The Semantic Encoding of New Words: Insights from Electrophysiological and Behavioural Measures

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DECLARATION

This thesis is the result of my own work. The material contained in the thesis has not been presented, nor is currently being presented, either wholly or in part for any other degree or qualification.

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Abstract

This thesis explored the acquisition and encoding of new words. We investigated the proposal that there is more than one way to know a word – that different words, and particularly words at different stages of learning, are encoded in different ways, calling on dissociable neural systems. We investigated this using electrophysiological and behavioural approaches.

In Chapter 2, we compared electrophysiological correlates of lexical processing between novel and familiar words. Adult participants learned novel word-object mappings, and later completed a cross-modal priming task to measure the EEG response to these words. The developmental literature makes a distinction between semantic knowledge of words, which is reflected in the N400 component (or an N400 effect), and associative knowledge of words, reflected in the N200-500 component (or a phonological lexical priming effect). We explored whether this dissociation can also be related to different stages of learning in adults. We found that neither novel nor familiar words elicited a pattern of activity consistent with the phonological lexical priming effect, while both sets of words elicited very similar N400 effects. This suggests that new words can engage in semantic processing immediately after acquisition and may suggest similar patterns of encoding between novel and familiar words.

In Chapters 3 and 4, we explored the nature of novel word semantic processing using semantic priming paradigms. We explored the possibility that semantic processing with new words is strategic in nature, compared to familiar words that are additionally subject to automatic processing mechanisms. One way to manipulate the recruitment of these respective mechanisms is by manipulating the stimulus onset asynchrony (SOA) between primes and targets in a semantic priming paradigm.

Chapter 3 explored novel word semantic priming across 3 SOA conditions: 200ms, 500ms, and 1000ms. We predicted that we would observe significant novel priming effects in the

latter two conditions, since these are within the activation window of strategic mechanisms (McNamara, 2005). The results showed a significant effect only at 500ms. However, no priming effects were seen in our familiar baseline condition, making the presence of an effect for the novel words difficult to interpret. To counteract this, in Chapter 4, we turned to the methodology of Tamminen and Gaskell (2013) who report significant effects in their familiar condition. Across two experiments, we found that new words did not semantically prime existing words with a 450ms SOA but can do so with a 1000ms SOA, whilst the reverse effect was true for the familiar stimuli. Hence, we found evidence of dissociable lexical behaviour.

Taken collectively, our findings suggest that many aspects of lexical knowledge and processing are available to the individual shortly after a new word is learned. However, we also found some evidence that such processing is strategic and non-automatic in nature. This is broadly consistent with theories of lexical acquisition which propose encoding differences between new and familiar words.

List of abbreviations

ATL	Anterior temporal lobe
BAS	Backward association strength
CLS	Complimentary learning systems
EEG	Electroencephalography
EMM	Estimated marginal mean
ERP	Event-related potential
FAS	Forward association strength
fMRI	Functional magnetic resonance imaging
IFG	Inferior frontal gyrus
LPC	Late positive component
NWR	Nonword ratio
pLDT	Primed lexical decision task
PLPE	Phonological lexical priming effect
pMTG	Posterior middle temporal gyrus
RP	Relatedness proportion
SJT	Semantic judgement task
SOA	Stimulus onset asynchrony
STG/S	Superior temporal gyrus/sulcus
TG13	Tamminen and Gaskell (2013)
UoSFN	University of South Florida Free Association Norms
VWP	Visual world paradigm

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Introduction

1.1 Word Knowledge and Semantics

The study of lexical processing in the cognitive sciences can be a tricky task to navigate. In part, this can be due to long-standing philosophical debates regarding how words are and should be defined. Deacon (1997), for example, classifies words into distinct levels, from *icons* which consist of an association between a phonetic pattern and a particular visual structure, to *symbols* which are used to represent elements of the world and convey shared meaning (Golinkoff et al., 2000). However, even highly-cited research articles are prone to subjectivity in how words are defined. Brysbaert et al. (2016) estimated that the average speaker of American-English understands 42,000 uninflected word forms. However, this analysis excluded words that refer to non-specialist concepts, such as chemical substances, as well as place names such as *Paris*. Despite having a unique phonological form and meaning (*the capital city of France*), in the same way as the word *cat* which was included in Brysbaert et al.'s analysis, *Paris* was disregarded as a word. Hence, how words are defined and used in psychological research may vary considerably across research groups, which likely impacts results and conclusions.

In the research presented in this thesis, we attempt to explore the acquisition of new words and their meanings, with a particular focus on the mechanisms and processes that regulate knowledge shortly after acquisition. Our specific research questions and aims will be discussed towards the end of this introductory chapter. First, however, given the problems associated with defining words, we will seek to establish a concrete understanding of how words are defined in the context of this thesis.

1.1.1 What Are Words?

Before proceeding, it is important to establish a benchmark on some frequently used terminology in this thesis. Throughout this thesis, we use the term *representation* to refer to a particular pattern of neural activity that encodes for some lexically-related factor, such as a coding for a particular word-form or a particular concept. The term *language network(s)* is a collective term that refers to the independent neural networks described in section 1.1.2. In the context of this thesis, *language network(s)* pertains exclusively to the processing of words and does not encompass other aspects of language (e.g., syntax).

Physically, words are units of sound and/or written alphabetic characters. For instance, the word *dog* is made up of three individual phonemes: */d/o/g/*. With learning and practise, these individual units that constitute words are likely stored as more holistic chunks in the brain to ease processing and articulation of the phonological form (Segawa et al., 2015, 2019). It is thought that the superior temporal gyrus/sulcus (STG/STS) plays a particularly important role in the storage of phonological representations (Hickok & Poeppel, 2004, 2007; Wilson et al., 2018). For instance, damage and electrical stimulation to these regions is implicated with phonological paraphrasia, characterised by phonetic speech errors (such as deleting or replacing a certain phoneme) whilst general speech comprehension is preserved (reviewed in Binder, 2017). The storage of orthographic information has been implicated with the *Visual Word Form Area*, comprising the left lateral and ventral occipitotemporal cortex (Dehaene & Cohen, 2011; Liu et al., 2008; Purcell et al., 2017).

Words, however, are not simply conjoined phonemes that are articulated arbitrarily without purpose. Instead, words carry meaning. For instance, the word *dog* refers to a kind of animal that is furry, has four legs, and is a common house pet, amongst many more features. Whilst *dog* is an example of a *concrete* word in which it has an associated referent in the visual world, *abstract* words concern words that do not represent a concept in the visual world, such as the word *good*. Thus, while imageability and concreteness varies considerably (Brysbaert et al., 2014; Paivio et al., 1968; Rofes et al., 2018), words are often viewed as symbols that represent meanings, which can be used to initiate meaningful actions and conversations.

1.1.2 Where Are Words Represented in the Brain?

Models of word representation often propose the existence of distinct neural networks and layers in the brain that are involved in the representation of word knowledge, with networks representing phonetic and orthographic knowledge along with separate semantic networks which represents conceptual understanding (Collins & Loftus, 1975; Dell et al., 1997; Gaskell, & Marslen-Wilson, 1997; Gow, 2012; Lerner et al., 2012, 2014; McClelland & Rumelhart, 1981; Hickok & Poeppel, 2004, 2007). Put more simply, these models suggest that there are parts of the brain concerned with the storage of phonological and word-form information (e.g., */d/o/g/*), and separate regions concerned with the storage and encoding of semantic knowledge (e.g., *is a kind of animal that is furry,* etc). The possible organisation of word knowledge and the interchange between different networks is illustrated below in Figure 1.

To combine these two sources of information into a single lexical unit, the posterior middle temporal gyrus (pMTG) is thought to play an important role. According to these hypotheses, the pMTG binds phonological representations located (anatomically) superiorly in the STG/STS with semantic representations located elsewhere (Gow, 2012; Lau et al., 2008). Thus, this region is often implicated in the storage and access of *words* themselves (Lau et al., 2008). For example, lesion damage to the pMTG is associated with *semantic paraphrasia,* defined as selecting a word in speech that is inappropriate yet still consistent with the context of the message (i.e., selecting the word *fork* instead of *spoon*). In this case, semantic understanding appears preserved (i.e., types of cutlery), whereas selecting and accessing the correct, specific word is impaired.

Where (and how – see below) semantic knowledge is stored in the brain is a hotly debated topic. One leading theory is that the anterior temporal regions serve this purpose. Models which propose a role for these regions often encompass a ‘hub-and-spoke’ perspective of semantic memory. Specifically, the anterior temporal lobe (ATL) serves as a convergence zone which binds together conceptual information contained in distributed modality-specific brain regions (Patterson et al., 2007; Ralph et al., 2017). Evidence for this proposition comes from the study of *semantic dementia*, characterised by a severe loss of conceptual knowledge, which is often associated with bilateral atrophy to the ATL (Hodges & Patterson, 2007).

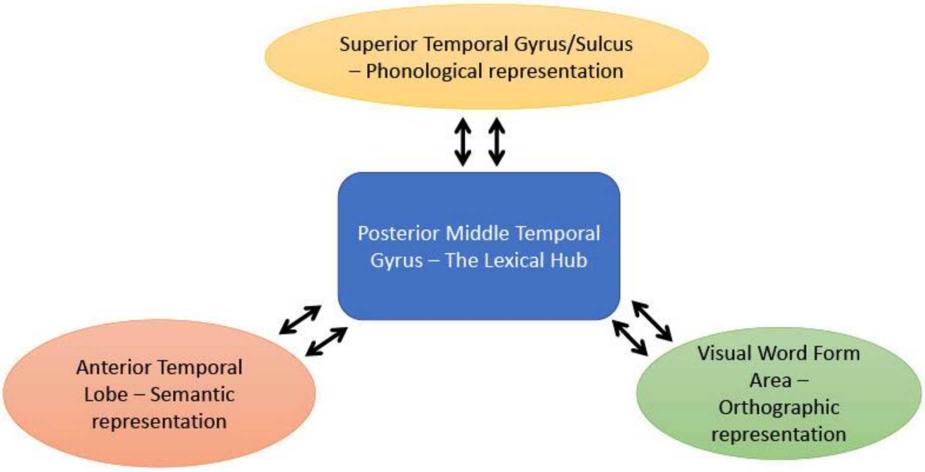

Figure 1: An illustration depicting the possible organisation and storage of word knowledge in the brain, based on the work of Hickok and Poeppel (2007) and Gow (2012). Arrows represent bi-directional connections between anatomical sites. The positioning of different brain regions is based loosely on their typical anatomical positions.

1.1.3 How Are Word Meanings Represented in the Brain?

Many distinct hypotheses have also been proposed for *how* semantic and conceptual knowledge is represented (for reviews see Jones et al., 2015; Kumar, 2021; McNamara, 2005). Holistic models of semantic representation (Anderson, 1983; Collins & Loftus, 1975; Collins & Quillian, 1969) propose that concepts are stored as single whole units within a semantic network and are connected to other concepts based on semantic similarity and learned associations. For example, the unit representing the concept *dog* will be connected with nodes representing *cat*, *walk*, *furry*, etc, yet will share fewer connections with *pencil*. According to these models, the semantic network is organised in a web-like fashion, with 'webs' spanning between related and associated concepts.

Distributed models of semantic memory propose that concepts are not represented as holistic units. Rather, concepts are represented as the strength of weighted connections between interconnected units (Farah & McClelland, 1991; Hoffman et al., 2018; McClelland et al., 1986; Rogers & McClelland, 2006). Concepts are therefore represented across a series of distributed units representing certain features, and it is the pattern of activity across these units which gives rise to a concept's representation. Thus, semantically similar concepts, such as types of birds, will share similar patterns of activation across distributed units since these concepts share similar features. These patterns could therefore be said to represent a *schema* of information. One advantage of this class of models is that they can simulate the learning of novel information (McClelland et al., 1995; McNamara, 2005; Rumelhart & Todd, 1993). Given a novel input, such as a new word-form, the model can be trained to fine-tune specific connection weights across featural units to settle on an appropriate output (i.e., the meaning of the given word-form).

As is evident from these (non-exhaustive) descriptions, there are numerous theories that attempt to explain the representation of word knowledge. Regardless of the plausibility of these respective hypotheses however, they all assume the fundamental idea that words carry a semantic meaning, and that these representations encode the relationship between semantically similar and associated words (e.g., through connections between nodes or via similar activation patterns).

1.2 Measures of Semantic Processing

The next important issue for this introductory chapter is to understand how semantic processing can be measured. Regardless of how exactly this information is represented, what tools are available to researchers to measure semantic processing in the brain? The following section will discuss two broad lines of enquiry. First, behavioural *semantic priming* will be discussed, with a particular focus on mechanisms of semantic priming. Electrophysiological research, with a particular emphasis on the *N400 component*, will be discussed, focussing on understanding the stages of processing that this component is thought to represent. Both of these measures are central components to the methodology and measures used in this thesis.

1.2.1 Behavioural Semantic Priming

Semantic priming is one of the most popular cognitive tasks for measuring online semantic processing (for reviews see Hutchison, 2003; Lucas, 2000; McNamara, 2005).

Often, but by no means exclusively, semantic priming is measured through the *primed lexical decision task* (pLDT). In a pLDT, participants make lexical decisions in response to real word (e.g., *dog*) or nonword (e.g., *dag*) targets. First discovered over half a century ago (Mayer & Schvaneveldt, 1971), a typical finding of such designs is the *semantic priming effect* – participants are quicker to respond to real word targets when it is preceded by a semantically related and/or associated prime (e.g., *cat*) compared to an unrelated prime (e.g., *pencil*).

Why, then, are related trials responded to more quickly, and what can this tell us about the organisation and operation of semantic memory?

1.2.1.1 Automatic Semantic Priming Mechanisms

The models of semantic representation that were discussed in the previous section indeed offer an explanation for the semantic priming effect, following their core theoretical assumptions. These models assume that their mechanism of action is automatic in nature.

That is, semantic priming results from quick, unintentional activity within the semantic network (Hutchison, 2003), which occurs as a result of processing the prime word.

Holistic models of semantic memory suggest that when the prime word is processed, it initiates a spread of activity towards connected nodes/concepts in the semantic network. According to this *spreading activation* account of semantic priming (Anderson, 1983; Collins & Loftus, 1975; Posner & Snyder, 1975), participants are quicker to respond to a related target word because its semantic representation is partially activated following the prime. Retrieving the concept completely – to the extent that it is accessed and recognised – is therefore facilitated by this influx of activity. Unrelated targets, on the other hand, will receive less-to-no activation from the prime, meaning its threshold for recognition receives no prior facilitation, hence delaying recognition/response time.

Distributed network models assume that semantic priming arises because semantically related concepts share activation patterns within semantic space. Thus, when the semantic network settles on the activation pattern for the concept *cat*, the network 'gets a head start' in settling on the activation pattern of the related target, resulting in quicker lexical decision times (McNamara, 2005). These models can also accommodate semantic priming based on association. For example, *cow* and *milk* are associated concepts but share little semantic resemblance, and thus result in different patterns of activity. Nonetheless, distributed network models can learn to settle on the activation pattern of an associated target more quickly through learned associations (Moss et al., 1994, as cited by Hutchison, 2003), resulting in quicker response times.

1.2.1.2 Strategic Semantic Priming Mechanisms

As described, both of these previous accounts explain semantic priming through automatic processing. There are, however, other mechanisms which may underlie the semantic priming effect. Rather than comprising fast, unintentional processes, these mechanisms are slow to engage, and may (or may not) be explicitly recruited by the participant to facilitate their performance on the task at hand. Such mechanisms are often referred to as *strategic* and *controlled* mechanisms, with both terms often used interchangeably in the literature. For simplicity, we will adopt the term **strategic mechanisms** for this thesis.

One example of a proposed strategic semantic priming mechanism is *expectancy generation* (Becker, 1980; Posner & Snyder, 1975). This account suggests that when presented with the prime word, participants have the capability to make explicit, conscious predictions regarding the upcoming targets identity. For example, if the participant recognises the semantic nature of the semantic priming task, then they can use the meaning of the prime to predict upcoming targets based on semantic similarity and/or association with the prime. In Becker's verification model (1980), for instance, the participants' lexical predictions are stored within an *expectancy set*. When the target appears, it is perceptually compared to items contained within the expectancy set. If the target is indeed contained in the expectancy set, then its recognition is facilitated, resulting in quicker lexical decisions. If, however, the target is not predicted, as is likely the case on unrelated prime-target trials, then recognition of the target is impaired due to the time spent searching through the expectancy set, without success, for a match.

This *inhibition* of unrelated trials is a unique component of strategic mechanisms. That is, whilst the recognition of related targets can be facilitated, the recognition of unrelated targets may also be inhibited as a direct consequence of employing these strategies. Concerning automatic mechanisms of priming however, unrelated target processing is not directly inhibited per se; they simply receive less prior activation from the prime than related concepts.

The use of expectancy generation by participants in priming experiments is thought to be affected by the *relatedness proportion* (RP), which refers to the proportion of related compared to unrelated prime-target trials in the primed lexical decision task (given that the target is a real word). The RP must be sufficiently large (> 0.2 - McNamara, 2005) for this strategy to be viable. If the participant recognises the presence of relatively many related trials (relative to unrelated trials), there is a relatively strong likelihood that the upcoming target - on any given trial - is related to its prime. In this case, making use of expectancy generation to predict upcoming targets would be a viable process to speed lexical decisions.

Semantic matching is another mechanism that has been suggested to be implicated in strategic semantic priming (Neely & Keefe, 1989). Under this account, when the target is processed, the participant actively checks back with the retrieved meaning of the prime, searching for a relationship. If a relationship between the target and prime is detected, this can bias and facilitate the participant to respond with a *word* response – the target must be a real word, for there to be a relationship with the prime. If, however, no relationship is detected, *but* the target is a real word (as is the case on unrelated prime- (word)target trials), then the participant must override the bias to produce a *nonword* response, delaying response time.

Semantic matching is thought to be affected by the nonword ratio (NWR). The NWR refers to the proportion of nonword to word target trials, given that the target is unrelated to its prime (Neely et al., 1989). When the NWR deviates from 0.5 (McNamara, 2005), the participant is more likely to recruit semantic matching, as the relationship between the prime and target becomes more important to the lexical decision.

1.2.1.3 The Role of Stimulus Onset Asynchrony on Semantic Priming Mechanisms

The recruitment of both of these strategies – expectancy generation and semantic matching – is contingent on the stimulus onset asynchrony (SOA). The SOA refers to the temporal delay between the presentation of the prime and presentation of the target. Although there is no absolute SOA threshold for determining an automatic – strategic division (Hutchison, 2003), it is widely recognized that as the SOA increases, so does the propensity for strategic priming mechanisms to be recruited by the participant (de Groot, 1984; den Hayer et al., 1983; 1985; Favreau & Segalowitz, 1983; Neely, 1977). This is because these mechanisms require sufficient time to develop. Take the expectancy generation account, for instance. If the participant is to make reliable predictions regarding the target's identity, they must first process the prime sufficiently to retrieve its meaning, and then begin to make lexical predictions (Neely & Keefe, 1989). Albeit, the exact reason for the dependency of *semantic matching* on SOA is poorly understood (McNamara, 2005). Thus, when the SOA is relatively short, semantic priming is believed to be more heavily attributable to activity in semantic memory (Lucas, 2000). As the SOA increases however, the use of conscious strategies recruited by the participants are more likely to influence behaviour. Furthermore, the effect of automatic mechanisms can be expected to decrease with increasing SOA due to their relatively short-lived effects. For instance, the spreading activation accounts assumes that the activity triggered by the prime towards related concepts soon dissipates following its onset (Collins & Loftus, 1975), possibly as short as a few hundred milliseconds (Anderson, 1983). This is to accommodate returns to baseline level of activation in the semantic network, for example when a prime stimulus is no longer being attended to.

Evidence for greater top-down and controlled influence at longer SOAs comes from functional magnetic resonance imaging (fMRI) studies of semantic priming. Such studies implicate the inferior frontal gyrus (IFG) in the recruitment of strategic processing, because this region is only active in semantic priming paradigms when the SOA is relatively long

(>600ms; Gold et al., 2006; Lau et al., 2008; Weber et al., 2016). The IFG has been separately implicated in controlled semantic retrieval and selection (Thompson-Schill et al., 1997), suggesting it may have an important role in the conscious retrieval of semantic information in the context of semantic priming. By contrast, the middle temporal gyrus (MTG) has been found to be activated in studies with both short and long SOAs (Gold et al., 2006; Lau et al., 2008; Weber et al., 2016). As mentioned, the pMTG may act as a 'lexical hub' and thus should be particularly involved in lexical access. Given the need to access words in a pLDT, it is no surprise therefore that the MTG should be consistently activated in these paradigms.

So far, the discussion of SOA has involved the use of relative terms such as 'short' and 'long' SOA. As mentioned, there is no absolute SOA threshold for establishing a strict automatic – strategic division (Hutchison, 2003). Further, participant characteristics such as attentional control also appear to influence the use of strategic mechanisms (Hutchison et al., 2014; Yap et al., 2016). Hence, it is difficult to pinpoint a precise SOA that generates an automatic-strategic dichotomy that would be consistent across experimental studies.

Nonetheless, a wealth of research has been carried out to establish reasonable SOA checkpoints for when strategic mechanisms might feasibly develop (and, likewise, for when automatic mechanisms might have a more subdued role). Neely (1977), for example, configured a slightly modified version of a typical pLDT, where participants were given instructions to generate words from a semantic category when they were presented with a specific, yet unrelated, prime word. For example, when the prime word was *body,* participants were instructed to generate words referring to building parts, such as *door.* Despite lacking any sort of semantic relation or association, these types of trials (e.g., *body – door*) facilitated target processing relative to a neutral baseline, and induced inhibition when an unexpected and unrelated target was encountered (e.g., *body – sparrow).* Crucially, however, these effects were observed with a minimum SOA of 700ms and 400ms respectively – they were not seen at 250ms. This demonstrates that the facilitative and inhibitory effects associated with generating target predictions require sufficient time, before the presentation of the target, to emerge (see also Burke et al., 1987; den Heyen et al., 1985; Favreua & Segalowitz, 1983). The only trials to elicit priming at an SOA of 250ms were those which contained a semantically related prime and target (e.g., *bird – robin),* which may be explained by automatic activity occurring in the semantic network, in the absence of any target prediction being made. Finally, in a review of the literature to date, McNamara (2005) recommended an SOA of 200ms or less if a researcher is interested in measuring the automatic component of semantic priming.

1.2.1.4 Limitations of the semantic priming paradigm

It is important to note limitations associated with the semantic priming paradigm. First, item-level priming effects have been shown to have poor reliability, based on both split-half and test-retest estimates (Heyman et al., 2016). This implies that attempts to predict semantic priming based on item-level characteristics will prove difficult. The unreliability of these effects has been argued to reflect the somewhat uncoordinated nature of semantic memory (Stolz et al., 2005).

Attempts to predict semantic priming are further confounded by the distributional properties of language. More specifically, not only do the frequencies of words change over time, but so too does the meaning of words. Resultantly, the way in which words are represented in conjunction with related words are not stable over time. As explained by Ramscar (2016), for example, the word *doctor* initially referred to a person of learning before the modern-day interpretation of physician emerged during the Victorian era, meaning *doctor* would not be expected to prime *nurse* until relatively recently. Similarly, keeping time constant, a given word is experienced and used in different ways across individuals. Hence, the prime-target pairing *duck-bowl* is likely to elicit faster response times in avid cricket fans compared to non-cricket fans. A given stimulus set is likely, therefore, to exhibit different behaviour across participants.

1.2.1.5 Summary of semantic priming

The semantic priming paradigm can be used to examine semantic processing in the brain. There are two potential avenues in which semantic priming is postulated to take effect. Semantic priming as a result of automatic processing is proposed to result from swift, unintentional activity within the semantic network, acting over shared connections and representation between related concepts. On the other hand, semantic priming can arise through more strategic processing, which is explicitly recruited by the participant. Under such accounts, the participant may use strategies to facilitate their performance on the task at hand. Finally, depending on their intended mechanisms of interest, the semantic priming researcher can manipulate the SOA between the prime and target to isolate the different mechanisms. Because conscious strategies require time to develop, semantic priming at shorter SOAs is more likely to reflect automatic semantic processing, whereas longer SOAs should permit the use of strategic processing to influence behaviour.

1.2.2 The N400 component

Electroencephalography (EEG) refers to the recording of electrical brain activity via electrodes placed on the scalp (Luck, 2014). The recorded EEG signal, in its raw form, represents electrical activity sourced from multiple neural populations. However, certain aspects of the signal represent electrical activity in response to particular sensory, cognitive, or motor events. Such activity can be extracted from the signal by averaging across a number of trials, allowing consistent responses in the signal to a particular event or stimulus to be enhanced. These sensory, cognitive, and motor-related responses are dubbed *event-related potentials* (ERP – Sur & Sinha, 2009). The ERP can be further broken down into *ERP components*, which refers to one of the component waves of the larger ERP response (Woodman, 2010). ERP components often correspond to additional activity recorded when a participant is processing, for example, an abnormal or unexpected utterance or situation (e.g., an ungrammatical sentence, oddball paradigm, etc.). An underlying assumption is that the abnormal utterance/situation triggers an enhanced processing stream compared to a more typical utterance/situation that is reflected in the ERP when comparing between conditions. Traditionally, ERPs have been named according to their polarity (i.e., *N* for a negative polarity; *P* for a positive polarity) and their latency in milliseconds (e.g., onset latency), such as the *P600.* In the language domain specifically, a myriad of unique ERP components have been identified and mapped onto distinct linguistic processes, including speech perception, production, and syntactic processing (for a review, see Kaan, 2007). This section of the thesis, however, will focus on and describe one such ERP component which has been consistently implicated with semantic processing – the *N400 component*.

The relationship between the N400 component and semantic processing was first observed in a study by Kutas and Hillyard (1980a). In this study, participants read a series of seven word sentences whilst connected to an EEG recording device. These sentences varied in their semantic ‘appropriateness’ based on the final word: some sentences contained a final word that was compatible with the context of the sentence (e.g., *I take my coffee with cream and sugar*), whilst others contained a final word that was incompatible and inappropriate relative to the sentence context (e.g., *I take my coffee with cream and socks*). Approximately 400ms following the onset of the final word at roughly centro-parietal regions of the scalp, words that were incompatible with the sentence elicited greater negativity in the ERP signal compared to compatible words; a response labelled the N400.

This difference in N400 amplitude across conditions is commonly referred to as the *N400 effect*, and since its discovery has been shown to be modulated by a range of lexical and contextual factors (see Kutas & Federmeier, 2011, for an extensive review). In the context of language, the N400 effect appears to have a particular association to the processing of meaning. For example, there is no significant increase in N400 activity for final sentence, semantically compatible, words that deviate physically based on font size (e.g., *I take my coffee with cream and* SUGAR) relative to other words of the sentence (Kutas & Hillyard, 1980b), which instead elicited a P300 response. The N400 effect is also not just restricted to sentence processing but is also sensitive to a range of contexts that integrate meaning across words, such as processing a list of words and semantic priming paradigms discussed earlier (Kutas & van Patten, 1988). The N400 effect can also be elicited in so-called *cross-modal* paradigms, in which words and objects are presented that vary in their semantic relatedness (Friedrich & Friederici, 2004). This paradigm is adopted in the current thesis and will be discussed in more detail later.

The exact stage of semantic processing that the N400 component reflects, however, is a hotly contested topic. The following sections provides overviews of these respective accounts.

1.2.2.1 The Semantic Integration Account of the N400

Early theories of the N400 component suggest that it is an index of the ease of integrating semantic information into the preceding context (Brown & Hagoort, 1993; Hagoort, 2008; Kutas & Hillyard, 1980a). This integration viewpoint of the N400 response posits that N400 activity is reduced when the target stimulus is congruous with the preceding context because integrating the target's semantic information is facilitated. This view of the N400 is *post-lexical* in the sense that the N400 mechanism is initiated following lexical/semantic access of the target stimulus, which is then integrated with contextual information.

Supporting evidence for this integration viewpoint comes from studies investigating the role of attention on the N400 effect. McCarthy and Nobre (1993) found that the N400 effect was only apparent in attended stimuli, and similarly it has been found that the N400 response to unrelated stimuli is attenuated when participants do not explicitly consider or identify their meanings (Chwilla et al., 1995). This suggests there is a controlled element to the N400 response in which semantic information is actively compared and integrated with prior contextual information. Similarly, the N400 response is attenuated following masked primes (primes that are not perceptually identifiable) in a pLDT (Brown & Hagoort, 1993). The inclusion of masked primes is supposed to make conscious identification of the prime more difficult, thus inhibiting the effectiveness of strategic mechanisms (Neely, 1991). The fact that the N400 therefore seems to depend on attending to stimuli lends itself to an integrative account in which semantic information is actively integrated with the preceding context.

1.2.2.2 The Lexical Access Account of the N400

The N400 response, however, is not just sensitive to the degree of semantic congruency between stimuli but also to predictability. That is, the N400 amplitude is strongly correlated with cloze probability – a measure of the number of respondents, given a particular, preceding context (i.e., an incomplete sentence with the final word absent), to produce a particular word (Kutas & Federmeier, 2011). This relationship was first reported by Kutas & Hillyard (1984). Here, participants were presented with a series of sentences which varied in the predictability of the final word, given the context of the sentence. Some sentences contained a highly predictable final word (e.g., *Don't touch the wet paint*), whilst others contained a less predictable, *yet still semantically congruous*, final word (e.g., *Don't touch the wet dog*). As with semantic anomalies, an N400 effect was discovered in which there was greater negativity in response to less predictable endings.

The integration viewpoint of the N400 has difficulty in explaining these findings because, across these two sentence types, there is no difference in the congruency of semantic information pertaining to the target relative to the context and therefore integrating this information should be of equal difficulty. Indeed, the original findings of Kutas & Hillyard (1980a) could be argued to reflect sensitivity to predictability compared to semantic congruency, since semantically congruous sentence-final words are inevitably more predictable than incongruous endings.

These findings instead favour a lexical access viewpoint of the N400 (Aurnhammer et al., 2021; Kutas & Federmeier, 2000; Lau et al., 2008). According to this hypothesis, the N400 is a marker of the ease of accessing a word from memory, and thus is *pre-lexical* in nature. Words that are made more predictable by the preceding context are accessed more easily, resulting in a reduced N400 response on related prime-target trials. This account therefore shares some assumptions with prospective mechanisms of semantic priming discussed earlier, such as spreading activation and expectancy generation. Indeed, the magnitude of the N400 effect in semantic priming paradigms is similar across SOAs (reviewed in Lau et al., 2008), suggesting that the N400 is at least partially indicative of mechanisms which facilitate the retrieval of expected words, whether they be fast, automatic mechanisms such as spreading activation, or more controlled in nature reflected top-down, conscious influences. In their review, Kutas and Federmeier (2011) explicitly state that the N400 cannot be mapped neatly onto either purely automatic or purely strategic processes. For example, whilst some studies argue that attention is important in eliciting the N400 effect (see the preceding section), others have observed N400 effects during sleep, when arguably attention is minimal (Ibáñez et al., 2006).

In further support of the lexical access viewpoint of the N400, research has implicated the pMTG as a possible neural generator for the response. As discussed earlier, the pMTG is consistently activated in a semantic priming task across SOA (Gold et al., 2006), as is the magnitude of the N400 effect (Lau et al., 2008). Similarly, magnetoencephalography (MEG) research has localised the N400 response to left temporal regions including the pMTG (Ghosh Hajra et al., 2018; Halgren et al., 2002; Helenius et al., 1998). Given the proposed role of the pMTG as acting as a 'lexical hub' (Gow, 2012), this implicates the N400 response in lexical retrieval processes.

1.2.2.3 Multiple-Generator Accounts of the N400

More recent research has explored the possibility of a 'multiple-generator' account, in which the N400 response could be a marker of *both* integration and prediction mechanisms (Lau et al., 2016; Nieuwland et al., 2020; Steinhauer et al., 2017). To investigate this, Lau et al., (2016) created two contextual conditions in which adjective-noun pairs varied in the extent to which the noun could be predicted based on the adjective (e.g., high predictability: *runny – nose*; low predictability: *dainty – nose*), and a second condition in which semantic congruity between the adjective and noun varied (e.g., congruous: *nervous – dog*; incongruous: *sheer – dog*). Crucially, predictability across congruity levels was kept low. In the predictability condition, a strong N400 effect emerged, with greater negativity in response to less predictable nouns. An effect, albeit weaker, was also observed in the semantic congruity condition, suggesting that the N400 is also sensitive to semantic anomalies, potentially independently from predictability.

It is also possible that the latency of the N400 response varies depending on the underlying mechanism that is currently active. In a re-analysis of a large-scale dataset (n = 334), Nieuwland et al. (2020) found that the effects of predictability on the N400 component begin around 200ms post-stimulus onset, with a peak difference between conditions around 330ms. In contrast, the effect of semantic congruency only began at 350ms, and followed a more prolonged time-course relative to the effect of predictability. The fact that the effect of semantic congruency was delayed compared to the effect of predictability support the notion that the semantic integration mechanism of the N400 – which is most sensitive to semantic congruency – is post-lexical in nature.

1.2.2.4 Summary of the N400 Component

As is apparent from the overview above, there is a long-standing and on-going debate in the literature regarding the functional interpretation of the N400 component, with more recent research suggesting that the N400 may not be exclusively triggered by one particular mechanism. What *is* clear, however, from decades of research, is that the N400 component may be used as a sensitive measure of online meaning processing, reflecting prediction mechanisms, in which related words are in some way cued based on the preceding context, and/or integrative mechanisms in which the meaning of the target stimulus is integrated into the preceding context.

1.3 Is It Possible to Dissociate Different States of Lexical Knowledge?

The focus of this introductory chapter has so far been on lexical knowledge; particularly on the idea that words carry a referential meaning. We have also discussed how the processing of these meanings between words can be measured via behavioural and electrophysiological means.

One question that arises from this discussion, however, is do words achieve this lexical ‘status’ straight away following acquisition? For instance, upon learning a new word, is this word immediately integrated into language networks and represented in the same manner as existing words, or is there a stage in learning when words are not represented in this way, and perhaps are encoded differently? Similarly, is there a stage in a word learners’ lifetime where the semantic meaning of a word is perhaps not recognised, due to the mechanism(s) necessary for extracting this understanding not yet being in place? Put differently, is there more than one way of *knowing* a word, and how can this be measured?

To discuss this possibility, we will consider three lines of enquiry. Firstly, we will discuss the infant word knowledge literature, and consider theories and studies which examine the state of word learning mechanisms and word representations in infancy. Secondly, we will discuss theories of typical lexical acquisition in adults, with a particular focus on the hypotheses these theories present regarding the encoding of recently learned words. Thirdly, we will explore word learning studies which probe these hypotheses.

1.3.1 Infant Lexical Knowledge

1.3.1.1 Nazzi and Bertoncini's (2003) Model of Infant Lexical Acquisition

At around 18-months of age, infants experience a *vocabulary spurt*, characterised by a sudden increase in vocabulary growth (Carey, 1978). According to some authors, the vocabulary spurt corresponds to a shift in the way words are acquired and ultimately represented. Nazzi and Bertoncini (2003) propose that infants initially start out with *proto-words*, whereby a particular sound pattern is linked with a specific object, which follows an associationist mode of lexical acquisition. Following the vocabulary spurt, infants then go on to acquire *genuine words,* whereby a specified sound pattern is linked with an unnamed object *category*, coinciding with a shift to a referential mode of lexical acquisition (Nazzi & Bertoncini, 2003). According to these models, an infant may initially associate the word 'dog' with their own pet dog. Later, however, this word is transformed into a more abstract token to represent the infant's understanding of the concept *dog*, such that it may be used to refer to other kinds of dogs, despite different exemplars having distinct perceptual properties (e.g., a Labrador vs. a Chihuahua).

The ability to generalise a new sound pattern to an object category was investigated by Nazzi and Gopnik (2001). Here, infants were presented with 3 unfamiliar and perceptually distinct novel objects, two of which were labelled as ‘tib’ and the other one ‘dap’. Following this labelling stage, the experimenter picked up one of the paired objects (i.e., one of the ‘tibs’) and asked the infant to provide the object (from the remaining two) which goes with this one. Twenty-month-olds (but not 16-month-olds) provided the paired object significantly more than chance level. Given the perceptual distinction between the paired objects, the authors concluded that these results indicate infants’ ability to form novel object categories that are represented via a single word. In Ferry et al. (2010), object categorisation was observed at younger ages of 3 and 4 months. Furthermore, categorisation was only observed with novel word stimuli and not with auditory tones, suggesting a particularly important role of words in this process.

1.3.1.2 Behavioural Investigations of Infant Lexical Knowledge

There is evidence from behavioural research on infant lexical knowledge that there may be different levels of knowledge. Part of this evidence stems from research showing that evidence of word comprehension appears dependent on the type of behavioural measure being administered.

Bannard and Tomasello (2012) investigated a contradiction in the infant word knowledge literature. On the one hand, there is evidence that infant word learning is dependent on social learning (Baldwin et al., 1996). On the other, there is also evidence that infants can acquire word-object associations independently from such learning environments (Schafer & Plunkett, 1998). To explain such contradictions, the authors argued that the behavioural task measuring comprehension may require a certain level of understanding and/or learning condition. Relatively implicit measures, such as preferential looking procedures, may suffice with simple learned associations between a word and object. More explicit measures however, such as asking the child to point to the target referent, could require an understanding of how words can be used interpersonally, which could be forged by social learning.

To test this prediction, infants learned novel word-object pairings in two learning conditions: a *coupled* condition, in which a visibly present experimenter produced a novel label while the child was attending to a novel object, and a *decoupled* condition in which the experimenter produced the novel label whilst they were out of view from the infant. Consistent with their predictions, there was equal level of performance across training conditions in a preferential looking measure (i.e., looking towards the correct target referent). However, when the child was asked to point towards the target object, performance was significantly better in the coupled learning condition. It would seem, therefore, that social learning environments allow infants to acquire an extra, perhaps 'symbolic' level of understanding (Bannard & Tomasello, 2012), that is dissociable from the apparent inferior level of knowledge that is acquired from non-social contexts.

