(ii.half) (i.half) (v.10.12)} {(ii)W(ii.10.13 – 10.18) (i.10.19 – 10.21) (vi.10.22 – 10.23antler h for sandstone abrader)} {(ii)S(ii.10.24 – 10.27) (iv.10.28) (vi.10.29sandstone abrader for antler h)} {(ii)26(ii.10.30 – 10.31) (v.10.32) (i.10.33 – 10.34) (vi.10.35 – 10.36antler h for sandstone abrader)} {(ii)S(ii.10.37 – 10.38) (iv.10.39) (vi.10.40 – 10.41sandstone abrader for antler h)} {(ii)27(ii.10.42) (i.10.43 – 10.44) (vi.10.45 – 10.46antler h for sandstone abrader) (i.10.47)} {(ii)t(ii.10.48) (iv.10.49)} {(ii)S(ii.10.50 – 10.52) (iv.10.53) (vi.10.54 – 10.55sandstone abrader for antler h)} {(ii)a(ii.10.56) (i.10.57)} {(ii)S(ii.10.58 – 11.00) (iv.11.01) (vi.11.02antler h for sandstone abrader)} {(ii)t(ii.11.03 – 11.05) (iv.11.06)} {(ii)S(ii.11.07 – 11.09) (iv.11.10) (vi.11.11sandstone abrader for antler h)} {(ii)28(ii.11.12 – 11.15) (vi.11.16 – 11.17antler h for sandstone abrader) (iv.11.18)} {(ii)a(ii.11.19) (i.11.20)} {(ii)S(ii.11.21 – 11.22) (iv.11.23) (vi.11.24 – 11.25sandstone abrader for antler h)} {(ii)b(ii.11.26) (v.11.27)} {(ii)b(ii.11.28) (v.11.29)} {(ii)29(ii.11.30) (i.half) (iv.half) (vi.11.32 – 11.33antler h for abrader) (iv.11.34) (i.11.35)} {(ii)S(ii.11.36) (iv.11.37) (vi.11.38 – 11.39sandstone abrader for antler h)} {(ii)a(ii.11.40) (i.11.41)} {(ii)a(ii.11.42 – 11.43) (i.11.44)} {(ii)a(ii.half) (i.half)} {(ii)Y(ii.11.46) (iv.11.47) (vi.11.48 – 11.51antler h for sandstone abrader) (i.11.52 – 11.53)} {(ii)S(ii.11.54 – 11.57) (iv.11.58) (vi.11.59 – 12.01sandstone abrader for antler h)} {(ii)b(ii.12.02) (v.12.03)} {(ii)30(ii.12.04) (i.12.05) (v.12.06) (iv.12.07) (vi.12.08 – 12.10antler h for sandstone abrader) (i.12.11 – 12.15) (iv.12.16)} {(ii)a(ii.12.17 – 12.19) (i.12.20)} {(ii)t(ii.12.21 – 12.24) (iv.12.25 – 12.26)} {(ii)a(ii.12.27 – 12.30) (i.12.31)} {(ii)a(ii.12.32 – 12.33) (i.12.34 – 12.35)} {(ii)a(ii.12.36 – 12.39) (i.12.40)} {(ii)28(ii.12.41 – 12.45) (vi.12.46sandstone abrader for antler h) (iv.12.47)} {(ii)a(ii.12.48) (i.12.49)} {(ii)a(ii.12.50 – 12.52) (i.12.53)} {(ii)a(ii.12.54 – 12.57) (i.12.58)} {(ii)31(ii.half) (v.half) (iv.13.00) (vi.13.01antler h to sandstone abrader) (i.13.02 – 13.03)} {(ii)15(ii.13.04 – 13.06) (iv.13.07) (vi.13.08 – 13.09leather muffler) (vi.13.10 – 13.12sandstone abrader for antler h)} {(ii)u(ii.13.13 – 13.17) (i.13.18) (v.13.19)} /{(ii)32(ii.13.20) (i.13.21) (iv.13.22) (viii.13.23leather muffler) (vi.13.24antler h for sandstone abrader) (i.13.25 – 13.29)} {(ii)S(ii.13.30 – 13.32) (iv.13.33) (vi.13.34 – 13.35sandstone abrader for antler h)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.13.37) (i.13.38)} {(ii)a(ii.half) (i.half)} {(ii)S(ii.13.40 – 13.42) (iv.13.43) (vi.13.44 – 13.45antler h for sandstone abrader)} {(ii)28(ii.13.46 – 13.48) (vi.13.49sandstone abrader for antler h) (iv.13.50)} {(ii)S(ii.13.51) (iv.13.52) (vi.13.53 – 13.54antler h for sandstone abrader)} {(ii)a(ii.13.55 – 14.02) (i.14.03)} {(ii)S(ii.14.04) (iv.14.05) (vi.14.06 – 14.07sandstone abrader for antler h)} {(ii)32(ii.14.08) (iv.14.09 – 14.10) (vi.14.11 – 14.12antler h for sandstone abrader) (i.14.13-14.14) (iv.14.15)} {(ii)S(ii.14.16 – 14.20) (iv.14.21) (vi.14.22 - 14.23sandstone abrader for antler h)} {(ii)a(ii.14.24 – 14.26) (i.14.27)} {(ii)a(ii.14.28) (i.14.29)} {(ii)27(ii.14.30) (i.14.31) (vi.14.32 – 14.33antler h for sandstone abrader) (i.14.34 – 14.37)} {(ii)S(ii.14.38 – 14.46) (iv.14.47) (vi.14.48sandstone abrader for antler h)} {(ii)33(ii.14.49) (i.14.50 – 14.51) (iv.14.52) (vi.14.53 – 14.55antler h for sandstone abrader) (i.14.56 – 14.59) (iv.15.00)} {(ii)a(ii.15.01 – 15.04) (i.15.05 – 15.06)} {(ii)t(ii.15.07 – 15.09) (iv.15.10)} {(ii)S(ii.15.11 – 15.19) (iv.15.20) (vi.15.21 – 15.23sandstone abrader for antler h)} {(ii)e(ii.15.24 – 15.26) (i.half) (v.half) (i.15.28)} {(ii)a(ii.15.29) (i.15.30)} {(ii)34(ii.15.31) (i.half) (v.half) (iv.15.33) (vi.15.34 – 15.36antler h for sandstone abrader)} {(ii)S(ii.15.37 – 15.44) (iv.15.45) (vi.15.46 – 15.47sandstone abrader for antler h)} {(ii)a(ii.15.48) (i.15.49)} {(ii)e(ii.15.50 – 15.51) (i.half) (v.half) (i.15.53)} {(ii)a(ii.15.54 – 15.55) (i.15.56)} {(ii)35(ii.15.57) (i.15.58 – 15.59) (iv.16.00) (vi.16.01 – 16.03antler h for sandstone abrader) (i.16.04)} {(ii)x(ii.16.05 – 16.08) (i.16.09 – 16.11) (iv.16.12)} {(ii)t(ii.16.13 – 16.16) (iv.16.17)} {(ii)J(ii.16.18) (vi.16.19 – 16.20sandstone abrader for antler h)} {(ii)W(ii.16.21) (i.16.22) (vi.16.23antler h for sandstone abrader)} {(ii)S(ii.16.24 – 16.26) (iv.16.27) (vi.16.28sandstone abrader for antler h)} {(ii)b(ii.16.29 – 16.37) (v.16.38)} {(ii)S(ii.16.39 – 16.41) (iv.16.42) (vi.16.43antler h for sandstone abrader)} {(ii)S(ii.16.44 – 16.48) (iv.16.49) (vi.16.50 – 16.51sandstone abrader for antler h) {(ii)36(ii.16.52) (i.16.53) (v.16.54) (vi.16.55 – 16.56antler h for sandstone abrader) (iv.16.57)} {(ii)a(ii.16.58 – 17.01) (i.17.02 – 17.03)} {(ii)S(ii.17.04 – 17.06) (iv.17.07) (vi.17.08 – 17.11sandstone abrader for antler h)} {(ii)x(ii.17.12 – 17.14) (i.17.15 – 17.18) (iv.17.19)} {(ii)a(ii.17.20 – 17.22) (i.17.23)} {(ii)a(ii.17.24) (i.17.25)} {(ii)a(ii.17.26 – 17.27) (i.17.28)} {(ii)a(ii.17.29 – 17.30) (i.17.31)} {(ii)W(ii.17.32) (i.17.33 – 17.34) (vi.17.35 – 17.36antler h for sandstone abrader)} {(ii)a(ii.17.37 – 17.40) (i.17.41)} {(ii)a(ii.17.42 – 17.50) (i.17.51 – 17.52)} {(ii)a(ii.17.53 – 17.55) (i.17.56)} {(ii)S(ii.17.57 – 18.01) (iv.18.02) (vi.18.03 – 18.04sandstone abrader for antler h)} {(ii)u(ii.18.05) (i.half) (v.half)} {(ii)e(ii.18.07) (i.half) (v.half) (i.18.09)} {(ii)t(ii.18.10 – 18.11) (iv.18.12)} {(ii)t(ii.18.13 – 18.15) (iv.18.16)} {(ii)a(ii.18.17) (i.18.18)} {(ii)32(ii.18.19) (iv.18.20) (vi.18.21 – 13.23antler h for sandstone abrader) (i.18.24 – 18.26) (iv.18.27)} {(ii)t(ii.18.28 – 18.30) (iv.18.31)} {(ii)t(ii.18.32 – 18.37) (iv.18.38)} {(ii)a(ii.18.39) (i.18.40)} {(ii)a(ii.half) (i.half)} {(ii)t(ii.18.42 – 18.44) (iv.18.45)} {(ii)a(ii.18.46 – 18.47) (i.18.48)} {(ii)x(ii.18.49 – 18.50) (i.18.51) (iv.18.52)} {(ii)t(ii.18.53 – 18.54) (iv.18.55)} {(ii)37(ii.18.56 – 18.59) (i.19.00) (iv.19.01) (vi.19.02 – 19.04sandstone abrader for antler h) (i.19.05 – 19.08) (vi.19.09antler h for sandstone abrader) (iv.19.10)} {(ii)U(ii.19.11 – 19.15) (vi.19.16sandstone abrader for antler h) (iv.19.17) (i.19.18 – 19.20)} {(ii)38(ii.19.21) (i.19.22 – 19.23) (viii.19.24antler h) (i.19.25 – 19.37) (v.19.38) (iv.19.39) (vi.19.40sandstone abrader)} {(ii)a(ii.19.41) (i.19.42)} {(ii)a(ii.19.43) (i.19.44 – 19.49)} {(ii)a(ii.19.50 – 19.51) (i.19.52)} {(ii)S(ii.19.53 – 19.54) (iv.19.55) (vi.19.56 – 19.57sandstone abrader for antler h)} {(ii)a(ii.19.58 – 19.59) (i.20.00 – 20.01)}

JD 3 – Prepared Core and Retouched Prepared Flake

JD 3a – prepare the core

{(i)c(i.00.00 – 00.01) (vi.00.02 – 00.04large micro-granite hs)} {(ii)w(ii.00.05 – 00.06) (i.00.07) (v.half) (iv.half) (i.00.09)} {(ii)d(ii.00.10) (v.half) (i.half)} {(ii)w(ii.00.12) (i.00.13) (v.00.14) (iv.00.15 – 00.16) (i.00.17)} {(ii)e(ii.00.18 – 00.20) (i.00.21) (v.00.22) (i.00.23 – 29)} {(ii)x(ii.00.30 – 00.31) (i.00.32 – 00.33) (iv.00.34)} {(ii)42(ii.00.35) (i.00.36) (v.00.37) (i.00.38) (iv.00.39)} {(ii)x(ii.00.40) (i.00.41) (iv.00.42 – 00.43)} {(ii)b(ii.00.44) (v.00.45)} {(ii)a(ii.00.46) (i.00.47)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.00.49) (i.00.50)} {(ii)a(ii.00.51) (i.00.52)} {(ii)18(ii.00.53) (i.half) (v.half) (iv.00.55)} {(ii)K(ii.half) (v.half) (iv.00.57)} {(ii)a(ii.00.58) (i.00.59)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.half) (i.half)} {(ii)42(ii.01.03 – 01.04) (i.half) (v.half) (i.01.06) (iv.01.07 – 01.08)} {(ii)e(ii.01.09) (i.half) (v.half) (i.01.11 – 01.15)} {(ii)w(ii.01.16) (i.01.17) (v.01.18) (iv.01.19) (i.01.20)} {(ii)v(ii.01.21 – 01.22) (v.01.23) (i.01.24 – 01.27) (iv.01.28)} {(ii)a(ii.01.29) (i.01.30)} {(ii)a(ii.half) (i.half)} {(ii)u(ii.01.32) (i.01.33) (v.01.34)} {(ii)b(ii.01.35) (v.01.36)} {(ii)K(ii.01.37) (v.01.38) (iv.01.39 - 01.40)} {(ii)a(ii.01.41) (i.01.42 – 01.43)} {(ii)d(ii.01.44) (v.01.45) (i.01.46)} {(ii)a(ii.01.47 – 01.50) (i.01.51)} {(ii)a(ii.01.52) (i.01.53)} {(ii)a(ii.01.54) (i.01.55)} {(ii)x(ii.01.56) (i.01.57 – 01.58) (iv.01.59)} {(ii)d(ii.02.00) (v.02.01) (i.02.02)} {(ii)a(ii.02.03 – 02.05) (i.02.06)} {(ii)a(ii.02.07 – 02.08) (i.02.09 – 02.11)} {(ii)a(ii.02.12) (i.02.13)} {(ii)x(ii.02.14) (i.half) (iv.half)} {(ii)x(ii.02.16 – 02.18) (i.02.19 – 02.21) (iv.02.22)} {(ii)a(ii.02.23 – 02.24) (i.02.25)} {(ii)a(ii.02.26) (i.02.27 – 02.28)} {(ii)43(ii.02.29 – 02.30) (i.02.31 -02.32) (v.02.33) (i.02.34 – 02.35) (viii.02.36leather muffler) (i.02.37)} {(ii)44(ii.02.38 – 02.39) (iv.02.40) (i.02.41 – 02.44) (vi.02.45 – 02.47large micro-granite hs for sandstone abrader)} {(ii)a(ii.02.48 – 02.49) (i.02.50)} {(ii)a(ii.02.51 – 02.52) (i.02.53)} {(ii)W(ii.02.54) (i.02.55) (vi.02.56 – 02.57sandstone abrader for large micro-granite hs)} {(ii)a(ii.02.58) (i.02.59)} {(ii)F(ii.03.00) (i.03.01) (iv.03.02) (i.03.03)} {(ii)d(ii.03.04) (v.03.05) (i.03.06)} {(ii)a(ii.03.07 – 03.09) (i.03.10} {(ii)x(ii.03.11) (i.half) (iv.half)} {(ii)x(ii.03.13) (i.03.14 – 03.16) (iv.03.17)} {(ii)x(ii.03.18) (i.03.19 – 03.25) (iv.03.26} {(ii)b(ii.03.27) (v.03.28)} {(ii)x(ii.03.29) (i.03.30 – 03.34) (iv.03.35)} {(ii)a(ii.03.36) (i.03.37)} {(ii)a(ii.03.38) (i.03.39 – 03.41)} {(ii)M(ii.03.42) (iv.03.43) (v.03.44)} {(ii)b(ii.03.45) (v.03.46)} {(ii)a(ii.03.47) (i.03.48)} {(ii)x(ii.03.49 – 03.50) (i.03.51) (iv.03.52)} {(ii)x(ii.03.53) (i.03.54) (iv.03.55)} {(ii)K(ii.03.56 – 03.57) (v.03.58 – 03.59) (iv.04.00 – 04.01)} {(ii)a(ii.04.02) (i.04.03)} {(ii)x(ii.04.04) (i.04.05) (iv.04.06)} {(ii)x(ii.04.07) (i.04.08) (iv.04.09)} {(ii)x(ii.04.10) (i.04.11 – 04.12) (iv.04.13)} {(ii)x(ii.04.14 – 04.15) (i.half) (iv.half)} {(ii)W(ii.04.17) (i.04.18) (vi.04.19 – 04.20large micro-granite hs for sandstone abrader)} {(ii)a(ii.04.21 – 04.22) (i.04.23)} {(ii)a(ii.04.24) (i.04.25)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.04.27) (i.04.28)} {(ii)a(ii.04.29 – 04.30) (i.04.31 – 04.32)} {(ii)a(ii.04.33 – 04.34) (i.04.35)} {(ii)a(ii.04.36 – 04.38) (i.04.39 – 04.40)} {(ii)a(ii.04.41 – 04.44) (i.04.45 – 04.47)} {(ii)a(ii.04.48) (i.04.49)} {(ii)a(ii.04.50 – 04.54) (i.04.55 – 04.56)} {(ii)x(ii.04.57 – 05.00) (i.05.01 – 05.03) (iv.05.04 – 05.05)} {(ii)d(ii.05.06 – 05.08) (v.05.09) (i.05.10)} {(ii)F(ii.05.11 – 05.12) (i.05.13 – 05.15) (iv.05.16) (i.05.17 – 05.18)} {(ii)a(ii.05.19 – 05.20) (i.05.21)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.05.23 – 05.25) (i.05.26)} {(ii)a(ii.05.27 – 05.28) (i.05.29)} {(ii)a(ii.05.30 – 05.32) (i.05.33)} {(ii)x(ii.05.34 – 05.36) (i.05.37 – 05.40) (iv.05.41)} {(ii)a(ii.05.42 – 05.43) (i.05.44)} {(ii)a(ii.05.45 – 05.49) (i.half)} {(ii)a(ii.half) (i.05.51 – 05.56)} {(ii)x(ii.05.57 – 06.00) (i.06.01 – 06.05) (iv.06.06)} {(ii)a(ii.06.07 – 06.08) (i.06.09)} {(ii)u(ii.06.10) (i.half) (v.half)} {(ii)a(ii.06.12 – 06.13) (i.06.14)} {(ii)t(ii.06.15 – 06.16) (iv.06.17)} {(ii)x(ii.06.18 – 06.20) (i.06.21) (iv.06.22)} {(ii)45(ii.06.23 – 06.28) (i.06.29) (iv.06.30) (vi.06.31 – 06.35leather muffler) (i.06.36 – 06.41)}