Similar findings have been observed by Hendrickson and colleagues (2015; 2017). These studies compared infants' knowledge in the visual and haptic modalities by presenting infants with a series of on-screen object pairs whilst prompting the infant to touch one of these images. Visual knowledge was quantified by looking behaviour, whilst haptic knowledge was determined based on touching responses. An interesting observation from these studies was that, on some trials, infants displayed a behavioural dissociation whereby there was evidence of knowledge in the visual modality (evidence by gazing towards the target) but not in the haptic modality (pointing towards the distractor object). The authors ascribe this pattern of results to *partial knowledge* of words; knowledge is 'robust' enough to initiate looking behaviour but is too weak to guide more explicit touching responses and ultimately inhibit incorrect responses to the distractor (Hendrickson et al., 2017). These findings thus provide further evidence to the idea that lexical knowledge – at least during infancy – can be dissociated, in that implicit aspects of knowledge can be apparent in the absence of more explicit responses.

Whilst not directly related to the idea of dissociating lexical knowledge according to behavioural response, there is also evidence in the literature that word comprehension in infancy may further depend on extra-linguistic cues. Expanding on earlier findings that infants appear to ‘know’ the meanings of common nouns in preferential looking paradigms (Bergelson & Swingley, 2012), Kartushina and Mayor (2019) tested the possibility that evidence of this knowledge in such paradigms may be dependent on extra-linguistic cues. For example, many of the word pairings in Bergelson and Swingley (2012) had imbalanced frequencies according to the CHILDES database, such as ‘hair-banana’. One possibility, therefore, is that infants may make use of this frequency cue as a means of fixating towards the correct target referent (i.e., fixating on a frequently seen object after hearing a high frequency label). Consistent with this idea, the study of Kartushina and Mayor (2019) observed a higher proportion of looks to the target referent in frequency imbalanced pairs compared to frequency balanced pairs (see Steil et al., 2021, for similar findings in German infants). Infants also appear sensitive to the speakers’ voice, with comprehension appearing hindered when the label is produced by an unfamiliar voice (Bergelson & Swingley, 2018; Steil et al., 2021).

Collectively, these findings raise an element of doubt regarding the proficiency of infant lexical knowledge, at least during the first few years of development. If infants truly understand the meanings of common nouns as has been claimed (Bergelson & Swingley, 2012; Tincoff & Jusczyk, 2012), an understanding that is semantic in nature, it is unclear why evidence of such knowledge would depend on additional cues such as frequency and speakers' voice. Perhaps one possibility is that knowledge is not truly semantic in nature at this stage but is rather quite rigid. In which case, lexical knowledge would be somewhat immature; dependent on extra-linguistic factors (Bergelson & Swingley, 2018; Kartushina & Mayor, 2019; Steil et al., 2021) and/or elicited only under certain measures (Bannard & Tomasello, 2012; Hendrickson et al., 2015; 2017).

1.3.1.3 Electrophysiological Correlates of Infant Word Knowledge

EEG is a useful methodology for measuring online language processes, particularly in infant research where explicit behavioural responses can be difficult to elicit (e.g., due to immaturity of attentional mechanisms). As has been explained, the N400 component is a sensitive measure of semantic processing, and indeed is commonly measured in infant research as a means of testing proficiency of word knowledge in infancy (for a recent review see Junge et al., 2021).

In infant research, a cross-modal paradigm is a popular technique for eliciting the N400 effect. In such paradigms, an on-screen object is displayed (e.g., the image of a dog), followed by a spoken label that is either the corresponding (e.g., *dog*) or an incongruous label (e.g., *pencil*). As with research described earlier, a greater N400 response is found following incongruous picture-word pairings than following congruous pairings.

Friedrich and Friederici (2004) first observed the N400 effect in infants using this paradigm, specifically at 19-months of age. The onset of this effect was delayed relative to adults and was seen at more frontal regions of the scalp. It should be noted though that across infant N400 studies there is considerable variability in N400 latency and distribution characteristics (Junge et al., 2021).

The N400 effect has since been observed at 24 months (Rämä et al., 2013), 20 months (Von Koss Torkildsen et al., 2007), 18 months (Rämä et al., 2013), 14 months (Friedrich &

Friederici, 2005a), 12 months (Friedrich & Friederici, 2010), and 9 months of age (Parise & Csibra, 2012). The variability within age groups however is noticeable. For instance, the N400 effect is more adult-like or even exclusive in infants with superior language abilities (Friederich & Friederici, 2004; 2010; Rämä et al., 2013), and is not observed in infants who are at risk of developing later language impairments such as developmental language disorder (DLD; Friedrich & Friederici, 2006) or dyslexia (Von Koss Torkildsen et al., 2007). Thus, N400 activity, and potentially underlying semantic processing, seems quite variable amongst infants, which seems associated to developmental profiles.

The youngest age at which N400-like activity has been observed is 6-months (Friedrich & Friederici, 2011). In this study, infants were trained on novel word-object associations. Across 8 presentations, some objects were consistently paired with the same novel word (consistent condition), whilst others were paired with a new novel word on each presentation (inconsistent condition). Across training, the consistent condition was associated with reduced negativity at parietal regions, suggesting the acquisition of some knowledge regarding words and their referents. There was, however, no significant N400 effect elicited via a cross-modal paradigm the next day, suggesting that these mappings were fragile and prone to decay.

The cross-modal paradigm that is often used in infant studies also commonly elicits a second ERP of interest: the *N200-500 component*. This component is attributed to indexing word-form familiarity and is enhanced in response to known relative to unknown/novel words (Koojiman et al., 2005; Mills et al., 1993; 1997). Whilst the effect is distributed around temporal electrodes in adults (Friedrich & Friederici, 2004), it is typically observed at frontal regions in infants (Friedrich & Friederici, 2004, 2005a, 2005b; Von Koss Torkildsen et al., 2007).

The N200-500 component is observed earlier than the N400 in the ERP signal (approximately 200-400ms post stimulus onset), and, in the context of a cross-modal priming paradigm, its amplitude is greater (i.e., more negative) in response to congruous picture-word pairings; thus, in the opposite direction to the N400 effect. The functional interpretation of this difference between congruous and incongruous pairings is that it reflects the facilitated retrieval of the associated word-form. Specifically, the object serves as a prime, which cues the associated, phonological form from memory. Accordingly, this difference between congruous and incongruous pairings has been named the *phonological-lexical priming effect* (PLPE; Friedrich & Friederici, 2004). Thus, this effect reflects the association between object and word-form representations in memory, and 'does not evidence higher-level semantic representations' (Friedrich et al, 2015, p.3).

1.3.1.4 The PLPE vs. N400 effect: A Tool for Dissociating Word Knowledge?

This distinction illustrates another potential means by which lexical knowledge can be dissociated, and indeed infant studies have observed dissociations between the PLPE and N400 effect. For example, Friedrich and Friederici (2005b) observed no N400 effect in 12-month-old infants but did observe a significant PLPE. This might suggest these infants have formed associations between specific objects and word-forms but have not established semantic representations for these words. Similarly, infants who are at risk of developing DLD or dyslexia (Friedrich & Friederici, 2006; Von Koss Torkildsen et al., 2007) display a prolonged PLPE, relative to a control group of infants, in the absence of an N400 effect. One explanation for this extended effect is that word-form processing is more effortful in these infants, requiring a longer time-course. Nonetheless, the presence a PLPE effect suggests that these infants still know something about these words, albeit that this knowledge may be non-referential and relatively more basic in nature.

Research has also examined the role of social learning on the ERP response to new words. Hirotani et al. (2009) taught 18–21-month-old infants novel word-object pairings in joint-attention (established eye contact between the experimenter and infant, positive tone when labelling the object, etc) and non-joint-attention conditions (no eye-contact, neutral tone, etc). In a later testing phase, words were presented with their congruous or an incongruous object. Words taught in both conditions elicited a response akin to the PLPE. However, only words learned via joint-attention elicited an N400 effect. These results are therefore akin to the behavioural findings of Bannard and Tomasello (2012) in that joint-attention learning conditions appear to provide an extra level of lexical knowledge beyond learned associations.

1.3.1.5 Summary of Infant Lexical Knowledge

This section has considered the idea that lexical knowledge in infancy can be dissociated into different levels, with behavioural and electrophysiological data suggesting that this is indeed possible. Behavioural data has shown that lexical knowledge can be dissociated according to the measure of interest, and that learning conditions appear to influence the quality of acquired knowledge. Whereas non-social learning appear to provide some understanding, joint-attention learning conditions appear to provide an additional important factor that is key to explicit understanding. Electrophysiological data also point towards a dissociation in showing there at least two distinct ERP components that are related to independent aspects of word knowledge. Following the functional interpretation of these ERPs, these studies suggest it is possible to observe associative knowledge (i.e., learned associations between an object and word) in the absence of semantic representation, either between subjects (i.e., based on language ability) or following experiment manipulations (i.e., learning conditions).

1.3.2 Models of Memory and Lexical Acquisition

The literature reviewed in the previous section suggests it is possible to dissociate and identify unique aspects of knowledge in infants. An ensuing question, then, is whether this is also true in the adult population, and if so, how is this dissociation characterised.

To explore this question, the following section will discuss theories of memory and lexical acquisition in adults. As will be discussed, a core assumption of these accounts is that knowledge is dissociable according to its state of representation. This dissociation can be described as a function of time, with more recent knowledge stored and represented independently from existing knowledge, before being slowly integrated with existing representations such that dissociations become weaker.

1.3.2.1 The Complementary Learning Systems Account of Memory

When learning a novel piece of knowledge, the Complementary Learning Systems (CLS) account of memory proposes that information is not integrated into cortical networks straight away. McClelland et al. (1995) rather propose the existence of two complimentary learning systems. The first learning stage involves the rapid acquisition of sparsely represented knowledge that is regulated by the hippocampus and surrounding, medial temporal lobe structures (Norman, 2010; Norman & O'Reilly, 2003). With time, this knowledge is slowly integrated into cortical networks, where novel representations integrate and overlap with representations of similar concepts, allowing this shared knowledge to be recognised.

The existence of two complementary learning systems appears necessary to prevent catastrophic interference when learning novel information (McCloskey & Cohen, 1989). That is, without an initial, supportive role of the hippocampus, new knowledge appears to overwrite existing knowledge in the cortex to the extent that existing knowledge is erased (McClelland et al., 1995). To prevent this, the hippocampus slowly 'teaches' the cortex about these novel events encoded during a learning episode, so that cortical representations are slowly adjusted to accommodate this new information whilst existing representations are preserved.

The integration process, characterised by knowledge gradually become less dependent on the hippocampus and interleaving with existing representations, is thought to be facilitated by offline consolidation that occurs during periods of sleep. Sleep enables hippocampal replay and reactivation, facilitating the encoding of knowledge into cortical networks (Schapiro et al., 2018; Stickgold & Walker, 2005; 2013; Tamminen et al., 2010; 2013; Tukker et al., 2020). For instance, slow-wave sleep (stages 3 and 4 of non-REM sleep) appears particularly important in establishing an offline synergy between the hippocampus and cortex (Born, 2010). That said, some theories propose that the effect of sleep on memory consolidation is more passive, in that sleep provides an optimal state of minimal interference from incoming stimuli compared to time spent awake (reviewed in Ellenbogen et al., 2006).

Rather than integrate an exact 'copy' of hippocampal memories, including the spatiotemporal context in which the memory occurred, the consolidation process is thought to create a 'gist-like' representation of encoded events, such that important features and regularities are extracted (Moscovitch et al., 2016; Winocur & Moscovitch, 2011). Hence, whilst learners may lose fine and specific details about a learning episode, the core features of this encoded knowledge are maintained. This process is quite easy to see in action. For example, over time, an individual likely builds up an understanding that the capital city of *France* is *Paris*. However, they are unlikely to recall exactly when or where they acquired this knowledge.

1.3.2.2 The CLS Account in the Context of Lexical Acquisition

Word learning does not stop functioning once we reach a certain age or reach a certain threshold of acquired words. Instead, the word learning process is continuously recruited throughout one's lifetime (Ramscar et al., 2014), and we similarly continue to update our understanding of known words (Klooster & Duff, 2015). This is a vitally important process given that the frequency and co-occurrence of words changes over time (Ramscar, 2016), and we must adapt to these changes to remain efficient language users. Consider, for example, the word *broadband*, a term introduced in the 1950s to refer to the transmission of data across a range of frequencies. This word was thus part of an abundance of new terms introduced to language as a result of technological advances in the 20th century. Yet, in order to be a part of such advances, humans must possess an intrinsic ability to acquire new terms as and when they appear.

Following the core principles of the CLS framework, Davis & Gaskell (2009) created a theoretical account explaining the properties and time-course of lexical acquisition. According to this model, newly acquired lexical knowledge is initially supported by the hippocampus, before being integrated with existing lexical knowledge in cortical language networks with time. A consequence of these different states of representation is that the ‘lexical’ status of new words is distinct from that of existing words, with the former classified as episodic in nature compared to true lexical units that are represented in language networks, independently from the hippocampus (Davis & Gaskell, 2009).

When a new word and its meaning is acquired, the representation of this novel piece of information is initially mediated by the hippocampus (see Stage 1 of Figure 2). For example, the mapping between word-form representations (e.g., *broadband*) and semantic representations (*a transmission technique using a wide range of frequencies*) is bound together and mediated by the hippocampus. With time and consolidation, the dependency on the hippocampus decreases as direct cortical mappings between word-form and semantics are developed, and novel knowledge is integrated with existing representations (see Stage 2 of

Figure 2). The second stage of the learning process, according to the CLS model, gives rise to true, 'lexicalised' words.

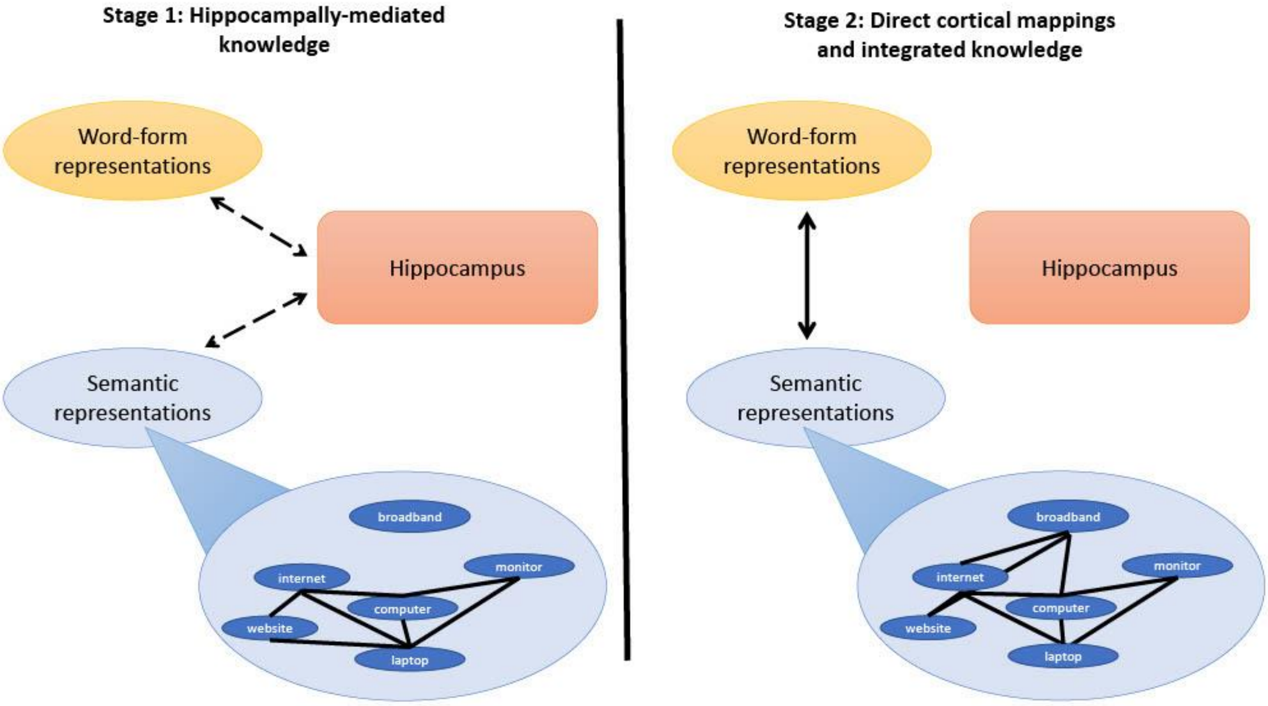

Figure 2: A simplified illustration of the CLS account of lexical acquisition. Knowledge is initially mediated via the hippocampus (dashed black lines) before direct cortical links develop (think black line). Within specific networks[1], novel knowledge is integrated with existing knowledge with consolidation. As mentioned, this is indeed a simplified diagram of modelling lexical processing. For instance, there is a likely a lexical interface layer which maps word-form onto meaning that is not included here (Gow, 2012). The key, nonetheless, is to illustrate the independence from the hippocampus as cortical mappings emerge.

As discussed earlier, the cortical mappings between word-form and meaning, including an intermittent lexical interface/hub layer, reflects the conventional means by which lexical knowledge is stored and represented, and likely comprises various regions of the temporal lobe (e.g., Hickok & Poeppel, 2004; 2007; Gow, 2012). This state of representation therefore has priority in terms of lexical processing, relative to the indirect route of knowledge that is initially governed by the hippocampus. As a result, when words are represented episodically (i.e., knowledge is mediated by the hippocampus), they are likely to be processed more

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[1] In this particular figure, the semantic network is illustrated as consisting of holistic units to represent concepts. This was done simply to illustrate the integration process as clearly as possible – we make no claims regarding the way in which semantic knowledge is represented in the brain.

slowly compared to existing items, and with lower priority (Davis & Gaskell, 2009; Lindsay & Gaskell, 2010). As direct cortical mappings develop, access to this knowledge becomes more automatic and ‘word-like’ (reviewed in McMurray et al., 2016). Nonetheless, the initial hippocampal route does still allow certain aspects of lexical processing to be fulfilled, such as allowing the meaning of a new word to be retrieved.

This theory of lexical knowledge thus proposes a dissociation in lexical knowledge, in terms of the state of underlying representation – a new word is represented via the hippocampus, while existing items are stored in language networks independently from episodic memory systems. This dissociation is largely dependent on time/consolidation. That is, with time, dependency on the hippocampus decreases as direct lexical pathways develop and novel knowledge is integrated with existing understanding.

1.3.2.3 Neuroimaging Support for the CLS Account of Lexical Acquisition

A fundamental assumption of the CLS account of lexical acquisition is that following a learning episode, hippocampal involvement in regulating knowledge should decrease as a function of time, whereas cortical systems should simultaneously become more involved (Gais et al., 2007; Takashima et al., 2006; 2009). A useful means of measuring this assumption is through fMRI, given the high spatial resolution of the fMRI signal.

Concerning hippocampal activity, Breitenstein et al. (2005) observed a linear decrease in hippocampal activity across training when novel words were consistently paired with the same objects. Hippocampal activity has also been found to decrease across days, with weaker activation found one day (Takashima et al., 2014) and seven days (Takashima et al., 2017) after training where activation was greatest, a finding that is also observed in children (Takashima et al., 2019). Similarly, the hippocampus is more active in response to unfamiliar novel word-forms, compared to novel word-forms taught the previous day (Davis et al., 2009).

In terms of cortical activity, Davis et al. (2009) reported greater STG activity in response to unfamiliar novel words, compared to novel word-forms taught the preceding day as well as existing words. The authors argued that this reflects more fine-tuned phonological representations for learnt (novel) and existing words. In Takashima et al. (2014; 2017), cortical activity was more widespread one day and seven days after learning, respectively, compared to on the day of learning. This includes greater STG activity, which is contrary to the findings of Davis et al. (2009). One possible explanation was the use of a pause-detection task in the Davis et al., during scanning. This requires a degree of acoustic analysis which may have left fewer resources available for accessing phonological representations (Takashima et al., 2014).

An interesting finding from Takashima et al. (2014) was more widespread cortical activity in response to new words taught with an associated meaning (in the form of an unusual object), compared to words without meaning (i.e., just the word-form was learnt). This potentially coincides with the recruitment of brain regions concerned with the representation of semantic meaning, including the anterior temporal lobes (Patterson et al., 2007).

Collectively, these data largely corroborate the core principles of the CLS framework to lexical acquisition. That is, in its early stages, lexical knowledge appears to recruit episodic memory systems, which maintain knowledge about the words' phonological/orthographic form and its meaning. With time, this knowledge is gradually consolidated into cortical language systems, and the dependency of knowledge on episodic systems is reduced as cortical language regions become more involved.

1.3.3 The Lexical Behaviour of New words

Leach and Samuel (2007) coined the terms *lexical configuration* and *lexical engagement* to classify distinct lexical processes. Lexical configuration broadly relates to factual information about a particular word, such as knowledge of its phonological form and meaning. Lexical engagement, however, concerns a word's ability to interact and engage with other lexical items. One such example of lexical engagement is semantic priming, where words interact with one another in the sense that the processing of a particular word is influenced by the meaning of another words. Words are said to be represented in cortical language networks (i.e., have a 'lexical' status) when they possess both of these unique aspects of lexical understanding (i.e., they behave like a true lexical item).

According to the CLS model of lexical acquisition, new words do not achieve a 'lexical' status until they have integrated into language networks and are no longer dependent on the hippocampus (Davis & Gaskell, 2009). What is the consequence of not bearing a 'lexical' status? Whilst some aspects of lexical processing can be completed without this status (i.e., retrieving the meaning of a new word), is there anything that these 'non-lexical' words cannot do?

The CLS model predicts that new words do not behave like existing words because, when represented via the hippocampus, they cannot interact or engage with other words in tasks such as semantic priming. Since these words are not integrated into cortical language networks, existing words are processed more quickly and with priority, meaning the potential influence of new words is negligible. Similarly, a word may elicit mechanisms such as spreading activation only if it has integrated with existing knowledge in semantic networks (Tamminen & Gaskell, 2013). Hence, new words may lack lexical engagement properties in early stages of learning.

The following sections will review evidence of this claim from the behavioural and electrophysiological literatures, respectively. They will predominantly focus on the engagement capabilities at the level of semantics via semantic priming; however, other methods comprising engagement from other aspects of knowledge (e.g., phonology) will also be discussed. As will become apparent, the interactive capabilities of new words do not appear as feeble as once thought, and lexical interaction seems possible under certain experimental conditions.

1.3.3.1 Semantic priming capabilities of new words

Studies that have used semantic priming to measure whether or not recently learned novel words can semantically prime related counterparts are summarised in Table 1. The rationale for adopting this method is that the semantic priming effect is (at least partially) assumed to be underpinned by the interaction between integrated representations in semantic networks (e.g., see section 1.2.1). If this hypothesis is true, then priming may depend on sleep-related consolidation, since sleep is thought to facilitate the integration of new words with existing knowledge (Davis & Gaskell, 2009). Accordingly, semantic priming has been used as a methodological tool for measuring how a given word and its meaning, at any given time, is encoded. This section of the thesis will discuss the literature pertaining to novel word semantic priming and what these results reveal concerning the encoding of new words.

Note that many of the studies presented in Table 1, whilst providing behavioural data, also recorded EEG activity simultaneously during the priming task to measure the electrophysiological signal in response to these words and to priming. These studies are labelled accordingly in Table 1 and their EEG results are discussed in more detail in section 1.3.3.3 and Table 2. Furthermore, note that hereafter we use the term *recently learned* *word(s)* to refer to words that are taught before a critical testing phase (i.e., semantic priming), *without* a period of offline consolidation in between.

Table 1: Summary of studies investigating novel word semantic priming effects. Studies labelled with a superscript ‘EEG’ additionally measured EEG activity (see Table 2 for EEG findings).

Study	Number of new words/concepts	Type of conceptual information	Method of training	Measure of semantic priming	SOA between the prime and target	Was there a significant semantic priming effect involving **recently learned** words	Was there a significant semantic priming effect involving **consolidated** words	How did participants perform on explicit knowledge measures for **recently learned** words?
Bakker et al., (2015)^{EEG}	40 (20 per level of consolidation)	Definitions	Explicit encoding	SJT. New words served as targets for related/unrelated existing primes	500ms	Yes	Yes (one day after learning)	**89% accuracy** on definition recall; **98% accuracy** on 4-AFC word recognition
Bakker – Marshall et al., (2018)^{EEG}	40 (20 per level of consolidation)	Definitions	Explicit encoding	pLDT. New words served as primes for related/unrelated targets	500ms	No	No	**96% accuracy** on definition recall. **75% accuracy** on 4-AFC word recognition
Balass et al., (2010)^{EEG}	105	Definition and example sentence	3 types of learning conditions (within-subjects): Orthography-to-meaning (OM); orthography-to-phonology (OP); phonology-to-meaning (PM)	SJT. New words served as primes for related/unrelated targets	1000ms	Yes, only for OM and PM words	Effect of consolidation was not measured	No measure of explicit knowledge included

Batterink & Neville (2011)^{EEG}	20	Novel words contained within a high or low constraining sentences	Reading a fictitious story containing the sentences/novel words	SJT and pLDT. For both, new words served as primes for related/unrelated targets	500ms	No	Effect of consolidation was not measured	Results not reported
Borovsky et al., (2012)^{EEG}	66	Novel words contained within a high or low constraining sentences	Reading a sentence to decipher the meaning of the novel word	pLDT. New words served as primes for related/unrelated targets	500ms	No	Effect of consolidation was not measured	No measure of explicit knowledge included
Breitenstein et al., (2007)	45	Images	Novel words consistently paired with the same familiar object across training	SJT. New words served as primes for their associated familiar object. Participants decided if object was animate or inanimate object	~1182ms	No	Yes. New words facilitated object recognition	
Coutanche and Thompson-Schill (2014)	16	Images	Explicit encoding or fast mapping (between-subjects)	pLDT. New words served as primes for related/unrelated targets	200ms	No	Yes, only for fast mapping words (one day after learning)	***68.45% accuracy** in judging picture-label pairings
Kaczer et al., (2018)^{EEG}	15	Definitions and images	Explicit encoding	SJT. New words served as targets for related/unrelated existing primes	500ms	No	No	**53% accuracy** on definition recall; **62% accuracy** on definition recall
Mestress-Misse et al., (2007)^{EEG}	Not explicitly stated	Novel words contained within a high	Reading a sentence to decipher the	SJT. New words served as primes for	500ms	No**	Effect of consolidation	No measure of explicit

		or low constraining sentences	meaning of the novel word	related/unrelated targets			was not measured	knowledge included
Perfetti et al., (2005)^{EEG}	60	Definitions of rare words	Self-paced reading of words and definitions	SJT. New words served as primes for related/unrelated targets	1000ms	Yes	Effect of consolidation was not measured	No measure of explicit knowledge included
Tamminen and Gaskell (2013) exp. 1	68 (34 per level of consolidation)	Definitions	Explicit encoding	pLDT. New words served as primes for related/unrelated targets	450ms	No	Yes (one day and eight days after learning)	*****~88%** accuracy on definition recall
Tamminen and Gaskell (2013) exp. 2	34	Definitions	Explicit encoding	pLDT. New words served as primes for related/unrelated targets	47ms	No	Yes (eight days after learning)	*****~96%** accuracy on definition recall
van der Ven et al., (2015)	64	Definitions	Self-paced reading of words and definitions	pLDT. New words served as primes for related/unrelated targets	250ms	No	Yes (one day after learning)	**97.5% accuracy** on 4-AFC definition recognition
van der Ven et al., (2017)	24	Definitions	Self-paced reading of words and definitions	pLDT. New words served as primes for related/unrelated targets	250ms	No**	Yes (one day after learning)	**81.4%** on 4-AFC definition recognition

Recently learned words refer to words taught prior to the semantic priming task without periods of offline consolidation. ***Consolidated*** words refer to words taught at least a day before the priming task.

*For simplicity, we have averaged accuracy rates across explicit encoding and fast mapping conditions. Accuracy was significantly greater in the explicit encoding compared to fast mapping group.

**Non-significant priming effects were also observed in the familiar word condition, meaning novel words should be interpreted cautiously.

***Numerical descriptive statistics are not reported in this paper. We therefore estimate these values based on figures of results reported in the paper.

One of the first studies to investigate semantic priming with new words was Perfetti et al. (2005). Here, participants learned the definitions of rare English words, which later served as primes for related or unrelated target words in a semantic judgement task (SJT). The SJT offers an alternative method to the pLDT for measuring semantic priming, where participants decide if the prime and target are semantically related or not (compared to deciding if the target is a real word or not in a pLDT). Crucially, it was found that response times were quicker on related compared to unrelated trials involving recently learned rare words. This same facilitation on related trials, however, was not observed in Mestress-Misse et al. (2007), whilst in Breitenstein et al. (2007) priming was observed following a 5-day training regime where new words were paired with familiar objects.

As described in Tamminen and Gaskell (2013; hereafter abbreviated to **TG13**), however, the effect of priming in these studies may not have directly tapped into activity within the semantic network. For instance, in Perfetti et al. (2005) the target words often appeared within the trained words' definition, whilst in Mestress-Misse et al. (2007) targets were the direct translation of learned novel words. In these cases, it is possible that any priming effect is sourced from an episodic memory system which detects similarities between the prime-target pairings of the priming task with learned associations formed during training (i.e., episodic prime-target associations). Because of this, the scope of these studies in measuring the integration of semantic representations with existing knowledge is limited.

In response to these limitations, TG13 established a paradigm with no overlap between training and priming materials. In their first experiment, 60 participants were taught 34 new words (e.g., *feckton*) and their meanings (in the form of a definition – *a type of cat that has stripes and is blueish-grey*) on the first day of the experiment (remote condition). Half of participants returned a day later to learn a second set of 34 words, whilst the other half returned a week later and also learned a second set of words (recent condition).

Following the second training phase, these new words served as primes for related and unrelated real word targets (and nonword targets as per the design of a pLDT). Related targets were identified by taking the core concept of the novel words (e.g., *cat*) and identifying three associates of this concepts (e.g., *dog*, *mouse*, *kitten*) from the University of South Florida Free Association Norms (UoSFN - Nelson et al., 2004). As can be seen, the associates were not presented as part of the novel word’s definition, making this design more sensitive to measuring lexical integration compared to previous designs.

Although the interaction between priming and time of testing (remote vs recent) was non-significant, analysing the priming effect separately revealed a significant semantic priming effect only for remote words. Similar findings were found in their second experiment, where the SOA between the prime and target was reduced from 450ms to 47ms. Here, a priming effect was only observed one week after the novel words had been learned (non-significant effects immediately after training and one day after training). Furthermore, when the data from both experiments was analysed collectively, a significant interaction between priming and time of testing was significant, such that semantic priming was only founds for words which experienced offline consolidation before the priming task, and not for words taught immediately before. These results argue that new words require at least one night of offline consolidation (post-learning) before they elicit semantic priming of related words, perhaps indicative of the integration of novel knowledge (Davis & Gaskell, 2009).

This finding that novel words cannot behaviourally prime existing words without periods of offline consolidation has been observed elsewhere (Bakker-Marshall et al., 2018; Batterink & Neville, 2011; Borovsky et al., 2012; Kaczer et al., 2018). Previous work has also replicated the finding that novel words can semantically prime existing words *following* offline consolidation (Coutanche & Thompson-Schill, 2014; van der Ven et al., 2015; 2017). Again, these data support the CLS account of lexical acquisition, in showing that the integration semantic representations, and ultimately semantic priming, appears at least partly dependent on offline consolidation periods.

That said, there has been some evidence of novel word semantic priming in the literature. As discussed, the findings from Perfetti et al. (2005) could be explained by episodic associations between primes and targets. However, significant effects were reported in Bakker et al. (2015) and Balass et al. (2010) where there was no overlap between priming and training materials. The locus of these effects may thus stem from processing occurring independently from episodic memory and could indeed reflect the immediate integration of words into language networks. Hence, while sleep may facilitate the integration process, it may not be a necessary factor as argued by the CLS account (Davis & Gaskell, 2009).

As is clear from Table 1, a range of SOAs have been recruited across studies. Some of these SOAs are thought to be short enough to bypass strategic mechanisms (McNamara, 2005). Significant priming effects also appear to emerge when the SOA is relatively long. That is, significant priming effects have been reported with SOAs of 500ms (Bakker et al., 2015) and 1000ms (Balass et al., 2010; Perfetti et al., 2005).

Given the role of the SOA in influencing the recruitment of respective priming mechanisms (McNamara, 2005; Neely, 1977), a tentative possibility could be that novel words may prime related counterparts, but this is more heavily dependent on strategic rather than an automatic processing system. In further support of this claim, all three of these studies recruited a semantic judgement task (SJT) to measure priming. Compared to a pLDT, semantic processing is deemed as more explicit and controlled in an SJT, given the requirement for semantic access and evaluation. Thus, strategic semantic processing is more likely to be encouraged in an SJT to facilitate performance.

Hence, while significant effects reported in the literature could be indicative of integrated lexical items, the fact that effects appear to emerge with relatively long SOAs could suggest that priming is more heavily dependent on strategic processing. For example, the meanings of recently learned words can be acquired and recalled quickly, as seen from good explicit knowledge performance across studies (see Table 1). Given that the meanings of new words can be recalled without offline consolidation, perhaps these meanings could be used in conjunction with strategic priming mechanisms, despite potentially being more reliant on episodic/hippocampal systems. In which case, fully integrated representations may not be a prerequisite for these mechanisms, and hence priming, to emerge.

In sum, the current evidence base largely favours the notion that recently learned words cannot semantically prime existing words, supporting the hypothesis that new words are not integrated into semantic networks soon after acquisition (Davis & Gaskell, 2009). Nonetheless, there is some evidence that new words can exhibit these effects, suggesting sleep may not be necessary for lexical integration. One possibility, however, is that significant effects could be underpinned by strategic processing, as opposed to automatic processing which may depend on the extent to which new words have been integrated with existing knowledge. However, to our knowledge, no prior study has explicitly manipulated the recruitment of respective priming mechanisms with novel words in a single experimental paradigm.

1.3.3.2 Phonological competition capabilities of new words

As with semantics, words can also engage with one another at the level of phonology. For example, phonologically similar words (e.g., *cat*, *cap*, *can*) share similar patterns of representation. When processing incoming speech therefore, a set of lexical candidates matching the speech stream are simultaneously activated, which are gradually eliminated as the speech stream unfolds to reveal a particular lexical candidate (Gaskell & Marlsen-Wilson, 1997). This co-activation of related word-forms, however, has the potential to impair the recognition and processing speed of the correct item (e.g., Allopenna et al., 1998). Evidence of this *lexical competition* can therefore be taken as evidence for integrated word-forms into phonological networks, making it a useful means of measuring the integration of novel words.

Gaskell and Dumay (2003) investigated novel word competition effects via a pause-detection task. In this task, a pause (e.g., 200ms long) is inserted within a particular word. The participant's task is to decide whether a pause was present. However, decision times are longer when lexical activity is high leading up to the pause (Mattys & Clark, 2002). This supposedly reflects the coactivation of phonologically similar words, leaving fewer resources available for pause detection. For example, when a pause is inserted in a word with a late uniqueness point[2] (e.g., *ca_t*), many lexical candidates (*cat, cap, can*) are active up to the point of the pause, delaying decision times. In Gaskell and Dumay, novel word-forms (e.g., *cathedruke*) were created which diverged from a real English word (*cathedral*) at the final vowel. The real English words were used as stimuli in a pause-detection task immediately after training and one week later. If the novel word-forms (*cathedruke*) had been integrated into lexical networks, then detecting a pause embedded within their base word should be slower. Such effect was not observed immediately after training but did appear one week later.

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[2] The uniqueness point of a word refers to the point at which a word diverges from all other words.

This effect was replicated in later studies which found that significant effects were observable 24 hours after initial acquisition (Dumay et al., 2004), an effect which is also apparent in children (Henderson et al., 2012; 2013; 2015). Dumay and Gaskell (2007) further sought to clarify whether this effect was simply due to the passage of time, or whether offline sleep periods had a particular causal role. To investigate this, one group of participants learned novel word-forms at 8am and returned to the lab 12 hours later at 8pm (wake group), whilst the other half were trained at 8pm and returned at 8am (sleep group). Thus, whilst the time between experimental sessions was equal, participants in the sleep group slept in between sessions. For both groups, competition effects were not observed immediately after training. In the sleep group, however, significant effects emerged in the second session, which was not observed in the wake group. Furthermore, Tamminen et al. (2010) found that the amount of sleep spindle activity, defined as 10-16Hz oscillations during non-REM sleep (Andrillon et al., 2011), is directly correlated with changes in overnight lexical competition. Since competition should rely on integrated phonological representations, the authors concluded that sleep spindles are directly involved in the integration of new words with existing knowledge.

More recent work, however, recruiting different methods of measuring competition, have reported significant competition effects without periods of offline consolidation. Some of these findings have raised doubt over the *necessity* of sleep to facilitate lexical integration, and whether in fact some aspects of knowledge are readily integrated without it.

These studies recruited the visual world paradigm (VWP) to measure lexical competition (Allopenna et al., 1998). In such designs, fixations towards an on-screen target object (e.g., click on the *beaker*) – an online measure of lexical processing – are impaired when the target is presented alongside a picture with the same phonetic onset (e.g., *beetle*) or a rhyming word (e.g., *speaker*). Again, the phonological overlap between these words is said to induce lexical competition due to the coactivation of respective representations in lexical memory.

Following earlier work (Marslen-Wilson & Warren, 1994), Kapnoula et al. (2015) devised a modified version of the VWP to measure novel word competition. For any given trial, looks to a target referent (e.g., *job*) were measured in one of four conditions: 1) the final portion of an auditory recording of the target word (e.g., *-b*) was spliced (i.e., joined) together with the initial portion of a separate recording of the same word (e.g., $jo_b b$); 2) the final portion of the target word was spliced with the initial portion of a phonological similar word (e.g., $jo_g b$); 3) the final portion was spliced with the initial portion of a trained nonword (e.g., $jo_d b$); 4) the final portion was spliced with the initial portion of an untrained nonword. These stimuli are argued to initiate lexical competition because the vowels in the mismatch conditions ($jo_g b$) should predict a final consonant (*-g*) that is not represented in the target (*job*), inhibiting target processing. Such inhibition however should only occur if a given word-form is represented in lexical memory (Kapnoula et al., 2015).

In Kapnoula et al. (2015), participants were trained on 10 novel word-forms prior to the VWP. Unlike previous investigations however, these trained novel word-form inhibited processing of their related targets (i.e., looks to the target referent (*job*) was impaired by trained $jo_d b$ stimuli). Furthermore, the time course of these effects was indistinguishable from the effects of existing words. These effects are also found when a different speakers produce the words across training and testing (Kapnoula & McMurray, 2016), suggesting these effects are not tied to episodic representations and may reflect the immediate integration of novel word-forms. In other words, these findings are inconsistent with the CLS account.

In another VWP study, Weighall et al. (2017) observed immediate competition effects from novel words taught with meaning. However, this behaviour was not considered ‘word-like’, due to observed differences in the time course and magnitude of the effect compared to familiar items. Accordingly, the authors interpreted these findings as consistent with CLS predictions. More specifically, Weighall and colleagues argued that new words *can* engage in competition when initially stored episodically. However, such competition may be dependent on the type of task administered (as well as other factors – reviewed in McMurray et al., 2016). Furthermore, the nature of novel word competition it likely to follow an extended time course, due to new words having lower priority relative to existing lexical items. This could explain differences in the literature regarding the presence of competition effects. The pause detection task, for example, requires a swift, speeded decision, which may be too demanding for information stored indirectly in the hippocampus. The VWP, however, measures competition across an extended time course, which 'may be better able to incorporate information arriving relatively slowly via recently learned hippocampal links' (Weighall et al., 2017, p.24). Access to lexical knowledge thus seems to become more automatic with time and consolidation (Geukes et al., 2015; McMurray et al., 2016; Tham et al., 2015), in that significant effects begin to emerge when the measured response relies on more automatic components of word processing (e.g., pause detection).

This relates to the possibility we raised earlier, that perhaps novel words can semantically prime via strategic mechanisms. However, the argument that the VWP may be better able to accommodate information arriving slowly from the hippocampus presents another interesting instance of SOA playing a role in semantic priming. That is, perhaps the long SOAs of previous work which report significant priming effects could also have accommodated information arriving slowly from the hippocampus. Hence, not only could a long SOA allow the participant to use strategic tactics, but it may be necessary to allow the hippocampal representations to engage sufficiently to retrieve novel word meaning.

In sum, findings surrounding the lexical competition effects of new words are quite mixed. On the one hand, pioneering research utilising the pause-detection paradigm largely suggests that offline consolidation periods are necessary before significant effects emerge. On the other, more recent research utilising the visual-word paradigm has revealed significant effects soon after learning, without sleep periods. These findings challenge the CLS account of lexical acquisition in showing that sleep may not be necessary for lexical integration. That said, some authors (Weighall et al., 2017) have argued that such effects could still be explained by assuming early words are initially hippocampal dependent, in that the hippocampus is selectively activated to different extents across tasks. However, further research is necessary to empirically investigate this claim, and it also remains unclear whether this explanation could extend to semantic processing.

1.3.3.3 Novel Words and the N400 effect

As a neural marker for integrated semantic representations, studies often measure the N400 component in response to processing new words. Studies often measure this effect, following the theoretical account that the N400 can reflect automatic aspects of lexical access (Aurnhammer et al., 2021; Kutas & Federmeier, 2000; Lau et al., 2008) which, as discussed, may only occur for integrated semantic representations.

Existing research in this area — which has measured novel N400 effects in the context of semantic priming paradigms — is presented and summarised in Table 2. Note that Table 2 specifically presents studies in which novel words and their meanings were taught to participants and then later served as stimuli in a priming task in an attempt to elicit the N400 effect.

Table 2: Summary of studies investigating novel word N400 effects in the context of novel word semantic priming.

Study	Number of new words/concepts	Type of conceptual information	How did participants learn meanings?	How was N400 effect measured?	SOA between the prime and target	Was an N400 priming effect present?	If N400 was present, did the topography differ to the familiar N400 effect?	How did participants perform on explicit knowledge measures?
Angwin et al., (2022)	12	Images	Cross-situational statistical learning	SJT. New words served as primes for related/unrelated existing primes	1000ms	Yes	Novel N400 had a left-hemisphere bias; familiar N400 right-hemisphere bias	**92% accuracy** on image recognition test
Bakker et al., (2015)	20	Definitions	Explicit encoding	SJT. New words served as targets for related/unrelated existing primes	500ms	No	N/A	**89% accuracy** on definition recall; **98% accuracy** on 4-AFC word recognition
Balass et al., (2010)	105	Definition and example sentence	3 types of learning conditions (within-subjects): Orthography-to-meaning (OM); orthography-to-phonology (OP); phonology-to-meaning (PM)	SJT. New words served as primes for related/unrelated targets	1000ms	Yes, only for OM and PM words	No difference in distribution between novel and familiar words (in SJT)	No measure of explicit knowledge included
Batterink & Neville (2011)	20	Novel words contained within a high or low	Reading a fictitious story containing the	SJT and pLDT. For both, new words served as primes for	500ms	Yes, only in the SJT	No difference in distribution between novel	Results not reported

		constraining sentences	sentences/novel words	related/unrelated targets			and familiar words (in SJT)	
Borovsky et al., (2012)	66	Novel words contained within a high or low constraining sentences	Reading a sentence to decipher the meaning of the novel word	pLDT. New words served as primes for related/unrelated targets	500ms	Yes, only for novel words contained in high constraining sentences	No difference in distribution between novel and familiar words	No measure of explicit knowledge included
Kaczer et al., (2018)	15	Definitions and images	Explicit encoding	SJT. New words served as targets for related/unrelated existing primes	500ms	No	N/A	**53% accuracy** on definition recall; **62% accuracy** on definition recall
Lie et al., (2022)	20	Definitions or Definitions and images (between-subjects)	Explicit encoding	SJT. New words served as targets for related/unrelated existing primes	500ms	No	N/A	***78% accuracy** on definition recall; **95% accuracy** on 4-AFC word recognition
Liu and van Hell (2020)	20	Definitions	Explicit encoding	SJT. New words served as targets for related/unrelated existing primes	500ms	No	N/A	****~62% accuracy** on definition recall; **~92%** accuracy on 4-AFC word recognition
Mestress-Misse et al., (2007)	Not explicitly stated	Novel words contained within a high or low constraining sentences	Reading a sentence to decipher the meaning of the novel word	SJT. New words served as primes for related/unrelated targets	500ms	Yes, only for novel words contained in high constraining sentences	The novel effect sourced from frontal regions; familiar effects from a temporal source	No measure of explicit knowledge included

Perfetti et al., (2005)	60	Definitions of rare words	Self-paced reading of definitions	SJT. New words served as primes for related/unrelated targets	1000ms	Yes	No difference in distribution between novel and familiar	No measure of explicit knowledge included

*For simplicity, we have averaged accuracy rates across the definition-only and definition-image groups. Definition recall was significantly higher in the definition-image group, whilst there was no significant difference in word recognition across groups.

**Numerical descriptive statistics are not reported in this paper. We therefore estimate these values based on approximation of statistics presented in figures.

As is clear from Table 2, the findings are quite mixed. Some studies have reported significant effects with recently learned words studies (Angwin et al., 2022; Balass et al., 2010; Batterink & Neville, 2011; Borovsky et al., 2012; Mestress-Misse et al., 2007; Perfetti et al., 2005) whilst others haven't (Bakker et al., 2015; Batterink & Neville, 2011; Kaczer et al., 2018; Lei et al., 2022; Liu & van Hell, 2020).

When significant N400 effects are observed, this is sometimes taken as evidence for the immediate integration of words into language networks (e.g., Borovsky et al., 2012). Bakker et al. (2015), however, have argued that at least some of the significant N400 effects reported in the literature could be sourced from representations that have not yet integrated into language networks. For instance, as discussed above, in Perfetti et al. (2005), the primes and targets often occurred together in the novel words' definition. In Mestress-Misse et al. (2007), the target word was often the direct translation of the learned novel words. In such cases, it was argued that significant effects reported elsewhere could have been sourced from episodic memory traces, rather than integrated semantic representations (Bakker et al., 2015).

As mentioned, studies in this area often explicitly use the N400 as a neural marker for integrated semantic representations (Bakker et al., 2015; Liu & van Hell, 2020; Lei et al., 2022). The CLS account of word learning would therefore predict that significant N400 effects with new words would not be seen immediately after acquisition, since integrated representations are developed with time. However, as we have discussed, there are other explanations of the N400 effect, which include the possibility that it may (also) index controlled aspects of semantic processing. In support of this, Batterink and Neville (2011) observed an N400 dissociation according to the task used to measure the N400. Significant effects with novel words were detected when participants completed an SJT but not during a pLDT. The authors argued that ‘explicit’ representations of new words can develop quickly, but more ‘implicit’ representations, such as those involved in more automatic semantic processes of a pLDT, may take longer to develop. The presence of an N400 effect in an SJT is akin to the presence of behavioural semantic priming effects that have also been reported using the same task (Bakker et al., 2015; Balass et al., 2010; Perfetti et al., 2005). Similarly, studies which report non-significant N400 effects often report clear late positive component (*LPC*) *effects* for new words (Bakker et al., 2015; Kaczer et al., 2018; Liu & van Hell, 2020; Lei et al., 2022). The late positive complex has been linked to more controlled aspects of semantic processing and retrieval (Hoshino & Thierry, 2012). Collectively, these findings raise the possibility that semantic processing in new words is relatively strategic in nature.

1.4 Summary of thesis

Broadly, the aim of this chapter was to introduce the concept of words. This chapter also described how words and their meanings are encoded in the human brain, and how researchers can measure semantic processing through behavioural and electrophysiological means.

One of the most important debates introduced in this chapter concerns the idea of whether lexical knowledge is dissociable, and this notion represents the core investigation of this thesis. Specifically, there is reason to believe that there are different ways of *knowing* a word, according to the way in which it is encoded in the brain, such that knowledge is dissociable through behavioural and electrophysiological measures.

Two strands of research were discussed which suggest this claim. Though these respective areas fundamentally suggest that there is more than one way of knowing a word, they make unique claims regarding the manner in which knowledge may be dissociable. In the infant word knowledge literature, there is evidence from behavioural and EEG research that there are at least two unique types of lexical knowledge: one which concerns associative knowledge between a word-form and object, and a second which concerns an understanding of a word's semantic meaning. Dissociations of knowledge have been observed through type of behavioural measure (e.g., implicit vs explicit measures of knowledge – Bannard and Tomasello, 2012) and through unique ERP effects (e.g., PLPE and N400 effect). Furthermore, there appears to be a stage during infancy when referential knowledge is not apparent, perhaps because the underlying mechanisms necessary to acquire this understanding are non-operational. Learning words in social contexts also appears to facilitate the acquisition of referential meaning.

The CLS model of lexical acquisition further suggests differences in how new and existing lexical knowledge is represented. According to this theory, knowledge starts out episodically, before being integrated into cortical language networks where words achieve their 'lexical' status (Davis & Gaskell, 2009). Evidence for this dissociation comes from neuroimaging studies, which largely show a decrease in hippocampal activity following word learning, alongside an increase in cortical activity. The CLS account also predicts that new words cannot engage with other words whilst represented episodically, since new knowledge has yet to integrate with existing representations. As discussed, however, the evidence surrounding this claim is quite mixed, with some reports of semantic priming and lexical competition effects with new words. Hence, some degree of integration may take place in the absence of sleep.

The infant literature suggests that lexical knowledge is dissociable via an associative – semantic dichotomy, where *semantic* is defined as knowledge about the referential nature of words. Whilst, according to the CLS theory, lexical knowledge is dissociable via an episodic – lexical dichotomy, where *lexical* is defined as the integration of words into language networks. Is there any way of bridging these two strands of research together? For example, could there be a link between the first level of these respective dichotomies, such that knowledge may start out as an episodic representation that acquires learned associations between a particular word and its referent? To the best of our knowledge, this question has not been considered or explored previously in the context of adult word learning. Chapter 2 explores this possibility via EEG.

A second core theme of this chapter was the discussion of the lexical behaviour of new words. Specifically, we discussed literature describing the ability of new words to engage and interact with existing lexical items. Concerning semantic priming, the evidence predominantly suggests that this is not possible without a period of offline consolidation. Concerning lexical competition, however, the findings appear more mixed, with consistent reports of competition effects when measured via the VWP. One possibility is that these results suggest integration with existing knowledge can occur at least to some extent without offline consolidation, and new words may exhibit similar patterns of behaviour as existing words.

When examining novel word interaction at the phonological level, significant effects are consistently observed when measured via a VWP. One possibility is that that the VWP is better able to incorporate information stored via the hippocampus, compared to methods that report non-significant effects (such as pause-detection) which appear to depend on automatic lexical access to a greater extent. This would mean that novel words can interact with existing words, but the task measuring such interaction may need to satisfy the requirements of the slow, indirect hippocampal route. Whether this is true in the context of novel word semantic priming, however, remains to be seen. Based on current evidence, priming via automatic mechanisms does not seem possible, but what about strategic mechanisms, and what can this tell us regarding the encoding of new words? We argued that perhaps the SOAs of previous work were too short, relative to the time required for the hippocampus to retrieve novel word meaning, to allow these mechanisms to occur. Thus, it is possible that these mechanisms could play a role, if enough time is allowed to retrieve new words and their meanings.

1.4.1 Chapter 2

Chapter 2 explored the ERP response to recently learned words, in adults. In doing so, we attempted to bridge together two separate strands of research. Specifically, is the PLPE – thought to be a marker of associative knowledge between a word-form and object in infants and adults – observable in adult participants following initial word learning? We know from the adult literature that the N400 effect is inconsistent across studies of novel word learning, However, could evidence of learned associations between novel word-forms and their objects be detectable and more consistent, in the form of a PLPE?

Note that the study design of Chapter 2 was designed with the intention of replicating parts of the design with infant participants in future studies, which represented the original aims of this thesis. Due to the COVID-19 pandemic, however, these studies and aims were abandoned.

1.4.2 Chapter 3

Chapter 3 examined novel word semantic priming. It specifically investigated whether significant semantic priming effects could be observed under strategic conditions, by specifically manipulating the SOA between novel prime words and their targets. We believe that manipulation of the SOA could have affected two independent, but crucial, factors. Firstly, if novel words are not yet integrated into core semantic networks, they should be unable to prime via automatic mechanisms, which is supported by evidence in the current literature. However, perhaps they could feasibly prime via strategic priming mechanisms. Second, if they are initially represented via a slow, indirect episodic pathway, the SOA would need be sufficiently long to allow this memory trace to be retrieved, before it can influence behaviour. Once it is retrieved, perhaps then strategic mechanisms be recruited. This follows the rationale of previous findings which suggests novel words can interact with other words if the task permits their underlying – possibly episodic – representations to come online. Priming from novel words was compared to a familiar prime word condition, which we expected to prime under more automatic conditions due to integrated semantic representations pertaining to these words. Thus, this would reveal at a dissociation between new and familiar words, possibly hinting at encoded differences.

1.4.3 Chapter 4

The findings in our familiar control condition in Chapter 3 were unexpected and meant that the effect of our SOA manipulation on semantic priming was difficult to interpret. To address this, Chapter 4 recruited the stimuli and design of TG13 – a published study in this area of research which observed a reliable baseline measure of priming. Chapter 4 therefore tests our SOA manipulation with these stimuli and design.

Chapter 2 – Can we Dissociate Lexical Knowledge Based on Electrophysiological Activity?

2.1 Abstract

This chapter investigated two independent event-related potential (ERP) effects in response to recently learned words to understand the quality of lexical knowledge shortly after acquisition, and compared these measures against the processing of established words. We measured two ERP effects – the phonological lexical priming effect (PLPE) and N400 – which are deemed to reflect associative and semantic word processing, respectively. Participants learned 16 novel object-label mappings in a training phase. In a subsequent testing phase, participants took part in a cross-modal priming paradigm where an on-screen object (a familiar object or a trained novel object) was followed by a congruous or incongruous label, stored within a larger carrier phrase. A non-parametric permutation analysis revealed a cluster of activity that was consistent with a canonical N400 effect, for both the novel and familiar conditions, with very similar spatiotemporal profiles. However, there appeared to be no cluster of activity revealing a PLPE for either condition. These results are interpreted as showing that new words can contribute to semantic processing immediately following acquisition. However, whether such processing is sourced from integrated representations in language networks remains to be seen. To examine this, future studies should examine semantic processing under more automatic conditions than present in this experiment.

2.2. Introduction

In the ERP literature, semantic processing is reflected by the N400 component – a negative deflecting component of the ERP that is generally observed over centro-parietal electrodes of the scalp between 200–600ms post stimulus onset (for a review see Kutas & Federmeier, 2011). The amplitude of the N400 component has been found to be inversely related to the congruency and predictability of a target stimulus, based on the preceding context, with a larger N400 in response to less congruent and less predictable stimuli (see Kutas & Federmeier, 2011, for a review). Thus, there appears to be a particular association between the N400 component and the processing of meaning. This difference in amplitude between target stimuli that are congruous or incongruous with the preceding context, or *N400 effect*, has also been observed in cross-modal priming paradigms, where an on-screen image of an object is followed by an audible word-form that is either congruous or incongruous with the preceding image (Friedrich & Friederici, 2004).

The cross-modal priming paradigm has also revealed a second ERP component of interest – the *N200-500 component.* In contrast to the N400 effect, the N200-500 component is larger in response to congruous pairings than it is to incongruous pairings and has been linked to word-form familiarity (Koojiman et al., 2005; Mills et al., 1997), with a left temporal distribution observed in adults (Friedrich & Frederici, 2004). Thus, in the context of cross-modal priming, the increased amplitude on congruous picture-word pairings has been interpreted to reflect the facilitated retrieval of a cued word-form, based on the associated picture, in both infants and adults (Friedrich & Friederici, 2004; 2005). This difference wave between congruous and incongruous pairings, referred to as the *PLPE,* is therefore assumed to reflect the association between word-form and visual object representations (Friedrich & Friederici, 2017). Accordingly, the PLPE is assumed to not be representative of higher-level semantic processing (Friedrich & Friederici, 2015), which is instead more closely coupled with the N400 component/effect.

These two ERPs therefore present a means by which unique aspects of lexical knowledge could potentially be independently observed and dissociated. The N200-500 component is indicative of associations between word-form and object representations (Friedrich & Friederici, 2017), such that a particular word-form may be cued by its associated object in a cross-modal priming paradigm. The N400 component, on the other hand, is thought to be representative of higher-level semantic processing between words and the current context (Kutas & Federmeier, 2011). The presence of an N400 effect therefore reveals an understanding of how a particular word is related to other concepts and the amplitude of the N400 has been found to be correlated with the degree of semantic anomaly (Kutas & Hillyard, 1980) and predictability (Kutas & Hillyard, 1984).

Given the functional interpretation of these two ERPs, it is possible to use them as a tool to differentiate the level of neural encoding familiar words that are established in language networks and recently acquired words. Are relatively basic associations initially formed, which may be reflected in a PLPE, or is a deeper level of understanding also acquired, such that words can engage in semantic processes, straight away, with other lexical items, as would be evident by an N400 effect, and thus behave in a manner that is consistent with well-known, familiar words? Despite the potential utility of these two ERPs to investigate early lexical representation however, we are unaware of a published study which has measured these two ERPs *collectively* within the same experiment in an adult word learning study. Whilst there is a large body of research which has examined the N400 in response to new words in adults (discussed in section 1.3.3.3), the N200-500 component appears to have been overlooked in the adult word learning literature.

It is clear from previous work that participants are quick to acquire some basic word understanding, given good performance on measures of explicit lexical knowledge that is consistently seen across studies (see Chapter 1 - Table 2). If there are inconsistencies in the literature regarding the presence of an N400 effect, then it is possible that explicit knowledge is more closely coupled with a different ERP. As discussed, some studies do report more consistent late positive component (LPC) effects in response to new words (Bakker et al., 2015; Kaczer et al., 2018; Liu & van Hell, 2020). Yet, given the functional interpretation of the PLPE, perhaps it is possible that participants acquire a basic mapping between word-form and object representations relatively quickly, which may drive explicit performance. For example, if participants learn associations between new word forms and their novel referents during training, these visual referents could cue their associated word-forms, evidenced by a PLPE. Perhaps acquisition of this understanding is partly responsible for participants' good explicit knowledge that is reported in many studies.

The aim of Chapter 2, therefore, is to investigate the electrophysiological correlates of recently learned words. Specifically, this study explored whether different states of lexical knowledge are dissociable based on two unique ERP effects: The PLPE and N400 effect, that are thought to be indicate of associative and semantic word knowledge, respectively. Whilst existing research is inconsistent regarding the ability of new words to engage in semantic processes soon after acquisition (based on the N400 response to new words), there nonetheless appears to be some level of understanding, which is partly evidenced by good performance on tests of explicit lexical knowledge. Perhaps this understanding could at least partly be sourced from an associative pathway between new word-forms and visual representations, which may be reflected by a PLPE. The ERP response to novel words was compared to that of familiar words. This allowed us to measure quantitative and qualitative

ERP differences across word types, which could be indicative in differences in underlying encoding.

It is important to note that the design of the current study differs from previous (adult) word learning studies in several key aspects:

I. Firstly, as mentioned, it will explicitly measure the PLPE effect in response to recently learned words in adult participants, which has not been considered before.

II. In order to elicit the PLPE effect, a cross-modal priming paradigm was adapted that has previously observed this effect in adult participants (Friedrich & Friederici, 2004; 2005). This differs from most previous adult word learning studies which typically elicited ERPs through semantic priming where the prime and target are presented in the same modality (e.g., in written format).

III. Unlike previous work, we presented our word stimuli within larger carrier phrases, such as "*Do you see the X?"* and "*Look at the X!"* (where *X* represents the target word). We adopted this approach because the design of this study was intended to be replicated with a sample of infant participants, where the use of carrier phrases aids in maintaining infant attention (e.g., Bergelson & Swingley, 2012; 2015). It could also be argued that presenting target stimuli within larger phrases better reflects natural speech, as opposed to presenting words sequentially in isolation.

IV. During the testing phase, we included trials where a familiar object was paired with a novel label, and vice versa (we call these *mixed incongruous* trials), which does not appear to have been considered before. The rationale for including mixed incongruous trials was to ensure that any findings associated with our novel stimuli were due to true or absent lexical and / or semantic effects, and not sourced from lower-level perceptual effects associated with the images and / or labels. For example, if we

> detected an absent N400 effect in the novel stimuli, this could be due to an absence of semantic representation, or it could be due to difficulty in encoding the items during the training phase, perhaps due to issues in processing the images and / or sound. If, however, we detect an N400 effect when, say, a familiar object is paired with a novel label, we can be more confident that the conditions in the training phase were sufficient enough to process the novel label, as the participant has detected the incompatibility between the familiar object and novel label.

The study has two stages: The training phase and testing phase. During the training phase, participants encountered novel word – object pairings and were instructed to remember, to the best of their ability, 16 such pairings. Immediately after training participants completed a cross – modal priming task which served as the testing phase. Here, an object (a familiar object or one of the 16 novel objects) was presented on screen, followed shortly after by an audibly presented target word, contained within a carrier phrase, that was congruous or incongruous with the on-screen object. It was during this stage of the experiment that EEG activity was recorded. Following the testing phase participants took part in a short 2–Alternative Forced Choice (2–AFC) task designed to measure explicit knowledge for the recently learned concepts. Based on prior research, we expected to observe both a PLPE and N400 effect for the familiar words, since semantic understanding should be well established for these items, as should associations between word-form and visual representations. For the novel words, we predict to only observe a PLPE; previous work regarding the presence of an N400 effect is inconsistent, yet participants clearly acquire some understanding of new words, which could be reflected by an associative pathway between new word-forms and objects.

2.3 Methods

2.3.1 Participants

25 participants contributed data to the current study (*M age* = 20 years, *SD* age = 5.30 years; 23 female). A further 7 participants completed the procedure but their data was excluded in the final analysis due to there being a large number of artefacts contaminating their EEG recordings. The following criteria were used to constrain participant recruitment: right-handed, native speakers of English, who has not suffered from any known neurological disorders. Participants were recruited from the undergraduate Psychology course at the University of Liverpool and received course credits for taking part in the study. Ethical approval was obtained from the Committee on Research Ethics at the University of Liverpool.

2.3.2 Stimuli

2.3.2.1 Familiar stimuli

Our familiar stimuli consisted of pictures and words corresponding to 40 common concepts, divided into 5 distinct categories: animals (n = 9), household objects (n = 9), vehicles (n = 8), body parts (n = 8), and food items (n = 6). Animals, vehicles, and household objects were selected based on similar cross-modal priming research (Hendrickson et al., 2015). Food items and body parts were chosen based on behavioural studies of word knowledge in infants (Bergelson & Swingley, 2012); this was done in order to allow comparability with subsequent studies that we had initially planned to run with infant participants. Visual images were selected from Google images, with prototypical exemplars chosen to avoid confusion with perceptually similar concepts. Images were coloured and presented against a white background. See Appendix 1.1 for a full list of the familiar stimuli.

Audio recordings of the stimuli were pre-recorded and produced by a female, native speaker of English from the Liverpool city region. As mentioned, the labels of concepts were presented within a larger carrier phrase, with two different carrier phrases used throughout the experiment: "*Look at the X*" and "*Do you see the X?*". Therefore, each label was recorded twice–once positioned at the end of each carrier phrase ("*Look at the dog*" and "*Do you see the dog?*").

2.3.2.2 Novel stimuli

Our novel stimuli consisted of 16 unfamiliar items. Images of unfamiliar objects, as well as novel labels, were selected from The Novel Object and Unusual Name (NOUN - http://www.sussex.ac.uk/wordlab/noun) database (Horst & Hout, 2016). Objects were selected so that there was little overlap of perceptual features between the 16 objects. This was intended to allow distinct visual representations to potentially develop throughout the training phase of the study. Images were coloured and presented against a white background. The novel labels consisted of words unknown to the participants. Whilst they were selected at random from the NOUN database, all novel words were monosyllabic (n=11) or disyllabic (n=5). Labels were pre-recorded and produced by the same female speaker who produced the familiar labels and were presented as part of the same two carrier phrases. The chosen object–label associations were selected at random and held consistent across participants. See Appendix 1.2 for full a list of the novel stimuli.

2.3.3 Experimental design

The current study used a within subjects design, with all participants included in all experimental conditions. The experiment was divided into two key sections, the *training phase* and *testing phase* which are described in turn, below.

2.3.3.1 Training phase

The purpose of the training phase was to present the novel stimuli to the participants, providing them with an opportunity to learn the correct novel object–label pairings. It was this stage of the experiment therefore where knowledge for the novel concepts could develop. Participants encountered each novel object–label pairing eight times throughout the training phase, with each object consistently paired with the same label. On four of these occasions, the label was presented as part of the carrier phrase "*Look at the X*". For the other four occasions the second carrier phrase was used ("*Do you see the X*"). There were 128 trials in this training phase, with the presentation of object – label pairings pseudorandomised across participants.

2.3.3.2 Testing phase

The testing phase of the experiment followed the training phase. The purpose of the testing phase was to examine the quality of word knowledge developed during the training phase for the novel stimuli, and to compare this to the knowledge of familiar words using the PLPE and N400 effect. Participants therefore encountered both the novel concepts taught in the training phase and the familiar stimuli in the testing phase.

The testing phase was divided into 4 blocks. Within each block, every object - novel and familiar - was presented on *at least* two occasions — once with its congruous label and once with an incongruous label, resulting in 112 trials. This design meant that each label and image was presented in the congruent and incongruent conditions. All incongruous labels diverged from the correct, congruous label at the initial phoneme. Across blocks, a different incongruous label was used for each object.

Mixed incongruous trials (see above for an explanation) were also included. For 16 of these additional trials, a familiar object was paired with a novel label, and for another 16 additional trials, a novel object was paired with a familiar label. The same mixed incongruous pairings were used across participants, with different pairings used across blocks. To prevent an imbalance of incongruous trials relative to congruous trials per block, 32 congruous trials (25 familiar and 7 novel) were presented again to participants. The total trial count per block therefore accumulated to 176 trials, with the order of trials across participants pseudorandomised.

2.3.4 Procedure

Upon arrival at the laboratory, participants provided written consent to taking part in the study and received information about the experimental tasks. Next, the experimenter secured the EEG cap onto the head of the participant and once secured, connected the cap to the EEG system. In this study, a 128-channel Geodesic EGI system was used to record EEG activity, with online activity referenced to the Cz electrode. The cap was positioned to three anatomical landmarks: the nasion, inion, and vertex. Before the experiment began, the experimenter checked electrode impedance levels which were kept below 50kΩ. Participants were asked to limit the amount of blinking where possible to reduce the quantity of blink artefacts.

Once the cap was secured, the experiment began with the training phase. Note that whilst the EEG setup was completed before the training phase, we did not record the EEG signal during the training phase, and instead began the recording at the start of the testing phase. For each trial in the training phase, a black fixation cross against a white background appeared in the centre of the monitor. After 2000ms, the fixation cross was replaced with an image of one of the novel objects. Once the image had remained on screen for 1500ms, a carrier phrase containing the correct, congruous label for the onscreen image was played through speakers. Following the offset of the phrase, the image remained on screen for a further 1000ms and was replaced by the fixation cross in preparation for the next trial (see Figure 3a for an illustration of the training phase). In total the training phase took approximately 15 minutes to complete.

Following the end of the training phase, the experimenter checked and corrected electrode impedance where necessary, which also allowed the participant to take a short break. The break continued for as long was necessary to correct electrodes and until the participant was ready to continue.

The next stage of the experiment involved the testing phase. For each trial in the testing phase, a black fixation cross against a white background appeared in the centre of the monitor and remained for 800–1500ms (randomised between this time range across trials). The fixation cross was then replaced with either a trained novel or familiar image. Once the image had been on screen for 1000ms, a carrier phrase was produced through the speaker, which contained either the congruous label for the onscreen image, or an incongruous label. Following the offset of the label, the image remained onscreen for a further 1000ms, and was then replaced with the fixation cross signalling the start of the next trial (see Figure 3b for a visual depiction of the testing phase). Participants were not required to produce a behavioural response at any point during the testing phase. Each block of the testing phase took approximately 12 minutes to complete. In between blocks, the experimenter again checked and corrected electrode impedances where necessary (maintained below 50kΩ), which also allowed the participant to take a short break.

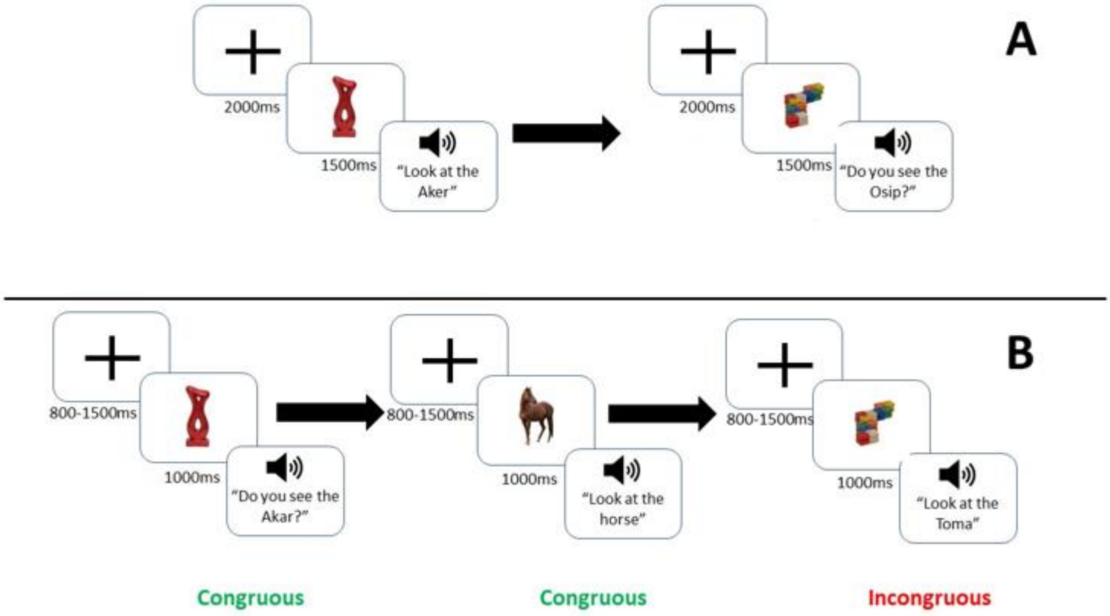


Figure 3: An illustration of the experiment. **A** represents an illustration of the training phase. **B** represents an illustration of the testing phase. Congruous and incongruous trials are labelled accordingly. Horizontal arrows represent the transition of trials.

The final stage of the experiment was the 2-AFC test. For a single trial in the 2-AFC test, an image of one of the novel objects appeared in the centre of the screen. In each of the top corners of the screen, a novel word was presented orthographically. One of these novel words was the correct label for the onscreen image, whilst the other served as a distractor, with pairings on a single trial held consistent across participants. Using a keyboard, the participant pressed the left arrow key if they believe the word on the left was the correct label for the image or pressed the right arrow key if they believed it was the word on the right. The location of the correct label on screen was balanced so that for half of the trials the correct label appeared on the left-hand side, and for the other half of appeared on the right-hand side. The order of presentation of trials was pseudorandomised across participants. The 2-AFC took approximately 5 minutes to complete. All stages of the experiment were programmed in the Matlab toolbox Psychtoolbox (Brainard, 1997).

2.3.5 EEG acquisition

EEG data was collected using a 128-electrode system (Electrical Geodesics Inc) referenced online to the vertex (Cz electrode) and sampled at a rate of 1000Hz. Electrode impedances were kept below 50kΩ and were frequently checked and corrected by the researcher. The onset of the critical word within the carrier phrases (i.e., the congruous or incongruous label) was marked by sending a digital input signal (DIN) to the recording which served as our event marker. To achieve this, we manually tagged the onset of each target word within the corresponding carrier phrase using Praat software (https://www.fon.hum.uva.nl/praat/). Before securing to the participant, the cap was soaked in a warm, saline solution.

2.3.6 EEG data preprocessing

The EEG data was preprocessed using EEGLAB toolbox for Matlab (Delorme & Makeig, 2004). For each participant, data was bandpass filtered at 0.2–45 Hz. The continuous signal was segmented into epochs of 1000ms, beginning 200ms before the onset of the target word (i.e., a 200ms baseline period) up to 800ms. Baseline correction was next performed by subtracting the mean of the signal away of each trial from the baseline period.

Artefact rejection next took place over the data. Trials on which 10% or more of electrodes displayed an amplitude deviation of ±40µV were removed. Of the remaining trials, electrodes displaying a deviation of ±40µV 50% or more trials were interpolated via a spherical spline interpolation method.

Offline, the data was re-referenced to the average reference of the signal across all electrodes, and a linear detrend algorithm was applied to remove slow-wave drifts from the data. This involved subtracting a line of best fit away from the signal. Finally, the data was separated into the 5 conditions. On average (± standard deviation), participants contributed 214 (± 28.34) congruous familiar trials, 133 (± 18.57) incongruous familiar trials, 76 (± 9.24) congruous novel trials, 52 (± 7.51) incongruous novel trials, and 105 (± 13.85) mixed incongruous trials. There was no significant difference in the number of congruous and incongruous trials contributed to the analysis (p=.74). Participants who did not contribute > 34 trials in one or more conditions were excluded from further analysis. This was the case for 7 participants. The threshold of > 34 trials was selected so that the least represented condition throughout the testing phase (incongruous novel, with 64 trials in total) contributed over half the possible number of trials in the final analyses (for each participant).

2.4 Results

2.4.1 Explicit knowledge of word-object mappings

Before presenting our EEG results, we briefly present our findings from the 2-AFC task, which served as a measure of explicit knowledge for the novel word-object mappings. On average, participants successfully recognised 96% of the word-object pairings (range 72% - 100%). This near ceiling performance suggests that participants had successfully acquired the vast majority of novel mappings. Whilst we suggest that the bulk of learning likely took place during the training phase, it is nonetheless possible that learning continued in the testing phase as participants reencountered correct word-object mappings in the form of congruous pairings (i.e., at least 6 congruous presentations per novel word-object pairing were encountered in the testing phase).

2.4.2 Non-parametric permutation analysis

Broadly speaking, our research questions concern differences in the quality and quantity of ERP signals across the familiar and novel conditions. To explore this, we employed a range of analytical techniques.

Our primary analysis plan, as outlined in the pre-registration documentation (osf.io/fxgce), involved non-parametric permutation testing. In addition, a number of follow-up analyses were also performed to further our understanding of the data. These exploratory analyses were performed over data averaged to Regions of Interest (ROI). ROIs were selected based on existing knowledge of the literature which is described below. Whilst we must be hesitant to draw strong conclusions from these follow up analyses, we believe they offer interesting insight, collectively with the pre-registered permutation results. In the following sections we provide a detailed description of each analysis performed over the data, including the steps involved to prepare the data where necessary. The permutation analyses and results are discussed first, followed by descriptions and results of the exploratory ROI analyses.

The rational for analysing our data using non-parametric permutation testing was to avoid the multiple comparison problem (MCP), commonly encountered in EEG research and analyses. EEG data is canonically organised into a two-dimensional matrix of time and space, averaged across trials. An individual data point therefore reflects the dependent variable, such as mean amplitude, at a specific point in time, recorded at a single electrode (time x electrode sample). Often, true experimental effects, or ERPs, will cover multiple samples; they are not restricted to a single point in time and space. Given the diverse spatial and temporal nature of ERPs, it is therefore necessary to compare data across multiple samples. And because this number of comparisons is often in the thousands (Cohen, 2014), it is not possible to control for family-wise error rates using conventional methods, such as Bonferroni correction, where the correction value would be extremely large. Furthermore, it is more intuitive to assume that two adjacent data points in time and/or space may not be independent from one another.