JD 3b – remove prepared flakes

{(vi)k(vi.06.42 – 06.47medium micro-granite hs) (i.06.48 – 06.53) (vi.06.54 – 06.55medium micro-granite hs for sandstone abrader)} {(ii)u(ii.06.56) (i.06.57) (v.06.58)} {(ii)a(ii.06.59 – 07.05) (i.07.06)} {(ii)a(ii.07.07) (i.07.08)} {(ii)a(ii.07.09) (i.07.10)} {(ii)a(ii.07.11 – 07.14) (i.07.15 – 07.16)} {(ii)a(ii.07.17) (i.07.18)} {(ii)46(ii.07.19 – 07.21) (i.07.22 – 07.26) (vi.07.27 – 07.35sandstone abrader for medium micro-granite hs) (i.07.36 – 07.40) (iv.07.41)} {(ii)y(ii.07.42 – 07.44) (iv.07.45) (i.07.46 – 07.48)} {(ii)12(ii.07.49 – 07.52) (viii.07.53leather muffler) (i.07.54 – 08.14) (xi.08.15 – 08.16tortoise core)}

JD 3c – retouch prepared flake into long blade

{(vi)(vi.08.17 – 08.22medium micro-granite hs for small micro-granite hs)} {(ii)J(ii.08.23 – 08.28) (vi.08.29small micro-granite hs for sandstone abrader)} {(ii)x(ii.08.30 – 08.31) (i.08.32 – 08.34) (iv.08.35)} {(ii)a(ii.08.36 – 08.38) (i.08.39)} {(ii)J(ii.08.40 – 08.41) (vi.08.42 – 08.43sandstone abrader for small micro-granite hs)} {(ii)a(ii.08.44) (i.08.45)} {(ii)a(ii.08.46) (i.08.47)} {(ii)a(ii.half) (i.half)} {(ii)16(ii.08.49 – 08.50) (i.08.51 – 08.53) (iv.08.54) (vi.08.55 – 08.56small micro-granite hs for sandstone abrader)} {(ii)a(ii.08.57 – 09.07) (i.09.08)} {(ii)J(ii.09.09 – 09.13) (vi.09.14sandstone abrader for small micro-granite hs)} {(ii)a(ii.09.15 – 09.18) (i.09.19)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.09.21) (i.09.22)} {(ii)a(ii.09.23) (i.09.24)} {(ii)x(ii.09.25) (i.09.26 – 09.29) (iv.09.30)} {(ii)a(ii.09.31 – 09.32) (i.09.33)} {(ii)a(ii.09.34 – 09.35) (i.09.36)} {(ii)a(ii.09.37) (i.09.38)} {(ii)a(ii.09.39 – 09.41) (i.09.42)} {(ii)a(ii.09.43) (i.09.44)} {(ii)x(ii.09.45) (i.half) (iv.half)} {(ii)x(ii.09.47 – 09.48) (i.09.49) (iv.09.50)} {(ii)W(ii.09.51 – 09.52) (i.09.53 – 09.54) (vi.09.55 – 09.56small micro-granite hs for sandstone abrader)} {(ii)28(ii.09.57 – 09.58) (vi.09.59sandstone abrader for small micro-granite hs) (iv.10.00)} {(ii)a(ii.10.01 – 10.02) (i.10.03)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.10.05 – 10.07) (i.10.08)} {(ii)16(ii.10.09) (i.10.10 – 10.11) (iv.10.12) (vi.10.13 – 10.14small micro-granite hs for sandstone abrader)} {(ii)J(ii.10.15 – 10.17) (vi.10.18 – 10.19sandstone abrader for small micro-granite hs)} {(ii)a(ii.10.20 – 10.21) (i.10.22)} {(ii)a(ii.10.23) (i.10.24)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.half) (i.half)} {(ii)16(ii.10.28) (i.10.29) (iv.10.30) (vi.10.31 – 10.32small micro-granite hs for sandstone abrader)} {(ii)S(ii.10.33 – 10.37) (iv.10.38) (vi.10.39 – 10.40sandstone abrader for small micro-granite hs)} {(ii)a(ii.10.41 – 10.42) (i.10.43)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.10.45) (i.10.46)} {(ii)a(ii.10.47) (i.10.48)} {(ii)a(ii.10.49 – 10.50) (i.10.51)} {(ii)a(ii.10.52 – 10.53) (i.10.54)} {(ii)a(ii.half) (i.half)} {(ii)y(ii.10.56) (iv.10.57) (i.10.58)} {(ii)x(ii.10.59 – 11.04) (i.11.05) (iv.11.06)} {(ii)a(ii.11.07 – 11.09) (i.11.10 – 11.22)}

KL 1(1) - Chopper

KL 1(1)b – remove flakes

{(i)(i.00.00 – 00.07)} {(ii)d(ii.00.08 – 00.11) (v.00.12) (i.00.13 – 00.17)} {(ii)b(ii.00.18) (v.00.19)} {(ii)b(ii.00.20 - 00.21) (v.00.22)} {(ii)b(ii.00.23 – 00.24) (v.00.25)} {(ii)b(ii.00.26 – 00.27) (v.00.28)} {(ii)b(ii.half) (v.half)} {(ii)d(ii.00.30) (v.00.31) (i.00.32 – 00.38)}

KL 1(2) - Chopper

KL 1(2)b – remove flakes

{(vii)h(vii.00.50 – 00.52) (vi.00.53 – 00.54)} {(ii)l(ii.00.55) (v.00.56) (i.00.57) (v.00.58) (iv.00.59) (i.01.00 – 01.02)} {(ii)K(ii.01.03) (v..half) (iv.half)} {(ii)K(ii.01.05) (v.01.06) (iv.01.07)} {(ii)b(ii.01.08) (v.01.09)} {(ii)K(ii.01.10) (v.half) (iv.half)} {(ii)K(ii.01.12) (v.half) (iv.half)} {(ii)K(ii.01.14) (v.half) (iv.half)} {(ii)K(ii.01.16) (v.half) (iv.half)} {(ii)t(ii.01.18 – 01.21) (iv.01.22)} {(ii)y(ii.01.23 – 01.24) (iv.01.25) (i.01.26 – 01.32)} {(ii)K(ii.01.33) (v.half) (iv.half)} {(ii)K(ii.01.35) (v.01.36) (iv.01.37)} {(ii)a(ii.01.38) (i.01.39 – 01.45)}

KL 1(3) - Chopper

KL 1(3)b – remove flakes

{(i)(i.02.34 – 02.35)} {(ii)K(ii.02.36) (v.02.37) (iv.02.38)} {(ii)K(ii.02.39 – 02.40) (v.half) (iv.half)} {(ii)K(ii.02.42) (v.half) (iv.half)} {(ii)K(ii.02.44) (v.02.45) (iv.02.46)} {(ii)K(ii.02.47 – 02.48) (v.02.49) (iv.02.50)} {(ii)K(ii.02.51) (v.02.52) (iv.02.53)} {(ii)K(ii.02.54) (v.half) (iv.half)} {(ii)K(ii.02.56) (v.half) (iv.half)} {(ii)K(ii.02.58) (v.half) (iv.half)} {(ii)a(ii.03.00 – 03.02) (i.03.03 – 03.04)} {(ii)K(ii.03.05) (v.half) (iv.half)} {(ii)L(ii.03.07) (v.03.08) (iv.03.09) (i.03.10)} {(ii)a(ii.03.11) (i.03.12)} {(ii)a(ii.03.13 – 03.15) (i.03.16 – 03.17)} {(ii)a(ii.03.18) (i.03.19 – 03.20)} {(ii)b(ii.03.21) (v.03.22)} {(ii)t(ii.03.23 – 03.25) (iv.03.26)} {(ii)t(ii.03.27) (iv.03.28)} {(ii)K(ii.03.29) (v.half) (iv.half)} {(ii)K(ii.03.31) (v.half) (iv.half)} {(ii)a(ii.03.33) (i.03.34 – 03.43)}

KL 1(4) - Chopper

KL 1(4)b – remove flakes

{(i)(i.03.48 – 03.58)} {(ii)d(ii.03.59) (v.04.00) (i.04.01 – 04.10)} {(ii)b(ii.04.11) (v.04.12)} {(ii)b(ii.04.13) (v.04.14)} {(ii)b(ii.04.15) (v.04.16)} {(ii)b(ii.04.17) (v.04.18)} {(ii)b(ii.04.19 – 04.20) (v.04.21)} {(ii)b(ii.04.22) (v.04.23)} {(ii)b(ii.half) (v.half)} {(ii)b(ii.half) (v.half)} {(ii)b(ii.half) (v.half)} {(ii)a(ii.04.27) (i.04.28)} {(ii)a(ii.04.29 – 04.31) (i.04.32 – 04.34)} {(ii)a(ii.04.35 – 04.36) (i.04.37 – 04.42)}

KL 1(5) – Chopper and Retouched Flake

KL 1(5)b – remove flakes

{(i)(i.04.55 – 05.03)} {(ii)t(ii.05.04 – 05.05) (iv.05.06)} {(ii)t(ii.05.07) (iv.05.08)} {(ii)M(ii.05.09) (iv.05.10) (v.05.11)} {(ii)K(ii.05.12) (v.05.13) (iv.05.14)} {(ii)K(ii.half) (v.quarter) (iv.quarter)} {(ii)b(ii.05.16) (v.05.17)} {(ii)N(ii.05.18) (v.half) (iv.half) (v.05.20)} {(ii)t(ii.05.21 – 05.22) (iv.05.23)} {(ii)K(ii.05.24 – 05.26) (v.05.26 and a half) (iv.half – 05.29)} {(ii)b(ii.05.30) (v.half)} {(ii)K(ii.half) (v.half) (iv.half)} {(ii)K(ii.05.33) (v.half) (iv.half)} {(ii)t(ii.05.35 – 05.36) (iv.05.37)} {(ii)N(ii.05.38) (v.half) (iv.half) (v.05.40)} {(ii)K(ii.05.41) (v.half) (iv.half)} {(ii)K(ii.05.43) (v.half) (iv.half)} {(ii)a(ii.05.45) (i.05.46 - 05.48)} {(ii)b(ii.05.49) (v.05.50)} {(ii)t(ii.05.51 – 05.54) (iv.05.55)} {(ii)K(ii.05.56) (v.half) (iv.half)} {(ii)K(ii.05.58) (v.half) (iv.half)} {(ii)x(ii.06.00 – 06.01) (i.06.02 – 06.03) (iv.06.04)} {(ii)O(ii.06.05) (vi.06.06 – 06.10) (i.06.11 – 06.12)} {(ii)t(ii.06.13) (iv.06.14)} {(ii)K(ii.06.15) (v.half) (iv.half)} {(ii)x(ii.06.17) (i.06.18) (iv.06.19)} {(ii)a(ii.06.20 – 06.21) (i.06.22 – 06.23)} {(ii)x(ii.06.24) (i.06.25) (iv.06.26)} {(ii)t(ii.06.27) (iv.06.28)} {(ii)t(ii.06.29) (iv.half)} {(ii)t(ii.half) (iv.half)} {(ii)t(ii.half) (iv.half)} {(ii)t(ii.half) (iv.06.32 and a half)} {(ii)a(ii.half - 06.34) (i.06.35 – 06.37)} {(ii)a(ii.06.38 – 06.39) (i.06.40 – 06.43)}

KL 1(5)c – retouch flake

{(vii)c(vii.07.45 – 07.46) (i.07.47 – 07.48)} / {(ii)a(ii.08.26 – 08.36) (i.08.37)} {(ii)y(ii.08.38) (iv.08.39 – 08.40) (i.08.41 – 08.46)} {(ii)a(ii.08.47- 08.48) (i.08.49 – 08.50)}

KL 2(1) – Flake-Based Handaxe

KL 2(1)b – remove flakes from large boulder

{(vi)(vi.02.58 – 03.24lump hammer)} {(ii)P(ii.03.25 – 03.48bent over) (viii.03.49 – 03.51lump hammer) (iii.03.52 - 03.57) (i.03.58 – 04.00) (vi.04.01medium hs) (i.04.02 – 04.23)} {(ii)W(ii.04.24 – 04.27kneeling) (i.04.28 – 04.36) (vi.04.37 – 04.43 medium hs for new medium hs)} {(ii)W(ii.04.44 – 04.47kneeling) (i.04.48 – 04.56) (vi.04.57 – 05.50medium hs for large hs)} {(x)d(x.05.51 – 06.01kneeling) (viii.06.02large hs) (iii.06.03 – 06.04) (i.06.05 – 06.27) (vi.06.28large hs) (i.06.29 – 06.38)} {(x)c(x.06.39 – 06.42kneeling) (viii.06.43large hs) (iii.06.44 – 06.47) (i.06.48 – 07.04) (vi.07.05 – 07.06medium hs)} {(ix)a(ix.07.07 – 07.13kneeling) (viii.07.14medium hs) (vi.07.15 – 07.18medium hs)} {(ii)R(ii.07.19 – 07.21kneeling) (viii.07.22medium hs) (v.07.23 – 07.24) (i.07.25 – 07.27) (vi.07.28 – 07.31large hs)} {(x)a(x.07.32 – 07.51) (viii.07.52large hs) (i.07.53 -08.22) (vi.08.23 – 08.24large hs)} {(x)b(x.08.25 – 08.29kneeling) (viii.08.30large hs) (iii.08.31 – 08.39) (i.08.40 – 08.45)}