One solution to this problem is non-parametric permutation testing (Maris & Oostenveld, 2007). Rather than treating the data as rigid points in time and space, non-parametric testing appreciates the fluidity of the EEG signal. Similar patterns of activity across temporally and spatially adjacent electrode sites are treated as single clusters which are discovered in the data. In our study we use non-parametric permutation testing to compare activity between congruous and incongruous object – label pairings. We did this separately for the familiar and novel conditions.

Firstly, differences in activity between congruous and incongruous pairings, at each time x electrode sample, were compared by the means of a t-statistic across the full spatial field, within a predefined time window of 0 – 800ms post target onsent. T-statistics with a p-value of <.05 were then selected, and the selected t-statistics were clustered together based on temporal and spatial adjacency to form a cluster of samples. In the current study, spatial adjacency was based on a hand-constructed map, which can be viewed in Figure 4. Here, each electrode was assigned ‘electrode neighbours’, visualised by connecting red lines between electrodes. An electrode neighbour is in close proximity with the electrode in question based on the numerical arrangement of the 128 Geodesic net. On average, each electrode was assigned five neighbours, with a range of 1 – 7 neighbours. Finally, for each cluster, a total observed t-statistic (cluster-level statistic) was calculated by summing together the t-statistics from within that cluster.

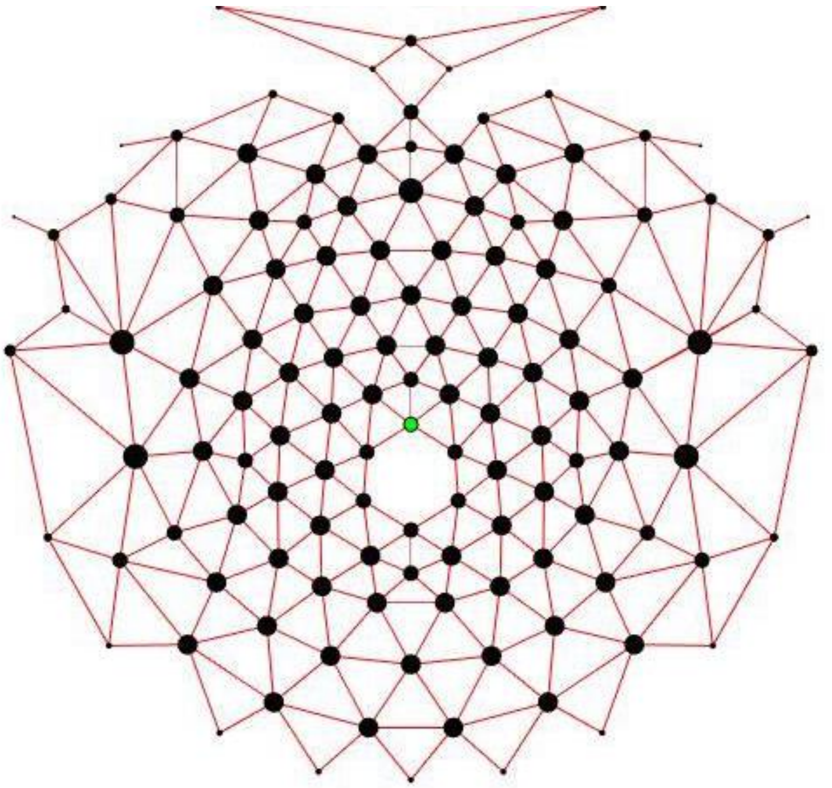


Figure 4: Our hand-crafted arrangement of electrode neighbours submitted to the permutation analyses. Neighbours are indicated by connecting red lines between electrodes (black circles). The size of the black circle is proportional to the number of electrode neighbours for that given electrode.

Next, the discovered clusters were subjected to a permutation procedure where data points were randomly shuffled between the two groups (congruous and incongruous). T-values were again calculated for this ‘new’ dataset using this same procedure as described above, with the largest t-statistics stored. Hence, these t-statistics can be thought to reflect activity under the null hypothesis of no difference(s) between the two conditions for the set of clusters.

After 10,000 permutations the observed cluster statistics were then compared against the t-statistics generated under the null hypothesis. For each observed cluster statistic, a p-value was calculated as the number of t-statistics generated from the permutation – under the null hypothesis – which are larger than the observed cluster statistic. Any cluster level statistic with a p-value of <.05 is taken to reflect a significant cluster, and hence a significant difference between congruous and incongruous pairings.

In the current study, the results from four separate permutation analyses are reported. The first and second permutation analyses compare congruous and incongruous activity in the familiar and novel conditions, respectively, whilst the third analyses compared familiar congruous activity with the mixed incongruous condition. The fourth permutation analysis was performed over down-sampled familiar data, to control for the difference in trial count across conditions. That is, the nature of the design meant that there more familiar than novel trials in the testing phase (a difference that is statistically significant, p< .001). Hence, it is possible that any differences in the number, or size, of significant clusters between the familiar and novel permutation could be a result of reduced power in the novel permutation, unable to detect significant differences. To address this issue, a fourth permutation was performed over *down sampled* familiar data, where the data was reduced to 52 trials per level of congruency for each participant. This figure was chosen as, on average, participants contributed 56 trials in the incongruous novel condition – the least represented condition in the experiment and analyses. Hence, reducing the size of the familiar dataset to a level comparable to the novel data increased our confidence that any difference(s) observed between the novel permutation and the full familiar sample were not due to discrepancies in statistical power. The permutation analyses were performed in Matlab using FieldTrip toolbox (Oostenveld et al., 2011). The FieldTrip software thus calculates the number quantity and significance of clusters. Note, however, that it is possible for significant clusters to be detected that have very similar temporal and/or spatial profiles (i.e., there could be a brief period in time where no significant difference is detected, thereby creating two distinct clusters). It is nonetheless possible that such clusters could represent the same or similar effects. Where applicable, we clearly flag such clusters in the following analysis.

In the following sections, we present significant clusters through topographic plots averaged to the epoch range of the cluster, and time-series plots to visualise ERPs averaged to all electrodes which are classified as being part of the cluster. Clusters are named according to their temporal order. Topographic maps were produced in Brainstorm (Tadel et al., 2011) and ERP plots were configured in RStudio via the ggplot2 package (Wickham, 2016). Congruous activity was subtracted from incongruous activity, so that negative clusters indicate greater negativity in time and space in response to incongruous object – label pairings, whilst positive clusters indicate greater negativity in response to congruous pairings.

In relation to our ERP components of interest and in line with previous research, an N400 effect is likely to be reflected by any negative cluster(s) within 200-600ms of the epoch. The PLPE, however, is likely to be reflected by any positive cluster(s) between 100-250ms.

2.4.2.1 Familiar permutation results

The results from the familiar permutation analysis revealed 6 significant clusters – 3 negative clusters and 3 positive clusters.

Table 3: Summary of all significant clusters discovered in the familiar permutation analysis. Clusters are named based on temporal order

Negative clusters	Epoch range(ms)	Spatial location	Significance value
Cluster 1	188 – 252	P, O	p =.03
Cluster 2	284 – 664	C, P, O, F	p<.001
Cluster 3	680 – 796	F, T	p =.02
Positive clusters			
Cluster 1	32 – 256	C, P, O, F, T	p<.001
Cluster 2	304 – 600	F, T	p<.001
Cluster 3	668 – 796	C, P, O	p<.001

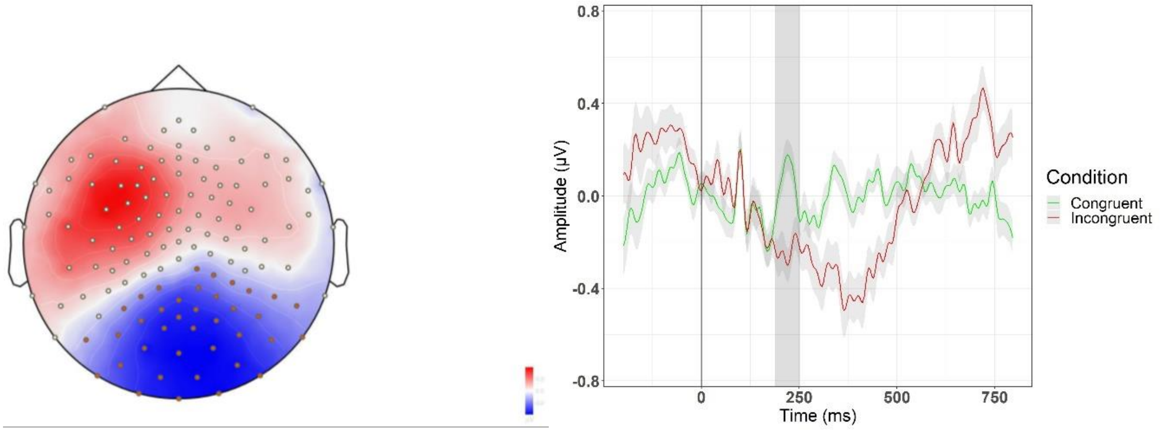
C = Central; P = Parietal; O = Occipital; F = Frontal; T = Temporal

Negative clusters

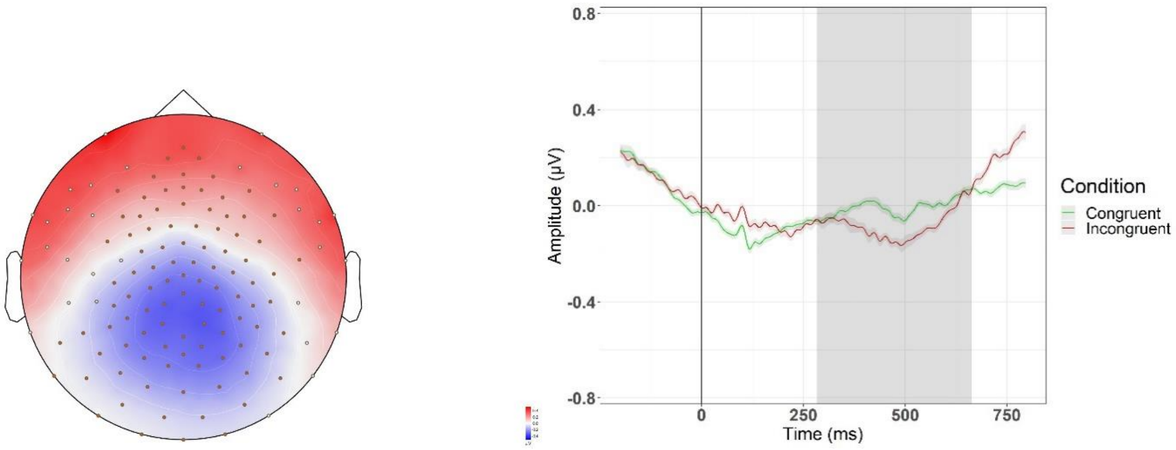
Between 188 – 252ms there was significantly greater negativity in response to incongruous relative to congruous pairings (p=.03, see Figure 5a). Within this epoch range, the effect was visible over parietal and occipital electrode sites. After a short 32ms period of no significant difference between the two pairing types, significant greater negativity in response to incongruous pairings re-emerged at 284ms which extended to 664ms (p<.001, see Figure 5b). The final negative cluster developed at 680ms and was found over frontal and temporal sites, extending up to the end of the epoch (p=.02, see Figure 5c).

Positive clusters

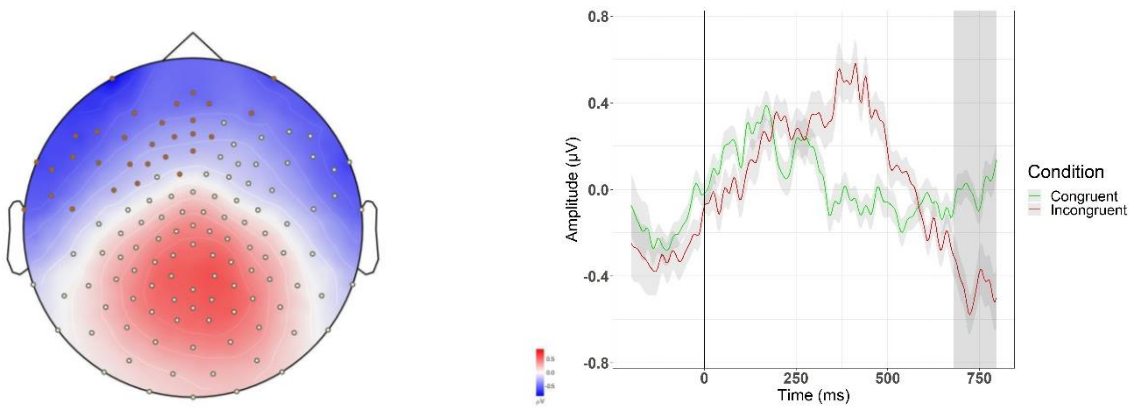
The emergence of positive clusters began very early – 32ms after the start of the epoch. This first cluster extended until 256ms and was located broadly across the scalp, comprising central, parietal, occipital, as well as some frontal and temporal sites (p<.001, see Figure 6a). The second positive cluster was discovered over roughly the same sites and emerged from 304ms until 600ms (p<.001, Figure 6b). The final positive clusters emerged at 668ms and remained until the end of epoch, over central, partial, and occipital electrode sites (p=.01, see Figure 6c).


0.8
0.4
0.0
-0.4
-0.8
Amplitude (µV)
0
250
500
750
Time (ms)
Condition
Congruent
Incongruent

A


0.8
0.4
0.0
-0.4
-0.8
Amplitude (µV)
0
250
500
750
Time (ms)
Condition
Congruent
Incongruent

B


0.8
0.4
0.0
-0.4
-0.8
Amplitude (µV)
0
250
500
750
Time (ms)
Condition
Congruent
Incongruent

C

Figure 5: Topographic maps and time-series plots of negative clusters observed in the familiar condition. Topographic maps are averaged to the time course of the clusters' epoch range. Electrodes that are coloured red were classified as part of the cluster. Time-series plots are averaged to each electrode that are classified as part of the cluster. The shaded area around the plotted signal reflects the standard error. **A**: Familiar negative cluster 1; **B**: Familiar negative cluster 2; **C**: Familiar negative cluster 3

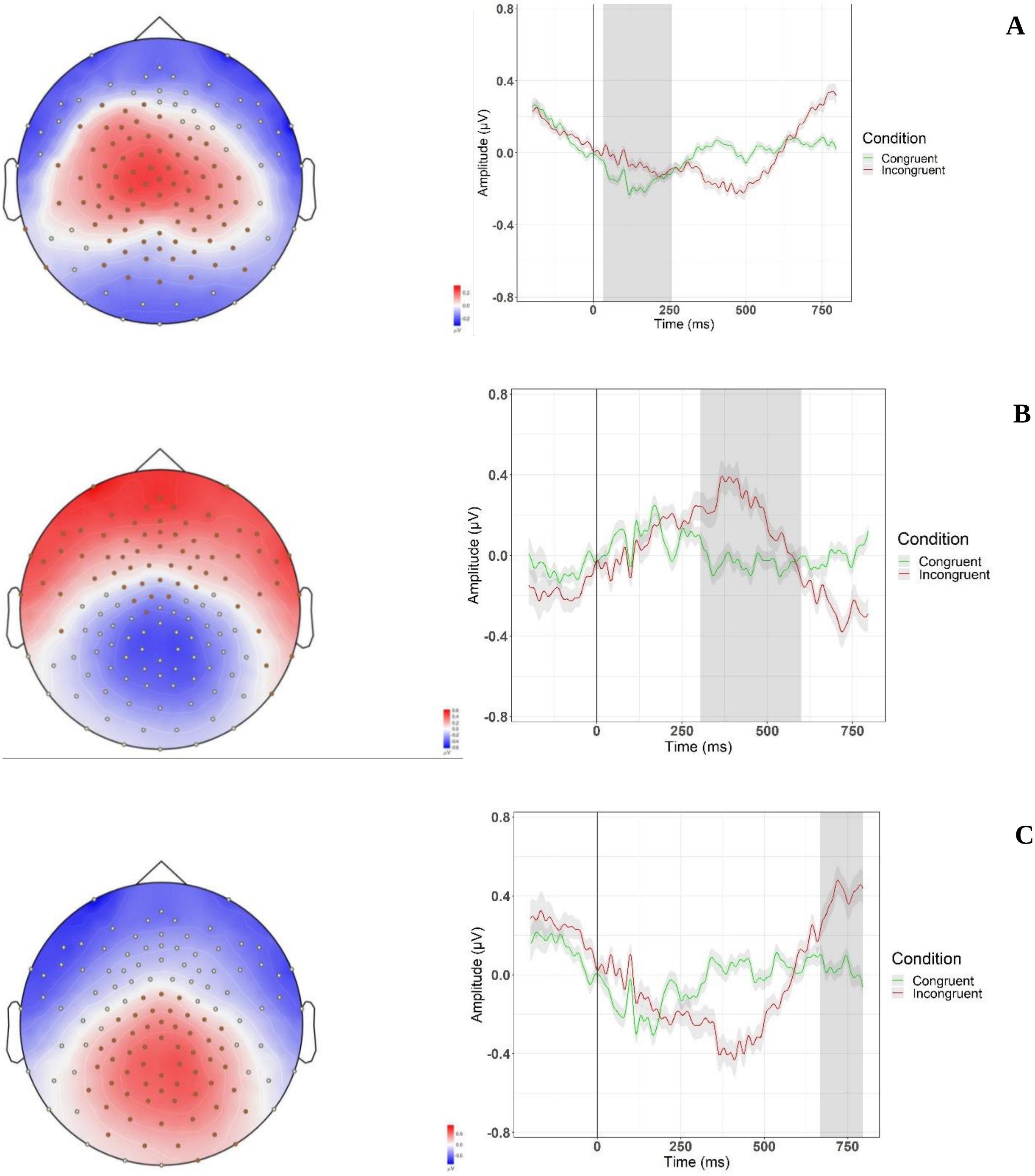


Figure 6: Topographic maps and time-series plots of positive clusters observed in the familiar condition. Topographic maps are averaged to the time course of the clusters' epoch range. Electrodes that are coloured red were classified as part of the cluster. Time-series plots are averaged to each electrode that are classified as part of the cluster. The shaded area around the plotted signal reflects the standard error. **A**: Familiar positive cluster 1; **B**: Familiar positive cluster 2; **C**: Familiar positive cluster 3.

2.4.2.2 Novel permutation results

Similar to the results of the familiar permutation analysis, the novel permutation revealed 5 significant clusters – 3 negative clusters and 2 positive clusters.

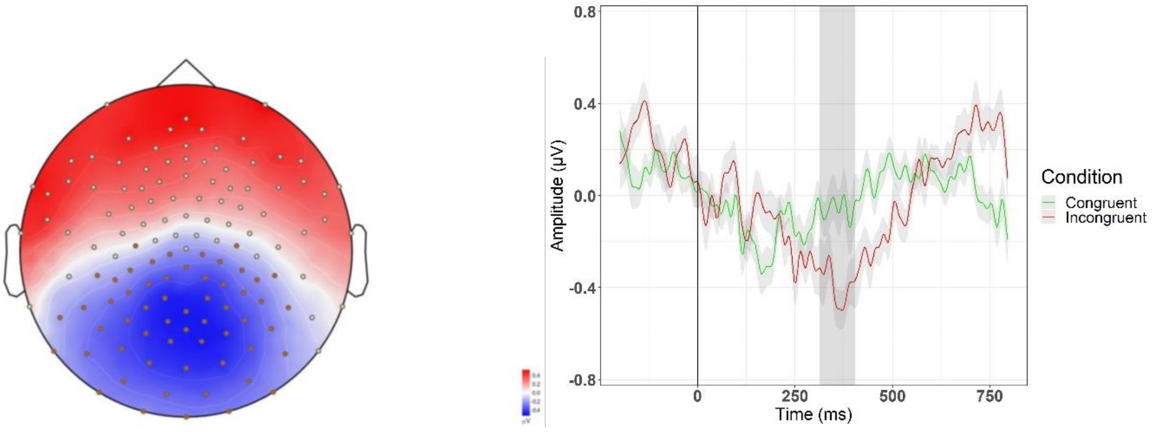
Table 4: Summary of all significant clusters discovered in the novel permutation analysis. Clusters are named based on temporal order.

Negative clusters	Epoch range	Spatial info	Significance value
Cluster 1	312 – 404	P, O	p=.02
Cluster 2	420 – 536	P, O	p=.02
Cluster 3	700 – 796	F, T	p=.03
Positive clusters			
Cluster 1	344 – 452	F, T	p=.04
Cluster 2	704 – 788	P, O	p<.001

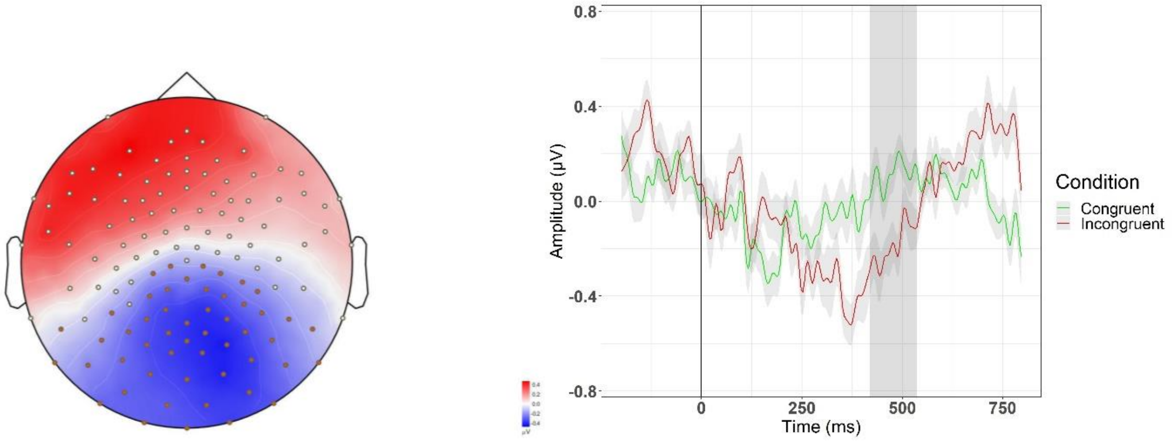
P = Parietal; O = Occipital; F = Frontal; T = Temporal

Negative clusters: Negative clusters emerged from the data 312ms into the epoch. This first negative cluster was located over parietal and occipital sites and remained until 404ms (p=.01, see Figure 7a). There was then a short 16ms window of no-significant differences between incongruous and congruous pairings, before reaching significance again at 420ms. The spatial distribution of this second negative cluster was very similar to that of the first cluster (p=.01, see Figure 7b). This second negative cluster remained until 536ms. The final negative cluster revealed began at 700ms into the epoch over frontal and temporal sites and remained until the end of the epoch (p=.02, see Figure 7c).

Positive clusters: The first positive cluster in the novel data set emerged at 344ms and extended until 452ms, located over frontal and temporal electrode sites (p=.04, see Figure 8a). The second and final positive cluster emerged at 704ms and remained until 788ms just before the end of the epoch and was located over parietal and occipital sites (p<.001, see Figure 8b).



A



B

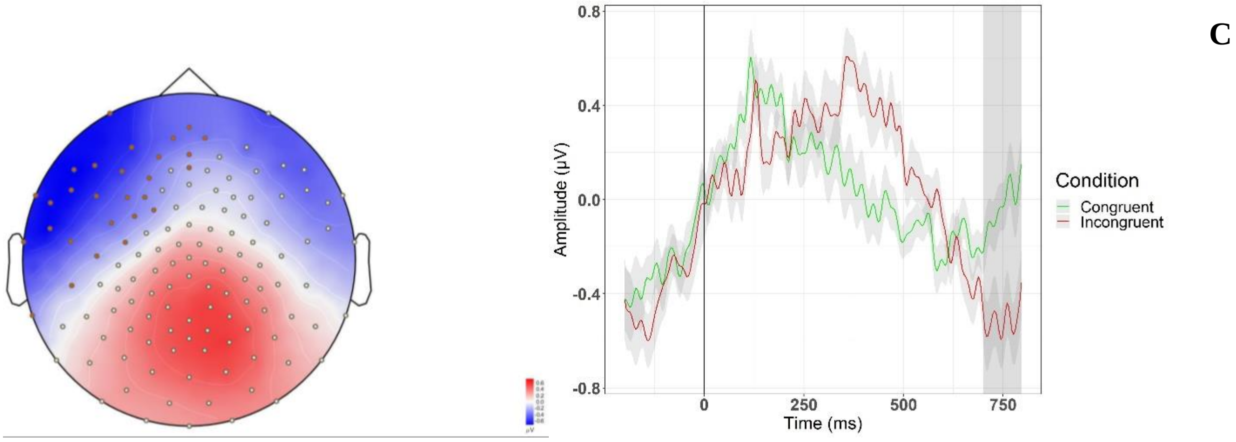


Figure 7: Topographic maps and time-series plots of negative clusters observed in the novel condition. Topographic maps are averaged to the time course of the clusters' epoch range. Electrodes that are coloured red were classified as part of the cluster. Time-series plots are averaged to each electrode that are classified as part of the cluster. The shaded area around the plotted signal reflects the standard error. **A**: Novel negative cluster 1; **B**: Novel negative cluster 2; **C**: Novel negative cluster 3.

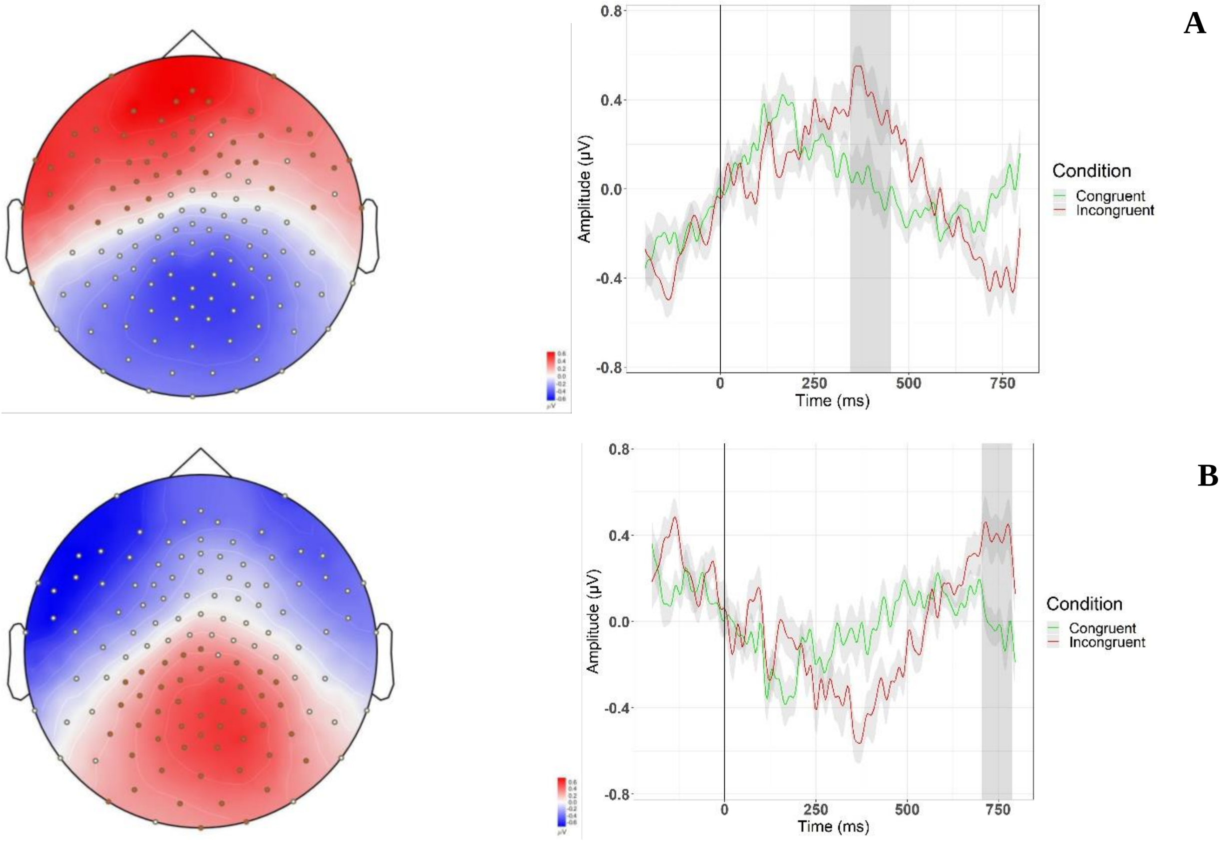


Figure 8: Topographic maps and time-series plots of positive clusters observed in the novel condition. Topographic maps are averaged to the time course of the clusters' epoch range. Electrodes that are coloured red were classified as part of the cluster. Time-series plots are averaged to each electrode that are classified as part of the cluster. The shaded area around the plotted signal reflects the standard error. **A**: Novel positive cluster 1; **B**: Novel positive cluster 2; **C**: Novel positive cluster 3.

2.4.2.3 Mixed permutation results

As a reminder, we included mixed incongruous pairings to increase our confidence that any effects associated with the novel stimuli were due to true or absent lexical and / or semantic effects (see the design section of the method). The results of the mixed permutation revealed 6 significant clusters – 3 negative clusters and 3 positive clusters.

Table 5: Summary of all significant clusters produced in the mixed permutation analysis. Clusters are named based on temporal order.

Negative clusters	Epoch range(ms)	Spatial location	Significance value
Cluster 1	324 – 584	C, P, O	p<.001
Cluster 2	624 – 708	F, T	p=.03
Cluster 3	680 – 796	F, T	p<.001
Positive clusters			
Cluster 1	324 – 564	F, T	p<.001
Cluster 2	636 – 796	C, P, O	p<.001

C = Central; P = Parietal; O = Occipital; F = Frontal; T = Temporal

Negative clusters: Significant negativity towards incongruous pairings began at 324ms and remained up to 584ms. The temporal and spatial location of negative cluster 1 is very similar to the pattern of activity observed from the first 2 negative clusters in the novel permutation (to an extent it is also similar to the negative cluster 2 of the familiar permutation, albeit it is temporally shorter). Negativity at more anterior regions began at 624ms. Although this cluster remains until 708ms, it appears to merge with negative cluster 3 which begins at 680ms and remains up to the end of the epoch.

Positive clusters: The first positive cluster emerged at 324 and remained up to 564. The second and final positive cluster began at 636ms and remained up to the end of epoch, of central, parietal, and occipital sites.

2.4.2.4 Down-sampled familiar permutation

To confirm that any discrepancies in the quality and/or quantity of clusters between the familiar and novel conditions were not due to discrepancies in power between the two permutations, we performed a third permutation analysis over down sampled familiar data. This data set was reduced to a trial count that is more compatible with the number of trials in the novel condition. The results from the down sampled familiar permutation revealed 5 significant clusters – 2 negative clusters and 3 positive clusters.

Table 6: Summary of all significant clusters discovered in the down sampled familiar permutation analysis. Clusters are named based on temporal order

Negative clusters	Epoch range	Spatial info	Significance value
Cluster 1	328 – 508	C, P, O	p<.001
Cluster 2	700 – 796	F, T	p=.02
Positive clusters			
Cluster 1	44 – 260	C, P	p<.001
Cluster 2	328 – 544	F, T	p<.001
Cluster 3	684 – 796	C, P, O	p<.001

C = Central; P = Parietal; O = Occipital; F = Frontal; T = Temporal

Negative clusters: The first negative cluster emerged at 328ms into the epoch and extended until 508ms. Located over central, parietal, and occipital electrodes, this cluster is similar to the first two negative clusters found in the novel permutation, temporally and spatially, as well as that found in the mixed permutation. The second negative cluster discovered also resembles the late shift towards frontal and temporal electrodes found in both the familiar and novel permutation analyses.

Positive clusters: The positive clusters uncovered mirrored those discovered in the familiar permutation involving the full sample. Interestingly, the very early positivity was again discovered in this reduced data set which was not found in the novel permutation.

2.4.2.5 Proportion of cluster membership

For both the familiar and novel conditions, we calculate the proportion of time that, throughout a typical N400 epoch range (200 – 600ms), each electrode was classified as part of a significant negative cluster. This was performed to investigate the consistency of specific electrodes in terms of observing significant differences between the congruous and incongruous conditions throughout the epoch of the cluster. Negative clusters are associated with greater negativity in response to incongruous picture – word pairings compared to congruous pairings and may therefore map onto an N400 response in this time region. The results from this analysis are displayed in the form of a heatmap over the 128 Geodesic layout, separately for the familiar and novel condition. Warmer colours are associated with a greater proportion of time spent as part of a significant cluster relative to cooler colours.

We did not perform this exercise over a typical PLPE ROI/time period, since the results from the permutation analyses suggest this effect was not present in the data (discussed in the interim discussion).

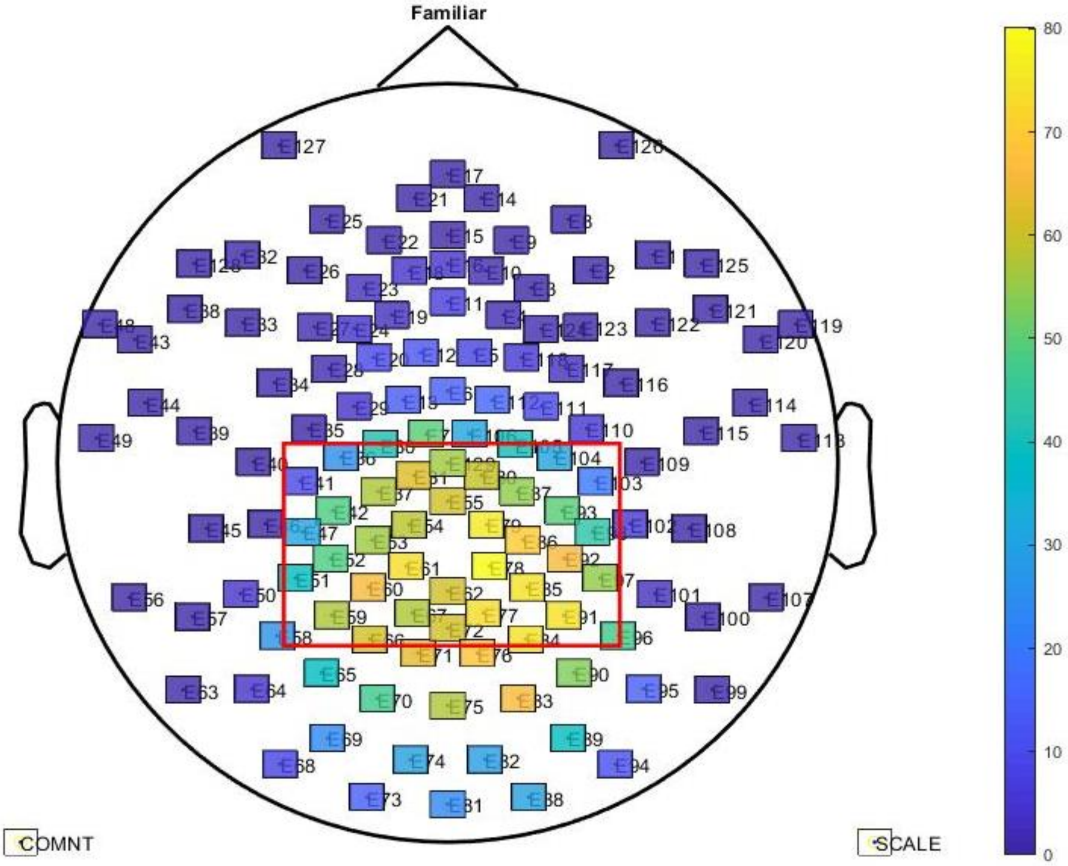


Figure 9: A heatmap displaying the percentage number of times each electrode was classified as part of a significant negative cluster in the N400 time window, in the familiar permutation analysis. The red rectangle highlights centroparietal electrodes where this effect is reported to be at maximum.