KL 2(1)c – create blank

{(vii)b(vii.09.47 – 09.54flake) (i.09.55 – 10.33) (vi.10.34 – 10.37medium quartzite hs) (i.10.38 – 10.39)} {(ii)d(ii.10.40 – 10.41) (v.10.42) (i.10.43 – 10.44)} {(ii)a(ii.10.45 – 10.49) (i.10.50)} {(ii)b(ii.10.51 – 10.54) (v.10.55)} {(ii)a(ii.10.56) (i.10.57)} {(ii)b(ii.10.58) (v.10.59 – 11.01)} {(ii)d(ii.11.02) (v.11.03) (i.11.04 – 11.10)} {(ii)b(ii.11.11 – 11.16) (v.11.17)} {(ii)x(ii.11.18 –

11.19) (i.11.20) (iv.11.21)} {(ii)y(ii.11.22 – 11.26) (iv.11.27) (i.11.28)} {(ii)b(ii.11.29 – 11.35) (v.11.36)} {(ii)d(ii.11.37) (v.11.38) (i.11.39)} {(ii)a(ii.11.40) (i.11.41)} {(ii)a(ii.half) (v.half)} {(ii)a(ii.11.43 – 11.45) (i.11.46 – 11.48)} {(ii)b(ii.11.49 – 11.51) (v.11.52)} {(ii)b(ii.11.53) (v.11.54)} {(ii)b(ii.11.55) (v.11.56)} {(ii)t(ii.11.57 – 11.58) (iv.11.59 – 12.00)} {(ii)b(ii.half) (v.half)} {(ii)a(ii.12.02) (i.12.03)} {(ii)a(ii.half) (i.half)} {(ii)b(ii.12.05 – 12.06) (v.12.07)} {(ii)t(ii.12.08) (iv.12.09)} {(ii)b(ii.12.10 – 12.13) (v.12.14)} {(ii)a(ii.12.15 – 12.16) (i.12.17)} {(ii)y(ii.12.18 – 12.19) (iv.12.20) (i.12.21 – 12.25)} {(ii)a(ii.12.26 – 12.32) (i.12.33)} {(ii)t(ii.12.34 – 12.35) (iv.12.36)} {(ii)b(ii.12.37) (v.12.38 – 12.40)} {(ii)b(ii.12.41) (v.12.42)} {(ii)a(ii.12.43 – 12.44) (i.12.45 – 12.50)} {(ii)a(ii.12.51) (i.12.52 – 12.59)} {(viii)h(viii.13.00 – 13.02medium quartzite hs) (xi.13.03 – 13.04handaxe blank) (vi.13.05 – 13.36medium granite hs) (vii.13.37 – 13.45handaxe blank) (i.13.46 – 13.48)} {(ii)a(ii.13.49 – 13.52edge strengthening) (i.13.53)} {(ii)a(ii.13.54) (i.13.55)} {(ii)a(ii.13.56 – 13.58) (i.13.59 – 14.00)} {(ii)a(ii.14.01 – 14.03) (i.14.04)} {(ii)x(ii.14.05) (i.14.06) (iv.14.07)} {(ii)t(ii.14.08 – 14.10) (iv.14.11)} {(ii)x(ii.14.12 – 14.14) (i.half) (iv.half)} {(ii)x(ii.14.16 – 14.18) (i.14.19) (iv.14.20)} {(ii)a(ii.14.21 – 14.24) (i.14.25)} {(ii)(ii.14.26)}

KL 2(1)d – thin and shape

{(vi)a(vi.14.27 – 14.31granite hs to antler h - thinning) (i.14.32)} {(ii)d(ii.14.33 – 14.38) (v.half) (i.half)} {(ii)a(ii.14.40 – 14.42) (i.14.43)} {(ii)u(ii.14.44 – 14.46) (i.14.47) (v.14.48)} {(ii)b(ii.14.49 – 14.52) (v.14.53)} {(ii)a(ii.14.54 – 14.55) (i.14.56)} {(ii)b(ii.14.57 -14.58) (v.14.59)} {(ii)a(ii.15.00 – 15.04) (i.15.05 – 15.06)} {(ii)J(ii.15.07 – 15.09) (vi.15.10antler h to granite hs – edge strengthening)} {(ii)S(ii.15.11 – 15.14) (iv.15.15) (vi.15.16 – 15.17granite hs to antler h)} {(ii)b(ii.15.18 – 15.19) (v.15.20)} {(ii)b(ii.15.21 – 15.25) (v.half)} {(ii)S(ii.half) (iv.15.27) (vi.15.28 – 15.29antler h to granite hs)} {(ii)S(ii.15.30 – 15.34) (iv.15.35) (vi.15.36granite hs to antler h)} {(ii)b(ii.15.37 – 15.38) (v.15.39)} {(ii)T(ii.15.40 – 15.43) (viii.15.44antler h) (i.15.45 – 16.00bimanual) (vi.16.01 – 16.03granite hs)} {(ii)a(ii.16.04 – 16.15) (i.16.16)} {(ii)a(ii.16.17 – 16.20) (i.half)} {(ii)a(ii.half) (i.16.22)} {(ii)U(ii.16.23 – 16.24) (vi.16.25granite hs to antler h) (iv.16.26) (i.16.27 – 16.29)} {(ii)b(ii.16.30 – 16.36) (v.16.37)} {(ii)T(ii.16.38) (viii.16.39antler h) (i.16.40 – 16.42bimanual) (vi.16.43-16.44granite hs)} {(ii)a(ii.16.45) (i.16.46)} {(ii)a(ii.16.47 – 16.48) (i.16.49)} {(ii)V(ii.16.50 – 16.55) (vi.16.56 – 16.57granite hs to antler h) (i.16.58 – 16.59) (iv.17.00)} {(ii)a(ii.17.01 – 17.04) (i.17.05 – 17.07)} {(ii)d(ii.17.08 – 17.10) (v.17.11) (i.17.12 – 17.13)} {(ii)b(ii.17.14) (v.17.15)} {(ii)a(ii.17.16) (i.17.17)} {(ii)b(ii.half) (v.half)} {(ii)a(ii.17.19 – 17.20) (i.17.21)} {(ii)t(ii.17.22 – 17.23) (iv.17.24)} {(ii)t(ii.17.25) (iv.17.26)} {(ii)W(ii.17.27) (i.17.28 – 17.29) (vi.17.30 – 17.31antler h to granite hs)} {(ii)S(ii.17.32 – 17.42) (iv.17.43) (vi.17.44granite hs to antler h)} {(ii)a(ii.17.45 – 17.47) (i.17.48)} {(ii)b(ii.17.49) (v.17.50)} {(ii)b(ii.17.51 – 17.53) (v.17.54)} {(ii)J(ii.17.55 – 17.59) (vi.18.00antler h to granite hs)} {(ii)S(ii.18.01 – 18.04) (iv.18.05) (vi.18.06granite hs to antler h)} {(ii)b(ii.18.07 – 18.09) (v.18.10)} {(ii)a(ii.18.11 – 18.12) (i.18.13)} {(ii)x(ii.18.14) (i.18.15) (iv.18.16)} {(ii)a(ii.18.17) (i.18.18)} {(ii)b(ii.half) (v.half)} {(ii)b(ii.half) (v.half)} {(ii)a(ii.18.21 – 18.23) (i.18.24)} {(ii)T(ii.18.25) (viii.18.26antler h) (i.18.27 – 18.28) (vi.18.29granite hs)} {(ii)a(ii.18.30 – 18.40) (i.18.41)} {(ii)X(ii.18.42 – 18.47) (i.18.48 – 18.52) (vi.18.53 – 18.54granite hs to antler h) (i.18.55 – 18.59) (iv.19.00) (vi.19.01 – 19.02antler h to granite hs) (iv.19.03) (i.19.04 – 19.09)} {(ii)a(ii.19.10 – 19.13) (i.19.14)} {(ii)Y(ii.19.15) (iv.19.16) (vi.19.17granite hs to antler h) (i.19.18 – 19.19)} {(ii)a(ii.19.20 – 19.21) (i.19.22 – 19.23)} {(ii)J(ii.19.24 – 19.32) (vi.19.33 – 19.34antler h to granite hs)} {(ii)J(ii.19.35 – 19.41) (vi.19.42 – 19.45granite hs to antler h)} {(ii)x(ii.19.46 – 19.56) (i.19.57 - 19.58) (iv.19.59)} {(ii)(ii.20.00 – 20.01)} change antler h to granite hs /**26**/ {(ii)a(ii.00.00 – 00.11) (i.00.12 - 00.14)} {(ii)S(ii.00.15 – 00.16) (iv.00.17) (vi.00.18granite hs to antler)} {(ii)b(ii.00.19 – 00.22) (v.00.23)} {(ii)1(ii.00.24) (v.00.25) (iv.00.26) (vi.00.27antler h to granite hs)} {(ii)S(ii.00.28 – 00.34) (iv.00.35) (vi.00.36 – 00.37granite hs to antler)} {(ii)b(ii.00.38 – 00.41) (v.00.42)} {(ii)b(ii.00.43 – 00.44) (v.00.45)} {(ii)t(ii.00.46) (iv.00.47)} {(ii)a(ii.00.48 – 00.51) (i.00.52)} {(ii)T(ii.00.53) (viii.00.54antler h) (i.00.55 – 00.59bimanual) (vi.01.00 – 01.01granite hs)} {(ii)a(ii.01.02 – 01.22) (i.01.23)} {(ii)S(ii.01.24) (iv.01.25) (vi.01.26 – 01.28granite hs to antler h)} {(ii)b(ii.01.29 – 01.33) (v.01.34)} {(ii)b(ii.01.35 – 01.38) (v.01.39)} {(ii)b(ii.01.40) (v.01.41)} {(ii)b(ii.01.42) (v.01.43)} {(ii)t(ii.01.44 – 01.45) (iv.01.46)} {(ii)t(ii.01.47) (iv.01.48)} {(ii)t(ii.01.49 – 01.54) (iv.01.55)} {(ii)a(ii.01.56 – 02.01) (i.02.02)} {(ii)a(ii.02.03 – 02.04) (i.02.05)} {(ii)b(ii.half) (v.half)} {(ii)b(ii.half) (v.half} {(ii)a(ii.02.08 – 02.10) (i.02.11 – 02.15)} {(ii)T(ii.02.16 – 02.21) (viii.02.22antler h) (i.02.23 – 02.27) (vi.02.28granite hs)} {(ii)t(ii.02.29 – 02.36) (iv.02.37 – 02.38)} {(ii)S(ii.02.39 – 02.49) (iv.02.50) (vi.02.51granite hs to antler h)} {(ii)b(ii.02.52) (v.02.53)} {(ii)b(ii.half) (v.half)} {(ii)b(ii.half) (v.half)} {(ii)a(ii.02.56) (i.02.57)} {(ii)S(ii.02.58) (iv.02.59) (vi.03.00 – 03.01antler h to granite hs)} {(ii)S(ii.03.02 – 03.09) (iv.03.10) (vi. 03.11granite hs to antler h)} {(ii)b(ii.03.12 – 03.13) (v.03.14)} {(ii)a(ii.03.15 – 03.16) (i.03.17)} {(ii)a(ii.03.18) (i.03.19)} {(ii)b(ii.03.20) (v.03.21)} {(ii)x(ii.03.22 – 03.23) (i.03.24) (iv.03.25)} {(ii)t(ii.03.26 – 03.28) (iv.03.29)} {(ii)t(ii.03.30 – 03.33) (iv.03.34)} {(ii)a(ii.03.35) (i.03.36)} {(ii)a(ii.03.37) (i.03.38)} {(ii)a(ii.03.39) (i.03.40)} {(ii)a(ii.03.41 – 03.43) (i.03.44)} {(ii)x(ii.03.45 – 03.46) (i.03.47) (iv.03.48)} {(ii)t(ii.03.49 – 03.53) (iv.03.54)} {(ii)a(ii.03.55) (i.03.56)} {(ii)a(ii.03.57 – 04.01) (i.04.02 – 04.03)} {(ii)a(ii.04.04 – 04.06) (i.04.07)} {(ii)t(ii.04.08 – 04.11) (iv.04.12)} {(ii)x(ii.04.13 – 04.16) (i.04.17) (iv.04.18 – 04.19)} {(ii)b(ii.04.20 – 04.22) (v.04.23)} {(ii)t(ii.04.24 – 04.25) (iv.04.26 – 04.29)} {(ii)t(ii.04.30 – 04.33) (iv.04.34 – 04.35)} {(ii)a(ii.04.36 – 04.41) (i.04.42)} {(ii)t(ii.04.43 – 04.44) (iv.04.45)} {(ii)y(ii.04.46) (iv.04.47) (i.04.48 – 04.53)}

KL 3(1) – Prepared Core and Retouched Prepared Flake

KL 3(1)b – prepare core

{(ii)b(ii.00.00 – 00.01) (v.00.02)} {(ii)b(ii.half) (v.half)} {(ii)b(ii.half) (v.half)} {(ii)a(ii.00.05 – 00.10) (i.00.11)} {(ii)a(ii.00.12 – 00.13) (i.00.14 – 00.15)} {(ii)a(ii.00.16 – 00.20) (i.00.21)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.00.24) (i.00.25 – 00.29)} {(ii)a(ii.00.30) (i.00.31)} {(ii)b(ii.00.32) (v.00.33)} {(ii)b(ii.half) (v.half)} {(ii)d(ii.00.35) (v.00.36) (i.00.37)} {(ii)b(ii.00.38) (v.00.39)} {(ii)b(ii.half) (v.half)} {(ii)a(ii.00.41) (i.00.42)} {(ii)a(ii.043) (i.00.44 – 00.46)} {(ii)b(ii.00.47 – 00.48) (v.00.49)} {(ii)b(ii.00.50) (v.00.51)} {(ii)d(ii.00.52) (v.00.53) (i.00.54 – 00.55)} {(ii)x(ii.00.56) (i.00.57) (iv.00.58 – 00.59)} {(ii)b(ii.01.00) (v.01.01)} {(ii)b(ii.01.02 – 01.05) (v.01.06)} {(ii)b(ii.01.07 – 01.09) (v.01.10)} {(ii)b(ii.half) (v.half)} {(ii)b(ii.half) (v.half)} {(ii)x(ii.01.13 – 01.14) (i.01.15) (iv.01.16)} {(ii)a(ii.01.17 – 01.20) (i.01.21)} {(ii)y(ii.01.22 – 01.23) (iv.01.24) (i.01.25)} {(ii)a(ii.01.26 – 01.27) (i.01.28 – 01.30)} {(ii)d(ii.01.31 – 01.34) (v.01.35) (i.01.36)} {(ii)a(ii.01.37) (i.01.38 – 01.39)} {(ii)a(ii.01.40 – 01.46) (i.01.47)} {(ii)a(ii.01.48) (i.01.49)} {(ii)a(ii.01.50) (i.01.51)} {(ii)a(ii.01.52 – 01.56) (i.01.57 – 01.58)} {(ii)a(ii.01.59) (i.02.00)} {(ii)a(ii.02.01) (i.02.02)} {(ii)a(ii.02.03) (i.02.04)} {(ii)a(ii.02.05) (i.02.06)} {(ii)a(ii.02.07) (i.02.08)} {(ii)b(ii.02.09 – 02.11) (v.02.12)} {(ii)a(ii.02.13 – 02.16) (i.02.17)} {(ii)a(ii.02.18 – 02.19) (i.02.20)} {(ii)a(ii.02.21) (i.02.22)} {(ii)x(ii.02.23 – 02.24) (i.02.25 – 02.32) (iv.02.33 – 02.34)}