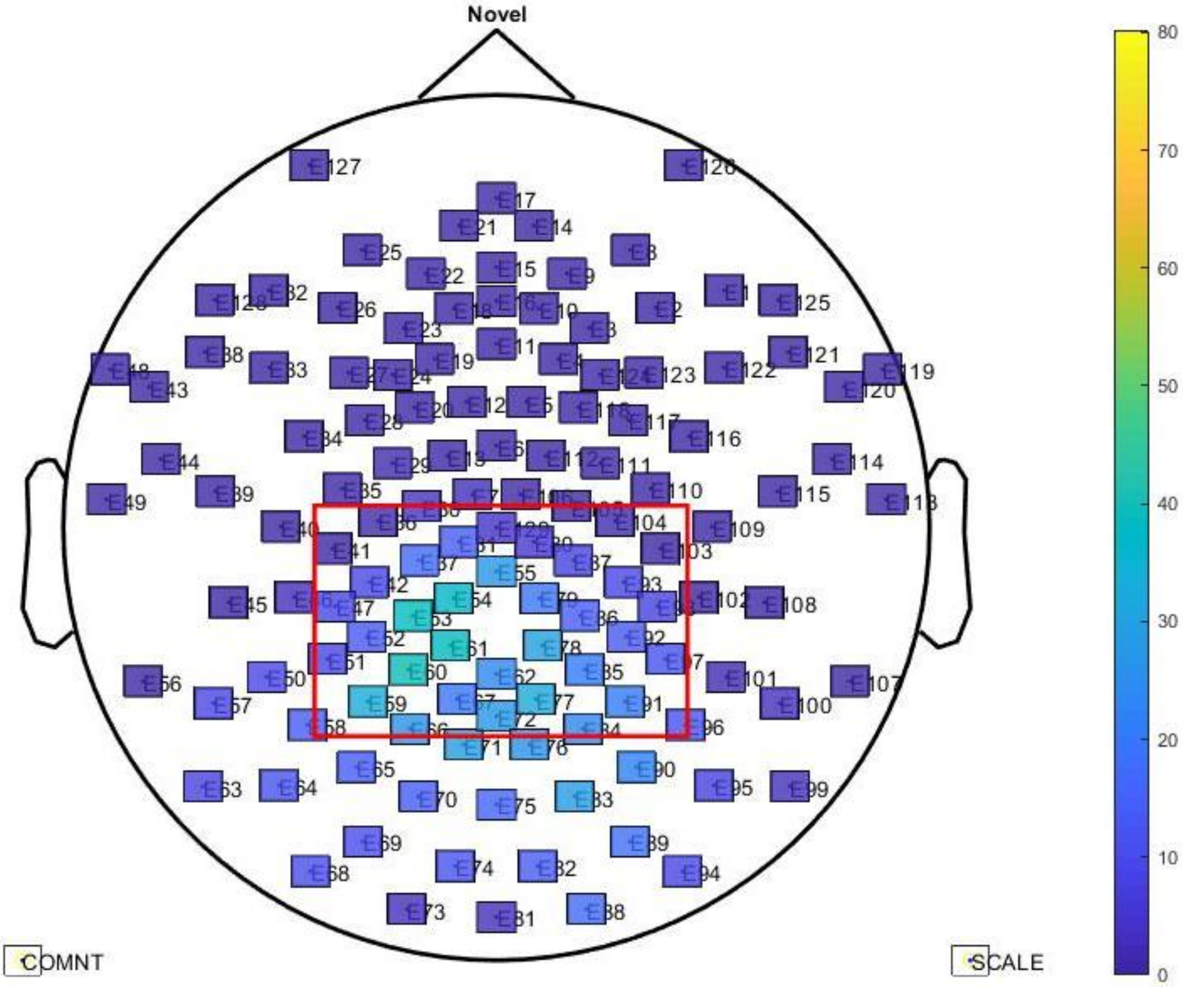


Figure 10: A heatmap displaying the percentage number of times each electrode was classified as part of a significant negative cluster in the N400 time window, in the novel permutation analysis. The red rectangle highlights centroparietal electrodes where this effect is reported to be at maximum.

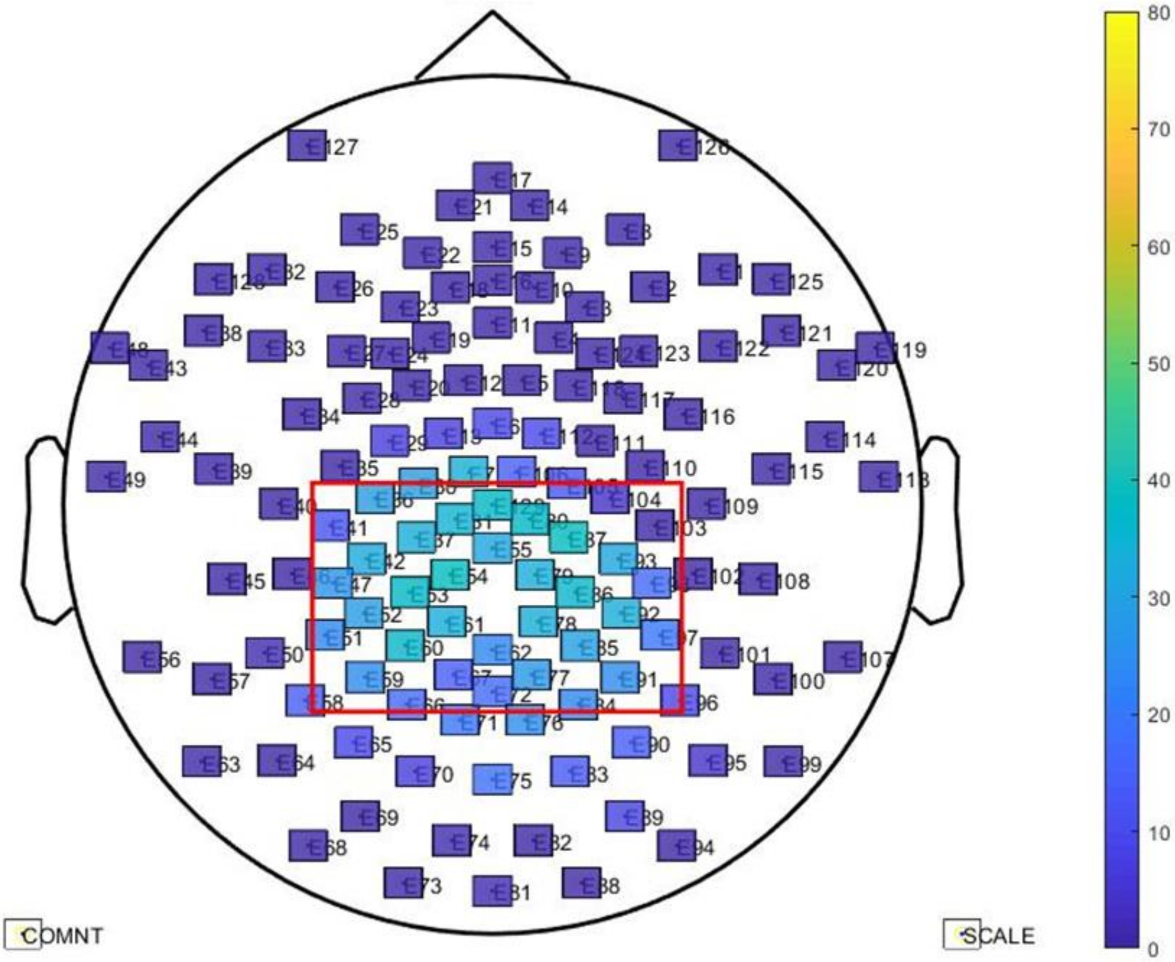


Figure 11: A heatmap displaying the percentage number of times each electrode was classified as part of a significant negative cluster in the N400 time window, in the down-sampled familiar analysis. The red rectangle highlights centroparietal electrodes where this effect is reported to be at maximum.

Whilst we can draw no statistical conclusions from these figures, they nonetheless demonstrate some differences in terms of the consistency of electrode activation between the familiar and novel condition. As can be seen in Figure 9, particularly within and around the CP region, electrodes consistently displayed significant differences in activation between incongruous and congruous pairings in the familiar condition. From the permutation results, we know these differences were the result of greater negativity in response to incongruous picture – word pairings, hence likely comprises an N400 effect. Such processing differences were consistently similar between adjacent electrodes for them to be considered as part of a cluster.

The results from the novel heatmap (see Figure 10), however, appear to display a slightly different pattern. Focusing again on the CP region, processing differences were not (as) consistently apparent; the percentage number of time spent within a significant cluster is clearly fewer for CP electrodes in the novel condition. That said, the heatmap produced over the down-sampled familiar dataset is remarkably similar to that of the novel words (see Figure 11). This means that the less consistent activation differences in the novel condition – relative to the familiar condition – may well be driven by the lower trial count compared to the familiar condition.

2.4.3 Interim discussion – summary of permutation results

Before proceeding onto the follow-up analyses, a summary of the permutation results is provided. This summary is organised according to the research aims and questions. Specifically, it will discuss whether an N400 and PLPE seem to be present in the data and for which class of words, as well as consider clusters which may map onto other ERPs/effects of interest.

Is an N400 effect present in the data? Beginning with the familiar condition, there appears to be a significant N400 effect. Within the typical N400 time window of 200 – 600ms, there was stronger negativity towards incongruous pairings relative to congruous. This is particularly apparent in negative cluster 2, where this difference in activity was apparent over centroparietal sites – the canonical location of the N400 effect - which also extended posteriorly. It is possible that this effect began earlier, specifically at 184ms where a significant effect emerged (negative cluster 1) until 242ms. Indeed, this earlier response was located over parietal and occipital electrodes - the same location as where negative cluster 2 emerged just 32ms later. Negative cluster 2 did shift towards more frontal sites at approximately 558ms; however, it may not reflect a continuation the N400 effect (see below).

In the novel condition, there also appears to be activity consistent with an N400 effect. Negative clusters 1 and 2 of the novel condition appear consistent with the spatiotemporal profile of the N400 effect, Similar activity was also observed in the mixed permutation, suggesting that the effect found in the novel permutation may be sourced from true lexico-semantic processing.

Whilst both the familiar and novel conditions appear to display an N400 effect, there does appear to be some minor quantitative differences. Temporally, the increased negativity towards incongruous pairings appears shorter in the novel condition. Negative cluster 1 and cluster 2 in the novel condition are active for 92 and 116ms respectively, compared to negative cluster 1 and cluster 2 in the familiar which are active for 64ms and 380ms (although, as mentioned above, the shift of familiar negative cluster 2 may not be a continuation of the N400 response – see below). The results from the down sampled, familiar permutation however revealed a negative cluster (negative cluster 1) which was remarkably similar to negative cluster 1 and cluster 2 of the novel permutation, both temporally and spatially. It is possible, therefore, that with a data set similar in size to the familiar condition, N400 like activity in the novel condition could resemble that found in the familiar permutation.

The consistency of processing differences at individual electrodes, across time, also appears dissimilar across the two conditions. As alluded to in the proportion of cluster membership section, electrodes within the N400 epoch range appear to show more consistent processing differences between incongruous and congruous in the familiar condition. That is, they appear to show significant differences in activation, with greater negativity towards incongruous pairings, more often within the N400 epoch range compared to the novel condition. However, the down-sampled familiar data produced a similar pattern of activity to the novel condition, suggesting that differences between the familiar and novel conditions may well be at least partly caused by discrepancies in trial count.

Is a PLPE present in the data? Based on previous research with adults (Friedrich & Friederici, 2004; 2005), the PLPE effect – if indeed it was elicited – was expected to appear around 100-250ms post stimulus onset, with a left temporal distribution. Across both the familiar and novel conditions however, there were no significant clusters which seemed to resemble this pattern of activity. In the familiar condition, there was a very early processing difference beginning at 32ms (positive cluster 1), with increased negativity in response to congruous pairings – consistent with the PLPE. However, given the promptness of this effect relative to the expected timing of the PLPE, and because this cluster comprised largely central sites, it may not reflect a PLPE.

Other clusters of interest: A relatively late positive cluster emerged in both the familiar and novel conditions over centroparietal sites, beginning around 668ms in the familiar condition and 704ms in the novel condition. Recall that in the familiar condition, negative cluster 2 shifted towards frontal sites around 558ms. One possibility is that this shift coincided with the development of this late positive cluster, which could resemble a different stage of processing.

Could these late positive clusters, in both the familiar and novel conditions, resemble a processing stage of interest? One possibility is that they both reflect an LPC effect, which is implicated in the controlled retrieval of semantic information (Hoshino & Thierry, 2012). The pattern of this effect is also consistent with similar word learning studies such as Kaczer et al., (2018), who report greater positivity in response to unrelated prime-target pairings in their LPC window (450ms-600ms).

Another possible explanation is that these clusters reflect a *post – N400 – positivity (PNP)*. Studies which have compared congruous and incongruous sentence endings have sometimes revealed a PNP in response to incongruous sentence endings; evident over central and parietal electrode sites which follows the N400 response (Van Patten & Luka, 2012). It is suggested that the PNP may share a similar interpretation to that of the P600 (Kim & Osterhout, 2005; Kolk et al, 2003). That is, in the context of sentential processing, the PNP represents a 're-analysis' of incongruous sentence endings – 'reviewing a prior context to determine what went wrong and if the problem might be repaired' (Van Patten & Luka 2012, p. 187), reflecting the difficulty of semantic integration which had come before. Whether this interpretation can be used to explain the late positive clusters here remains to be seen. Unlike sentences which feature a complex integration of syntactic and semantic information, making re-analysis necessary following an erroneous interpretation of the sentence, the congruency between a picture and a word is more straightforward to decipher. This is particularly true in the current study whereby incongruous pairings were not semantically related.

2.4.4 Follow-up analyses

Following the results of the permutation analyses, a number of follow-up analyses were performed. The rationale for performing these analyses was largely to investigate if similar results are also apparent when using other methods of EEG analysis, such as ANOVA. Whilst we must be hesitant to draw strong conclusions from these follow up analyses, we believe they offer insight, alongside the pre-registered permutation results.

To prepare the data for these analyses, the data was averaged to regions of interest (ROIs) where our effects of interest are canonically reported. The N400 ROI was defined over centroparietal sites (Kutas & Federmeier, 2011), whilst the PLPE was defined with a left temporal distribution (Friedrich & Friederici, 2004; 2005). Figure 12 highlights the electrodes that were selected for these respective ROIs on the 128 Geodesic system. Although there is no direct mapping of these regions from the 128 Geodesic system to the traditional 10-20 map, the selected electrodes of both ROIs offer a good estimate of these regions.

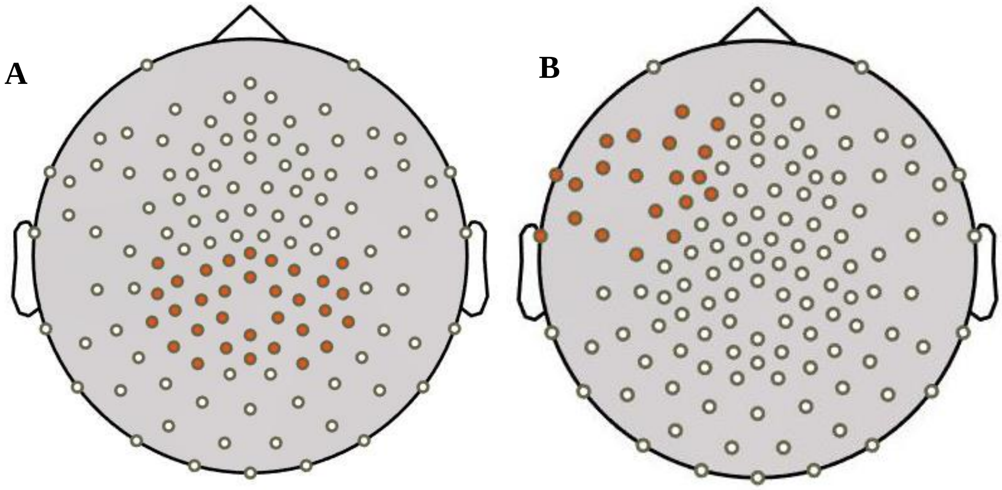


Figure 12: 128 Geodesic system electrode layout. Electrodes selected as part of ROI analyses are highlighted in red. **A:** Electrodes selected as part of the N400 ROI, comprising centro-parietal region of the scalp. **B:** Electrodes selected as part of the N200 – 500 ROI, comprising the left temporal region.

For some of these follow-up analyses, it was also necessary to average the data over time as well. These time points were also approximated according to the existing literature, with a 200-600ms epoch range selected for the N400 effect (Kutas & Federmeier, 2011) and a 100-250ms epoch range selected for the PLPE (Friedrich & Friederici, 2004; 2005).

2.4.4.1 Follow-up analyses results - ANOVA

Averaged data along the ROI and time of interest for all participants was extracted and entered into two, 2x2 within-subjects ANOVAs. These ANOVAs featured the factors of Lexicality (familiar, novel) and Congruency (congruent, incongruent). The first ANOVA reports findings over data averaged to the N400 ROI and time, whilst the second reports findings from data averaged to the PLPE ROI and time. Thus, for each ANOVA, participants contribute 4 mean scores – one for each condition (congruous familiar, incongruous familiar, congruous novel, incongruous novel). Both main effects and the interaction between the two factors are reported.

N400 ANOVA: A significant main effect of Congruency was observed F (1, 24) = 47.47, p<.001, np2 = .66. This was a result of greater negativity in response to incongruous pairings (-0.3μV) compared to congruous pairings (-.04μV). There was no significant main effect of Lexicality F (1, 24) = .08, p=.774, np2 = .00, and no significant Congruency x Lexicality interaction F (1, 24) = 1.56, p=.224, np2 = .06. These findings are visualised in Figure 13.

PLPE ANOVA: There was no significant main effect of Congruency F (1, 24) = 2.58, p=.12, np2 = .10, no significant main effect of Lexicality F (1, 24) = .09, p=.771, np2 = .00, and no significant Congruency x Lexicality interaction F (1, 24) = .45, p=.511, np2 =.02.

The results of this follow-up ANOVA analysis are congruent with the findings from the permutation analyses: No effect is detected in the PLPE time window, while a N400 effect is observed for both the novel and familiar words. The lack of a significant interaction between congruency and lexicality suggests that the magnitude of the N400 effect was not significantly different between the familiar and novel condition at this region. We did previously note that the possible N400 effect in the permutation analyses appeared extended in time, somewhat, in the familiar condition. This could have increased the magnitude of this effect throughout the defined N400 epoch here, which may have been revealed via a significant interaction. However, this does not seem to be the case.

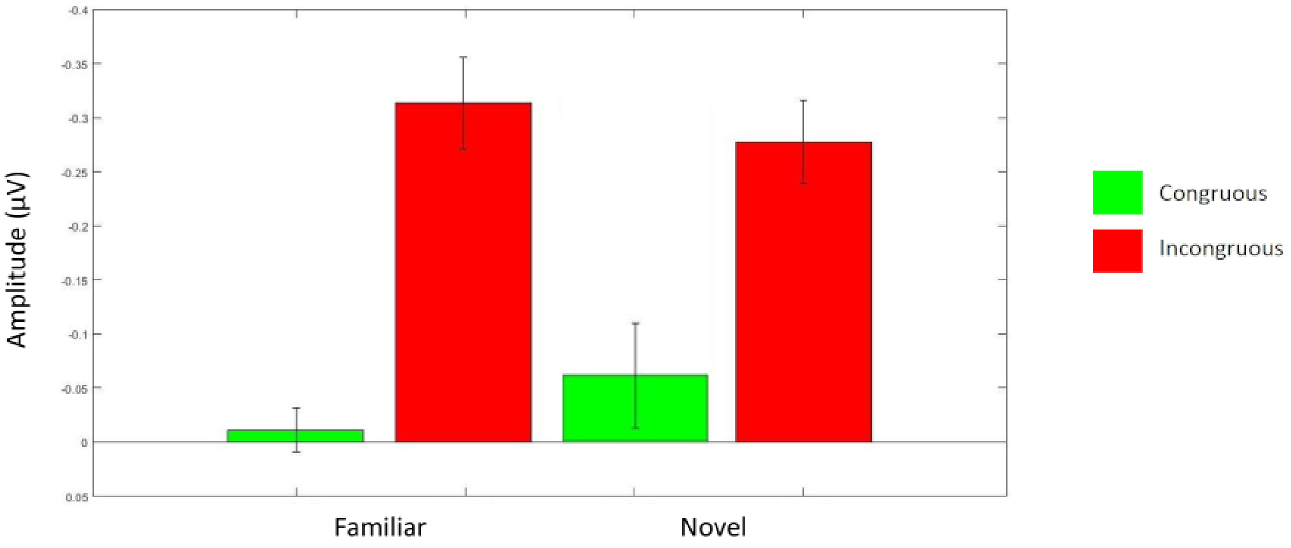


Figure 13: Bar chart displaying mean amplitude for each condition, averaged to the N400 ROI and 200 – 600ms. Negativity is plotted upwards.

The PLPE ANOVA did not uncover any main effects or interaction. Thus, as with the permutation results, there does not appear to be increased negativity towards congruous pairings at left temporal sites from 100-250ms, which is the documented pattern of the PLPE.

2.4.4.2 Follow-up analyses results – Peak amplitude and latency

Up to this stage of the analyses – including the permutation and ANOVA analyses – the data has not revealed a pattern of activity that seems consistent with a PLPE. Because of this, the remaining follow-up analyses focuses solely on the N400 effect, which seems to be apparent in the data from the analyses reported thus far, for both lexicality conditions.

In ERP research, the peak amplitude of the signal is defined as the absolute value recorded throughout the epoch of a difference wave (lowest if interested in negative effects, such as the current study). Peak latency is simply defined as the exact time point within the epoch at which the peak amplitude occurs. These measures were investigated here to determine if peak N400 amplitude and / or latency may differ between the familiar and novel conditions.

To prepare the data for this analysis, an incongruous – congruous difference wave was calculated for each participant, separately for the familiar and novel conditions, with the signal averaged to the N400 ROI. For each difference wave, the lowest voltage (peak amplitude) throughout the N400 epoch range (200 – 600ms) was selected, as well as the time at which this occurred (peak latency). These measures were independently compared between the familiar and novel condition via a dependent samples t-test.

Comparison between the familiar and novel conditions revealed a significant difference in peak **amplitude** t (24) = .21, p=.036, d=0.58. Peak amplitude in the novel condition was significantly larger (mean -1.32μV) compared to the familiar condition (mean -1.08μV). There was no significant difference in peak **latency** between the two conditions (t (24) = .21, p=.838, d=.05, familiar mean = 421ms, novel mean = 416ms).

These findings suggest that the magnitude of the N400 is *larger* in the novel compared to familiar condition. Whilst this could reflect a true effect, one possible confound concerns the study design. Peak amplitude measures are more susceptible to the effects of high frequency noise than other measures such as mean amplitude. High frequency noise is likely to be more prominent in the novel condition, due to the reduced trial count of this condition compared to the familiar condition – the more trials available, the more likely high frequency noise is 'smoothed' from the averaged signal. Considering this, the analysis was repeated using the down sampled familiar data set to compare against the novel condition. This revealed a marginally significant difference in peak amplitude between the two conditions t (24) = 2.10, p = .051, d= 0.54, with the direction of this difference reversed compared to the original analysis (mean familiar = -1.60μV, mean novel = -1.32μV).

2.4.4.3 Follow-up analyses results – integral of the signal

As defined by Luck (2014), an EEG signal can be visualised as having a geometric area, which is the shape of the signal relative to the baseline of 0μ. The negative area of the signal is simply the sum of all negative voltages throughout a given epoch range, and positive area is the sum of all positive voltages. As amplitude is expressed in microvolts and time in ms, the area is expressed as μV.ms. The integral of the signal is the negative area subtracted from the positive area. Therefore, a negative integral would indicate overall greater negativity throughout the given epoch range. Given this, differences in overall integral values between the familiar and novel conditions were investigated.

To calculate this, for each participant, we calculated the integral from 200 – 600ms over the familiar difference wave and the novel difference wave. These difference waves were calculated by subtracting the congruous signal from the incongruous signal, averaged to the N400 ROI. The integral values were then analysed with a dependent samples t-test.

This analysis revealed no significant difference in integral values between the familiar and novel conditions t (24) = -1.20, p=.241, d=.32. The mean integral value for the familiar condition was -30.33μV.ms, compared to -22.33μV.ms for the novel condition.

2.5 Discussion

The current study aimed to investigate the quality of lexical representations for recently learned novel words, and to determine whether lexical knowledge can be dissociated based on ERP responses. To achieve this, participants learned novel words via exposure to novel word-object mappings in the training phase of the study. Following training, participants took part in a cross-modal priming paradigm wherein an object was paired with its congruous label, or an incongruous label. During this testing phase, participants were connected to an EEG system in an attempt to record ERPs associated with different forms of lexical knowledge.

As expected, there appeared to be an N400 effect in the familiar condition. Contrary to our expectations, however, this same effect was also observed in the novel condition, with increased negativity over roughly centroparietal regions in response to incongruous object – word pairings. Neither condition appeared to elicit a PLPE, which was also contrary to our predictions.

We begin the discussion by outlining our findings in relation to the PLPE, and possible reasons for why we did not observe this effect. We then discuss the findings in relation to the N400 effect. In particular, we discuss what these results might inform us regarding the representation of new words.

The phonological lexical priming effect

The PLPE – characterised by greater negativity in response to congruous compared to incongruous object-label trials, peaking at left temporal sites (in adults) around 100-250ms post stimulus onset – is thought to be representative an associative pathway in memory between a particular word-form and object representation (Friedrich & Friederici, 2017). This effect is therefore thought to be independent of higher-level semantic processing (Friedrich & Friederici, 2015).

There did not seem to be a cluster in the data which resembled this effect, in either the novel or the familiar condition. In the familiar condition, there was a cluster (positive cluster 1) which resembled greater negativity in response to congruous object-label pairings. However, there are a couple of reasons to be sceptical about whether this reflects a PLPE. Firstly, it began very early – 32ms post target onset, which is considerably quicker than what is reported in the literature (e.g., Friedrich & Friederici, 2004). Secondly, although the cluster did comprise some left temporal regions, it appeared to also comprise central regions of the scalp.

An additional question is why, assuming that this cluster in the familiar condition did reflect a PLPE, which is supposed to reflect simple associative knowledge, is it not observed in the novel condition as predicted? One possible explanation concerns the presence of carrier phrases when presenting the target words. The familiar words used in the current study would have been encountered on numerous occasions throughout the participant's lifetime in a range of different formats – orthographically, as part of a multiword sequence, in isolation, etc. Due to this repeated exposure, the phonetic arrangement of these words is likely well known, and hence phonological representations are likely to be well established. The novel words, however, are unlikely to have been encountered prior to the study, and thus phonological representations should not exist before training. Hypothetically, because the novel words were featured within a phrase, it could be that the phonetic arrangement of the word could not be extracted efficiently from within the wider phonetic arrangement of phrase. For the familiar words, however, because phonological representations are well established, listeners can identify the word form more efficiently from within a phrase. This account is at odds, however, with theories of statistical learning, which suggest that both adults and infants are able to extract novel words from a speech stream by recognising the repeated syllable structures. Indeed, even infants require little exposure of the speech stream to do so (Saffran et al., 1996; Yu & Smith, 2007).

Thus, in reality, it is unclear a) whether a PLPE was present at all, and b) if it was present in the familiar, why it was not present in the novel word condition.

An N400 effect for novel words: Evidence of integrated semantic representations?

As has been discussed throughout this thesis, the N400 component is sensitive to meaning processing, with a greater N400 response observed when the target stimulus is unexpected and/or incompatible with the preceding context (Kutas & Federmeier, 2011). The presence of an N400 effect in response to recently learned novel words therefore suggests that these words can contribute to semantic processes straight away from acquisition. Furthermore, despite an extensive analytical approach, including a non-parametric permutation analysis and ANOVA, there appeared to be no clear quantitative difference in the spatiotemporal profile of the effect between the novel and familiar conditions.

The findings in the literature regarding the presence of novel N400 effects are inconsistent (see section 1.3.3.3). When significant effects are reported, this is sometimes taken as evidence for the immediate integration of semantic representations (Borovsky et al., 2012), such that the representation of new and existing words shares similar neural substrates. Given the similar spatiotemporal profiles between the novel and familiar conditions observed in Chapter 2, this might lend further support to this claim. Hence, these findings could indicate the immediate integration of semantic representations, given that we found no clear dissociable ERP effects between novel and familiar words.

There is also some evidence in the literature to suggest that knowledge acquisition can bypass the initial hippocampal route and integrate more readily into cortical networks under certain conditions. It is worthy to consider, therefore, whether any such conditions were present in our experiment that could have facilitated integration. For example, rats with hippocampal lesions can still acquire novel spatial information if new information is consistent with a pre-existing ‘schema’ of similar spatial knowledge (Tse et al., 2007), a phenomenon that has been incorporated into more recent models of the CLS approach to knowledge acquisition (McClelland, 2013). Furthermore, in the lexical acquisition literature specifically, there is evidence that fast mapping training styles facilitate integration into cortical networks compared to explicit encoding (Coutanche & Thompson-Schill, 2014). In the present study, however, *novel* objects and words were selected, which were unlikely to map onto a pre-existing schema of visual or phonological information, respectively. Secondly, a fast-mapping training style was not adopted (participants passively observed each object-word pairing sequentially). Thus, it is not clear how pre-existing information or training method could have facilitated the integration of novel object-label mappings into cortical language networks in the current study. To get a better understanding of the mechanisms underlying our results, in the following section, we review the literature in relation to our findings. In doing so, we also aim to probe more closely the apparent inconsistencies regarding novel N400 effects.

One important factor which appears to modulate the presence of novel N400 effects concerns the length of the delay between novel word training/learning and the critical testing phase. When significant N400 effects have been observed with new words, including the current study, the testing phase appears to take place immediately or soon after training/exposure (Borovsky et al., 2012; Mestress-Misse et al., 2007; Perfetti et al., 2005). This is compared to studies which observe non-significant effects, which explicitly state a (relatively) substantial delay between training and testing, including 30 minutes (Kaczer et al., 2018) and up to one hour (Bakker et al., 2015; Lei et al., 2022; Liu & van Hell, 2020). It has been claimed by some authors (Bakker et al., 2015) that novel N400 effects reported in the literature could be explained by the explicit retrieval of non-lexical, perhaps episodic, representations. If this is true, such representations may be subject to hippocampal decay over time (Hardt et al., 2013), meaning their utility in supporting cognitive processes should be decrease as a function of time following encoding. Due to such decay, dissociable effects between novel and familiar words may begin to emerge when training and test sessions are separated by a relatively long timeframe.

A second important factor could concern the stimulus onset asynchrony (SOA). In the semantic priming domain, as the SOA increases, so does the propensity for strategic priming mechanisms to emerge (McNamara, 2005; Neely, 1977). In the current study, the SOA between the object and label was 1506ms (*SD* ± 64.9ms), on average. That is, the onset of the carrier phrase occurred 1000ms after the presentation of the image. Within these carrier phrases, the onset of the target word was 506ms on average.

This long SOA could have, therefore, encouraged the use of strategic mechanisms employed by the participant, in response to the novel stimuli. For example, although the participant was not required to provide an overt behavioural response in the testing phase, they could nonetheless have strategically predicted the identity of upcoming labels after retrieving the label of the on-screen objects, and/or attempted to integrate the label onto pre-activated semantic information (i.e., semantic matching). Strategic processing has been suggested to be implicated in novel N400 effects before (Bakker et al., 2015). Indeed, the magnitude of the N400 effect is consistent across SOA lengths (Lau et al., 2008), which suggests that the N400 may be a marker of any mechanism – whether it be bottom-up automatic activity or top-down prediction processes – that facilitates lexical access. This is important here because if novel words have not yet integrated into language networks (Davis & Gaskell, 2009) – thus may not be exposed to automatic activity – strategic mechanisms could still have an effect, where the participant explicitly considers the learned meaning of the word, which affects the processing of the congruous/incongruous label. Thus, whilst previous work has explicitly considered the N400 effect to be a marker of relatively *automatic* lexical access and hence integrated semantic representations (e.g., Bakker et al., 2015; Liu & van Hell, 2020), the fact that N400 amplitude is consistent across SOA may suggest non-automatic components of lexical processing are also implicated in this effect. In relation to the current findings, it may be possible that such non-automatic processes were operating for both the novel *and* familiar words, leading to similarities in the observed N400 effect.

Claims that novel N400 effects may be sourced from episodic representations (Bakker et al., 2015) leads to the assumption that N400 effects between novel and familiar words could be sourced from distinct neural networks and representations. Whereas the novel N400 effect may be sourced from episodic representations, whereby the participant explicitly retrieves learned object-label mappings to perhaps predict upcoming labels (in the testing phase) and/or integrate a label onto the current context (i.e., the on-screen image), the familiar N400 effect is likely to be sourced from activity within language networks and/or the additional use of strategic mechanisms. If this is true, then topographical differences between conditions should feasibly be observed, reflecting the recruitment of these distinct neural networks and/or mechanisms. Indeed, in Mestress-Misse et al. (2007), for example, the novel word N400 effect was believed to be sourced from frontal brain regions, compared to the familiar N400 effect which was ascribed with a temporal source. The authors argued that semantic processing for new words may therefore require more cognitive control. This frontal distribution thus coincides with the anatomical position of the inferior frontal gyrus (IFG), which, as discussed, is implicated in the controlled retrieval of semantic information (Thompson-Schill et al., 1997).

Accordingly, the lack of clear topographical differences in Chapter 2 pose a challenge to the idea that the representation of new and familiar words call on separable neural systems. More specifically, the qualitatively similar N400 responses may argue that new words are not initially dependent on hippocampal processing and may integrate and interact with other words soon after acquisition, a finding that is inconsistent with the CLS account (Davis & Gaskell, 2009). There are, however, some methodological factors which could have contributed to the lack of topographical differences. One possible reason concerns task difficulty. In the present study, word-object pairings were either fully congruous or incongruous, compared to prior work which typically elicited the N400 effect by presenting words that are either semantically related or unrelated to the novel word. Recognising the congruency between an object and label is possibly less cognitively challenging than recognising the semantic relationship between two words, which requires some level of scrutiny. Secondly, the current study did not require participants to make a behavioural response, compared to previous work where participants have typically made a lexical or semantic decision. It could be argued that, collectively, these two factors required less cognitive control compared to previous research where tasks appear (relatively) more difficult, which may result in less activation of frontal regions. Again, the testing phase of the current study was made relatively easy and passive due to planned future studies with infant participants.

Another possible reason for the lack of topographical differences in the current study also concerns the SOA. In the semantic priming domain, the effects of automatic activity such as spreading activation is most dominant at short SOAs, as this activity is swift and soon dissipates following its onset (Collins & Lofts, 1975; McNamara, 2005), thus having a weaker influence as the SOA increases. This could have implications for the current results, if again we assume that novel words have not yet integrated into language networks. Specifically, the long SOA could have failed to capture any automatic-like mechanism that the familiar words – but not the novel words – are exposed to, which could influence the observed location of the N400 effect. Indeed, Perfetti et al. (2005) and Balass et al. (2010), who used a 1000ms SOA, similar to that used here, do not report any clear topographical differences between familiar and recently learned words (thought see Angwin et al. (2022) for topographical differences between novel and familiar words). One issue with this explanation, however, is that conscious and controlled strategies are more likely to feature at longer SOAs, which has been shown to be linked with activation of the IFG (Lau et al., 2008). In the current study, however, the topography of the N400 effect was located around centroparietal regions for both the familiar and novel words; not over frontal regions. In sum, it is possible that certain parameters of our experiment made it difficult to observe potential differences in the ERP response between novel and familiar words.

Given that our stimuli were repeated several times across the testing phase, we must also consider the potential influence of practice effects on our results. Across the course of the testing phase, each word-object pairing was encountered on at least 4 occasions. This is particularly important given evidence that the N400 is reduced on repeated presentations of a given word (Laszlo & Federmeier, 2007; Laszlo et al., 2012; Rugg, 1990), which may reflect the enhanced accessibility of a (repeated) representation over the course of the experiment (Hsu & Lee, 2023). Importantly, this could have nullified differences between the congruous and incongruous conditions in our design. Similarly, for the novel stimuli, these repeated presentations may also have presented further opportunities to enhance learning. It has recently been proposed that retrieval opportunities may act as a mechanism of cortical consolidation (Antony et al., 2017). Whilst the testing phase did not require the explicit retrieval of words, participants could nonetheless have made implicit predictions of the word based on the onscreen object. In theory, this could have promoted the integration of cortical representations for these new words, which would lead to similar N400 profiles.

Limitations

We have noted several times that the passive nature of the experiment may have inhibited the extent to which we could observe clear differences in the ERP signal between novel and familiar words. It should also be noted, too, that passive listening tasks have been shown to elicit weaker N400 effects compared to more explicit paradigms (reviewed in Cruse et al., 2014), possibly due to a reduced capacity for semantic evaluation. Hence, with a more explicit paradigm, such as a semantic judgement task, larger N400 effects may be elicited, possibly revealing differences between new and familiar words.

The relative frequency of familiar compared to novel trials may also have impacted the ERP response. This imbalance could have given rise to an oddball scenario. While oddball paradigms have typically been implicated with the P300 response (Picton, 1992), recent research has revealed a sensitivity of the N400 to deviant and 'oddball' stimuli. Lindborg et al. (2023) presented participants with words from different semantic categories presented sequentially in groups of 10 words per category. The presentation of a 'deviant' word from a different category (e.g., 10 words referring to different animals, followed by the word "hammer") elicited a stronger N400 response compared to a word from the same semantic category. This suggests that the N400 is sensitive to the element of semantic surprise. In context of our experiment, the relatively infrequent novel items may have elicited similar surprisal effects, impacting how these words were initially processed.

To summarise, the current chapter explored whether lexical knowledge is dissociable based on ERP response. To examine this, we explored two unique ERP effects – the PLPE and N400 effect – and asked whether it is possible to observe associative word knowledge in the absence of semantic processing, in an attempt to bridge together two separate strands of research which make the somewhat similar claim that there are different ways of knowing a word.

A PLPE did not seem to be present in either the novel or familiar conditions. Given that this effect has been observed in adults before, it is possible that our design was not sensitive enough to trigger the associative pathway that the effect is deemed to represent. For example, our use of carrier phrases differs from previous work which presented targets words in isolation, which could have hindered the activation of specific word-form representations.

However, as discussed in the discussion, this explanation does not sit well against the statistical learning literature.

For both classes of words, an N400 effect seemed to be present. This suggests that new words can engage in semantic processes immediately after acquisition. Whether this effect is sourced from integrated semantic representations, however, cannot be directly answered from these current results, and represents a long-lasting debate in the literature. Indeed, the spatiotemporal profile of the N400 effect is very similar between the novel and familiar conditions, which may suggest such representations had developed. On the other hand, there is evidence that these representations take time to develop, and that new words and their meanings are initially represented episodically via the hippocampus. Furthermore, both intrinsic and extrinsic factors that may facilitate the consolidation process (pre-existing information and training style) were also unlikely to have an effect in the current study. Again, the results of the current study cannot support the claim of initial hippocampal representation, but it is possible that certain parameters of the experiment could have promoted the use of conscious and strategic mechanisms over these proposed episodic representations, to the extent that potential topographical differences between novel and familiar words were nullified.

This design of this study was intended to be replicated in infant participants to measure ERP effects of word knowledge in this population. As discussed, these studies were abandoned due to the COVID-19 pandemic. Nonetheless, the results of the current study opened up other interesting avenues to explore, which are investigated in Chapter 3.

The results of Chapter 2 fundamentally suggest that new words can contribute to semantic processing, straight away from acquisition. The locus of this phenomena was explored further in Chapter 3, where we investigated the conditions which may elicit similar patterns of behaviour between new and familiar words, and what this may reveal regarding the encoding of new words. We specifically explored the mechanisms that may contribute to novel word semantic processing using a behavioural semantic priming paradigm. We investigated the proposition that this processing may be more strategic than automatic in nature, by systematically varying the SOA within a semantic priming task.

Chapter 3 – Revisiting Novel Word Semantic Priming: The Role of Strategic Priming Mechanisms

3.1 Abstract

In Chapter 3, we explored what factor(s) influences semantic processing in relation to new words, causing the observed behaviour of these words to be similar to that of familiar words, as found in Chapter 2. Our investigation particularly focused on the role of the stimulus onset asynchrony (SOA) length in supporting novel word semantic priming. By manipulating the SOA, we aimed to tap into distinct priming mechanisms and measure the role of these processes with novel words. Participants first learned 30 rare (thus providing novelty) English words and their meanings (e.g., *Calloo – a kind of duck found in the Arctic*). These words then served as primes for related and unrelated target words, where participants probed the association between the prime and target (i.e., an SJT). Crucially, each block of the SJT used a unique SOA length: 200ms, 500ms, or 1000ms. Whilst 200ms should promote more automatic mechanisms of semantic priming, 500ms and 1000ms are considered long enough to allow for the development of strategic mechanisms. Semantic priming elicited by the rare words was compared to priming elicited by semantically matched familiar prime words (e.g., *Goose*). Response time data was analysed with linear mixed-effect models, with the factors SOA, prime-target relatedness, and prime lexicality included. For the rare prime words, a semantic priming effect was apparent exclusively at 500ms. For the familiar primes, however, there was no evidence of semantic priming for any of the SOA condition. This finding is problematic since these familiar words served as a baseline measure and were expected to elicit semantic priming. Possible reasons for these results are discussed. However, they ultimately limit the informativeness of findings observed with the rare prime words. Thus, further investigations are necessary to examine the role of SOA length on novel word semantic priming.

3.2 Introduction

The results of Chapter 2 revealed similar patterns of semantic processing between new and familiar words. Whether this is indicative of integrated semantic representations for new words, however, is unclear. Hence, in Chapter 3, we aimed to investigate the parameter(s) that could be implicated in producing this similar pattern of behaviour between these words, to further understand the nature of initial word representation. The parameter of interest in Chapter 3 was the SOA, which was manipulated in the context of a *behavioural* semantic priming task.

N400 effects are argued, by some, to reflect automatic retrieval processes (Kutas & Federmeier, 2010; Lau et al., 2008), which may depend on words being integrated into semantic networks. However, some researchers have argued that N400 effects may also be sourced from controlled and strategic retrieval mechanisms, possibly acting upon episodic representations (Bakker et al., 2015). Under this account, new, and not yet integrated, words can still engage in semantic processing, it is simply the manner in which they do so that differs from familiar words.

Consistent with this claim, there are some reports in the literature of significant novel word semantic priming effects when the SOA is relatively long, such as 500ms (Bakker et al., 2015) and 1000ms (Balass et al., 2010; Perfetti et al., 2005). Because strategic mechanisms are more likely to emerge at longer SOA (McNamara, 2005; Neely 1977), this could implicate these mechanisms in novel word semantic priming, and semantic processing more broadly, corroborating Bakker and colleagues' claim regarding novel N400 effects. Furthermore, these studies recruited a semantic judgement task (SJT) to measure semantic priming, which could encourage the recruitment of these mechanisms more so than a primed lexical decision task (pLDT) (see section 1.3.3.1), since retrieval of word meaning is necessary in an SJT.

It is useful to consider the process of how these mechanisms could take effect. Firstly, since novel words are not initially integrated into semantic networks (Davis & Gaskell, 2009), it is deemed that automatic priming mechanisms, such as spreading activation, cannot take effect (Tamminen & Gaskell, 2013). However, the hippocampal pathway that represents early lexical knowledge still allows many aspects of lexical processing to occur, such as retrieval of the meaning of a new word. This is evident in participants' explicit knowledge of new words shortly after acquisition (see Chapter 1 - Table 1 and Table 2), which is also apparent in the 2-AFC task reported in Chapter 2. If the participant is able to recall the learned meaning of a novel word that acts as a prime word, perhaps they could predict semantically related upcoming targets (expectancy generation) and/or perform a retrospective semantic matching strategy, *if* the SOA is sufficiently long.

As mentioned in the introduction of this thesis, the SOA could affect the extent to which we see lexical competition and engagement with new words. Weighall et al. (2017) proposed that (phonological) competition effects can arise between novel and existing items, but certain parameters may need be in place to allow this happen. One such factor concerns the task measuring lexical competition, which must be able to incorporate information arriving slowly from the hippocampus. This is because the initial hippocampal pathway represents an indirect route of memory retrieval, which is slower than direct cortical pathways of existing knowledge (Davis & Gaskell, 2009; Lindsay & Gaskell, 2010).

What does this mean for semantic processing with recently learned words, particularly in the context of semantic priming? If a recently learned word serves as the prime word, it may require more time to be processed than a familiar word. For this process to be complete before the target appears, a sufficiently long SOA would be necessary. For example, if a short SOA is used, then the meaning of the prime novel word may not be retrieved in time for the target. This would hinder the effectiveness of any strategic mechanism that the participant is able to use (i.e., one cannot predict upcoming targets effectively without first identifying the meaning of the prime word). This, however, should not be an issue for familiar words since automatic mechanisms, which dominate at short SOA, are likely to have an effect.

We believe that manipulation of the SOA in a semantic priming task can provide valuable insights into the representation and encoding of new words. If new words are initially dependent on hippocampal processing, and have not yet integrated with existing word knowledge, then they should be more dependent on strategic processing compared to more automatic mechanisms. In which case, evidence of semantic priming will be more likely when there is a relatively long SOA operating in a semantic priming task. Furthermore, the SOA can offer insight into the time course of novel word retrieval, which is argued to be slower than that of familiar words (Davis & Gaskell, 2009). Similarly, the ability of a new word to prime other words may also require a sufficiently long SOA. Crucially, because familiar words are represented by integrated semantic representations and are processed more quickly than new words, they should also engage in priming under shorter SOA conditions, indicative of automatic processing. Hence, the SOA could be used as a means of dissociating lexical knowledge on a behavioural level.

We are unaware, however, of previous work which has explicitly considered or manipulated the SOA as a tool for understanding the representation of new words, in the context of semantic priming. This was investigated in Chapter 3. In this experiment, we measured semantic priming across three SOAs within a single semantic priming task: 200ms, 500ms, and 1000ms. The 200ms SOA should favour automatic priming mechanisms, since it should be too short to allow effective strategies to emerge (McNamara, 2005). The 500ms and

1000ms SOAs, however, should be long enough to allow strategies to unfold. Indeed, priming has been observed before at these SOAs (Bakker et al., 2015; Balass et al., 2010; Perfetti et al., 2005). Accordingly, we predicted that novel words would show evidence of semantic priming at 500ms and 1000ms only.

Familiar prime words were also included to act as a baseline measure of priming. Because these words should have well established representations in semantic networks, they should also benefit from automatic priming mechanisms. As such, it was predicted that the familiar words would show evidence of priming across all 3 SOA conditions.

3.3 Methods

3.3.1 Participants

A total of 75 participants (46 females) completed the experiment (*M age* = 34.30 years, *SD age* = 11.06 years). All participants were recruited via Prolific (https://prolific.co/) - an online platform for participant recruitment - and received £7.50 for their participation. Participants reported English to be their first language and reported no known language related disorders. A further 16 participants also took part in the experiment, but their data were not included in statistical analyses for the following reasons: Did not complete the whole experiment (n = 8); did not answer a single trial correctly during the semantic priming task (n = 7); a technical error (n = 1).

As outlined in our Open Science Framework pre-registration (https://osf.io/zarnb), our sample size was identified using bootstrapping simulations over data collected from 10 pilot participants. We created 1000 simulated data sets, up to a sample size of 110 participants. These simulations suggested a semantic priming effect would emerge at 200ms for the novel words with a sample size of 75 participants (at 80% power). We therefore chose this as our target sample size as a) it would allow us to confirm this informative effect which was counter to our pre-pilot predictions and b) it would allow us to exploratorily examine any difference between the effect and the effects seen in other word type/SOA combinations.

3.3.2 Experimental design

This study had two parts. The first part of the experiment was a training phase, in which participants learnt the meanings of rare English words. The second part of the experiment consisted of a semantic priming task, where participants made a decision regarding the semantic relationship between a prime and target word (an SJT). We opted for an SJT compared to a pLDT because previous work that has observed novel priming effects also recruited an SJT. We anticipated that this choice of task would make priming more likely. During the priming task, the rare words taught in the preceding training phase, as well familiar English words, served as prime words for related and unrelated target words.

Our primary dependent measure was measured during the semantic priming task, which was the time taken by participants, measured in milliseconds, to make their decision (response time). This dependent measure was exposed to a mixed-factorial design, with the within-subject factors of Lexicality (rare or familiar prime word), Relatedness (related or unrelated prime-target pairing) and SOA (200ms; 500ms; 1000ms) all operating during the priming task. As is standard, priming would be said to have occurred where the decision time was significantly shorter for related than unrelated pairs.

3.3.3 Stimuli

3.3.3.1 Primes and training materials

Thirty rare English words (e.g., *Calloo*), from an initial pool of 54 words, were selected for this study to serve as novel word stimuli (see Appendix 2.1 for a full list of rare words and their definitions). These words were taught to participants in the training phase, and later served as prime words in the semantic priming task for related/unrelated targets. To ensure rarity and hence novelty, the selected words do not appear in the British National Corpus across spoken and written modalities and range from frequency band 1 (0 occurrences per million words) to frequency band 3 (0.01 – 0.099 occurrences per million words) in the Oxford English Dictionary (OED) frequency distributions (The OED recruits Google Books Ngrams Data to determine frequency – see http://public.oed.com for more information).

In order for participants to learn the meanings of the rare words, we also presented their corresponding definitions during the training phase (e.g., *Calloo – a kind of duck that is found in the Arctic*). The definitions were taken from the OED ($M_{\text{words per definition}} = 5.67$; $SD = 1.88$).

Thirty familiar English words, again from an initial pool of 54, were also selected and served as familiar primes in the semantic priming task (see Appendix 2.2 for a full list of familiar words). A familiar priming condition was included to generate a baseline reading of priming behaviour to compare against the rare prime condition, and to ascertain that the design of the semantic priming task was indeed sensitive enough to elicit priming effects. We selected familiar primes by matching them to the rare words on the level of semantics (e.g., *Goose* was selected as a matched familiar prime for the rare prime *Calloo*).

Next, we reduced the number of rare words from 54 to 30 – a figure that we deemed more appropriate considered memory and time constraints of the experiment. To do so, we selected the 30 words that, conceivably, should be most likely to elicit semantic priming. Specifically, in order to increase the likelihood of observing semantic priming, it is desirable to use prime-target pairings that have a relatively strong association and/or relation. Considering this, we selected the 30 rare words that had the strongest association with 3 related (target) words. We define *strongest* in this context as the number of respondents to produce a particular target word after processing a particular prime word, which was measured via pre-rating surveys completed by a set of independent respondents. These surveys are discussed below.

This approach of selecting related targets was based on the work of van der Ven et al. (2015) who also trained rare (Dutch) words to participants.

3.3.3.2 Identifying related target words

In total, four unique pre-rating surveys were produced and administered on JISC Online Surveys (https://onlinesurveys.ac.uk). Respondents completed just one survey, with each survey completed by 20 different respondents. Two of the surveys contained 14 of the rare and 13 of the familiar words (vice versa for the other two surveys), along with their definitions. Respondents viewed each word and its definition in turn and were instructed to type ‘up to 5 words which come to mind’ after processing the word and definition. Unlimited time was provided, and respondents were instructed that they did not have to provide a response if nothing came to mind. Respondents were also instructed that responses could have any part of speech.

For each prime word, every unique word (henceforth referred to as the target word) that was provided across respondents received a *forward association strength* (FAS) value, which was the proportion of respondents to produce the given target word after processing the particular prime word. This is akin to the association statistics that are presented in conventional association norms (e.g., Nelson et al., 2004). For each prime word, we selected the 3 targets with the greatest FAS scores, from the pool of *all* targets that were generated in response to the given prime. These 3 scores were then averaged to create a *mean FAS* score, which was ascribed to that particular prime. For example, the mean FAS of the prime word *Calloo* is .45, which represents the average FAS across its 3 most produced targets: cold (.80 - produced by 80% of respondents), ice (.30 – produced by 30% of respondents), and quack (.25 – produced by 25% of respondents). At this stage of the analysis, FAS scores for singular and plural forms (e.g., *egg* and *eggs*) and singular forms and adjectives (e.g., *smell* and *smelly*) were combined, and the singular form was kept. Throughout this process, we also considered the following factors:

I. If, for a single prime word, there were equal FAS scores across target words, making it impossible to select 3 words (i.e., four target words had a FAS score of .25), target words were selected at random from this pool.
II. In the case of duplicate target words across prime words (i.e., if two or more prime words produced the same target word), the prime word which produced the target word most consistently (i.e., had the greatest FAS score) received that particular target word. This step was performed across rare and familiar prime words.
III. When selecting target words for the rare prime words, we discarded any target word which appeared in the definition of the rare word. Because the definitions for the rare words were presented during the training phase, it is possible that episodic associations between the prime and target developed during training, could drive any subsequent priming behaviour. This criterion was not considered when selecting target words for the familiar primes, since these words were not trained to participants and hence their definitions were not presented to participants at any point in the experiment.

After calculating a mean FAS score for each prime word, we then selected the 30 rare prime words with the greatest mean FAS scores to serve as rare stimuli in the experiment. The rationale for this was that these mean FAS scores quantify the strength of association between the primes and their targets - the greater these respective scores, then the more likely semantic priming should theoretically ensue. Hence, the 3 target words per prime word served as related targets of the prime in the semantic priming task. As for the familiar prime words, we simply selected the matched familiar counterpart (e.g., *Goose*) of the selected rare words, along with their 3 strongest target words (e.g., *Bird*, *Duck* and *Pond* served as related targets for *Goose*) Hence, whilst we did not systematically select familiar primes based on mean FAS score, mean FAS values were still equal across conditions (Rare .33; Familiar .33). Across primes, all target words were unique. The reader is directed to Appendix 2.1 and Appendix 2.2 for related target words to the rare and familiar words, respectively.

Throughout the whole experiment – including the training tasks and semantic priming task – all words were presented in lowercase the participant's computer screen.

3.3.4 Procedure

The experiment was programmed and administered in Gorilla Experiment Builder (Anwyl-Irvine et al., 2020 – https://Gorilla.sc), and participants could complete it on their own computer. Potential participants could view the experiment on Prolific, where a link to the study was displayed. Upon selecting the link, participants were redirected to Gorilla Experiment Builder, where they were invited to read the participant information sheet and provide written consent to take part. The whole experiment took approximately 70 minutes to complete. Participants were instructed to complete the experiment in a quiet location with just themselves present where possible.

As stated previously, the first part of the experiment consisted of a training phase, designed to teach participants the meanings of the 30 rare words. As part of this training phase, participants completed a series of tasks. The tasks we selected are based on the training tasks used in Bakker et al. (2015) who also taught participants the definitions of (fictitious) words. For a visual depiction of the training phase, see Figure 14 below. Before the training tasks commenced however, participants first completed the Familiarisation phase. Here, participants simply viewed every rare word and its definition in succession. Each word and definition remained on screen for 5 seconds.

Following the familiarisation phase the training tasks began. The first training task was the *2-Alternative Forced Choice (AFC) Definition – Word Matching* task. In this task, a definition of one of the rare words was presented in the centre of the screen. Below this were two words options to the left and right quadrants; one of which was the word referring to the definition, whilst the other was another (incorrect) rare word. The participant's task was to select the correct word using their mouse cursor. Each word was cued by its definition three times.

The following task – the *2-AFC Word – Definition Matching* task – was similar, except this time a word was presented in the centre of the screen, along with two definitions below; one of which was the definition of the on-screen word, the other was another (incorrect) definition referring to another rare word. Each definition was cued by its word three times. For both 2-AFC tasks, feedback was provided to the participant regarding the accuracy of their response on a trial-by-trial basis.

The subsequent task was the *Word Recall* task. Here, a definition was presented in the centre of the screen, and participants were asked to type the word they believed referred to the definition. Each word was cued once. The following task was the *Definition Recall* task, which was similar to the word recall task, except a word was presented on screen and participants were asked to type the definition of that word. Each definition was cued once. In both the word and definition recall tasks, participants received feedback regarding the accuracy of their responses, and the correct response was displayed for 2 seconds following the participant's response, regardless of their accuracy. Note that in terms of the Definition Recall task, we acknowledge difficulty in providing feedback in this instance, given that the participant needed to recall the definition in its entirety in order to receive a ‘correct’ response.

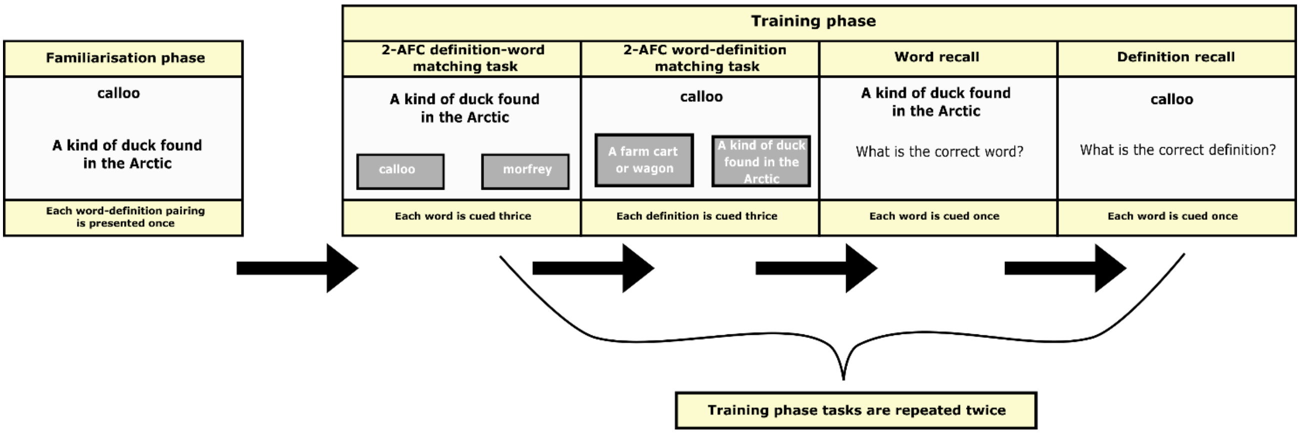


Figure 14: An illustration of the training phase. Arrows depicts the order of events. Once participants had completed the first round of Definition recall, they completed each task again in the same order.

Each task of the training phase was completed twice – after completing each task once, participants completed a second round of each task in the same order. Hence, throughout the whole training phase, including the familiarisation phase, each rare word was presented 17 times along with its definition. Participants were in control of when each task began, meaning they could take a short break between tasks if they required it. However, participants were informed that taking excessively long breaks could risk exceeding the maximum completion time for the study (156 minutes[3]); a problem that was encountered by a couple of pilot participants who ultimately exceeding the maximum completion time. For both the familiarisation phase and training tasks, the trial order was randomised across participants.

Following the training phase participants completed the semantic priming task, where the trained rare words, as well as semantically matched familiar words, served as primes for related/unrelated targets. Before commencing, participants were instructed to press ‘A’ on

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[3] The maximum completion time is computed by Prolific by taking into account the expected completion time of the study (70 minutes). The maximum completion time is always substantially larger than the expected time in order to allow more time for slower participants to complete the study.

their keyboard if they believed the prime and target were related, or ‘L’ if they believed they were unrelated.

Note that prime words were split into 3 lists of 20 primes (10 rare primes and 10 familiar primes). These lists determined the primes (and, hence, targets) that appeared in each block of the priming task. Every prime word was represented 6 times within these lists – 3 times with a related target, and 3 times with an unrelated target. Unrelated prime-target pairings were created by randomly shuffling targets across primes within lists. Hence, every block of the priming task consisted of 120 trials, with 60 related and 60 unrelated trials. Whilst the division of words to lists was largely arbitrary, the number of prime letters and syllables, as well as the number of target letters and syllables, did not significantly differ across lists. Furthermore, we ensured that matched rare and familiar primes did not appear in the same list, to ensure as little semantic overlap within lists as possible. The order of lists across participants was fixed, such that List A always occupied block 1 of the priming task. To ensure that each SOA appeared in each block of the task an equal number of times across participants, we included a between-subjects factor of Order. This factor determined the SOA used in each block (within participants). However, it also ensured that each SOA occupied each block of the priming task an equal number of times across participants. This served to prevent any order effects associated with the position of the SOA within the priming task.

Regardless of which SOA was operating, every trial of the priming task began with a fixation cross for 500ms. This was then replaced by the prime word, presented for 200ms. In the 200ms SOA condition, the prime word was immediately replaced by the target word. In the 500ms SOA condition, the prime word was replaced with a blank screen which remained for 300ms and was then replaced with the target word. The 1000ms SOA condition was identical to the 500ms SOA condition, except that the blank screen remained for 800ms. Across all SOA conditions the target word remained for 2000ms, and participants could respond as soon as the target word appeared. Once a response was provided, the target word was replaced by the fixation cross in preparation for the next trial. If a response was not provided before 2000ms had elapsed, the target word was replaced with the fixation cross in preparation for the next trial (see Figure 15, below, for a visual depiction of the semantic priming task).

The order of trials during the priming task was randomised across participants. However, we ensured that the same prime or target word did not appear in successive trials, and the same level of Lexicality (rare or familiar prime) and Relatedness (related or unrelated trial) did not appear in more than 4 successive trials.

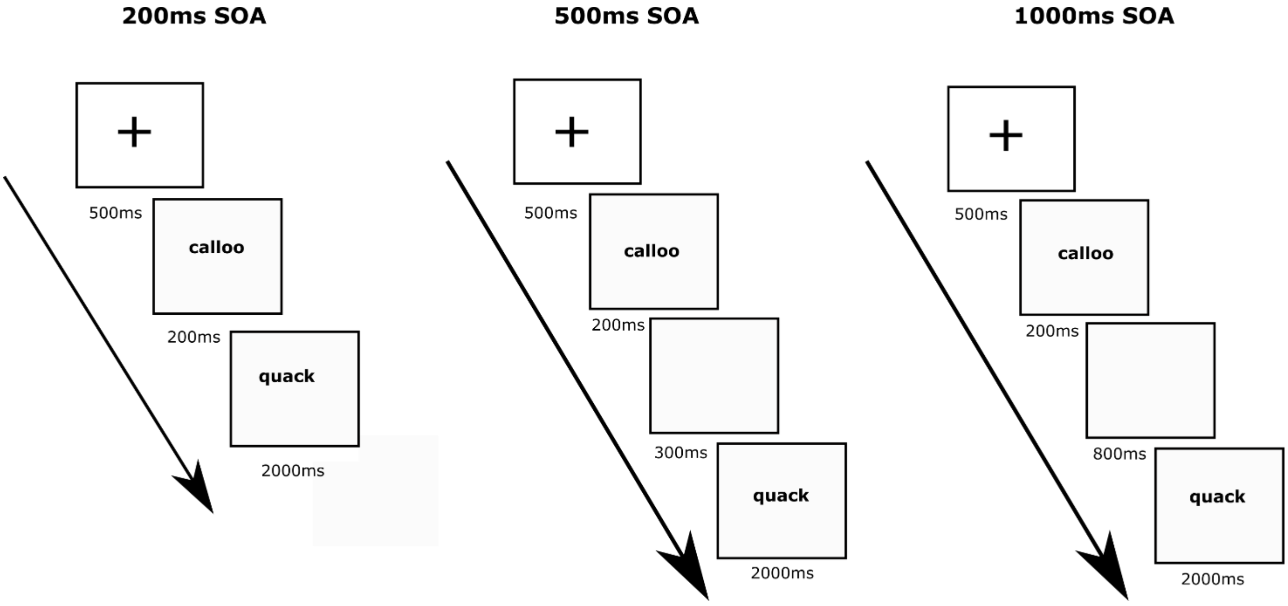

Figure 15: An illustration of the semantic priming task, demonstrating the format of a single trial in each SOA condition (200ms, 500ms, 1000ms). Whilst a time of 2000ms is allowed to respond to the target word (in this example, quack), this represents the maximum time allowed for participants to respond. As soon as a response was provided, the target word was replaced by the fixation cross in preparation for the next trial.

Following the semantic priming task, participants completed a 4-Alternative Forced Choice (AFC) task. This served as a measure of explicit knowledge for the newly learned rare words following training. In this test, a definition of one of the rare words was displayed in the centre of the screen, with 4-word options located below. One of these words was the correct word for the on-screen definition; the other 3 were other (incorrect) rare words. Each word was cued by its definition once.

3.4 Results

3.4.1 Explicit Word Knowledge

Explicit word knowledge was measured via the 4-AFC task. A successful hit was simply defined as selecting the correct rare word that referred to the cued definition. On average, participants had a successful hit rate of 29/30 trials (range 14-30 correct trials), with all participants performing above chance level (11/30 correct trials)[4]. This near ceiling level of performance suggests that participants had successfully retained the meanings of the rare words from training, at least up to the point of the 4-AFC task.

3.4.2 Semantic Priming

Prior to analysing the data from the semantic priming task, we first removed response times <150ms and >1500ms which were considered as outliers, along with incorrect responses. This resulted in the removal of 28.6% of data. Data trimming results for each condition can be found in Appendix 2.3. The remaining response time data was then log transformed to reduce the effects of positive skew on the data, which is typical with response time data.

Response time data was analysed via linear mixed-effect modelling in RStudio (*R* version 4.0.4 – R Core Team, 2022). Models were configured via the *lmer* function from the *lme4* package (Bates et al., 2015) using the bobyqa optimizer. We included the fixed-effects of SOA (200ms, 500ms, 1000ms), Relatedness (related and unrelated prime-target pairings) and

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[4] Chance level was calculated by running 10,000 simulations. In each simulation, we created an array of 30 randomly selected integers (with replacement) between 1-4. This array represented the correct response on a given trial in the AFC task, which was compared to another array generated by the same procedure. This latter array represented the participant's responses in the AFC task; where the participant's response matched the correct response was coded as a successfully hit. Hit rates across simulations were compiled, and chance level was taken from the 95th percentile.

Lexicality (rare and familiar primes) to the model, including all possible 2-way interactions as well as the 3-way interaction between the three terms. Our random effects included random intercepts for participants, primes, and targets to account for variability between participants and items.

As for our random slopes, we included the most complex random effect structure that would converge successfully and had no singular fit warnings (to eliminate redundancy) in R. To achieve this, we built an equivalent model in *Julia* (https:// https://julialang.org/) with a full random-effect structure in order to provide an estimate of all terms. Using a step-wise elimination process, we systematically removed the random effect term which accounted for the least variability in the data in turn from our lme4 model in R, until it converged and had no singular fit warnings. This model included the following random-effects structure: For participants, random slopes for all 3 fixed effect terms were fitted; for targets, random slopes for Relatedness were fitted, whilst no random slopes were fitted for primes.

To determine the significance of our predictors and interactions, we report Type III tests of fixed effects - implementing Satterthwaite's method for approximating degrees of freedom – which were identified via the anova function from the *lmerTest* package (Kuznetsova et al., 2017). Where appropriate, significant effects and interactions were explored further by running post-hoc pairwise comparisons over specific contrasts using the *emmeans* package (Lenth, 2019). All p-values generated from pairwise comparisons are adjusted according to Bonferroni correction by adjusting or the number of comparisons. Note that whilst model estimates and pairwise comparisons were conducted over log transformed data, statistics reported in the following text and figures have been transformed back to the response scale using exponential transform, for the purpose of improving readability.

Type III tests of fixed effects are presented in Table 7. As can be seen, there was a statistically significant main effects of SOA and Relatedness, as well as significant 2-way interactions between SOA and Relatedness, and SOA and Lexicality. The 3-way interaction between SOA, Relatedness and Lexicality was also significant.

Table 7: Type III tests of main effects. Statistically significant terms are highlighted in bold.

	F-value	P-value
SOA	**168.28**	**<.001**
Relatedness	**4.11**	**.044**
Lexicality	0.29	.592
SOA*Relatedness	**5.73**	**.003**
SOA*Lexicality	**72.13**	**<.001**
Relatedness*Lexicality	3.62	.059
SOA*Relatedness*Lexicality	**3.63**	**.027**

This model was configured over 19,288 observations, comprising 75 participants, 60 primes and 180 target words.

To explore the main effect of SOA, data was collapsed across Relatedness and Lexicality for each SOA. This revealed significantly slower response times at 200ms SOA (*EMM* = 825.90ms, *SE* = 17.16ms, *95%CI* = 792.94ms-860.23ms) compared to 500ms SOA (*EMM* = 703.92ms, *SE* = 16.04ms, *95%CI* = 673.17ms-736.07ms) (*p* <.001) and 1000ms SOA (*EMM* = 730.48ms, *SE* = 16.94ms, *95%CI* = 698.02ms-764.45ms) (*p* <.001). There were also significantly slower response times at 1000ms SOA compared to 500ms (*p* <.001). Hence, participants appeared relatively delayed in making their decision at 200ms (see Figure 16). This makes intuitive sense; since participants have less time to process the prime in the 200ms SOA condition, they are likely delayed in their evaluation of the association between the prime and target.

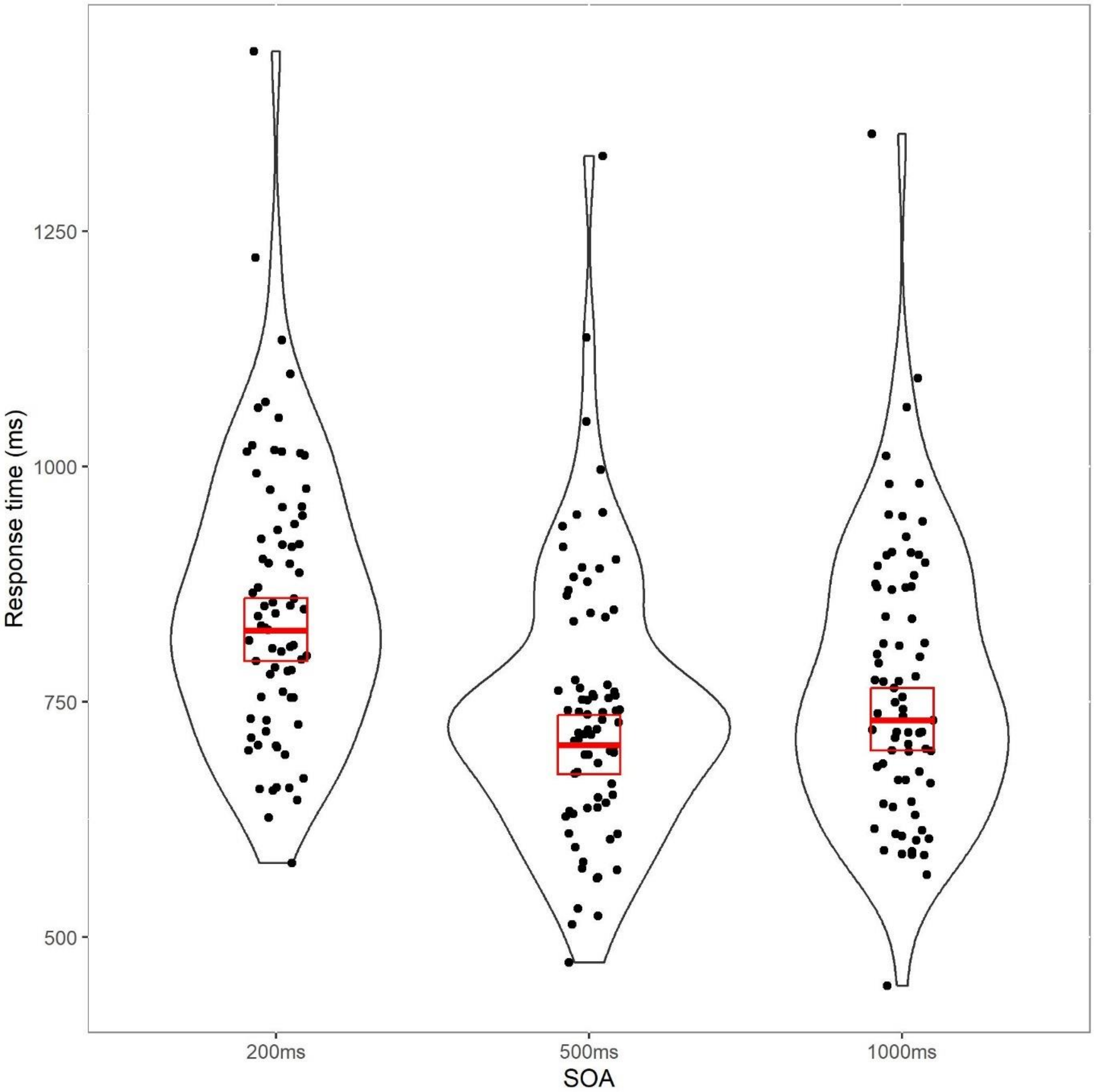

Figure 16: The effect of SOA on response time. Estimated marginal mean is reflected by each middle horizontal bar, surrounded by the upper and lower 95% confidence intervals bands. Individual points reflect participant mean scores.

To explore the main effect of Relatedness, the data was collapsed across SOA and Lexicality conditions. Response time was significant slower in the unrelated (*EMM* = 759.74, *SE* = 16.55ms, *95%CI* = 727.99ms-792.89ms) than the related (*EMM* = 743.66ms, *SE* = 16.32ms, *95%CI* = 712.35ms-776.34ms - see Figure 17). Hence, this is indicative of a semantic priming effect.

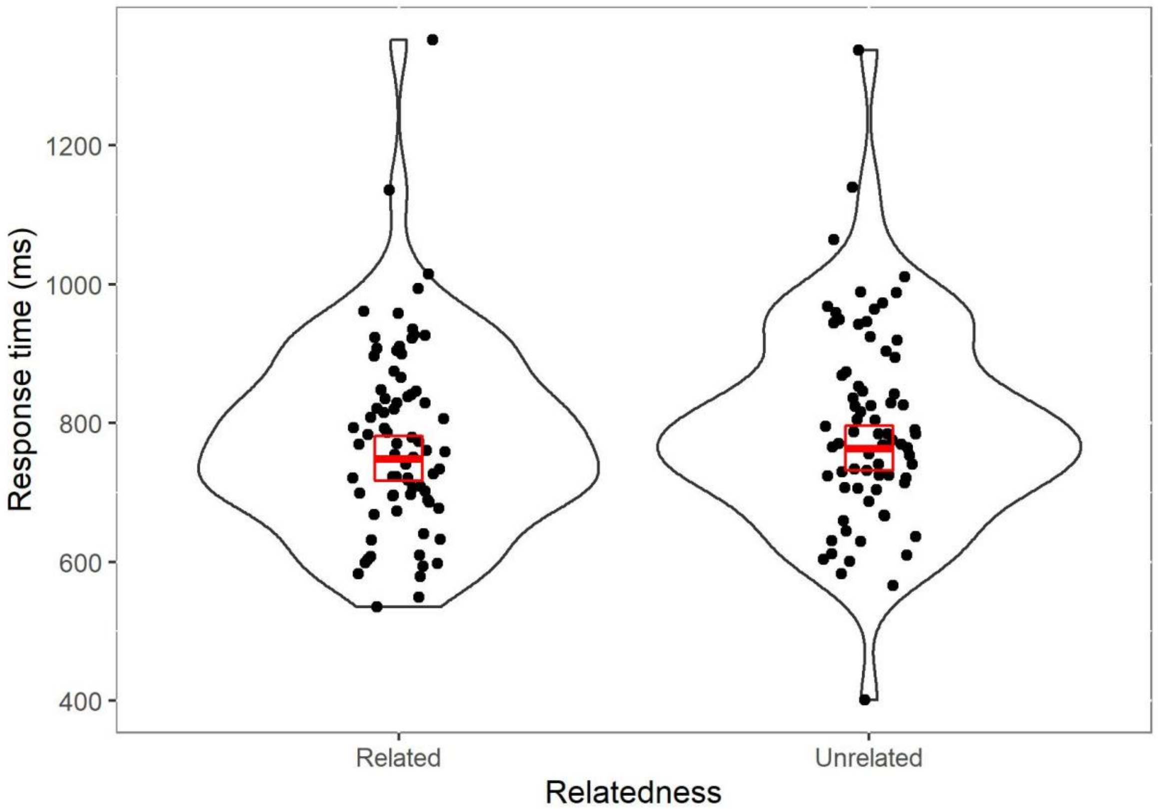

Figure 17: The effect of prime-target relatedness on response time. Estimated marginal mean is reflected by each middle horizontal bar, surrounded by the upper and lower 95% confidence intervals bands. Individual points reflect participant mean scores.

The interaction between SOA and Relatedness was explored by collapsing the data across Lexicality and comparing response time in the related and unrelated conditions at each SOA. At 200ms, response times were significantly slower in the unrelated (*EMM* = 840.68ms, *SE* = 18.49ms, *95%CI* = 805.22ms-877.71ms) compared to the related condition (*EMM* = 811.74ms, *SE* = 17.60ms, *95%CI* = 777.96ms-846.99ms; *p* = .009 - see Figure 18). There was however no significant difference between the related and unrelated conditions at 500ms (*p* = .118) or 1000ms (*p* = 1.00). This suggests that there was a semantic priming effect exclusively at 200ms, across rare and familiar primes.