KL 3(1)c – remove flakes

{(ii)2(ii.02.45 – 02.48) (viii.02.49medium hs) (i.02.50 – 03.09) (iii.03.10 – 03.11)} // {(vi)d(vi.03.40medium hs) (i.03.41 – 03.43) (iv.03.44) (vi.03.45 – 03.52medium hs to small hs)} {(ii)3(ii.03.53) (i.half) (v.half) (i.03.55 – 04.00) (v.04.01)} {(ii)d(ii.04.02 – 04.03) (v.04.04) (i.04.05)} {(ii)b(ii.04.06) (v.04.07)} {(ii)d(ii.04.08 – 04.13) (v.half) (i.half)} {(ii)a(ii.04.15) (i.04.16)} {(ii)b(ii.04.17 – 04.20) (v.04.21)} {(ii)d(ii.04.22) (v.04.23) (i.04.24)} {(ii)b(ii.04.25 – 04.26) (v.04.27)} {(ii)u(ii.04.28 – 04.29) (i.half) (v.half)} {(ii)a(ii.04.31 – 04.33) (i.04.34 – 04.35)} {(ii)x(ii.04.36 – 04.38) (i.04.39 – 04.42) (iv.04.43)} {(ii)t(ii.04.44 – 04.45) (iv.04.46)} {(ii)a(ii.04.47 – 04.48) (i.04.49)} {(ii)x(ii.04.50 – 04.52) (i.04.53 – 05.00) (iv.05.01)} {(ii)a(ii.05.02 – 05.04) (i.05.05)} {(ii)F(ii.05.06 – 05.13) (i.05.14 – 05.16) (iv.05.17) (i.05.18 – 05.25)} {(ii)4(ii.05.26 – 05.27) (viii.05.28small hs) (i.05.29 – 05.35) (vii.05.36first flake) (i.05.37 – 05.47)}

KL 3(1)d – retouch prepared flake into backed sidescraper

{(vi)a(vi.08.00 – 08.23small quartzite hs) (i.08.24 – 08.32)} {(ii)a(ii.08.33 – 08.57) (i.08.58 – 09.00)} {(ii)a(ii.09.01 – 09.06) (i.09.07)} {(ii)a(ii.09.08 – 09.12) (i.09.13)} {(ii)a(ii.09.14 – 09.20) (i.09.21 – 09.22)} {(ii)a(ii.09.23 – 09.28) (i.09.29)} {(ii)a(ii.09.30) (i.09.31)} {(ii)a(ii.09.32 - 09.41) (i.09.42 – 09.43)} {(ii)a(ii.09.44 – 09.45) (i.09.46 – 09.52)} {(ii)a(ii.09.53 – 09.59) (i.10.00 – 10.09)}

<u>KL’15 1(1) – Unfletched Arrow</u>

KL’15 1(1)a – pressure-flake old point

{(vi)o(vi.00.00antler pressure flaker) (vi.00.01leather pad) (vii.00.02point)} {(ii)W(ii.00.03 - 00.04pressure flake) (i.00.05 – 00.08) (vi.00.09 – 00.14small quartzite hs)} {(ii)8(ii.00.15 – 00.19retouch) (viii.00.20 – 00.22small quartzite hs)} {(ii)a(ii.00.23 – 00.38pressure flake) (i.00.39)} {(ii)a(ii.00.40 – 00.57) (i.00.58 – 01.00)} {(ii)a(ii.01.01 – 01.48) (i.01.49 – 01.53)} {(ii)a(ii.01.54 – 02.00) (i.02.01 – 02.10)} {(ii)a(ii.02.11 – 02.26) (i.02.27 – 02.28)} {(ii)a(ii.02.29 – 02.36) (i.02.37)} {(ii)a(ii.02.38 – 02.41) (i.02.42 – 02.44)} {(ii)a(ii.02.45 – 02.50) (i.02.51 – 02.54)} {(ii)a(ii.02.55 – 02.59) (i.03.00 – 03.01)} {(ii)a(ii.03.02 – 03.08) (i.03.09 – 03.12)} {(ii)a(ii.03.13 – 03.21) (i.03.22 – 03.24)} {(ii)a(ii.03.25 – 03.31) (i.03.32 – 03.34)} {(ii)a(ii.03.35 – 03.49) (i.03.50 – 03.53)} {(ii)W(ii.03.54 –

03.58) (i.03.59 – 04.07) (vi.04.08 – 04.11antler pressure flaker & pad for small quartzite hs)} {(ii)J(ii.04.12 – 04.13retouch) (vi.04.14 – 04.18small quartzite hs for antler pressure flaker & pad)} {(ii)a(ii.04.19 – 04.28) (i.04.29 – 04.31)} {(ii)a(ii.04.32 – 04.44) (i.04.45 – 04.54)} {(viii)j(viii.04.55 – 04.56antler pressure flaker) (viii.04.57pad) (vi.04.58small quartzite hs)} {(ii)12(ii.04.59retouch) (viii.05.00 – 05.01small quartzite hs) (i.05.02 – 05.03) (xi.05.04point)}

KL'15 1(1)b – strip and trim hazel shaft

{(vii)n(vii.05.24 – 05.26trimmed branch) (v.05.27 – 05.30) (xi.05.31point) (vi.05.32 – 05.45flint flake)} {(xvi)c(xvi.05.46 – 05.49) (v.05.50) (i.05.51 – 05.52)} {(xvi)i(xvi.05.53 – 05.57) (v.05.58 – 05.59)} {(xvi)i(xvi.06.00 – 06.05) (v.06.06)} {(xvi)i(xvi.06.07 – 06.09) (v.06.10 – 06.11)} {(xvi)i(xvi.06.12 – 06.13) (v.06.14 – 06.15)} {(xvi)i(xvi.06.16 – 06.18) (v.06.19)} {(xvi)i(xvi.06.20 – 06.21) (v.06.22)} {(xvi)i(xvi.06.23 – 06.24) (v.06.25 – 06.26)} {(xvi)a(xvi.06.27 – 06.29) (i.06.30 – 06.32)} {(xvi)i(xvi.06.33 – 06.41) (v.06.42 – 06.44)} {(xvi)a(xvi.06.45 – 06.52) (i.06.53 – 06.57)} {(xvi)a(xvi.06.58 – 07.11) (i.07.12 – 07.20)} {(xvi)e(xvi.07.21 – 07.26) (i.07.27 – 07.28) (v.07.29 – 07.30) (i.07.31 – 07.32)} // {(xvi)i(xvi.07.55 – 08.06) (v.08.07)} {(xvi)d(xvi.08.08 – 08.18) (i.08.19 – 08.33) (v.08.34)} {(xvi)j(xvi.08.35 – 08.47) (v.08.48) (iv.08.49 – 08.50)} {(xvi)a(xvi.08.51 – 08.58) (i.08.59)} {(xvi)a(xvi.09.00 – 09.12) (i.09.13)} {(xvi)k(xvi.09.14 – 09.22) (v.09.23 – 09.24) (i.09.25 – 09.28) (v.09.29 – 09.30)} {(xvi)l(xvi.09.31 – 09.33) (v.09.34) (i.09.35 – 09.37) (iv.09.38 – 09.39)} {(xvi)i(xvi.09.40) (v.09.41 – 09.42)} {(xvi)g(xvi.09.43 – 09.50) (vi.09.51 – 09.56flint flake for flint chunk)} {(xvi)m(xvi.09.57 – 10.11) (iv.10.12 – 10.14) (i.10.15 – 10.19)} {(xvi)n(xvi.10.20 – 10.24) (i.10.25) (iv.10.26 – 10.28) (i.10.29 – 10.55) (iv.10.56 – 10.57) (i.10.58 – 11.00)} {(xii)a(xii.11.01 – 11.03) (i.11.04)} {(xii)b(xii.11.05 – 11.22) (viii.11.23flint chunk) (i.11.24 – 11.28)} {(xiii)b(xiii.11.29 – 11.42) (xi.11.43 – 11.46end of shaft) (vi.11.47flint chunk)} {(xvi)o(xvi.11.48 – 11.56) (viii.11.57flint chunk) (i.11.58) (v.11.59) (i.12.00 – 12.16) (v.12.17 – 12.20) (vi.12.21 – 12.23flint chunk)} {(xvi)a(xvi.12.24 – 13.24) (i.13.25 – 13.27)} {(xvi)p(xvi.13.28 – 13.39) (viii.13.40flint chunk) (i.13.41 – 13.42) // (vi.14.41 – 14.42flint chunk) (iv.14.43)} {(xii)a(xii.14.44 – 15.05) (i.15.06)} {(xii)d(xii.15.07 – 15.09) (viii.15.10flint chunk) (xiii.15.11 – 15.14) (xi.15.15end of shaft) (vi.15.16 – 15.19flint chunk)}/ {(xvi)q(xvi.15.20 – 15.26) (viii.15.27 – 15.28) (i.15.29 – 15.33)}

KL'15 1(1)c – create distal cleft and create haft

{(vi)k(vi.16.06 – 16.09thin flake) (i.16.10) (vi.16.11 – 16.13small quartzite hs} {(ii)8(ii.16.14 – 16.20back flake) (viii.16.21 – 16.22small quartzite hs)} {(xxviii)a(xxviii.16.23 – 16.43) (xxv.16.44) (i.16.45 – 16.46)} {(xxviii)b(xxviii.16.47 – 16.52) (i.16.53 – 16.54) (vi.16.55small quartzite hs)} {(xiv)a(xiv.16.56 – 16.59) (i.17.00)} {(xiv)a(xiv.17.01 – 17.02) (i.17.03 – 17.06)} {(xv)b(xv.17.07 – 17.11) (i.17.12 – 17.16)} {(xxviii)d(xxviii.17.17 – 17.20) (i.17.21) (xxv.17.22) (vii.17.23 – 17.24point)} {(xvii)c(xvii.17.25 – 17.33) (i.17.34 – 17.36) (xi.17.37point) // (vi.19.40thin flake)} {(xvi)a(xvi.19.41 – 20.01tapering distal ends) // (i.00.00 – 00.01)} {(xvi)i(xvi.00.02 – 00.07) (v.00.08)} {(xvi)a(xvi.00.09 – 00.13) (i.00.14)} {(xvi)i(xvi.00.15 – 00.18) (v.00.19

– 00.20)} // {(xvi)a(xvi.00.21 – 00.22) (i.00.23 – 00.28)} {(xvi)i(xvi.00.29 – 00.36) (v.00.37)} {(xvi)a(xvi.00.38 – 00.40) (i.00.41)} {(xvi)a(xvi.00.42 – 00.47) (i.00.48)} {(xvi)a(xvi.00.49 – 00.51) (i.00.52 – 00.54)} {(xvi)a(xvi.00.55 – 00.57) (i.00.58)} {(xvi)a(xvi.00.59 – 01.02) (i.01.03 – 01.04)} {(xvi)a(xvi.01.05 – 01.06) (i.01.07)} {(xvi)a(xvi.01.08 – 01.12) (i.01.13 – 01.14)} {(xvi)a(xvi.01.15) (i.01.16 – 01.22)} {(xvi)a(xvi.01.23 – 01.25) (i.01.26)} {(xvi)a(xvi.01.27 – 01.30) (i.01.31 – 01.32)} {(xvi)a(xvi.01.33 – 01.35) (i.01.36)} {(xvi)a(xvi.01.37 – 01.40) (i.01.41)} {(xvi)a(xvi.01.42 – 01.43) (i.01.44 – 01.45)} {(xvi)a(xvi.01.46 – 01.53) (i.01.54)} {(xvi)a(xvi.01.55 – 01.59) (i.02.00)} {(xvi)a(xvi.02.01- 02.05) (i.02.06)} {(xvi)a(xvi.02.07 – 02.12) (i.02.13)} {(xvi)a(xvi.02.14 – 02.17) (i.02.18)} {(xvi)a(xvi.02.19 – 02.26) (i.02.27 – 02.29)} {(xvi)a(xvi.02.30 – 02.35) (i.02.36 – 02.37)} {(xvi)a(xvi.02.38 – 02.43) (i.02.44 – 02.45)} {(xvi)a(xvi.02.46 – 02.47) (i.02.48)} {(xvi)a(xvi.02.49 – 02.52) (i.02.53)} {(xvi)a(xvi.02.54 – 02.57) (i.02.58 – 02.59)} {(xvi)a(xvi.03.00) (i.03.01 – 03.02)} {(xvi)a(xvi.03.03 – 03.11) (i.03.12)} {(xvi)r(xvi.03.13 – 03.15) (viii.03.16 – 03.17thin flake)} {(vii)d(vii.03.18point) (xvii.03.19 – 03.27) (i.03.28 – 03.35) (xi.03.36point) (vi.03.37thin flake)} {(xvi)a(xvi.03.38 – 03.40) (i.03.41)} {(xvi)a(xvi.03.42) (i.03.43)} {(xvi)a(xvi.03.44 – 03.45) (i.03.46)} {(xvi)a(xvi.03.47 – 03.51) (i.03.52)} {(xvi)a(xvi.03.53 – 03.54) (i.03.55)} {(xvi)a(xvi.03.56 – 03.57) (i.03.58)} {(xvi)a(xvi.03.59 – 04.01) (i.04.02)} {(xvi)a(xvi.04.03 – 04.06) (i.04.07)} {(xvi)r(xvi.04.08 – 04.14) (viii.halfthin flake)} {(vii)g(vii.halfpoint) (xvii.04.16 – 04.20) (i.04.21 – 04.51)}

KL'15 1(1)d – complete haft

{(xi)(xi.00.00 – 00.07point)} {(xxvii)b(xxvii.00.08 – 00.14) (xxii.00.15 – 00.27) (xxx.00.28 – 00.42)} {(vii)o(vii.00.43 – 00.47dried lime-bark strip) (xviii.00.48 – 01.37)} {(xix)a(xix.01.38 – 01.49) (xxix.01.50 – 1.55to remove binding splinters)} {(i)g(i.01.56 – 01.57bound haft) (i.01.58 – 02.01adhesive)} {(vi)q(vi.02.02stick) (xxxi.02.03 – 02.09)} {(xxi)b(xxi.02.10 – 02.17) (viii.02.18stick) (xxx.02.19 – 02.32) (vi.02.33stick)} {(xxi)b(xxi.02.34 – 02.44) (viii.02.45stick) (xxx.02.46 – 03.08) (vi.03.09stick)} {(xxi)c(xxi.03.10 – 03.20) (viii.03.21stick) (xxx.03.22 – 03.44) (i.03.45 – 03.47) (vi.03.48stick)} {(xxi)d(xxi.03.49 – 03.54) (viii.03.55stick) (xxx.03.56 – 04.14) (i.04.15 – 04.16)} {(xxx)a(xxx.04.17 – 04.22) (i.04.23 – 04.41)} {(xxix)a(xxix.04.42 – 05.00soften adhesive) (xxx.05.01 – 05.29)} {(xxix)b(xxix.05.30 – 05.39soften adhesive) (xxx.05.40 – 06.01) (i.06.02 – 06.07)}

<u>KL 4(1) – Hafted End Scraper</u>

KL 4(1)a – trim handle

{(vi)a(vi.04.47 – 04.51denticulated flake) (i.04.52 – 04.53)} {(xii)a(xii.04.54 – 04.59) (i.05.00 – 05.01)} {(xii)a(xii.05.02 – 05.05) (i.05.06 – 05.07)} {(xii)a(xii.05.08 – 05.13) (i.05.14 – 05.15)} {(xii)a(xii.05.16 – 05.23) (i.05.24 – 05.25)} {(xii)a(xii.05.26 – 05.33) (i.05.34)} {(xii)b(xii.05.35) (viii.05.36denticulated flake) (i.05.37)} {(xiii)a(xiii.05.38 – 05.53under left foot on ground) (xi.05.54residual hazel) (i.05.55 – 05.59bi-manual)}