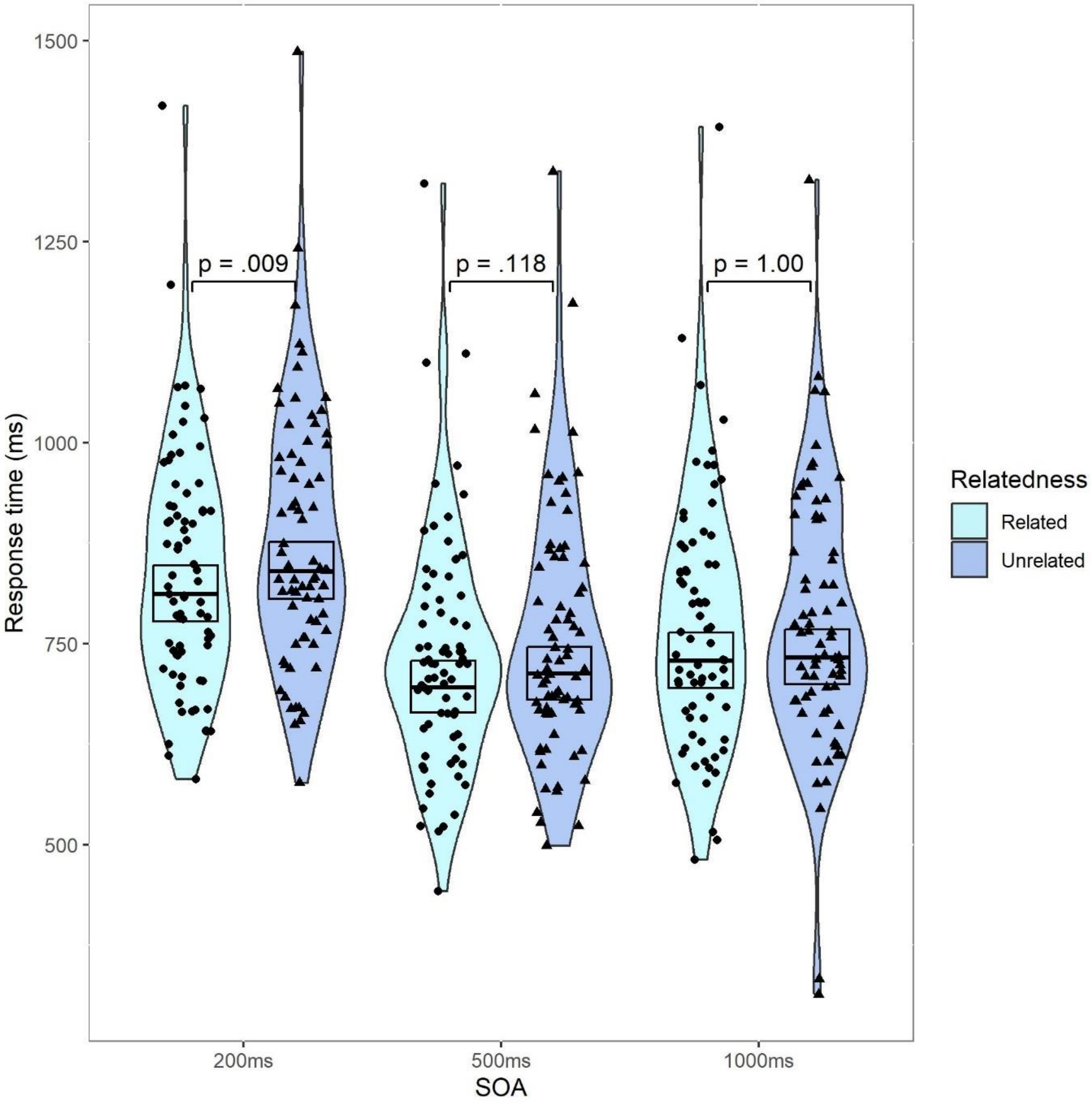

Figure 18: The interaction between SOA and Relatedness. Estimated marginal mean is reflected by each middle horizontal bar, surrounded by the upper and lower 95% confidence intervals bands. Individual points reflect participant mean scores.

The interaction between SOA and Lexicality was explored by collapsing the data across Relatedness and comparing response times between the two levels of Lexicality at each SOA. This revealed significantly slower response times in the rare prime condition (*EMM* = 850.08ms, *SE* = 18.58ms, *95%CI* = 814.43ms-887.29ms) compared to the familiar prime condition (*EMM* = 802.41ms, *SE* = 17.39ms, *95%CI* = 769.04ms-837.22ms) at 200ms (*p* <.001). The reverse pattern was observed at 1000ms, with significantly slower responses in the familiar (*EMM* = 747.19ms, *SE* = 18.01ms, *95%CI* = 712.71ms-783.33ms) compared to the rare prime condition (*EMM* = 714.15ms, *SE* = 17.17ms, *95%CI* = 681.627ms-748.61ms) (*p* = .001). There was no significant difference in response time between the rare and familiar conditions at 500ms (*p* = 1.00 - see Figure 19).

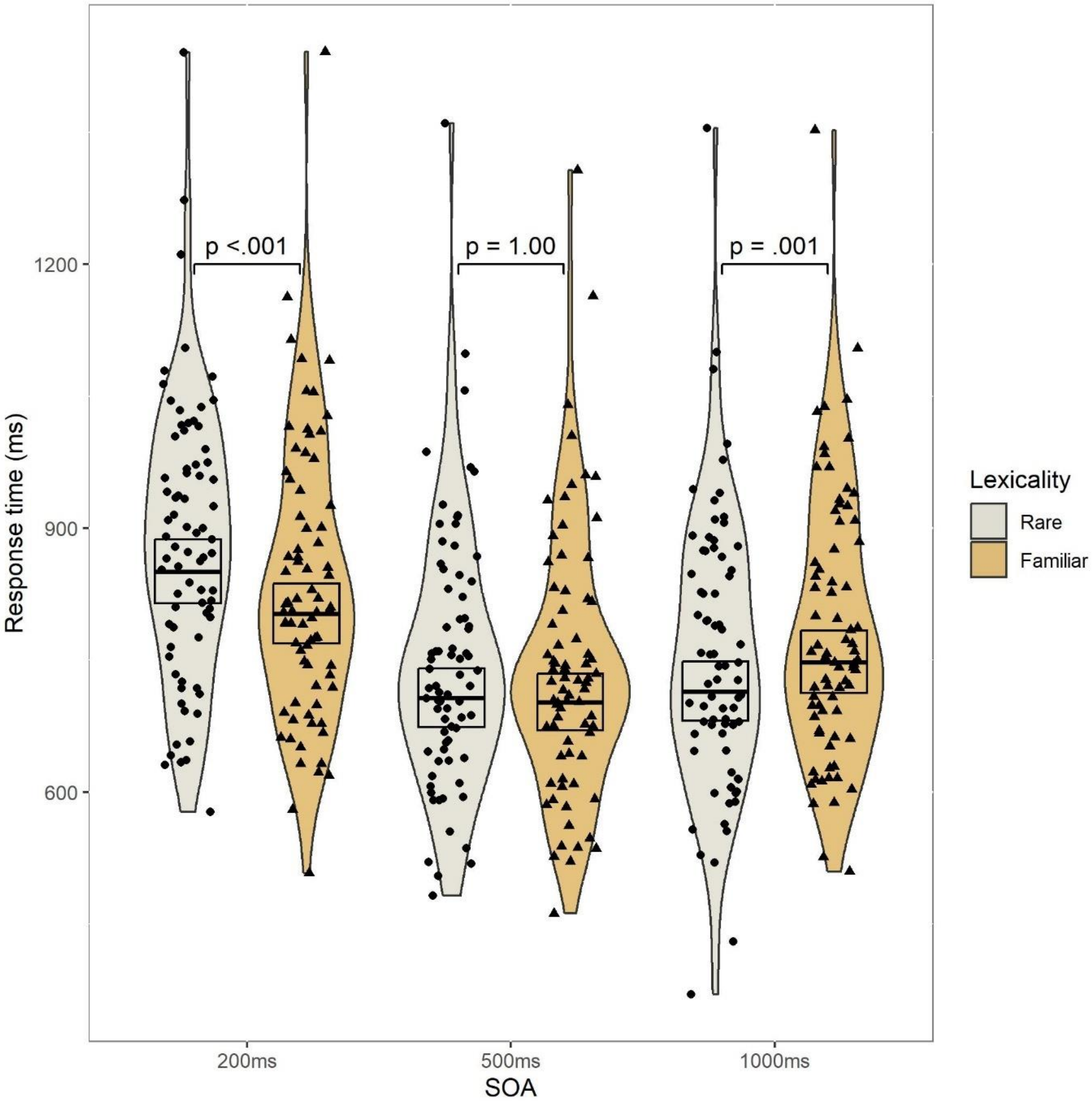

Figure 19: The interaction between SOA and Lexicality. Estimated marginal mean is reflected by each middle horizontal bar, surrounded by the upper and lower 95% confidence intervals bands. Individual points reflect participant mean scores.

Finally, to explore the significant 3-way interaction between SOA, Relatedness and Lexicality, response times in the related and unrelated conditions were compared at each SOA, separately for the rare and familiar prime conditions. This is effectively measuring whether the magnitude of any semantic priming effect is dependent on the SOA and Lexicality of the prime; thus, is a direct test of our hypotheses.

Across the 6 comparisons that were made, only one significant difference between the related and unrelated conditions emerged. In the rare prime condition at 500ms, responses were significantly slower in the unrelated (*EMM* = 720.84ms, *SE* = 17.92ms, *95%CI* = 686.56ms-756.83ms) compared to the related condition (*EMM* = 692.11ms, *SE* = 17.53ms, *95%CI* = 658.59ms-727.33ms) (*p* = .043 - see Figure 20). At 200ms, there was a trend towards a semantic priming effect in the rare (*p* = .079) but not in the familiar (*p* = .217) condition. This casts additional light on the significant priming effect reported at 200ms by the SOA x Relatedness interaction — a significant effect emerges when the data is collapsed across Lexicality conditions, but not when viewed separately for rare and familiar primes. Likewise, the absence of semantic priming at 500ms, when averaged across Lexicality, appears to be driven by the non-significant effect at 500ms in the familiar condition (*p* = 1.00), despite the effect appearing in the rare condition. At 1000ms, no significant effect emerged in either the rare (*p* = .208) or familiar (*p* = .997) conditions.

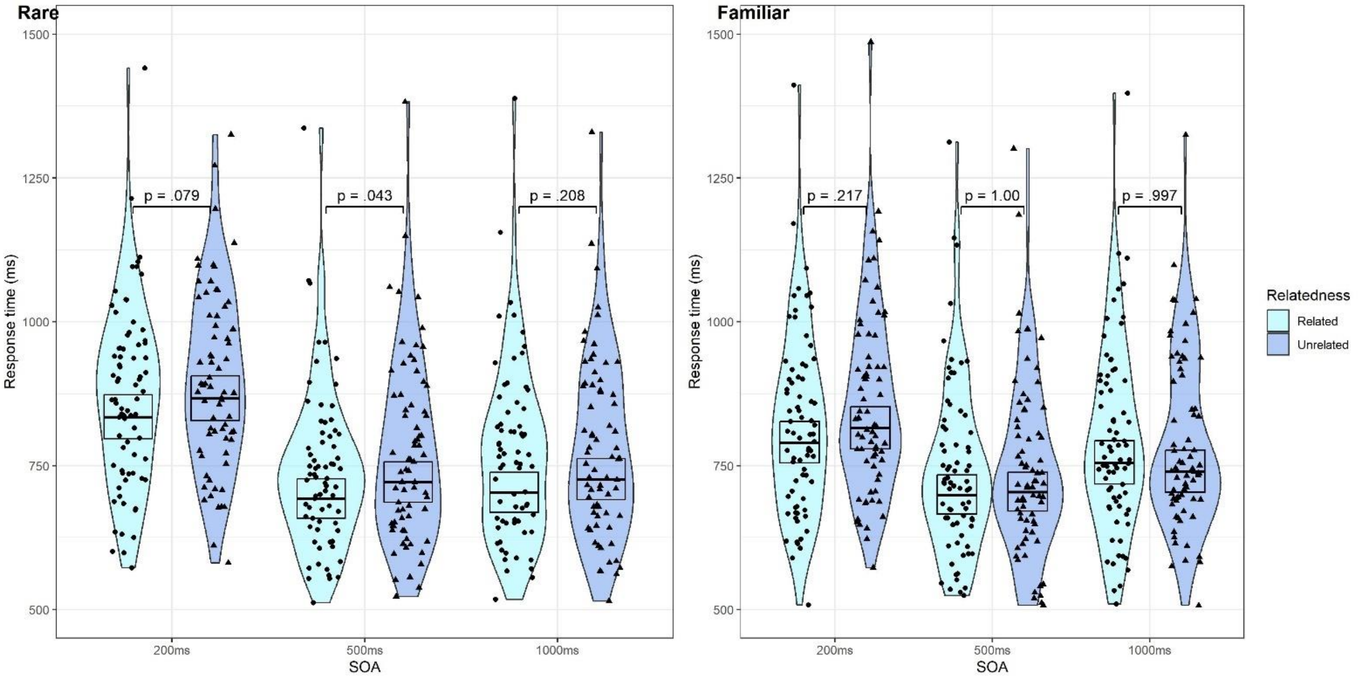

Figure 20: The interaction between SOA, Relatedness, and Lexicality. Estimated marginal mean is reflected by each middle horizontal bar, surrounded by the upper and lower 95% confidence intervals bands. Individual points reflect participant mean scores.

3.4.3 Interim discussion

The results reported above are not only consistent with our predictions but are unexpected in another way. That is, semantic priming proved non-significant in the familiar prime condition across all 3 SOAs. Given their relative frequencies, we had expected to observe priming in all 3 SOA conditions for the familiar primes. The absence of such effects calls into question whether our design was sensitive enough to uncover priming in the rare word condition. Given these unexpected findings, it is difficult to interpret the results in the rare condition with any real confidence, and thus they need consideration.

Why was semantic priming not observed with the familiar primes? Firstly, our method of identifying related targets to the prime words may not have been the optimal procedure. Previous work on novel word semantic priming has often consulted association norms for identifying related stimuli (e.g., Bakker et al., 2015; Kaczer et al., 2018; Tamminen & Gaskell, 2013). Such repositories present associates for a given word which are often generated by a considerable number of participants. For instance, the UoSFN presents lexical associates generated from approximately 150 participants (Nelson et al., 2004). This sample is considerably larger than that used here, where each prime word was processed by 20 participants. Thus, the reliability and precision of our related targets is likely to be inferior compared to conventional association norms.

This alone, though, does not explain why there was some evidence of priming for the rare words, by contrast with the familiar condition where there was little-to-no priming. Such discrepancy could be explained by how we processed responses from the pre-rating surveys. As a reminder, when selecting the rare words to be included in the current experiment, we quantified a mean prime 'FAS' score, which represented the mean percentage of independent respondents to produce the 3 most frequently produced targets, for the given rare (prime) word. For instance, the mean FAS score for the rare/prime word *Calloo* is .45. This is derived from the individual FAS scores of its selected targets: *Cold* (.80), *Ice* (.30), *Quack* (.25).

We selected the 30 rare words with the largest mean FAS scores out of a pool of 54 words; the rationale being that out of the 54 provisional rare words, these 30 words have the strongest association with their 3 targets, on average, and thus are most likely to elicit priming behaviour. When selecting the familiar words though, we simply selected the semantically matched familiar counterparts of the selected 30 rare words. Thus, although the familiar words were exposed to the same pre-study judgements to identify associated targets, we did not select the familiar prime words that necessarily represented the largest mean FAS scores. As such, although the mean prime FAS score is equal across conditions (rare = .33, familiar = .33), there is somewhat more variability in mean prime FAS scores within the familiar (SD = ±.13) compared to the rare condition (SD = ±.8). This meant that there were more primes in the familiar condition that could be considered as, on average, having relatively weaker associations with their targets compared to primes in the rare condition, based on our method of target identification.

Furthermore, when examining the individual FAS scores of the selected targets, the median score FAS is slightly lower in the familiar (.25) compared to the rare prime condition (.30). This suggests that, again, there are somewhat weaker targets in the familiar condition (i.e., bearing a lower FAS score). By having more variation in the strength of prime-target associations, and through having somewhat weaker targets compared to the novel condition, the magnitude of semantic priming in the familiar prime condition could have been weakened by these two factors.

Identifying related targets independently from existing norms has however been used in this area of research. Van der ven et al. (2015) used similar methods to identify associates, and observed semantic priming for their familiar prime words. Differences lie, however, in terms of the measure of semantic priming; whereas van der Ven and colleagues used a pLDT to measure priming, an SJT was used in Chapter 3.

The use of an SJT could have exacerbated the effect of the association characteristics in the familiar condition (described above) relative to a pLDT. As discussed, semantic processing is deemed more explicit in an SJT, given the need for direct semantic evaluation. Thus, the quality of the association between two words may have a greater effect on the degree of semantic priming. Take, for instance, the related pairing of *singer – concert* used in the current experiment. The extent to which these two words are deemed associated could vary considerably across participants and could largely be influenced by participants' experiences with the two words. This could lead to quicker responses in those who are quicker to appreciate the association, whereas response time may be delayed in those who do not recognise this relationship quite as clearly. However, if associate strength is more varied in the familiar condition, and with somewhat weaker targets overall, then recognition of the relationship between words (on any given trial) may have been more difficult in the familiar prime condition, increasing response time on related trials. This is compared to the required behavioural response in a pLDT, where the classification of *concert* as a real word should be a more unambiguous decision, producing more consistency across participants and items.

With more varied and somewhat weaker FAS scores in the familiar condition, it is possible that the familiar primes were more susceptible to an *associative strength effect*. The associative strength effect is the finding that priming effects are stronger for targets that have a stronger association with their prime. For example, FAS significantly predicts the magnitude of semantic priming at short SOA (Hutchison et al., 2008; see Stolz & Neely, 1995, for a significant FAS effect at longer SOA); targets with greater FAS scores elicited greater semantic priming, whilst weaker targets were associated with weaker priming effects.

The associative strength effect can be explained by distinct theoretical accounts of semantic priming. According to spreading activation theories, for example, the amount of activity produced from the prime begins to dissipate with increased distance in the semantic network (Collins & Loftus, 1975; Posner & Snyder, 1975). Concepts with stronger associations to the prime thus receives more activation relative to concepts with little-to-no association, meaning these concepts are retrieved and recognised more quickly. The expectancy generation account of semantic priming (Becker, 1980) also predicts that targets with a greater association to the prime are more likely to be predicted compared to weaker targets. If these targets are more likely to be predicted, this would lead to stronger priming effects with these words.

With the data that we have available, we have our own association strength statistics, albeit generated by fewer participants compared to common measures such association norms (e.g., Nelson et al., 2004). That is, for each target, we have quantified a FAS score as the proportion of participants to produce the given target after processing its prime. And, for each prime, we have quantified a mean FAS score as the proportion of participants to produce its 3 targets. Considering the unexpected findings in the familiar condition, and with some evidence for the role of associative strength on semantic priming, it was deemed interesting prospect investigate the possible role of associative strength in our study, given the subtle differences in associative characteristics between the rare and familiar primes (described above).

The following exploratory analysis is split into two parts. In the first section, the role of mean prime FAS score in predicting the magnitude of semantic priming is explored. Because semantic priming appears sensitive to the strength of the relationship between prime and targets, it is possible that we observed an effect of associative strength in the familiar condition (at least one that is stronger compared to the rare primes), given the greater variability in prime association strength.

The second section of this exploratory analysis will explore the effect of individual target FAS score on semantic priming. Whilst variability in FAS scores are similar between the familiar and rare conditions, examining the median scores suggests the familiar condition contains slightly weaker targets overall. It is possible that the inclusion of such targets may weaken or reverse the priming effect overall in the familiar condition, which could be evident by an analysis of associative strength.

3.4.4 Exploratory analysis

3.4.4.1 By-item analysis – mean prime FAS score

To explore the effect of mean prime FAS score on semantic priming, for each prime we calculated a prime-specific semantic priming effect by subtracting the mean (log transformed) response time when the prime was paired with a related target, from the mean (log transformed) response time when the prime was paired with an unrelated target.

The resulting by-prime semantic priming effects were used as the outcome measure in a linear regression model via the *lm* function in R. These effects were regressed against standardised mean prime FAS score. Since rare and familiar primes were included together, lexicality was maintained as a predictor, and was sum coded (Rare = -0.5; Familiar = 0.5).

This model - with by-prime semantic priming effects predicted by prime total association strength, lexicality, and the interaction between both terms - was repeated three times, assessing the magnitude of semantic priming in each SOA condition separately. The results of these models are presented below in Table 8.

Table 8: The effects of mean prime FAS score, lexicality, and the mean FAS*lexicality interaction on the magnitude of semantic priming, at each SOA.

SOA		Estimate	Std. Error	t value	p value
200ms					
	Intercept	0.04	0.01	4.72	<.001
	Mean FAS	0.02	0.01	1.96	.055
	Lexicality	0.00	0.01	0.23	.817
	Mean FAS*Lexicality	0.00	0.01	0.24	.814
500ms					
	Intercept	0.02	0.01	2.24	.029
	Mean FAS	0.00	0.01	0.23	.821
	Lexicality	0.01	0.02	1.77	.083
	Mean FAS*Lexicality	0.00	0.01	0.78	.441
1000ms					
	Intercept	0.01	0.00	0.72	.474
	Mean FAS	0.02	0.01	1.32	.191
	Lexicality	0.02	0.01	1.85	.069
	Mean FAS*Lexicality	0.01	0.01	0.92	.361

As can be seen from Table 8, mean prime FAS score did not predict the magnitude of semantic priming at any SOA. There was an effect of mean FAS score that approached significance at 200ms SOA, suggesting primes with a stronger association to their targets may have elicited greater semantic priming at this specific SOA.

In sum, mean prime FAS score did not predict the magnitude of semantic priming, in either the rare or familiar prime conditions. Thus, the increased variability in prime association strength in the familiar condition does not appear to contribute to the absence of priming in this condition.

3.4.4.2 By-item analysis – target FAS score

As with the preceding analysis, for each target, we calculated a by-target semantic priming effect by subtracting the mean (log transformed) response time when the target was paired with a related prime, from the mean (log transformed) response time when paired with an unrelated prime. This was used as the outcome measure in a linear regression model which included standardised target FAS score, lexicality, and the interaction between the two terms as predictors. The model was again repeated three times, assessing priming at each SOA.

Table 9: The effects of target FAS score, lexicality, and the FAS*lexicality interaction on the magnitude of semantic priming, at each SOA

SOA		Estimate	Std. Error	t value	p value
200ms					
	Intercept	0.03	0.01	3.22	.002
	FAS	**0.03**	**0.01**	**2.75**	**.007**
	Lexicality	0.01	0.01	0.35	.724
	FAS*Lexicality	0.02	0.01	1.83	.069
500ms					
	Intercept	0.02	0.01	1.85	.066
	FAS	**0.02**	**0.01**	**2.23**	**.027**
	Lexicality	0.02	0.01	1.84	.068
	FAS*Lexicality	0.02	0.01	1.73	.086
1000ms					
	Intercept	0.01	0.01	0.49	.622
	FAS	0.02	0.01	1.51	.132
	Lexicality	**0.02**	**0.01**	**1.98**	**.049**
	FAS*Lexicality	0.02	0.01	1.74	.084

At 200ms and 500ms, target FAS score was a significant predictor of the magnitude of semantic priming, with semantic priming effects increasing as a function of association strength (see Figure 21). This is thus indicative of associative strength effect (de Groot et al., 1982; Frishkoff, 2007; Hutchison et al., 2008; Ruiz et al., 2018; Stolz & Neely, 1995). Lexicality was also a significant predictor at 1000ms, reminiscent of findings from the main analysis of quicker response times in response to rare primes at this SOA.

An intriguing observation from this analysis is the marginally significant interaction found across all SOAs. This suggests that the effect of target FAS score (on semantic priming) may be dependent on lexicality condition. Indeed, when the data is collapsed across SOA, the interaction between association strength and lexicality is statistically significant (*p* = .002). As can be seen in Figure 22, this seems to be driven by a stronger effect of target FAS score in the familiar prime condition, whereas there appears to be no such effect in the rare prime condition.

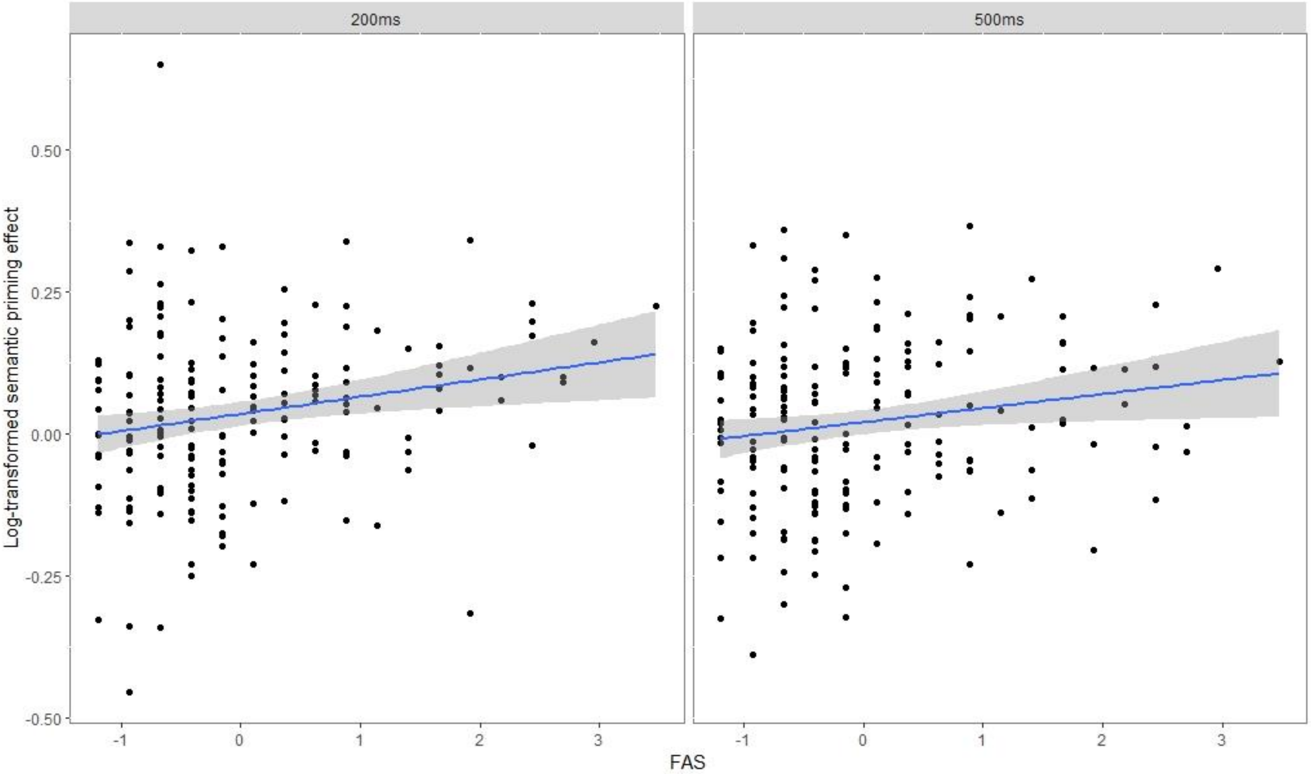

Figure 21: The association between target FAS score and semantic priming at 200ms and 500ms SOA.

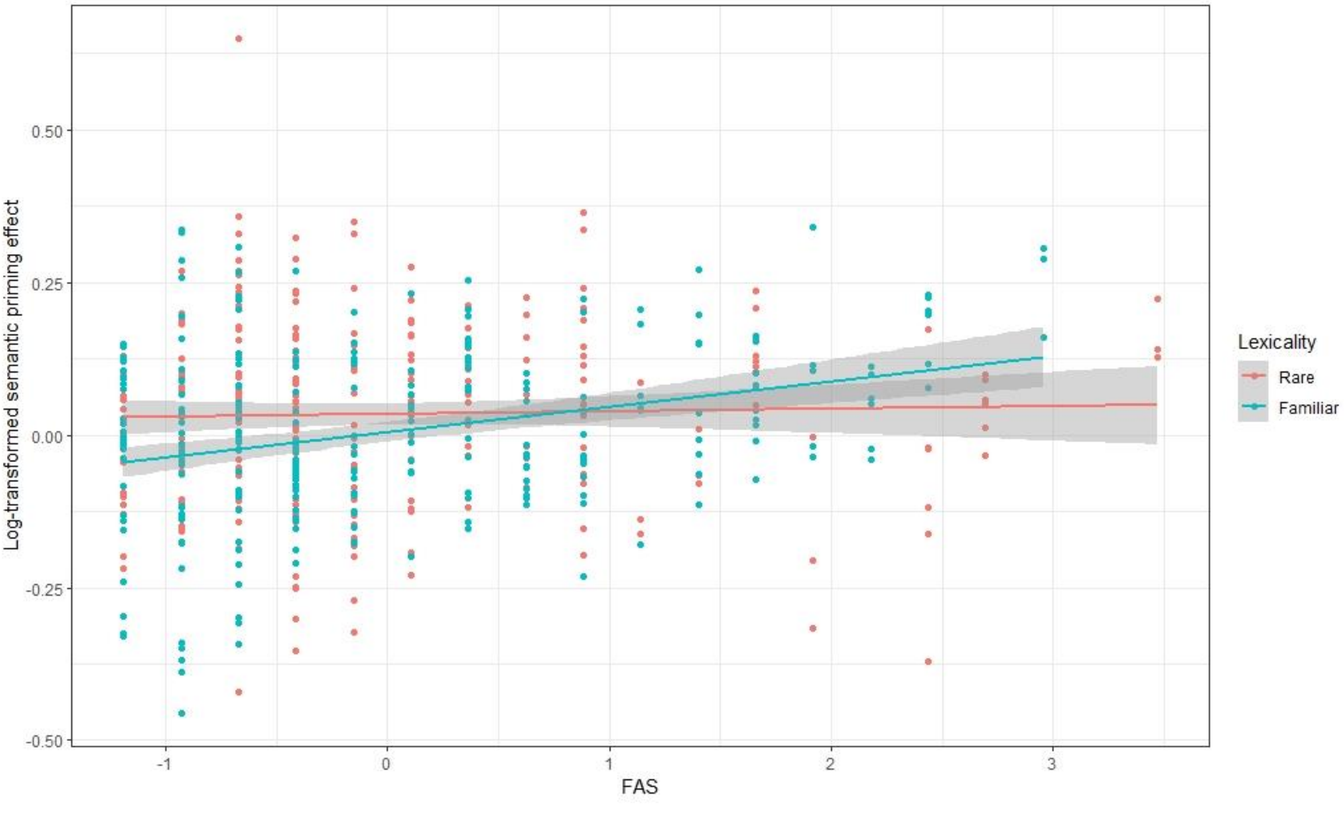

Figure 22: The interaction between target FAS score and lexicality when averaged across SOA.

The finding of an interaction between target FAS score and lexicality suggests that in the familiar prime condition at least, the strength of the association between the primes and targets at least partly modulated the magnitude of semantic priming, whilst it had a more subdued effect in the rare prime condition.

An associative strength effect such as this, means that weaker targets were associated with eliciting weaker priming, whilst stronger targets were associated with stronger semantic priming. One possibility is that this effect was only found in the familiar prime condition, since there were somewhat weaker prime-target associations in this condition (at least when considering the median target association strength score). With somewhat numerically stronger targets in the rare prime condition overall, and with less varied mean prime FAS score, priming appears more stable and consistent across primes/targets, as evident by the weaker effect of association strength for the rare primes.

It should be said, though, that the familiar prime condition *should* be more sensitive to any effect of association strength related to the rare prime condition, regardless of any differences in association scores between the two conditions. For example, if the rare prime words are not yet integrated into semantic networks, then spreading activation mechanisms will not operate in a graded fashion (i.e., stronger associates will not receive *more* activation stemming from the prime – Collins & Loftus, 1975). In terms of strategic mechanisms, participants should be more likely to produce more precise and confident predictions following familiar primes, given the relative frequencies of these words. Accordingly, weaker targets should be less likely to be predicted, resulting in weaker semantic priming.

In sum, when considering target FAS scores, there appears to be an effect of associative strength operating in the familiar prime condition, which is not observed in the rare prime condition. Due to somewhat weaker targets overall in the familiar condition, along with more varied prime association strength scores, it is possible that these factors contributed to the lack of semantic priming in the familiar condition.

3.5 Discussion

Chapter 3 investigated the mechanisms that underpin novel word semantic priming to gain insight into the encoding of new words, as well as how knowledge may be dissociable from familiar words based on priming behaviour. It explored this by measuring the effect of SOA length on novel word semantic priming. It was hypothesised that novel words would significantly prime related counterparts in the 500ms and 1000ms SOA conditions, but not at 200ms. This reasoning stems from arguments that the route to priming with novel words is via strategic and controlled mechanisms, which are most active when the SOA is sufficiently long. Furthermore, a sufficiently long SOA may be required to allow enough time for newly-formed hippocampal representations to retrieve new words and their meanings, which is argued to be a relatively slow process compared to the retrieval of existing words via direct cortical mappings.

For the rare words, semantic priming was only observed in the 500ms SOA condition. Thus, in this regard, our predictions are partly met (there was no priming at 200ms as predicted; however, there was also no priming at 1000ms, which is contrary to our predictions). These findings could offer potential support to the idea that new words may initially rely more heavily on strategic processing. However, we also would have expected to observe priming in the 1000 ms SOA condition. Furthermore, there was also a trend of a semantic priming effect in the 200ms SOA condition. This pattern was not predicted since priming at this SOA is thought to depend more heavily on automatic processing, which may depend on integrated representations. Hence, this result would be inconsistent with the CLS account (Davis & Gaskell, 2009).

A problematic finding, though, was the lack of semantic priming in the familiar prime condition, which was not observed at any SOA. Given the relative frequencies of these words, we had expected to observe significant priming effects, and the presence of such effects would have confirmed that the design of our task was at least sensitive enough to elicit semantic priming in the rare word condition. These findings therefore complicate interpretation of the results observed with the rare primes.

An exploratory analysis was conducted to investigate the results in the familiar condition further. The analysis inspected the role of FAS on the magnitude of semantic priming, due to some (albeit quite minor) differences in FAS scores between the rare and familiar prime words. There appeared to be an associative strength effect operating in the familiar but not the rare prime condition, which could be attributed with these FAS differences. It was also argued that the use of an SJT to measure semantic priming could have exacerbated the effect of associative strength, given that the quality of association between the prime and target is arguably more salient compared to a pLDT.

These factors may thus have contributed to the absence of semantic priming in the familiar prime condition. It is beyond the scope of this thesis to investigate these suggestions further. Nonetheless, the lack of semantic priming with the familiar primes is important because it complicates interpretation of the results associated with the rare/novel words. Thus, the research questions outlined at the start of this chapter largely remain unanswered.

To rectify this and to address our research questions, we must establish a reliable baseline measure of semantic priming from familiar prime words, which can then be compared to priming behaviour from recently learned words.

To do so, we turned our attention to the work of TG13, who report significant priming effects in their familiar baseline condition. The stimuli for this study is available online in Jakke Tamminen's thesis (https://core.ac.uk/download/pdf/43394.pdf). Given the ability of these familiar prime words to elicit semantic priming, it was deemed appropriate to firstly replicate these results, alongside our SOA manipulation.

Chapter 4 therefore serves two broad purposes via two experiments. Firstly, experiment one aims to provide an empirical replication of *part* of the TG13 study. Specifically, we investigate whether recently learned novel words are unable to prime related counterparts with an operating SOA of 450ms, a finding from TG13's first experiment. Secondly, in experiment two, we investigate whether novel words may prime related counterparts with an operating SOA of 1000ms, whilst keeping all other experimental parameters constant from experiment one. This thus incorporates our research question regarding the potential role of SOA on semantic priming with new words. Crucially, by adopting the stimuli and design of TG13, we should hopefully observe semantic priming with familiar primes (at least with a 450ms SOA, as per TG13), giving us more confidence in interpretating any finding associated with novel prime words.

Chapter 4 – The Role of Strategic Priming Mechanisms and SOA on Novel Word Semantic Priming: Replicating Tamminen and Gaskell (2013)

4.1 Abstract

Chapter 4 aimed to examine the research questions laid out in Chapter 3 by using part of the design and stimuli of Tamminen and Gaskell (2013; TG13). We recruited components of TG13 since this study reported a significant priming effect in the familiar baseline condition, which was not detected in Chapter 3. In experiment one, 60 participants learned 34 novel words and their meanings (e.g., *blontack – a type of cat that has stripes and is blueish-grey*). These novel words served as primes for related (e.g., *dog, mouse, kitten*) and unrelated real word, and nonword targets, in a subsequent primed lexical decision task (pLDT). A pLDT involving familiar primes was also included which, crucially, elicited semantic priming in TG13. With an operating stimulus onset asynchrony (SOA) of 450ms in experiment one, novel words did not semantically prime related counterparts, whilst the familiar primes did. This result thus replicates the findings of TG13. In experiment two, with an independent group of 60 participants, we kept all experimental parameters constant from experiment one, except for increasing the SOA to 1000ms. In line with our predictions, a significant semantic priming effect then emerged. We propose that the 1000ms SOA allowed the slow hippocampal representations that are thought to regulate knowledge at this stage to activate, underpinning the use of strategic mechanisms. Contrary to our predictions, however, we did not find clear evidence of priming for familiar words at the longer SOA. We interpret both of these findings in terms of an account in which the processing of familiar and novel words is qualitatively different.

4.2 Introduction

As with the previous chapter, Chapter 4 investigated the encoding of new words by investigating the role of SOA length on novel word semantic priming, this time building on the design and stimuli used in TG13, where, unlike the previous study reported in Chapter 3, priming was found for familiar words.

Two experiments are reported. The first experiment effectively sought to replicate the 'recent' condition of experiment one in TG13. In this condition, participants learned 34 novel words and their meanings, which served as primes for related and unrelated real word targets (and nonwords) in a subsequent pLDT. In the pLDT, an SOA of 450ms was used. In experiment two, with a set of independent participants who did not participate in experiment one, we kept all experimental parameters constant, except for increasing the SOA to 1000ms in the pLDT.