KL 4(1)b – create distal cleft

{(v)a(v.06.00 – 06.10wood fibres) (vi.06.11 – 06.21debitage wedge)} {(i)c(i.06.22 – 06.31) (vi.06.32 – 06.34antler h)} {(xiv)a(xiv.06.35 – 06.36) (i.06.37)} {(xiv)a(xiv.06.38 – 06.39) (i.06.40)} {(xiv)a(xiv.06.41) (i.06.42 – 06.45)} {(xv)a(xv.06.46 – 06.52) (xi.06.53handle) (viii.06.54 – 06.59debitage wedge;antler h)}

KL 4(1)c – remove blade from blade core

{(i)(i.00.00 – 00.19)} {(ii)b(ii.00.20 – 00.21) (v.00.22)} {(ii)b(ii.00.23) (v.00.24)} {(ii)b(ii.00.25-00.26) (v.00.27)} {(ii)b(ii.00.28) (v.00.29)} {(ii)b(ii.00.30 – 00.32) (v.00.33)} {(ii)a(ii.00.34 – 00.38) (i.00.39)} {(ii)a(ii.00.40 – 00.43) (i.00.44)} {(ii)5(ii.00.45 – 00.48) (iii.00.49) (i.00.50) (vi. 00.51 – 01.00small hs to medium hs)} {(ii)a(ii.01.01 – 01.03) (i.01.04)} {(ii)b(ii.01.05 – 01.06) (v.01.07)} {(ii)d(ii.01.08 – 01.12) (v.01.13) (i.01.14)} {(ii)a(ii.01.15 – 01.17) (i.01.18 – 01.21)} {(ii)I(ii.01.22 – 01.24) (iii.01.25 – 01.26)} {(ii)a(ii.01.27 – 01.30) (i.01.31)} {(ii)a(ii.01.32 – 01.34) (i.01.35)} {(ii)I(ii.01.36 – 01.37) (iii.01.38 – 01.40)} {(ii)a(ii.01.41 – 01.45) (i.01.46)} {(ii)b(ii.01.47 – 01.49) (v.01.50)} {(ii)a(ii.01.51 – 01.54) (i.01.55)} {(ii)a(ii.01.56 – 01.58) (i.01.59)} {(ii)I(ii.02.00) (iii.02.01 – 02.04)} {(ii)a(ii.02.05 – 02.06) (i.02.07)} {(ii)b(ii.02.08) (v.02.09)} {(ii)b(ii.02.10 – 02.11) (v.02.12)} {(ii)a(ii.02.13 – 02.14) (i.02.15)} {(ii)a(ii.02.16 – 02.18) (i.02.19)} {(ii)6(ii.02.20) (v.02.21) (xi.02.22) (viii.02.23medium hs)}

KL 4(1)d – retouch blade

{(vii)c(vii.02.24 – 02.25blade) (i.02.26 – 02.36bimanual)} {(vi)a(vi.02.37 – 02.44small quartzite hs) (i.02.45 – 02.52)} {(ii)a(ii.02.53 – 02.58) (i.02.59 – 03.00)} {(ii)a(ii.03.01 – 03.04) (i.03.05)} {(ii)x(ii.03.06) (i.03.07) (iv.03.08)} {(ii)a(ii.03.09 – 03.10) (i.03.11)} {(ii)a(ii.03.12 – 03.13) (i.03.14)} {(ii)a(ii.03.15 – 03.18) (i.03.19)} {(ii)a(ii.03.20 – 03.21) (i.03.22 – 03.25)} {(ii)x(ii.03.26 – 03.30) (i.03.31 – 03.34) (iv.03.35)} {(ii)a(ii.03.36 – 04.02) (i.04.03)} {(ii)a(ii.04.04 – 04.17) (i.04.18 – 04.19)} {(ii)t(ii.04.20 – 04.21) (iv.04.22)} {(ii)a(ii.04.23) (i.04.24)} {(ii)a(ii.04.25) (i.04.26)} {(ii)t(ii.04.27) (iv.04.28)} {(ii)a(ii.04.29 – 04.32) (i.04.33)} {(ii)a(ii.04.34 – 04.36) (i.04.37)} {(ii)a(ii.04.38 – 04.40) (i.04.41 – 04.42)}/ {(ii)7(ii.04.43 – 04.46) (i.04.47) (viii.04.48small quartzite hs)}

KL 4(1)e – create haft

{(vii)p(vii.04.49 – 04.50clefted handle) (xvii.04.51 – 05.01) (i.05.02 – 05.24) // (xi.05.52 – 05.55insert) (vi.05.56 – 05.58debitage flake)} {(xvi)s(xvi.05.59 – 06.11) // (xvi.00.00 – 00.42) (viii.00.43debitage flake) (i.00.44)} {(vii)q(vii.00.45 – 01.00insert) (xvii.01.01 – 01.14) (vi.01.15small quartzite hs)} {(ii)48(ii.01.16 – 01.19proximal laterals) (xvii.01.20 – 01.23)} {(ii)8(ii.01.24 – 01.35proximal laterals) (viii.01.36small quartzite hs)} {(xvii)a(xvii.01.37 – 01.38) (i.01.39)} {(xvii)a(xvii.01.40 – 01.49) (i.01.50)} {(xvii)a(xvii.01.51 – 01.56) (i.01.57 – 02.00)}

KL 4(1)f – complete haft

{(vii)f(vii.00.00 – 00.02dried sisal length) (xviii.00.03 – 00.04) (i.00.05 – 00.07)} {(xviii)a(xviii.00.08 – 00.32) (vii.00.33 – 00.36dried sisal length) (xviii.00.37 – 01.29) (i.01.30 – 01.35)} {(xvii)a(xvii.01.36 – 01.38) (i.01.39 – 01.54)} {(vi)e(vi.01.55 – 02.01debitage flake) (xix.02.02 – 02.16) (viii.02.17debitage flake) (i.02.18)}

KL 4(2) – Laterally Hafted Knife

KL 4(2)a – trim handle

{(vi)b(vi.00.00 – 00.08small hs) (vii.00.09 – 00.11debitage flake)} {(ii)a(ii.00.12 – 00.16denticulate flake edge) (i.00.17)} {(ii)a(ii.00.18 – 00.21) (i.00.22)} {(ii)4(ii.00.23 – 00.26) (viii.00.27small hs) (i.00.28) (vii.00.29wooden stick) (i.00.30 -00.40)} {(xii)a(xii.00.41 – 00.47)(i.00.48 – 00.49)} {(xii)a(xii.00.50 – 00.55)(i.00.56)} {(xii)a(xii.00.57 – 01.03)(i.01.04)} {(xii)a(xii.01.05 – 01.12) (i.01.13)} {(xii)e(xii.01.14 – 01.21) (viii.01.22denticulated flake) (xiii.01.23 – 01.34under right foot in standing) (vi.01.35denticulated flake) (i.01.36 – 01.38)} {(xiia(xii.01.39 – 01.47) (i.01.48)} {(xii)a(xii.01.49 – 01.51) (i.01.52 – 01.53)} {(xii)a(xii.01.54 – 01.58) (i.01.59)} {(xii)a(xii.02.00 – 02.10) (i.02.11 – 02.15)} {(xii)a(xii.02.16) (i.02.17 – 02.18)} {(xii)f(xii.02.19 – 02.25) (viii.02.26denticulated flake) (xiii.02.27 – 02.48under right foot in standing) (i.02.49 – 03.19) (vi.03.20denticulated flake) (i.03.21 – 03.26)} {(xii)a(xii.03.27 – 03.41) (i.03.42)} {(xii)a(xii.03.43 – 03.51) (i.03.52 – 03.53)} {(xii)a(xii.03.54 – 04.00) (i.04.01)} {(xii)a(xii.04.02 – 04.08) (i.04.09 – 04.11)} {(xii)g(xii.04.12 – 04.17) (viii.04.18denticulated flake) (xiii.04.19 – 04.34under right foot in standing) (xi.04.35unwanted wooden stick) (i.04.36 – 04.46)}

KL 4(2)b – create lateral cleft

{(vi)(vi.00.00 – 00.02hooked flake)} {(xx)b(xx.00.03 – 00.13) (i.00.14 – 00.15)} {(viii)l(viii.00.16hooked flake) (xi.00.17trimmed handle) (vi.00.18 – 00.43small quartzite hs) (vi.00.44hooked flake)} {(ii)47(ii.00.45 – 01.01sharpen) (viii.01.02small hs) (vii.01.03 – 01.06trimmed handle) (i.01.07 – 01.10)} {(xx)a(xx.01.11 – 01.30) (v.01.31 – 01.33)} {(xx)a(xx.01.34 – 01.41) (v.01.42 – 01.45)} {(xx)a(xx.01.46 – 01.59) (v.02.00 – 02.01)} {(xx)a(xx.02.02) (v.02.03)} {(xx)a(xx.02.04 – 02.19) (v.02.20 – 02.25)} {(xx)a(xx.02.26 – 02.40) (v.02.41 – 02.45)} {(xx)a(xx.02.46 – 02.52) (v.02.53 – 03.00)} {(xvi)a(xvi.03.01 – 03.07cleft surface) (i.03.08)} {(xx)a(xx.03.09 – 03.16) (v.03.17 – 03.22)} {(xx)a(xx.03.23 – 03.30) (v.03.31 – 03.40)} {(xx)b(xx.03.41 – 03.55) (i.03.56)} {(xx)a(xx.03.57 – 04.09) (v.04.10 – 04.13)} {(xx)b(xx.04.14) (i.04.15 – 04.17)} {(xx)c(xx.04.18 – 04.28) (v.04.29 – 04.33) (i.04.34 – 04.35)} {(xx)c(xx.04.36 – 04.49) (v.04.50 – 04.52) (i.04.53 – 04.54)} {(xx)a(xx.04.55 – 05.15) (v.05.16 – 05.17)} {(xx)a(xx.05.18 – 05.21) (v.05.22 – 05.26)} {(xx)d(xx.05.27 – 05.37) (v.05.38 – 05.42) (viii.05.43hooked flake) (i.05.44 – 05.57)}

KL 4(2)c – create haft

{(vii)e(vii.00.25 – 00.26first blade) (xvii.00.27 – 00.28)} {(vii)g(vii.00.29 – 00.31second blade) (xvii.00.32 – 00.38) (i.00.39 – 00.43)} // {(xi)(xi.01.22 – 01.24both blades)}

KL 4(2)d – trim and strip handle

{(i)c(i.01.31 – 01.33) (vi.01.34 – 01.42debitage flake)} {(i)c(i.01.43 – 01.44) (vi.01.45small abrading stone)} {(ii)8(ii.01.46 – 01.48back flake) (viii.01.49small abrading stone)} {(xvi)b(xvi.01.50 – 02.22distal end) (iv.02.23)} {(xvi)a(xvi.02.24 – 03.03proximal end) (i.03.04 – 03.07)} {(xvi)a(xvi.03.08handle area) (i.03.09)} {(xvi)a(xvi.03.10 – 03.17handle area) (i.03.18)} {(xvi)a(xvi.03.19 – 03.29handle area) (i.03.30)} {(xvi)a(xvi.03.31 – 03.36handle area) (i.03.37 – 03.40)} {(xvi)a(xvi.03.41 – 03.48handle area) (i.03.49)} {(xvi)a(xvi.03.50 – 03.58handle area) (i.03.59)} {(xvi)c(xvi.04.00 – 04.10handle area) (v.04.11) (i.04.12)} {(xvi)a(xvi.04.13 – 04.30handle area) (i.04.31)} {(xvi)d(xvi.04.32 – 04.33handle area) (i.04.34) (v.04.35)} {(xvi)e(xvi.04.36 – 04.44) (i.04.45) (v.04.46 – 04.47) (i.04.48)} {(xvi)f(xvi.04.49 – 04.50handle area) (viii.04.51debitage flake) (i.04.52 – 04.59) (xi.05.00 – 05.02handle)}

KL 4(2)e – complete haft

{(i)b(i.01.32 – 01.33) (vi.01.34stick) (i.01.35 – 01.36adhesive consistency)} {(xxi)a(xxi. 01.37 – 02.10cleft) (viii.02.11stick)} {(vii)g(vii.02.12 – 02.13first blade) (xxii.02.14 – 02.20) (vi.02.21 – 02.22stick)} {(xxi)a(xxi.02.23 – 02.46cleft) (viii.02.47stick)} {(vii)g(vii.02.48 – 02.50second blade) (xxii.02.51 – 03.07) (vi.03.08stick)} {(xxi)a(xxi.03.09 – 04.41around inserts) (viii.04.42stick)} {(i)e(i.04.43 – 04.50) (xxiii.04.51 – 5.09)}

KL 4(3) – Thrusting Spear

KL 4(3)a – trim shaft

{(vii)h(vii.00.31 – 00.35hazel length) (vi.00.36 – 00.48denticulated flake)} {(xii)a(xii.00.49 – 01.06length on chair seat in standing) (i.01.07 – 01.08)} {(xii)a(xii.01.09 – 01.17length on chair seat in standing) (i.01.18)} {(xii)c(xii.01.19 – 01.24length on chair seat in standing) (viii.01.25 – 01.26denticulated flake)} {(xiii)a(xiii.01.27 – 01.52on edge of chair seat) (xi.01.53 – 01.54excess hazel length) (i.01.55 – 02.04)} {(vi)(vi.02.05 – 02.06denticulated flake)} {(xii)a(xii.02.07 – 02.11length on chair seat in standing) (i.02.12 – 02.13)} {(xii)a(xii.02.14 – 02.22length on chair seat in standing) (i.02.23 – 02.25)} {(xii)c(xii.02.26 – 02.44length on chair seat in standing) (viii.02.45denticulated flake)} {(xiii)a(xiii.02.46 – 02.49on edge of chair seat) (xi.02.50 – 02.52excess hazel length) (i.02.53 – 03.02)}

KL 4(3)b – create distal cleft

{(vi)a(vi.03.09 – 03.34first flake wedge) (i.03.35 – 03.41)} {(vi)(vi.03.42 – 03.48antler h)} {(xiv)a(xiv.03.49 – 03.53) (i.03.54)} {(xiv)a(xiv.03.55 – 03.56) (i.03.57)} {(xiv)a(xiv.03.58 – 04.03) (i.04.04 – 04.06)} {(xxv)a(xxv.04.07first wedge) (i.04.08 – 04.19)} {(xxiv)a(xxiv.04.20 – 04.26) (xxvi.04.27 – 04.32in crouching – shaft on ground – first wedge) (viii.04.33antler h) (i.04.34 – 04.35)} {(vi)a(vi.04.36 – 04.42second flake wedge) (i.04.43)} {(v)b(v.04.44 – 04.45using second wedge) (xv.04.46 – 04.53distally) (vi.04.54antler h)} {(xiv)b(xiv.04.55 – 05.01second wedge) (xv.05.02)} {(xiv)a(xiv.05.03 – 05.06first wedge falls out) (i.05.07 – 05.08)} {(xiv)a(xiv.05.09 – 05.10) (i.05.11 – 05.14)} {(xiv)a(xiv.05.15 – 05.16) (i.05.17)} {(xiv)c(xiv.05.18 – 05.21) (xxv.05.22 – 05.25second wedge) (viii.05.26 – 05.27second wedge) (i.05.28 – 05.31)} {(v)c(v.05.32 – 05.44from inside cleft) (i.05.45 – 05.57) (viii.05.58 – 05.59antler h)} {(vi)a(vi.06.00 – 06.04first flake wedge) (i.06.05 – 06.06)} {(v)d(v.06.07 – 06.14from inside cleft using first wedge) (i.06.15 – 06.18) (viii.06.19first wedge) (i.06.20 – 06.23)} {(xi)(xi.06.24 – 06.25)}

KL 4(3)c – detach blade from core and retouch

{(vi)j(vi.00.00 - 00.01small quartzite hs) (vii.00.02blade core) (i.00.03)} {(ii)b(ii.00.04 – 00.05) (v.00.06)} {(ii)d(ii.00.07 – 00.12) (v.00.13) (i.00.14 – 00.15)} {(ii)a(ii.00.16 – 00.23) (i.00.24)} {(ii)J(ii.00.25 – 00.29) (vi.00.30 – 00.40small quartzite hs for medium quartzite hs)} {(ii)I(ii.00.41) (iii.00.42 – 00.44)} {(ii)a(ii.00.45 – 00.46) (i.00.47)} {(ii)b(ii.00.48 – 00.49) (v.00.50)} {(ii)d(ii.00.51) (v.half) (i.half)} {(ii)a(ii.00.53 – 00.57) (i.00.58 – 01.00)} {(ii)a(ii.01.01 – 01.02) (i.01.03 – 01.06)} {(ii)a(ii.01.07 – 01.08) (i.01.09)} {(ii)d(ii.01.10 – 01.11) (v.01.12) (i.01.13 – 01.18)} {(ii)(ii.01.19 – 01.21)} {(vii)i(vii.01.22flake) (i.01.23) (xi.01.24 – 01.27blade core) (vi.01.28medium quartzite hs for small quartzite hs)} {(ii)t(ii.01.29 – 01.35retouch flake) (iv.01.36 – 01.38)} {(ii)a(ii.01.39) (i.01.40 – 01.41)} {(ii)a(ii.01.42) (i.01.43)} {(ii)t(ii.01.44) (iv.01.45)} {(ii)(ii.01.46 - 01.47)} {(xi)b(xi.01.48 – 01.55broken flake pieces) (vii.01.56 – 01.57blade core) (vi.01.58 – 02.01medium quartzite hs)} {(ii)a(ii.02.02 – 02.04) (i.02.05 – 02.06)} {(ii)b(ii.02.07 – 02.08) (v.02.09 – 02.14)} {(ii)a(ii.02.15 – 02.16) (i.02.17)} {(ii)I(ii.02.18 – 02.20) (iii.02.21)} {(ii)a(ii.02.22 – 02.23) (i.02.24)} {(ii)a(ii.02.25 – 02.27) (i.02.28 – 02.29)} {(ii)a(ii.02.30 – 02.32) (i.02.33 – 02.37)} {(ii)(ii.02.38 – 02.40)} {(vii)j(vii.02.41flake) (i.02.42 – 02.44) (iii.02.45 – 02.46)} {(ii)a(ii.02.47 – 02.52) (i.02.53 – 02.55)} {(ii)b(ii.02.56 – 02.59) (v.03.00)} {(ii)t(ii.03.01 – 03.02) (iv.03.03)} {(ii)(ii.03.04)} {(vii)k(vii.03.05flake) (i.03.06 – 03.08) (iii.03.09 – 03.13) (i.03.14 – 03.19)} {(ii)(ii.03.20 – 03.23)} {(vii)j(vii.03.24flake) (i.03.25) (iii.03.26)} {(ii)b(ii.03.27 – 03.29) (v.03.30) (i.03.31 – 03.37)} {xi)c(xi.03.38blade core) (viii.03.39medium quartzite hs)} {(vii)l(vii.03.40flake from cache) (i.03.41) (vi.03.42small quartzite hs)} {(ii)u(ii.03.43 – 03.46retouch flake) (i.03.47) (iv.03.48)} {(ii)a(ii.03.49 – 03.53) (i.03.54)} {(ii)a(ii.03.55 – 03.57) (i.03.58)} {(ii)a(ii.03.59 – 04.02) (i.04.03)} {(ii)a(ii.04.04) (i.04.05)} {(ii)a(ii.04.06 – 04.07) (i.04.08)} {(ii)a(ii.04.09) (i.04.10 – 04.14)} {(ii)a(ii.04.15 – 04.16) (i.04.17)} {(ii)a(ii.04.18 – 04.23) (i.04.24 – 04.27)} {(ii)a(ii.04.28 – 04.30) (i.04.31)} {(ii)u(ii.04.32 – 04.37) (i.half) (iv.half)} {(ii)a(ii.04.39 – 04.40) (i.04.41)} {(ii)a(ii.04.42 – 04.45) (i.04.46)} {(ii)a(ii.04.47 – 04.49) (i.half)} {(ii)t(ii.half) (iv.04.51)} {(ii)a(ii.04.52 – 04.55) (i.04.56)} {(ii)x(ii.04.57 – 05.00) (i.05.01 – 05.02) (iv.05.03)} {(ii)t(ii.05.04) (iv.05.05)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.05.08 – 05.09) (i.05.10)} {(ii)y(ii.05.11) (iv.05.12) (i.05.13)} {(ii)a(ii.05.14 – 05.15) (i.05.16)} {(ii)a(ii.05.17 – 05.18) (i.05.19)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.05.22 – 05.25) (i.05.26)} {(ii)a(ii.05.27) (i.05.28)} {(ii)a(ii.05.29 – 05.31) (i.05.32 – 05.34)} {(ii)t(ii.05.35 – 05.36) (iv.05.37)} {(ii)a(ii.05.38 – 05.39) (i.05.40)} {(ii)a(ii.05.41 – 05.42) (i.05.43 – 05.46)} {(ii)a(ii.05.47) (i.05.48)} {(ii)a(ii.05.49) (i.05.50)} {(ii)a(ii.05.51) (i.05.52)} {(ii)a(ii.05.53) (i.05.54)} {(ii)a(ii.05.55) (i.05.56)} {(ii)a(ii.05.57) (i.05.58)} {(ii)a(ii.05.59) (i.06.00)} {(ii)a(ii.06.01 – 06.04) (i.06.05)} {(ii)t(ii.06.06) (iv.06.07)} {(ii)x(ii.06.08) (i.06.09 – 06.10) (iv.06.11)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.06.13) (i.06.14)} {(ii)a(ii.06.15 – 06.18) (i.06.19)} {(ii)a(ii.06.20 – 06.22) (i.06.23)} {(ii)a(ii.06.24 – 06.25) (i.06.26)} {(ii)a(ii.half) (i.half)} {(ii)x(ii.06.28) (i.06.29) (iv.06.30)} {(ii)x(ii.06.31 – 06.33 (i.06.34 – 06.37) (iv.06.38)} {(ii)x(ii.06.39 – 06.45) (i.half) (iv.half)} {(ii)a(ii.06.47) (i.06.48)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.half) (i.half) {(ii)a(ii.half) (i.half)} {(ii)a(ii.half) (i.half)} {(ii)a(ii.06.53 – 06.55) (i.06.56)} {(ii)a(ii.06.57 – 06.58) (i.06.59 – 07.01)}/ {(viii)f(viii.07.02 – 07.03small quartzite hs) (xi.07.04 – 07.05point)}

KL 4(3)d – create haft

{(vii)e(vii.07.06 – 07.08shaft) (xvii.07.09 – 07.15)} {(xi)d(xi.07.16point) (xi.07.17shaft) (vi.07.18flint flake) (vi.07.19 – 07.21small quartzite hs)} {(ii)a(ii.07.22 – 07.24retouch flake laterals) (i.07.25)} {(ii)9(ii.07.26 – 07.33) (viii.07.34small quartzite hs) (i.07.35) (vii.07.36shaft)} {(xvi)g(xvi.07.37 – 07.38) (vi.07.39small quartzite hs)} {(ii)8(ii.07.40 – 07.47flake laterals) (viii.07.48 – 07.49small quartzite hs)} {(xvi)a(xvi.07.50 – 08.06tapering cleft prongs) (i.08.07)} {(xvi)a(xvi.08.08 – 08.43) (i.08.44 – 08.47)} {(xvi)g(xvi.08.48 – 08.49) (vi.08.50small quartzite hs)} {(ii)10(ii.08.51 – 09.10flake laterals) (viii.09.11small quartzite hs) (i.09.12)} {(xvi)a(xvi.09.13 – 09.56tapering cleft prongs) (i.09.57 – 09.58)} {(xvi)a(xvi.09.59 – 10.20) (i.10.21 – 10.22)} {(xvi)a(xvi.10.23 – 10.25) (i.10.26)} {(xvi)a(xvi.10.27 – 10.28) (i.10.29 – 10.31)} {(xvi)h(xvi.10.32 – 11.35) (viii.11.36flake) (vii.11.37point)} {(xvii)b(xvii.11.38 – 11.47) (vi.11.48 – 11.50small quartzite hs)} {(ii)a(ii.11.51 – 11.55bulb & butt) (i.11.56)} {(ii)a(ii.11.57 – 12.01) (i.12.02 – 12.03)} {(ii)a(ii.12.04 – 12.06) (i.12.07)} {(ii)a(ii.12.08) (i.12.09)} {(ii)a(ii.12.10) (i.12.11)} {(ii)a(ii.12.12) (i.12.13 – 12.14)} {(ii)a(ii.12.15 – 12.24) (i.12.25 – 12.26)} {(ii)a(ii.12.27) (i.12.28)} {(ii)a(ii.12.29 – 12.33) (i.12.34)} {(ii)a(ii.12.35 – 12.37) (i.12.38 - 12.40)} {(ii)a(ii.12.41) (i.12.42)} {(ii)a(ii.12.43) (i.12.44)} {(ii)11(ii.12.45 – 12.48) (i.12.49) (viii.12.50small quartzite hs) (i.12.51 – 12.52)} {(xvii)(xvii.12.53 – 13.06)}

KL 4(3)e – strip shaft

{(vi)(vi.13.07 – 13.10first flint flake)} {(xvi)a(xvi.13.11 – 13.20) (i.13.21 – 13.22)} {(vi)(vi.13.23 – 14.15first flint flake for flint chunk)} {(xvi)a(xvi.14.16 – 14.30) (i.14.31 – 14.32)} {(xvi)a(xvi.14.33) (i.14.34 – 14.42)} {(xvi)a(xvi.14.43) (i.14.44)} {(xvi)a(xvi.14.45 – 14.46) (i.14.47)} {(xvi)c(xvi.14.48 – 15.00) (v.15.01) (i.15.02 – 15.08)} {(xi)e(xi.15.09shaft) (vi.15.10 – 16.14flint chunk for second flint flake) (vi.16.15small quartzite hs)} {(ii)a(ii.16.16 – 16.26) (i.16.27 – 16.29)} {(ii)(ii.16.30 – 16.36)} {(viii)i(viii.16.37small quartzite hs) (vii.16.38 – 16.41shaft)} {(xvi)a(xvi.16.42 – 16.48) (i.16.49)} {(xvi)i(xvi.16.50 – 17.00) (v.17.01)} {(xvi)a(xvi.17.02 – 17.08) (i.17.09)} {(xvi)a(xvi.17.10 – 17.17) (i.17.18 – 17.20)} {(xvi)a(xvi.17.21 – 17.38) (i.17.39)} {(xvi)a(xvi.17.40 – 17.55) (i.17.56)} {(xvi)d(xvi.17.57 – 18.04) (i.18.05 – 18.08) (v.18.09)} {(xvi)a(xvi.18.10 – 18.19) (i.18.20 – 18.26)} {(xvi)a(xvi.18.27 – 18.55) (i.18.56 – 18.59)} {(xvi)i(xvi.19.00 – 19.10) (v.19.11 – 19.19)} {(xvi)a(xvi.19.20 – 19.25) (i.19.26)} {(xvi)d(xvi.19.27 – 19.38) (i.19.39 – 19.48) (v.19.49 – 20.01)}

KL 4(3)f – complete haft

{(vii)m(vii.00.19 – 00.26dried lime-bark strip) (vii.00.27 – 00.28shaft) (vii.00.29 00.30point)} {(xxvii)a(xxvii.00.31 – 00.44) (xvii.00.45 – 00.55)} {(xviii)b(xviii.00.56 – 01.43) (xix.01.44 – 01.45) (vii.01.46 – 01.49dried lime-bark strip)} {(xviii)c(xviii.01.50 – 02.36) (vi.02.37 – 02.39flint flake) (xix.02.40 - 03.11) (viii.03.12flint flake)} {(vi)n(vi.03.13 – 03.20stick from adhesive container) (xxi.03.21 – 06.15) (viii.06.16stick) (i.06.17 – 06.18)}

Appendix 3

Glossary

Word or Phrase to be Defined	**Reference by Section Within the Thesis**

Action set The most basic action unit given a code in the second pilot study. A sequence of repeated functional gestures judged by an observer without technological measuring equipment to be the same gesture made with the same intention once or more than once. Action set numbers increase gradually across reductive tools as duration increases. The exception is fine handaxes where the duration increases greatly and the number of action sets more than doubles. Action set numbers tend to decrease across hafting task stages as information search decreases, except for haft creation and completion stages where a wide range of different gestural types may be needed.	**Section 7.2, 7.3, 8.2, 8.3**
Action set group A group of action sets. During reductive activity the group has clearly demarcated boundaries. Each action set group is given a code in the second pilot study according to the precise sequence of action sets that it contains. In total 215 action set group types were identified but only 15% of them (the shorter ones) were re-used across tasks and by different tool-makers. Long action set groups were associated with an unusually difficult task stage and reduced experience levels. An action set group consists of more than one action set. The same action set type can be repeated within an action set group so long as it is not the main action set type. During reductive activity a new action set group starts when the main action set type is performed and is followed by a sequence of non-main action sets. The action set group closes with the last action set performed before the next main action set type, which when performed opens a new action set group. The clarity of action set group boundaries was lost during some hafted tool task stages. This loss was relevant to the question being asked but the lack of clarity that resulted needs addressing in future trials. Action set group numbers increase gradually across all reductive tools except for fine handaxes where they double. They decrease across hafting task stages, probably as a result of a loss of action set repetition and also of loss of information search.	**Section 7.2, 7.4, 7.6.1 Appendix 1 Table 7.5, 8.2, 8.3**
Action set group pattern Different patterns of arrangements of action sets within action set groups emerged out of the coding, and the variation in patterns was associated with different types of task stages with different levels of cognitive loading. Four main patterns were described (see below) and these were Rythmic Repetition (a), Slow Rhythmic Repetition (b), Complex Rhythmic Repetition (c) and Narrative (d). Narrative patterns were associated with a breakdown in the clarity of the action set group boundaries. A	**Section 7.5.1, 7.5.2, 7.6.1 Appendix 2**

narrative pattern (d) underlies all complex rhythmic repetition patterns (c) but is obscured by the high volume of reductive gestures.	
Action set group type Each action set group is given a code depending on the specific internal arrangement of action sets that it contains. Each action set group code denotes a different action set group type. Quantifications for each task stage in Chapter 7 show both the number of action set groups within each task stage, and also the number of action set group types used. A low number of action set group types in a task stage with a high number of action sets indicates a high level of repetition. If the action set group types only contain up to three action sets each then the repetition is likely to be highly rhythmic (quantified as 'rhythmic repetition'). Where a proportionately high number of action set group types are present there is a tendency for the length of the action set groups to be longer on average (quantified as less 'efficient') and for the level of rhythmic repetition to be reduced. This is one of the reasons for identifying a (b) pattern rather than an (a) pattern. Only short action set group types are re-used across task stages and across tool-makers. Using progressively shorter action set group types for the same task stages through time has been identified as a possible marker of a learning process.	**Section 7.4** **Appendix 2** **Table 7.5, 8.2**
Action set type Each action set is given a code depending on the particular functional gesture that it contains. Each action set code denotes a different type of functional gesture. Quantifications for each task stage in Chapter 7 show both the number of action sets within each task stage, and also the number of action set types used. All stone reduction task stages have a consistently low number of action set types in relation to the number of actual action sets as the raw material and available tool-types constrain the variability of gestures that can be successfully used to modify the stone. This ratio indicates a high level of repetition and results in (a) or (b) patterns. Non-knapping hafting task stages contain new action set types as different raw materials and tool-types are introduced and this can result in (c) or (d) patterns. Particularly in relation to hafted-tool haft construction and completion task stages the ratio of action set types in relation to the number of actual action sets is very high. This results in (d) patterns. It indicates a complete loss of gestural repetition and a new high requirement for attentional, sequencing and sub-goal manipulation cognitive skills.	**Section 7.2, 7.3.2, 7.3.3, 7.5, 8.2, 8.3** **Table 7.2** **Figure 7.2, 7.3**
Action units Defined by Edward Reed (1996:68) as a unit of behaviour or	**Section 3.2.1, 4.2.4, 4.3**

single gesture that results in a change in the relationship between an agent and her environment. Units are arranged into 'ecologically meaningful patterns'. The use of this term indicates that behaviour is being analysed as a stream of information consisting hierarchically of gesture components, gestures, groups of gestures or sequences of gesture-groups. It will depend on the type of analysis being carried out as to how the main unit of action or action unit is to be defined. This is because any particular gesture or gestural sequence is always capable of being subdivided into smaller component parts – it is up to the researcher to denote the point past which further subdivision is not necessary to their project and that point becomes the action unit for the project. The first pilot study considered different possible action units and it was decided that the smallest action unit for the second pilot study would be described as one or more comparable functional gestures made in sequence (the action set). In a study of single knapping blows action units could well be set at a much higher level of magnification and describe individual muscle contributions to the overall gesture, or a range of neuronal action potentials. The term can also be general and denote the building block used to make up a gestural sequence without being specific about what that building block is.	
Agents The word 'agent' is used throughout this Thesis in its complex adaptive system (CAS) theory interpretation. An agent can be any component of a behavioural system which has the ability to change the nature of information passing through its boundaries. Information changes are made by agents in order to make the final outcome of the behavioural system as flexible and specific as possible. Hominins working together as a group to create a hafted tool are each agents in respect of the part of the process which they control. But an agent does not have to be an organism. Raw material can be an agent in a behavioural context. For example the specific nature of the raw material in use at any particular time (the affordance) requires a particular set of gestural responses from the organism using it and is therefore capable of controlling and altering the information stream or sequence of gestures in progress (Malafouris 2013). The connection between agents and boundaries is also important in CAS theory. Task stages might be considered as agents surrounded by boundaries. For a hafted-tool in the process of being made its information at any given moment must represent a specific format in order to pass through a task stage boundary. Tool parts entering a new boundaried space or a new task stage undergo new gestural sequences so that their constituent information is altered again to bring them closer to the finished product. The more agents or task stages there are	**Section 3.1, 3.2**

in a tool-making task, the more specific the end-product can be and thus the more flexible the whole system becomes. In CAS theory high numbers of agents within a given system makes emergent change more likely as variability is increased.	
Bottom-up and top-down processes These terms are common in tool-use cognition literature. The term bottom-up process usually refers to the use of basic information to complete a task. In perception action theory the basic information is perceptual information about affordances and action on affordances that is used to continue to direct the process of working on the affordance. The term top-down process usually refers to information that has become highly recombined over time and no longer represents episodic memory but has instead taken on a declarative or conceptual format. This information, usually in some kind of memory format, can also be drawn on during the course of a task. Both types of information are capable of interacting and mutually affecting the course of the task. Without bottom-up information it is not possible to locate or use affordances at all. The additional use of top-down information allows for the formation and manipulation of goals and sub-goals and the more specific structuring of the task, and possibly for the de-contextualisation of bottom-up information between tasks. Top-down information appears to require a higher attentional capacity than bottom-up information and to be slower and more cumbersome to use.	**Section 4.3.3, 4.3.4, 4.4**
Boundaries, permeable and impermeable The concept of boundaries is connected with the concept of 'agents' by complex adaptive systems (CAS) theory. Agents within a CAS system are surrounded by boundaries through which information strings must pass in their journey through the system. Information must be constituted in a particular way in order to pass through a boundary. Information constituting a retouched flake tool can pass through the Oldowan-Acheulean and Acheulean-Middle Stone Age boundaries as flakes are easy to acquire and have a wide range of uses. In other words these boundaries are permeable to flake technology. The Acheulean-Middle Stone Age boundary is increasingly impermeable to bifaces which are effortful to make and become redundant with the advent of hafting skills. A haft completion boundary would be impermeable to a shaft with a distal cleft that had been allowed to travel too far down into the wood and rendered it potentially unstable if built into a haft. Boundaries enclose spaces within which particular types of operations are more easily carried out because affordances are available and appropriate. These spaces can be represented by modern workshop spaces or the networked spaces where	**Section 1.6.2, 3.1, 7.6.3**

hominin haft completion operations were carried out (Keller and Keller 1996; Rots 2013; Baber et al 2014). Appropriately pre-processed materials are carried into these spaces separately, and leave as recombined components of completed artefacts (Arthur 2009).	
Cognitive model A cognitive model should explain what cognition is and how it is generated within the anatomical structures which appear to support it. It should allow its users to predict changes in cognitive abilities through time and how those changes are likely to have been generated. Beer (2000) states that a cognitive model should profoundly influence the empirical analysis of cognition, the phenomena studied, the questions asked and the interpretations of data carried out. Since cognition is a subject which is generally not defined or analysed even when its evolution is under discussion, different cognitive models have not been aired or debated within the archaeological discipline. Wynn and Coolidge (20016) acknowledge their reliance on a cognitive model known as cognitivism. Archaeologists who rely on these authors for cognitive information are therefore using the cognitivist model without even being aware of it or attempting to compare it with alternative models. This is despite the fact that palaeoanthropological hypotheses generated by the model are increasingly at odds with the archaeological record itself, and cognitivism is being challenged by academics outside of archaeology. A very important alternative cognitive model which influences modern cognitive scientists and psychologists concerned with investigating tool-use and cognition-in-action, is the perception action model which is explored in this Thesis as the most appropriate cognitive model for understanding cognitive evolution.	**Section 2.1, 2.2, 2.3, 2.4, 3.2** **Appendix 3**
Cognitive scaffolding This concept refers to the process whereby an organism can challenge and develop its own cognitive abilities by trying out new experimental behaviours which cause adaptive changes to its brain structures. The behaviour itself becomes the scaffolding which allows for the unrolling of an increasingly effective cognitive system as a result of learning. The concept relies on the use of a perception action cognitive model. It also relies on cognitive science concepts of brain plasticity and metaplasticity which explain how we experience lifetime structural changes to our brains constantly as a result of learning new behavioural routines. Lifetime plasticity and inherited levels of plasticity (metaplasticity) are essential concepts for much modern cognitive science research but are never discussed in palaeoanthropological literature in relation	**Section 1.4, 2.5.4, 3.2.3, 4.2.2**

to cognitive mechanisms of change.	
Combinatorial technology This is one of three different categories of early technology suggested by the author. The three categories are reductive technology, induced-change technology and combinatorial technology. Combinatorial technology involves the use of more than one material in the creation of a single artefact and some kind of engineering process which combines them into a single entity. Early combinatorial technologies include any use of a binding agent such as sinew or twine in combination with another material, or the creation of twine itself by twisting together single strands of fibrous vegetable matter. More complex technologies with well-defined task stages such as hafting can include a mosaic of all three technologies. Hafting is a combinatorial technology in its own right, but can for example make use of a combinatorial adhesive, an induced-change fresh wood shaft straightened by being held over a fire, and a reductive stone insert. Combinatorial technology has the most obvious hierarchical structure of these three types as all component parts of the end-product have their own production process before they are engineered together at assembly stage to form the final object. The elements that are combined when a new combinatorial technology comes into existence are likely to be earlier separate types of technology in their own right which are now chunked together into larger units with an increased hierarchical format. This kind of developmental pattern is what we would expect from changes in information moving through through a complex adaptive system.	**Section 1.3, 1.6.1**
Complex rhythmic repetition pattern (c) One of four different patterns of action set arrangements within action set groups and task stages identified by the second pilot study. This pattern shows rhythmic repetition as for patterns (a) and (b). But it is different from them in that while rhythmic repetition is present throughout the task stage, the nature of the rhymic repetition differs as the tool-maker changes between different types of reductive activity and uses different tool and object pairs as a result. The (c) pattern forms a bridge between basic rhythmic repetition (a) and (b) patterns and narrative (d) patterns which are driven by an increased need to sequence discrete gestures in a precise order to achieve a meaningful result. Because it represents the ability to move between different techniques, tools, objects and affordances and to sequence activity more closely, it is suggested that the cognitive load for (c) patterns is higher than that implied by (a) and (b) patterns. Task stage quantifications show that (c) patterns are characterised by raised levels of action sets, action set types, action set groups and action set group types, high	**Section 4.3.1, 4.3.2, 7.5.1, 7.5.2, 7.5.4, 7.6.1, 8.3**

rhythmic repetition and efficiency ratings, increased tool and object numbers, and a high transit change or well-marked boundary.	
Entrainment This is a word that describes the effect of a detected internal or external rhythm on internal and external processes of an organism. The organism's behaviour can be 'entrained' so that it displays the same rhythmic regularity as the detected beat. The organism's neuronal responses can also be entrained by an external beat so that cognitive functions are refreshed as each new beat occurs. Internal regular oscillations in one neuronal network can entrain other neuronal networks so as to form a larger temporarily united neuronal network capable of dealing with a more complex function.	**Section 2.3.4, 4.3.1, 4.3.2, 4.3.4, 4.4.3**
Flexible task stage sequencing Flexible task stage sequencing is the opposite to fixed task stage sequencing. Task stages must occur in a particular order in reductive tool-making tasks resulting in a fixed sequence. It is not possible to thin a biface before creating the blank. This is likely to reduce the cognitive load in terms of construction as there is less necessity to decide what to do next. However it can also increases the stress of tool-making, particularly in relation to fine bifaces, because if a mistake is made towards the end of a task, a new tool-making process needs to be commenced starting right back at the beginning. Hafted tool task stages are more flexible and can be carried out in any order that is most convenient up to the assembly stage and even within the assembly stage to a degree. While this increases the long-term planning cognitive load, it also means that it is likely that if a mistake is made during one task stage, only that one task stage will need to be repeated rather than the whole tool-making task. The cognitive load can also be reduced by sharing out the task between different tool-makers at the easily-identifiable task-stage boundaries. Task-stage flexibility was quantified by giving the task stage in question a score of '1' where it can only be carried out in its current position in the task stage sequence; '2' where its position can be varied and '0' where it is the only task stage in the task.	**Section 7.5.1**
Gesture This word is used here to represent any combination of small movements and neuromuscular events that go to make up what the observer might characterise as a single movement of part of the body that has intentional content. The gesture might be the use of the distal end of the upper limb to bring a hammerstone into contact with a core, or the dipping of an open-clefted shaft into hot adhesive. Any gesture also causes multiple	

adjustments to fix other parts of the body in order to provide a stable base for the required movement, but these are not generally observed and are not analysed here.	
Goal and sub-goal sequencing Occupational therapists often have to break down action sequences into smaller chunks in order to teach them to patients who have motor and cognitive problems and find new learning difficult. Most daily activities can be naturally broken down into smaller gestural sequences each concerned with a sub-goal or sub-sub-goal of the overall main task goal. Often patients with cognitive problems can complete each small separate sequence without problem but are unable to work out without support which sequence to move onto next, or are unable to judge when to stop one sequence and move onto the next. OT's refer to this kind of problem as a 'sequencing' problem which adversely affects the functionality of the overall task. The need to be able to sequence small gestural sequence units to create a longer, more complex sequence with an increasingly specific outcome is shown by the results here to become increasingly necessary through archaeological time. Sequencing ability is equated in the literature with a particular prefrontal brain area which deals specifically with the ability to juggle hierarchical arrangements of sub-sub-goals and sub-goals during a task in order to achieve a successful outcome.	**Section 4.3.3, 4.3.4**
Hafted technology A term used for the earliest type of tool known about in the archaeological record which is not reductive, or hand-held. Hafted tools are also frequently known as combinatorial tools. A hafted tool is made out of component parts which are engineered so that they fit together at the haft of the tool. The main component parts can be classed as a shaft or handle, an insert which constitutes the working edge and a haft or join. Different materials for securing the haft are additional components. The tools can be made out of a range of different raw materials depending on local resources and intended use of the tool. The haft arrangement varies a lot for the same reasons. The main intention for early hafting attempts appears to have been to attach a handle to the cutting or working edge of the tool in order to improve on the functional performance offered by earlier hand-held reductive bifaces. Later hafted tools were constructed with shafts which could be connected to projectile machines such as bows or spear throwers for increased function in hunting tasks. Identification of ancient hafted tools is problematic because the organic tool-components do not survive. Only stone inserts are generally retrieved and these often require microscopic analysis before they can be reliably identified as hafting inserts rather than	**Section 1.5, 1.6**

hand-held tools. Hafted tools continue to be used on a daily basis up to the present time.	
Hierarchical technology This description has been used by a variety of authors to describe different technologies. In a general sense it denotes a technology which is not just a fixed linear process but instead includes recursive activity-flows. It has been used about later reductive stone tool technologies with reference to the nesting of different sub-sequences which re-occur throughout a reductive process, for example in connection with the removal of a number of prepared flakes from a prepared core. It has also been used about the manual handling of objects by primates. Different layers of analysable activity occur at the same time. There is no consensus as to what activity represents the first hierarchical technology or which species was responsible for it. Hafting represents a more obvious hierarchical structure than reductive tools, because the tools themselves are made up from a range of different components each of which has gone through its own preparatory processes. However if a reliable measure of hierarchical patterns that applied across all tool types could be used, it is likely that it would be established that hierarchical patterns are present in technology from an early stage but become more marked in various different ways through archaeological time, emerging clearly with hafted tools. Identifying hierarchies in a technology is important in relation to analysing cognitive processes. Increasingly hierarchical gestural structures are likely to require a higher level of attention-driven organising cognitive processes and may involve higher levels of inter-individual cooperation requiring raised communication skills. Increasing levels of hierarchical structuring in a technological system are also indicators of the development of a complex adaptive system (CAS) and the applicability of a CAS internal set of structural rules or 'grammar'.	**Section 1.6.1, 3.1, 4.3.4 5.3.2**
Induced change technology A technology which uses detailed knowledge and probably past experimentation (top down information) to predict what changes will take place in a raw material which is placed into a specifically controlled environment for a set length of time. Sinews used as binding have been deliberately placed in an environment where they can dry whilst maintaining their length. Lime bark is placed under the surface of flowing water to wash away the unwanted fibrous material and just leave the strong longitudinal fibres required for twine. Birch bark is placed in a heated and reduced oxygen environment so that it becomes tar.	**Section 1.6.1**
Information search	**Section 3.2,**

The combination of motor action units that firstly enables the gathering of information about resources or affordances in the environment, and secondly monitors the ongoing results of motor actions on those affordances, and allows for continual adjustment of motor activity to maximise the efficiency of affordance exploitation. Perceptual information is gathered by sensory gateways which in hominins consist of soundwaves collected by the ears, lightwaves collected by the eyes, a wide range of sensory information (including weight, centre of gravity, position in relation to the hand, texture, temperature, contour or shape and flexibility/rigidity of objects) collected by sensory receptors on the body surface and within muscle bodies, taste information gathered by receptors in the mouth and odour information gathered by receptors in the nose. Continuous information search is required as raw data for the cognitive organisation of motor gestures during a task and for the potential organisation or reorganisation of goals and sub-goals according to circumstances. The act of searching for this data during a tool-making task should be observable in the form of object manipulations which are not accompanied by gestures intended to modify the object. Information search is also likely to be occurring at the same time as object modification is taking place but may be restricted. For example in stone reduction visual information about the result of a flake removal is not available during delivery of the hammer-blow and the tool-maker relies on sound and sensory feedback for immediate information. This restriction results in frequent pauses while the tool-maker turns the core to retrieve visual information. During wood-shaving visual information is contantly available alongside sensory and auditory information and pauses in activity for information search are shown as reduced in Chapter 7. Recognition of the importance of information search and how it forms an integral part of cognitive processes is only possible within a perception action cognitive model. Cognitivist models never consider the need for information input at all. Necessary information is presumed to be already present within the tool-maker's internal 'representations'.	**3.2.1, 3.2.2, 3.2.3, 4.4.2, 4.4.3 Chapter 6, 7**
Main action set type The main action set type in a reductive sequence either in relation to stone or wood, is the action set type that constitutes the main reductive gesture. In reductive sequences the main action set type is usually followed by a couple of different action set types such as information search or debris clearage which make up the rest of the action set group. When the main action set type is repeated again a new action set group is started. Some examples of main action set types are dominant hand knapping, wood shaving, sawing, and hammering a wedge into	**Section 7.3.3, Table 7.2**

a shaft.	
Manually differentiated control This is the ability in all primates to use both hands together in the same task but have them carry out different but complementary gestures which, if they occur at the right moment in relationship to each other, allow complex exploitation of an affordance. This kind of exploitation is more complex than that provided by two hands doing the same thing at the same time, or the use of one hand only. It requires a cognitive ability to retrieve perceptual information as a whole and distribute it appropriately and very quickly between the two hands, but also to preserve an overall awareness of the combined effect of the two hands acting together through ongoing perceptual assessment. In relation to primates that retain arboreal locomotion skills this differentiation may be observable in their feet as well as their hands. Manual differentiation appears in primate gestural routines where posture is stable and where the required gestural sequence involves tool-use or objects being manually processed to a high level. The preferred dominance ('left' or 'right') of manually differentiated control is not thought to be a genetically inherited trait but shows signs of being an ontogenetically learned, emergent level of a manual dynamic system which appears when the activity being carried out is complex enough to require it.	**Section 3.2.3, 5.3.2**
Metaplasticity This term is used to describe the amount of plastic change or plasticity within brain neuronal networks which is available to any particular individual at any given moment. Being able to change the structure of neuronal networks within the brain quickly and to a high level is a derived ability in modern humans which supports constant new learning, but plastic changes must not be allowed to run out of control and cause damage. Metaplasticity levels control the quality and type of plasticity that is available through time. Metaplasticity levels have been shown to be reduced in individuals in stressful environments. They may possibly be increased as a result of repeated positive learning experiences. Adjustments in metaplasticity levels ontogenetically and phylogenetically are thought to be the product of epigenetic processes.	**Section 4.2.1, 4.2.2, 4.2.3, 4.2.4**
Microanalysis The methodology involved in using microscopes to collect information from reductive stone artefacts which cannot be seen by the naked eye. This methodology is currently the main way of differentiating between reductive hand-held stone tools and knapped artefacts intended for use or used as inserts in	**Section 1.6.3**

hafted tools. Microanalysis can reveal wear caused by a haft arrangement, and even what kind of haft arrangement was used. It can also provide information about breakages during use and the kind of force and direction of use that would have caused those particular breaks. Microscopic differences between wear patterns can be attributed to the different raw materials on which the tool has been used. Finally microanalysis can sometimes reveal traces of organic adhesive compounds, and on one occasion has provided evidence of the presence of anthropogenically twisted fibre on the proximal end of a stone artefact. The methodology needs to be used in a more regulated way and to become more easily accessible if we want to become better informed about the first appearance of hafted tools in the archaeological record.	
Motifs This term is used explicitly in complex adaptive systems (CAS) theory and refers to a small pattern in an information string that is observed as being repeated from time to time. The repetition of motifs in this context indicates that the information is carrying meaning and is complex rather than random. In behavioural contexts a motif constitutes a short recurring behavioural pattern that can be recognised and used as a first step towards parsing large volumes of behavioural information generated by conspecifics. It is contained in descriptions by Byrne of gorillas learning by observation to manually process difficult-to-access foods, and in descriptions by linguists of modern human infants learning to make sense of the long verbal strings articulated by adults. It also occurs in descriptions by researchers of implicit learning processes carried out by modern humans repeatedly presented with strings of novel information which they are unable to understand at first but which they can gradually learn to break down and re-use using subconscious processes. Finally, the concept of a repeated motif that provides meaning is embedded in the rhythmical chunking of action units into larger units in order to increase the length, specificity and meaning of particular motor activities.	**Section 3.1, 4.3.1, 4.4.1, 4.4.2, 4.4.3** **Table 7.5**
Narrative pattern (d) One of four different patterns of action set arrangements within action set groups and task stages identified by the second pilot study. This pattern shows a complete lack of any kind of repetition let alone rhythmic repetition. It has only been identified in one knapping task stage which was a highly constrained flake removal task from a large immobile boulder. It was not possible to repeat flake removal gestures a sufficient number of times to generate a rhythm and multiple tools were tried out during the task stage. Otherwise the (d) pattern is	**Section 4.3.2, 7.5.1, 7.5.2, 7.5.4, 7.6.1, 8.3** **Table 7.8, 7.13, 7.14, 7.15**

only present in haft creation and haft completion task stages. It is characterised by a very low proportion of action sets in relation to a high number of action set types. Action set groups are poorly defined as a result and are very low in number. The proportion of action set groups in relation to action set group types is almost 1:1. The number of tools and objects used is relatively high as is the efficiency rating. Information search is low. The rhythmic repetition level is very low. It is not present at all in one of the two haft creation stages and is absent from all haft completion stages. Transit change scores are high for haft creation stages but are not given for haft completion stages. The (d) pattern describes a series of discrete actions which must be sequenced in a highly precise order so as to create a meaningful end-product. It requires a high level of differentiated, context-free technical skills, frequent decision-making and a wide range of affordance recognition skills. High levels of sequencing skills are required. None of these cognitive processes is supported by the automatic refreshing of attentional skills supplied by rhythmic repetitive processes. An alternative task structuring mechanism appears to be created from the manipulation of sub-sub-goal and sub-goal sequencing processes and increased attentional abilities.	
Plasticity The modern human central nervous system is frequently referred to as highly plastic in cognitive science literature because the neuronal networks appear to be able to change their connective arrangements through epigenetic processes, both ontogenetically and phylogenetically. Ontogenetic plastic change in brain networks has been frequently observed as the result of long-term expert learning and also of short-term one-off learning sessions, although in the latter case change is likely to be reversed quite quickly. Phylogenetic plastic change is hypothesised because some kinds of epigenetic change are heritable between generations. The amounts and types of plastic change that can occur in modern humans is controlled by metaplasticity levels.	**Section 4.2.1, 4.2.2, 4.2.3, 4.2.4**
Preparatory and Assembly stages A hafted tool construction process requires a range of organic components each of which may only be available at certain times of year and requires specific processing for further use. It makes sense to assume that frequently the tools are not made during one prolonged tool-making session, but are processed in bulk, task stage by task stage, possibly by different individuals, with components being stored inbetween sessions before being worked on again. These task stages which are highly flexibly sequenced are referred to here as the preparatory stage of hafted-tool making. The task stages analysed in the two pilot	**Section 1.6.3, 7.6.4**

studies include some potential preparatory stage task stages such as stripping and trimming handles and shafts, although here they the wood was used fresh rather than seasoned, and was processed as part of the assembly stage. (A distal cleft cut into fresh wood retains a better spring and provides a tighter fit around the insert.) The two task stages analysed here which are exclusively assembly stage tasks are haft creation and haft completion stages. The haft completion task stage is fixed as the final task stage but otherwise the assembly stage still has some measure of flexibility compared with reductive technologies.	
Reductive technology Any technology where the main technique employed is to sequentially remove small sections of raw material from a larger section of substrate until the required morphology is achieved; in lithic technology this means the removal of flakes from a stone core using a stone or organic hammer. Wood technologies require the removal of wood shavings from a piece of wood, and bone technologies similarly involve the shaving or gouging out of pieces of bone. In these latter cases the working tool is likely to be a stone flake, either hand-held or hafted. Changes in stone reduction techniques over archaeological time have been closely studied and there is evidence that as control over the flake removal gesture improves and becomes more accurate, more variability can be introduced into the process and a wider range of morphologically specific artefacts can be produced. Reductive tools are referred to as hand-held because no handles have been attached as in hafted tools. However some reductive tools are usefully regarded as having in-built handles, particularly stone bifaces and picks and hammers made from antler.	**Section 1.1, 1.3, 1.5, 3.2, 3.2.1, 3.2.3**
Rhythmic repetition level Rhythmic repetition level was one of the quantifications of coded data collected during the second pilot study. Each task stage was given a figure for the level of rhythmic repetition which it contained. It was not possible to measure rhythmicity of repeated movements. Instead the action set groups within a task stage with a maximum of 3 action sets that were used more than once were identified. The proportion of the total action set groups that these action set groups represented was calculated. In the hands of the most experienced tool-maker this score could reach over 90 (for example shaping a prepared core – KL3 1(b)) and could drop down to 0 when completing a hafted tool. Rhythmic repetition is present in patterns (a), (b) and (c) but not in pattern (d).	**Section 7.5**
Rhythmic repetition pattern (a)	**Section 4.3.1, 7.1.3, 7.4,**

One of four different patterns of action set arrangements within action set groups and task stages identified by the second pilot study. This pattern shows the repetition over a substantial time-period of the same or very similar short action set groups which gave rise to an audible (in knapping sequences) and visible rhythmicity. The pattern is at its strongest during knapping task stages (especially retouch sequences) where blows to the core are interspersed at fast, regular intervals with pauses for visual information search. The (a) pattern is associated with a high proportion of action set and action set group numbers compared with action set types and action set group types. In other words the variability in the kind and sequences of gestures used was restricted and the same individual and grouped gestures were repeated over and over again. Numbers of tools and objects are low and the proportion of time taken up with information search is often high. Efficiency ratings and rhythmic repetition levels are also high.	**7.5.1, 7.5.3, 7.5.4, 7.6.1, 8.2, 8.3**
Slow repetition pattern (b) One of four different patterns of action set arrangements within action set groups and task stages identified by the second pilot study. This pattern shows a rhythmically repeated pattern of action sets and action set groups as for pattern (a), but alternation between sequences of modifying the object worked and information search occurs less rapidly. The difference between (a) and (b) patterns is particularly marked in relation to efficient stone reduction task stages and efficient wood reduction task stages as there is less need during wood reduction to stop getural activity in order to search for information. Only one knapping task stage was classed as a (b) pattern (JD1(1)) because the quartz was resistant to flaking and was simply hard to work at any speed. Most (b) patterns were associated with wood-working. The pattern is associated with speed levels that indicate that the average durations of action sets within the task stage become longer. Information search is reduced (except for JD1(1) where it is very high). Rhythmic repetition scores remain high.	**Section 7.5.1, 7.6.1, 8.2, 8.3**
Task speed An attempt to compare the speed at which tool-makers were performing action sets across tool-types and task stages was made by dividing the duration of each task stage by its total number of action sets. It was noted during quantification that where average action set durations were longer there was also less information search going on. It was concluded that this quantification could not provide a true measure for comparing speed, but it did allow for the comparison between patterns (a) and (b). It highlighted the unique problems of information search during knapping processes where the results of flake	**Section 7.5.1, 8.2, 8.3**

removal cannot be seen without ceasing to deliver blows and turning the core. This highly emphasised alternation between delivering blows and core-turning provides an accentuated rhythmic quality to knapping task stages. During wood-working, information about progress continues to be available haptically and visually as gestures are performed, although the tool-maker still stops at intervals to examine his work more closely. The average action set duration remained steady across all knapping tasks except for handaxes where it doubled. Across hafted tool task stages there is an increase in the average length of action sets generally as information search can be carried out at the same time as the relevant gestures, and information search levels drop.	
Task stage The largest sub-division of each task analysed here is the task stage. This is the level at which quantifications have been carried out. For reductive tasks the literature has already reached some kind of consensus as to what the main task stages of the technologies analysed should be, and tool-makers are likely to observe them because they are highly aware of the literature themselves. Task stages appear to be consistently separated by a change in sub-goal, and sometimes by changes in tools and objects worked on. For more complex tools these kinds of changes can also take place inside task stages as well. Reductive task stages as defined by the literature are occasionally reinforced by archaeological evidence of partly completed tools. The number of task stages in each reductive tool-type analysed here went up gradually over archaeological time. Hafting task stages were higher in number per tool-type even though not all hafting task stages for each hafting tool-type were analysed here. There was no literary precedent for defining hafting task stages and they had to be inferred by the author by observing the hafted tool maker, the way that he signalled pauses in activity and the comments he made about what he was doing. The identification of the following task stages for hafting worked well and provided good comparative information: insert preparation, wooden shaft or handle stripping and trimming, cleft creation, haft creation and haft completion. Hafting task stages are more flexible than reductive task stages and the sequence in which they are carried out can be varied. Their boundaries also represent changes in sub-goals but internally the hafting task stage may contain more marked divisions of those sub-goals into sub-sub-goals than reductive task stages. The boundaries themselves are more highly marked than the boundaries of reductive task stages with pattern change, and high levels of transit change scores.	**Section 6.2, 6.3.12-6.3.17, 6.4, 7.1.3, 7.2, 7.5, 7.6, 8.2, 8.3** **Table 7.1**
Task stage efficiency	**Section 7.5.1**

This quantification was introduced in order to be able to distinguish between task stages with short action set groups and very long action set groups. It was assumed that the shorter action set groups were more efficient and were the basis of rhythmic repetition while the longer ones were the product of indecision about how to proceed. The quantification gives the proportion of action set groups in the task stage that are of a length of four or more action sets. The task stage efficiency score is lower for more efficient performances. High scores represent inefficient task stages. This quantification acts as a good comparator for reductive task stages. However as repetition levels reduce and the action set group boundaries become harder to define in the non-reductive hafted-tool task stages the quantification loses its applicability. The efficiency rating improves as rhythmic repetition increases. The chopper efficiency scores were less efficient than the chopper and flake tasks because of the high efficiency scores added by the flake retouch task stage. Efficiency scores were at their worst for the fine handaxes with their high cognitive load. Prepared core and flake scores had a worse efficiency score than choppers and flakes but were more efficient than the handaxes. There is a marked tendency across reductive tool-makers for efficiency scores for the same technology task stages to increase according to individual knapping experience, indicating that becoming an expert knapper involves amongst other things an ability to generate short efficient action set groups more consistently.	**Table 7.5, 7.15** **Appendix 1**
Transit change The transit change is calculated by adding together the number of tools and objects relinquished as the task stage finishes, and the number of different tools and objects that are selected for use as the new task stage starts up. A tool or object retained across the boundary is not counted. A major change in posture across the task stage boundary is also counted. The transit change score shows how marked the boundary between task stages is, and by implication gives some indication as to how permeable the task stage barrier is likely to be. A high transit change score indicates that a higher level of specificity is involved in what should have happened in the task stage in question, and what is expected to happen in the subsequent task stage. The end product of task stages with higher transit change scores should be more specific in terms of morphology and more likely to consist of different components than an end product of task stages with lower transit change scores. All hafted task stages have higher transit change scores than all knapping task stages. This includes the insert knapping stages because a different range of tools and objects are required for	**Section 7.5.1, 8.2** **Table 7.15**

the subsequent task stage which involves non-knapping sequences.	

<u>Appendix Four</u>

Fairlie, J.E., Barham, L.S., 2016. From chaîne opératoire to observational analysis: A pilot study of a new methodology for analysing changes in cognitive task-structuring strategies across different hominin tool-making events. *Cambridge Archaeological Journal* 26(4), 643-664