Whilst they share the same broad aims, there are some noticeable differences between the designs of Chapters 3 and 4. Firstly, Chapter 3 reported three unique SOA conditions (200ms, 500ms, and 1000ms), compared to Chapter 4 which reports two (450ms and 1000ms). In TG13's second experiment, a 47ms SOA – which should bypass the use of strategic priming mechanisms (McNamara, 2005) – was used, and it was found that recently learned words did not prime their related targets. Thus, with the stimuli of TG13 at least, it would seem that novel words cannot prime existing words when the SOA is between 47ms – 450ms. Hence, the 200ms SOA of Chapter 3 was dropped. Similarly, because experiment one of this chapter aims to replicate the findings of TG13's first experiment, a 450ms SOA was adopted instead of the 500ms SOA of Chapter 3. Nonetheless, the duration of these SOAs are very similar.

Secondly, whereas a semantic judgement task (SJT) was used to measure semantic priming in Chapter 3, a pLDT is employed in Chapter 4. As discussed in Chapter 3, an SJT was originally favoured to potentially increase the likelihood of observing novel word semantic priming, given that previous work has observed significant effects when this task is used (Bakker et al., 2015; Balass et al., 2010; Perfetti et al., 2005). Again, though, remaining consistent with TG13, Chapter 4 adopts a pLDT, along with the same prime-target pairings and nonwords as TG13.

Finally, and possibly most crucially, different stimuli are used in Chapter 4. The trained stimuli consists of 34 novel words and their meanings, compared to the rare yet real words of Chapter 3. Consequently, Chapter 4 recruits different target words in the priming task. Unlike the pre-rating surveys of Chapter 3, related targets in Chapter 4 were sourced from the UoSFN (Nelson et al., 2004). As discussed earlier, such database will likely provide more reliable and precise estimates regarding the strength of association between two words, compared to the pre-rating surveys of Chapter 3. The familiar primes of TG13 also replaced those of Chapter 3.

It is perhaps worth making clear that the current chapter does not investigate the role of offline consolidation on novel word semantic priming, which was a central component of TG13. This chapter simply uses aspects of the establish design from that paper to investigate semantic priming in response to recently learned words (without an intermittent period of offline consolidation), in conjunction with our SOA manipulation.

In the present study, then, participants first learned 34 novel words and their meanings across a series of training tasks. These words later served as primes for related/unrelated real word and nonword targets in a pLDT. Participants completed two pLDTs, one involving the recently learned novel words and another involving familiar prime words. Participants in experiment one completed the pLDT with a 450ms SOA, whilst experiment two participants completed the task with a 1000ms SOA.

Our hypotheses are as follows: In experiment one, and following the results of TG13, we expect that novel words will not semantically prime existing words in experiment one. In experiment two though, with an increased SOA of 1000ms, we predict that novel words will semantically prime existing words. This is because the SOA may be sufficiently long to allow encoded hippocampal representations of the new words to engage, facilitating the retrieval of new words and their meanings, and ultimately allowing these meanings to be used in conjunction with strategic priming mechanisms. Thus, the 1000ms SOA may elicit similar patterns of behaviour (i.e., semantic processing) between novel and familiar words.

4.2 Experiment 1

4.2.1 Methods

4.2.1.1 Participants

Participants were recruited through *Prolific* and received £11 for their participation. Sixty-one participants completed the experiment in total, of which 60 contributed data to the analysis (*M age* = 40.59 years; *SD age* = 13.58; 27 males). One participant was removed from analysis for failing to provide a correct response in the pLDT. All participants reported no known language related disorders and reported English to be their native language.
As outlined in the pre-registration (https://osf.io/6xvzp/), we recruited the same number of participants as TG13 to ensure as close to a replication as possible.

4.2.1.2 Stimuli and experimental design

The published TG13 articles derives from work reported in Jakke Tamminen’s thesis, which contains the stimuli used. When describing the methods of the current chapter therefore, we are largely presenting information contained within the thesis and published article. There are, however, some differences between the methods of the current study and that described in TG13, which will be highlighted.

We selected the 34 novel words and meanings that were used in experiment 2 in TG13. These meanings were selected based on performance in a separate experiment, where participants decided if a novel word's meaning and a real word target were semantically related. The researchers selected the 34 meanings that elicited the highest overall accuracy. The rationale being that higher accuracy represents a relatively clear relationship/association between the novel word's meanings and its related targets, increasing the likelihood of a semantic priming effect.

The novel words (e.g., *blontack*) were originally sourced from the nonword stimuli used in Deacon et al. (2004). (mean length of novel words = 6.4 letters, range = 5-8 letters). The meanings of the novel words were created by taking a familiar concept (e.g., *cat*) and pairing it with two distinct semantic features to set the (novel) meaning apart from existing concepts (e.g., *is a type of cat that has stripes and is blueish-grey*). The novel word-meaning pairings were held consistent across participants (see Appendix 3.1 for a full list of novel words their meanings). The novel words and their meanings were taught to participants during training (see procedure, below) and served as primes in a subsequent pLDT. As such, for each novel word, three familiar associates (e.g., *dog*, *mouse*, *kitten*) were selected to act as related targets in the pLDT. Associates were sourced by finding associates to the core concept of the novel word meanings (e.g., *cat*) in the University of South Florida Free Association Norms (Nelson et al., 2004). The average forward association strength (FAS) between the primes and targets was 0.18 (mean CELEX frequency of associates = 99.6, mean length of associates = 6 letters). Associates to the novel words can be found in Appendix 3.2.

A pLDT including familiar primes (e.g., *clinic*) was also included to establish a baseline measure of semantic priming. Relatively low frequency familiar primes (mean CELEX frequency = 9) were purposely selected to match them as closely as possible with the nil frequencies of the novel words/primes. Three associates (*doctor*, *sick*, *health*) were selected per prime, using the same selection procedure as the novel primes (mean FAS = 0.16, mean CELEX frequency of associates = 66, mean length of associates = 6.02 letters). Associates of the familiar primes can be found in Appendix 3.3. For both lexical decision tasks, unrelated prime-target pairings were created by randomly shuffling targets across primes within tasks.

The pLDT required participants to decide whether the target word on a given trial was a real word or nonword. Nonword targets were therefore required. These were created by substituting a single letter from the real word targets (e.g., *dox*, *wouse*, and *kitgen* were derived from *dog, mouse*, and *kitgen*, respectively) to create a nonword.

4.2.1.3 Procedure

The experiment took place online via Gorilla Experiment Builder. This differs from TG13 where data collection took place in the lab. The experiment was restricted to PC, laptop or Mac users, thereby excluding smartphone and tablet users.

Broadly, the experiment consisted of two sections: The training phase and testing phase. The *training phase* was designed to teach participants the meanings of the 34 novel words and consisted of a series of distinct tasks: a word-to-meaning matching task, a meaning-to-word matching task, a sentence plausibility task and a meaning recall task. Figure 23 (below) presents a visual depiction of all four training tasks.

In the *word-to-meaning matching* task, a novel word was presented in the centre of the screen. Below this were 2 meanings in the left and right quadrants - one of which was the meaning of the on-screen novel word, whilst the other was the meaning of a different novel word. The participant was required to select, using their mouse cursor, the correct meaning of the on-screen word. The *meaning-to-word matching* task was very similar, except this time a meaning was displayed on-screen, and below were two novel word alternatives, with participants asked to select the word that referred to the on-screen meaning.

For both tasks, the correct response appeared an equal number of times on both sides. Across participants, the correct response was always paired with the same foil word/meaning. This appears to differ from TG13 where '...the incorrect option was randomly picked from the pool of [words/]meanings used in the current session by the experimental software.' (Tamminen & Gaskell, 2013, p.1009). In both tasks, the correct word/meaning remained on-screen for 1,500ms following the participant's response, and unlimited time was allowed to provide a response. Within each block (of both tasks), each word/meaning was presented as a response option twice: once as the correct response and once as the incorrect foil.

In the *sentence plausibility* task, the novel words were presented at the end of a sentence. Based on the meaning of the novel word (e.g., *blontack – is a type of cat that has stripes and is blueish-grey*), participants were asked to judge if the sentence was plausible (e.g., *The woman liked to listen to the purring of her blontack*) or implausible (e.g., *The monkey was too frightened to climb the blontack*). The sentence was presented in the centre of the screen, with the options 'plausible' and 'implausible' presented below in the left and right quadrants, respectively. Each novel word was presented four times throughout this task, three times within a plausible sentence and once within an implausible sentence. This imbalance was designed to minimise the novel word’s appearance in the presence of an incorrect meaning which might interfere with learning. On each presentation, a different sentence was used (see Appendix 3.4 for a full list of sentences). Following the participant's response, feedback was provided in the form of a green tick for a correct response and a red cross for an incorrect response. The novel word and its meaning were then presented on screen for 1,500ms.

In the *meaning recall* task, participants were presented with a novel word in the centre of the screen and were prompted to type the meaning of the on-screen word. Unlimited time was allowed, and the correct meaning was displayed on-screen for 1,500ms following the participant's response. Participants were encouraged to type the full meaning of the word to the best of their ability. Within a single block of the meaning recall task, each novel word was presented once.

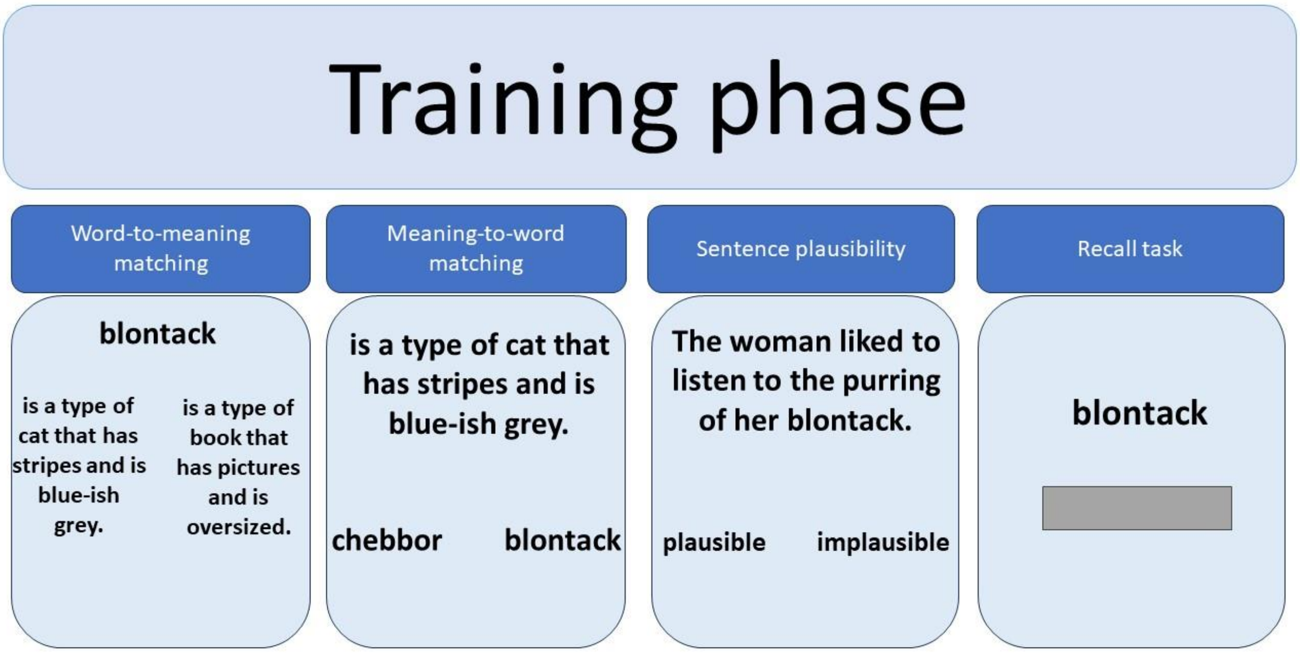

Figure 23: A visual depiction of the 4 training tasks recruited in Chapter 4. The grey horizontal bar in the meaning recall task represents the response box participants were provided with the type the meaning of the cued novel word.

The order of the training tasks throughout the training phase is as follows. First, participants completed 3 blocks of the word-to-meaning task followed by one block of the meaning recall task. This was followed by 2 more blocks of the word-to-meaning matching task followed by another single block of meaning recall. Following this was 3 blocks of the meaning-to-word matching task followed by another, and final, single block of meaning recall. Finally, 2 more blocks of the meaning-to-word matching task was followed by four blocks of the sentence plausibility task. Across all training tasks, the presentation of trials was randomised across participants. Participants were in control of when each training block commenced and were instructed that they could use the time between blocks to take a short break.

Following training the participant immediately moved onto the *testing phase* which consisted of two key tasks: A meaning recall task and two primed lexical decision tasks. The meaning recall task was identical to the meaning recall tasks presented during training. This task served as a measure of explicit knowledge pertaining to the novel words once all training tasks had been completed. Each novel word was presented once.

Following the meaning recall task, participants completed two pLDTs - one involving the recently learned novel words as primes and a second involving the familiar prime words. The order of these tasks was counterbalanced across participants.

Before the task commenced, participants were provided with instructions. They were told that they would view two words in quick succession and should decide if the second (target) word was a real word in English or not. For half of the participants, the 'A' key was pressed for a real word response and 'L' for a nonword, whilst the key arrangement was reversed for the other half of participants. As per TG13, participants were also explicitly told that on some trials, the prime and target will be related.

A single trial began with the presentation of a fixation cross for 500ms. Then, the prime word appeared for 200ms, followed by a blank screen for 250ms (therefore creating an SOA of 450ms). This was replaced by the target word which remained on screen for 200ms. Participants could make their decision as soon as the target appeared and had up to 2,000ms to respond (see Figure 24A for a visual depiction of the pLDT in experiment one). To encourage accurate and quick responses, feedback was provided in the form of a green tick for a correct response or a red cross for an incorrect response, along with the presentation of the response time for that trial, for 500ms. This was then replaced by the fixation cross in preparation for the next trial. The presentation of trials was randomised across participants. However, the trial order was constrained so that there were no more than 4 consecutive trials of the same prime-target relatedness (related or unrelated), and no more than 8 consecutive trials of the same target lexicality status (real or nonword). These constraints differ slightly from TG13 who allowed no more than 3 consecutive trials of the same prime-target relatedness and no more than 4 of the same target lexicality trials. The current study also did not contend with constraining trial order based on time-of-testing (as did TG13), since words were not taught at different intervals. This meant that our novel lexical decision had half as many trials as the novel task in TG13, who taught participants 68 novel words across separate days.

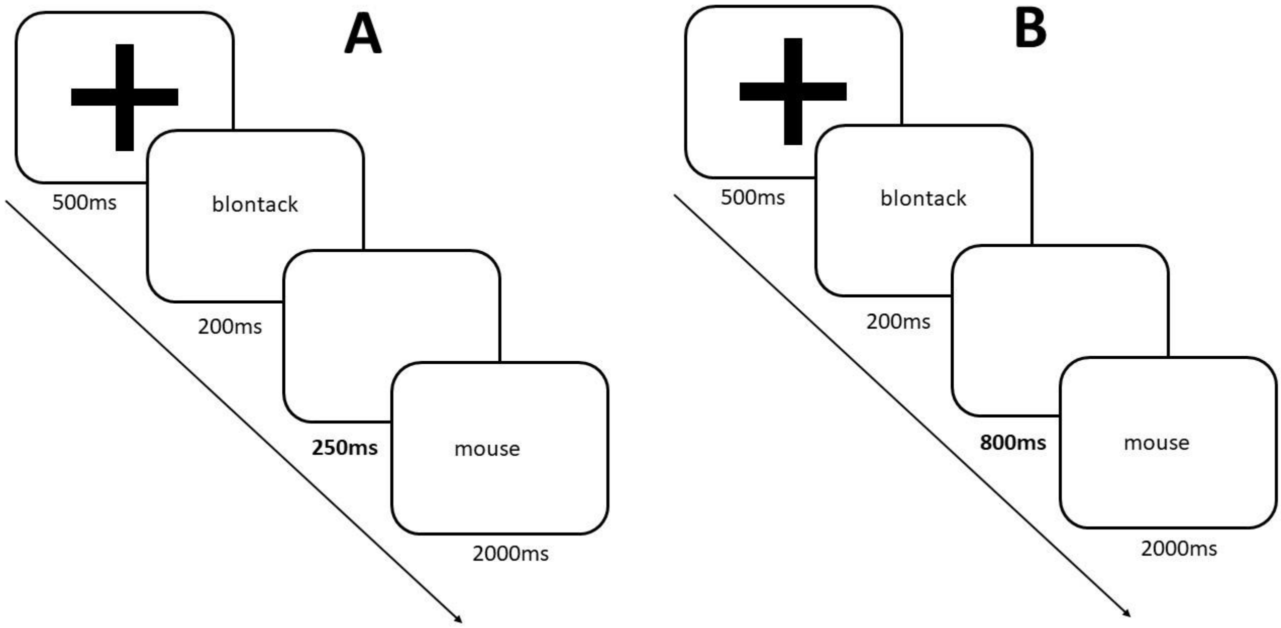

Figure 24: An illustration of the pLDT recruited in Chapter 4. Arrows represent the order of stimuli within a single trial. **A** illustrates stimulus timings in experiment one; **B** illustrates stimulus timings in experiment two. Notice that the only difference between experiment one and two concerns the duration of the blank screen, which is highlighted in bold text.

Every target (real and nonword) was presented once per participant, with each prime appearing six times - on three occasions with a real word target and three occasions with a nonword. This meant that per participant, primes were not presented an equal number of times with a related and unrelated real word target. To counteract this, two versions of each lexical decision task were created, with participants completing just one version. Each prime appeared twice with a related and once with an unrelated target in one version of the task, and twice with an unrelated and once with a related target in the other version. This meant that across participants, each prime was presented an equal number of times with a related and unrelated real word target.

The pLDTs were divided into 3 blocks. Each prime appeared twice per block, once with a real word target and once with a nonword target. Participants could use the time in between blocks to take a short break. Further, the participants' cumulative accuracy rate - across blocks and tasks (novel and familiar) - was presented in between blocks, again to encourage accurate responses.

Each pLDT therefore consisted of 204 trials: 102 nonword target trials, 51 (word) related target trials and 51 (word) unrelated target trials. Accordingly, the relatedness-proportion was 0.5, and the nonword ratio was 0.67. In line with McNamara (2005), these parameters should at least permit the use of strategic priming mechanisms (expectancy generation and semantic matching, respectively), in conjunction with a sufficiently long SOA.

4.2.2 Results

4.2.2.1 Explicit recall of novel word meaning

As per TG13, recall was considered as correct if the participant successfully recalled the core concept of the novel word's meaning (e.g., *cat* in *is a type of cat that has stripes and is blueish-grey*). On average, participants successfully recalled 29/34 (84%) (*SD* ± 0.19) novel word meanings, suggesting participants had acquired the meanings of the vast majority of the novel words. Indeed, 52/60 participants performed above chance level (68% of meanings recalled). Chance level was calculated by performing 10,000 simulations of 34 Bernoulli trials (34 being the number of trials in the meaning recall task). Comparing correct responses to a critical alpha level of .05 revealed that ≥23 correct trials (or 68%) corresponded to above chance level of performance.

4.2.2.2 Lexical decision times with familiar primes

Our analysis of data from the primed lexical decision tasks followed the same procedures as TG13. Incorrect responses were removed, as were response times <150ms and >1500ms which were considered as outliers. For the familiar task, participant on average (± standard deviation) contributed 46 trials (± 5.87) in the related condition and 44 trials (± 6.63) in the unrelated condition. The resulting response time was used as the outcome variable in a linear mixed-effects model and was log-transformed to reduce the effect of positive skew on the data. The model included the fixed effect of prime-target relatedness (related or unrelated) and included random intercepts for participants, primes, and targets. Random slopes would have been included if they significantly improved model fit. However, for all models reported in this study (including experiment 2), no random slopes improved the fit of any model. We report Type-III tests of main effects to establish the effect of prime-target relatedness on lexical decision times.

Statistical models were configured in *RStudio* (*R* version 4.0.4 – R Core Team, 2022) using the *lmer* function from the *lme4* package (Bates et al., 2015). Estimated marginal mean response times, reported in tables and figures, were calculated using the *emmeans* package (Lenth, 2021). While response time was log-transformed when configuring statistical models, response time has been converted back to the response scale in tables and figures to aid readability.

Table 10: Estimated marginal mean response times in Experiment 1. Standard errors are presented in parentheses.

	Related	Unrelated	Priming effect (ms)
Familiar	530.28 (±11.52)	539.53 (±11.72)	9.25
Novel	540.54 (±12.94)	544.30 (±13.04)	3.76

Due to a technical error, we removed data from one target in the familiar lexical decision task as this incorrectly appeared with two unrelated primes (across participants). This was the case for all analyses involving the familiar priming task reported throughout the article. Estimated marginal mean response times for experiment 1 are presented in Table 10. In the familiar lexical decision task, there was a significant main effect of prime-target relatedness on lexical decision times (F (1, 5258.9) = 10.94, *p* <.001). Response time to the target was significantly faster following a related compared to an unrelated prime (see Figure 25), revealing a significant semantic priming effect.

4.2.2.3 Lexical decision times with novel primes

Following outlier removal, participants on average contributed 45 trials (± 7.85) in the related condition and 45 trials (± 9.12) in the unrelated condition. The analysis revealed no significant main effect of prime-target relatedness on lexical decision times (F (1, 5224.1) = 1.90, *p* = .168). As can been see in Table 10 and Figure 25, response times to the target were numerically quicker following a related prime, however this did not reach significance.

4.2.3 Interim discussion – Experiment one

The results of Experiment 1 replicate the findings of the 'recent' condition of TG13's first experiment - recently learned novel words, with an SOA of 450ms between the prime and target in a primed lexical decision task, do not facilitate the recognition of associated (familiar) counterparts, while familiar words do.

As in TG13, the priming effect associated with the familiar primes was numerically rather small. This is possibly due to the relatively weak prime-target associations on average (average forward association strength = .16). Given that each prime was presented 3 times throughout the experiment to provide a sufficiently large trial count, it is very difficult to identify 3 (relatively) strongly associated targets per prime (Tamminen & Gaskell, 2013). Furthermore, the backward association strength (BAS) scores in the familiar condition were even smaller (average BAS = .06). This may have limited the influence of semantic matching, which is most sensitive to the association between the target and prime (Neely & Keefe, 1989), and thus may have further weakened the overall priming effect. We return to this observation in section 4.3.3.

One noticeable difference between the findings of our experiment and that of TG13 is the overall increased response time in the present experiment. We believe that one explanation for this concerns the participant sample. Our sample contained noticeably older participants (mean age = 41 years) compared to TG13 (mean age = 21 years). Older participants have been shown to produce delayed lexical decision times (regardless of prime-target relatedness) compared to their younger counterparts (Gold et al., 2009; Madden, 1992), possibly due to general age-related changes in brain circuitry (e.g., Giorgio et al., 2010). Alternatively, given that vocabulary size increases across the lifespan, older individuals may exhibit slower lexical decisions relative to their younger counterparts due to the fact that the presence of more information (words) places strains on processing demands (Ramscar, 2022). Whatever the case, it is possible that these age-related differences between samples are at least partly responsible for the observed numerical differences in response times overall.

In experiment two, we increase the SOA from 450ms to 1000ms. We believe that in doing so, the temporally limited hippocampal representations of the novel primes are provided more time to engage before the presentation of the target. If prime meaning retrieval is complete, or enhanced relative to experiment one, before the presentation of the target, then the effectiveness of strategic priming mechanisms (expectancy generation and/or semantic matching) should increase, possibly allowing an overall significant semantic priming effect to appear (or at least produce a stronger effect than that found in experiment one).

4.3 Experiment 2

4.3.1 Methods

4.3.1.1 Participants

Participants were again recruited through *Prolific* and received £11 for their participation. In total, 68 participants completed the experiment, of whom 60 contributed data to the analysis (*M* age = 41.51 years; *SD* age = 13.24; 27 males). The attrition breakdown for the eight rejected participants is as follows: exceeding the studies maximum completion time (217 minutes; *n* = 6), failure to provide a correct response in the priming task (*n* = 1); technical error (*n* = 1). All participants reported no known language related disorders and stated English to be their native language. Potential participants could not access the experiment (on Prolific) if they took part in experiment one.

4.3.1.2 Stimuli, experimental design, and procedure

The only methodological difference between experiment 1 and experiment 2 was an increase in SOA from 450ms to 1000ms in the primed lexical decision tasks. Specifically, the display duration of the blank screen between the prime and target presentation was increased from 250ms to 800ms (see Figure 24B).

4.3.2 Results

4.3.2.1 Explicit recall of novel word meaning

On average, participants successfully recalled 29/34 (86%) (*SD* ±0.19) of the novel word meanings, suggesting participants had acquired and retained the meanings of the vast majority of words. Indeed, 53/60 participants performed above chance level (range 3-100%). There was also no significant difference in recall accuracy across experiments (p = .673), meaning any differences in novel priming across experiments is unlikely to be due to differences in the quality of encoded knowledge.

4.3.2.2 Lexical decision times with familiar primes

The same data trimming and model fitting procedures as used in experiment one were used again to analyse the lexical decision data collected in experiment two. For the familiar priming task, participants on averaged contributed 47 trials (± 6.27) in the related condition and 45 trials (± 6.83) in the unrelated condition. We again report Type-III tests of main effects to explore the effect of prime-target relatedness on lexical decision times.

Table 11: Estimated marginal mean response times in Experiment 2. Standard errors are presented in parentheses.

	Related	Unrelated	Priming effect (ms)
Familiar	548.32 (±11.21)	553.08 (±11.32)	4.76
Novel	531.91 (±10.71)	540.62 (±10.88)	8.71

Estimated marginal mean response times for experiment 2 are presented in Table 11. Unlike experiment 1, there was no significant semantic priming effect in the familiar lexical decision task (F (1, 5304.9) = 2.55, *p* = .11). Nonetheless, there was a trend towards a significant effect of facilitated response time on related prime-target trials (see Table 11 and Figure 25).

4.3.2.3 Lexical decision times with novel primes

Following outlier removal, participants on average contributed 47 trials (± 5.81) in the related condition and 46 trials (± 5.76) in the unrelated condition. There was a significant main effect of prime-target relatedness on response time in the novel lexical decision task (F (1, 5404.7) = 9.64, *p* = .002). Response time to the target was significantly quicker following a related compared to an unrelated prime (see Table 11 and Figure 25). Thus, there was a statistically significant semantic priming effect involving novel primes.

4.3.3 Interim discussion – Experiment two

The results of experiment 2 show that recently learned novel words can facilitate the recognition of associated (familiar) counterparts. We suggest that these results reflect two factors: 1) The recruitment of strategic priming mechanisms, and 2) activation of the newly encoded hippocampal representation which regulate knowledge at this stage of learning. Crucially, both factors appear to necessitate a sufficiently long SOA.

An unexpected finding from experiment was that no significant priming effect was seen in the familiar condition. Given the presence of an effect in experiment 1 this pattern requires some explanation. Why might we see a priming effect for these items at shorter SOA (in our experiment 1 and TG13), but not at longer SOA? It seems plausible that the early effect of automatic spreading activation had faded before the presentation of the target, given the propensity for activation to soon dissipate following prime onset (Collins & Loftus, 1975). However, would we not expect to observe strategic priming for the familiar items too? A potential explanation as to why we might not relates to the BAS statistics that were discussed previously. As a reminder, the BAS statistics in the familiar condition are very low (average

BAS of .06) and are considerably lower than the novel prime condition (average BAS of .16). There is evidence from prior work that semantic priming is more sensitive to BAS at long SOAs (compared to a shorter SOA). For example, Hutchison et al., (2008) found that the magnitude of semantic priming is predicted by BAS with an SOA of 1,200ms (similarly, see Thomas et al., 2012 with an SOA of 800ms). That is, weaker BAS is associated with weaker semantic priming.

BAS is thought to be associated with the strategic semantic priming mechanism of semantic matching - the participant checks back the association between the target and prime (Neely & Keefe, 1989; Neely et al., 1989). When an association is detected (from the target towards the prime), this can bias and facilitate the participant to respond with a *word* response in the lexical decision task (i.e., the target must be a word, since there is an association with the prime). However, when no association is detected but the target is a real word, the participant must override the bias to respond with *nonword*, inducing a slight delay in response time. The implication of this is that in the present study, with very low BAS scores in the familiar condition, the ability of semantic matching to facilitate related target response time may have been minimal, since, overall, the association between the targets and their primes was very weak. In contrast, semantic matching may have had a greater impact in the novel condition where BAS statistics are considerably larger, and thus could have facilitated related target response time to a greater degree.

We also acknowledge the increased response times to familiar primes on the whole compared to the novel primes, as well as compared to the familiar primes of experiment 1. We are unsure of a definitive conclusion for this finding. One possibility is that it relates to the same issue as the lack of an overall priming effect. That is, early automatic effects of spreading activation should have dissipated before target onset given the long SOA. Similarly, if the effectiveness of the semantic matching strategy was impaired in the familiar prime condition, this should delay response times in both the related and unrelated prime-target conditions.

4.4 Exploratory analyses

4.4.1 Combined analysis of data across experiments

As outlined in the study pre-registration, we conducted a combined analysis of data across both experiments. This allowed for a clear investigation into the effect of experiment/SOA on novel word (and familiar) semantic priming. This model, with log-transformed response time as the outcome variable, included prime-target relatedness, prime lexicality, and experiment (between subjects) as predictors. These predictors were sum coded (-0.5, +0.5) to ease the interpretation of interactions between predictors. The model output is presented in Table 12.

Table 12: Predictors of response time across both experiments. Statistically significant terms are highlighted in bold.

Fixed effects	*b*	*se*	*t*	*p*
Intercept	6.291	0.014	435.17	<.001
Relatedness	**-0.006**	**0.001**	**-4.20**	**<.001**
Lexicality	0.006	0.004	1.63	.104
Experiment	-0.008	0.014	-0.55	.581
Relatedness:Lexicality	-0.000	0.001	-0.51	.611
Relatedness:Experiment	0.000	0.001	0.07	.947
Lexicality:Experiment	**-0.008**	**0.001**	**-5.95**	**<.001**
Relatedness:Lexicality:Experiment	**-0.003**	**0.001**	**-2.16**	**.031**
Random effects	Variance	SD		
Participants (Intercept)	0.02	0.15		
Prime (Intercept)	0.00	0.01		
Target (Intercept)	0.00	0.04		
Residual	0.04	0.20		

The model was configured over 21,869 observations, from 120 participants across 68 primes and 203 targets. Because the model was configured over log transformed data, the resulting beta coefficients and standard errors are rather small. We therefore present these values to 3 decimal points to illustrate the size of these statistics more clearly.

There was an effect of prime-target relatedness on response time, revealing an overall semantic priming effect (EMM related trials = 536.80ms (*SE* ±7.79), unrelated trials = 542.87ms (*SE* ±7.88)). The significant prime interaction between lexicality and experiment was driven by significantly slower overall response time following a familiar compared to a novel prime, but only in the second longer-SOA experiment (EMM familiar primes = 551.60ms (*SE* ±10.97), novel primes = 536.69ms (*SE* ±11.02), p <.001).

Finally, there was a significant 3-way interaction between all 3 factors. This was explored further by comparing response time between related and unrelated pairings, separately for novel and familiar primes and each experiment. This resulted in four contrasts (1: familiar related vs. unrelated experiment 1; 2: novel related vs. unrelated experiment 1; 3: familiar related vs. unrelated experiment 2; 4: novel related vs. unrelated experiment 2), with a Bonferroni p-value adjustment applied to control for multiple comparisons. In experiment 1, there was a significant semantic priming effect involving familiar (p = .003) but not novel (p = 1.00) primes. In contrast, in experiment 2, there was a significant effect involving novel (p = .011) but not familiar (p = .764) primes. The interaction can be visualised in Figure 25.

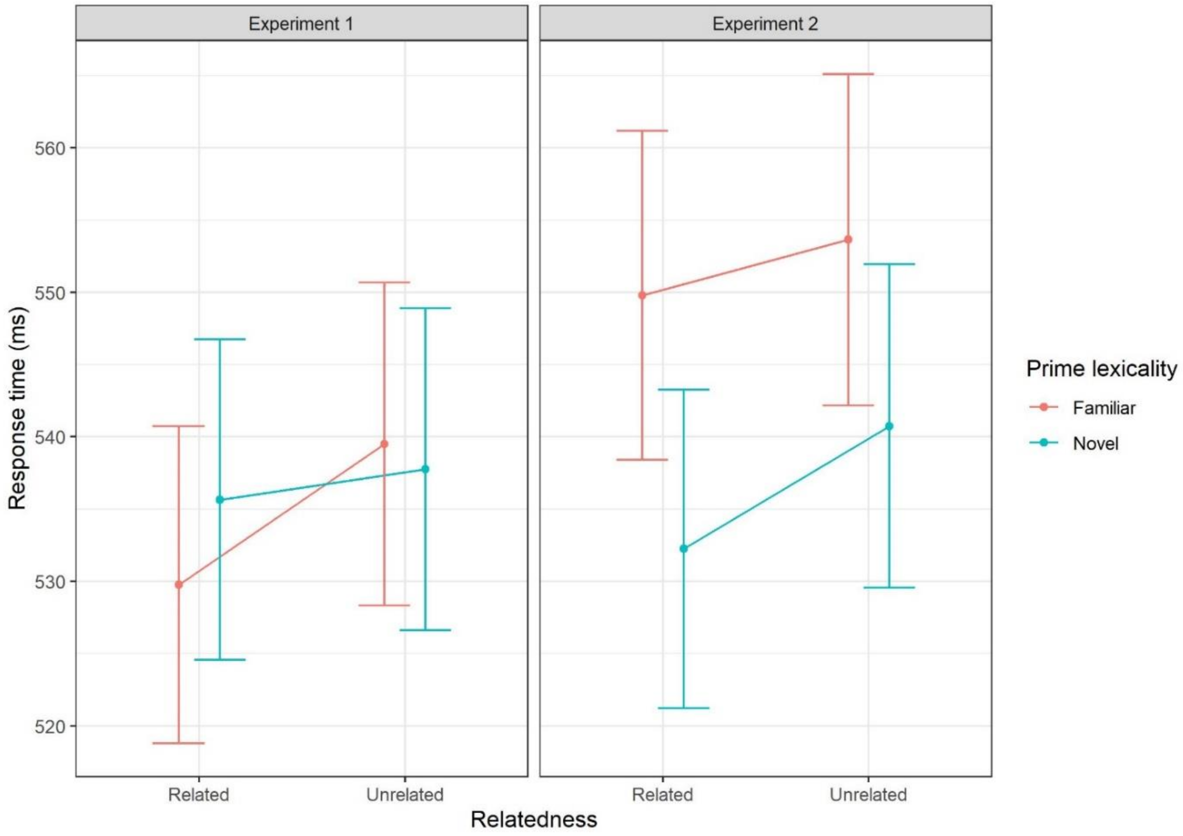

Figure 25: Semantic priming effects as a function of prime lexicality and experiment. Points represent estimated marginal mean response time and error bars represent standard error from the mean.

4.4.2 Removal of participants based on performance

Thus far, the models reported in this chapter have been configured over a sample of 60 participants, who contribute at least one data point to the analysis. However, it is possible that some participants performed relatively poorly in the pLDT and that this might have had an effect on the priming results. To determine any detrimental effect that such participants could have had on the observed results, we performed a follow-up analysis whereby the data was cut to various accuracy deciles. That is, the first accuracy decile will remove any participant who provides fewer than 10% of correct responses for any relatedness condition (related or unrelated), in *either* the novel or familiar priming task. This process is repeated in a stepwise process, requiring an additional 10% accuracy threshold each iteration (i.e., the second accuracy decile will require a 20% accuracy rate). The final iteration requires an accuracy rate of 63%. This value denotes chance level performance, which was calculated by performing 10,000 simulations of 51 Bernoulli trials (51 being the number of trials per relatedness condition in the pLDT). Comparing correct responses to a critical alpha level of .05 revealed that ≥32 correct trials (or 63%) corresponded to above chance level of performance.

A series of models were thus configured, with the data trimmed according to the given accuracy threshold. Type-III main effects of prime-target relatedness are reported as per the main analysis, and the models are summarised in Table 13.

Table 13: Model summaries over data trimmed to various accuracy deciles. The number of participants removed in each decile is denoted by *n*.

Experiment	Prime Lexicality	Model	F-value	P-value
Experiment 1 (450ms SOA)	Familiar primes	<10% accuracy rate (*n* = 1 removed)	12.78	<.001
		<20% accuracy rate (*n* = 1 removed)	12.78	<.001
		<30% accuracy rate (*n* = 1 removed)	12.78	<.001
		<40% accuracy rate (*n* = 2 removed)	12.09	<.001
		<50% accuracy rate (*n* = 2 removed)	12.09	<.001
		<63% accuracy rate (*n* = 4 removed)	11.90	<.001
	Novel primes	<10% accuracy rate (*n* = 1 removed)	1.92	.166
		<20% accuracy rate (*n* = 1 removed)	1.92	.166
		<30% accuracy rate (*n* = 1 removed)	1.92	.166
		<40% accuracy rate (*n* = 2 removed)	1.62	.203

		<50% accuracy rate (*n* = 2 removed)	1.62	.203
		<63% accuracy rate (*n* = 4 removed)	2.04	.153
Experiment 2 (1000ms SOA)	Familiar primes	<10% accuracy rate (*n* = 0 removed)	2.55	.110
		<20% accuracy rate (*n* = 1 removed)	2.53	.112
		<30% accuracy rate (*n* = 1 removed)	2.53	.112
		<40% accuracy rate (*n* = 2 removed)	1.41	.235
		<50% accuracy rate (*n* = 3 removed)	1.14	.286
		<63% accuracy rate (*n* = 6 removed)	1.86	.172
	Novel primes	<10% accuracy rate (*n* = 0 removed)	9.64	.002
		<20% accuracy rate (*n* = 1 removed)	8.25	.004
		<30% accuracy rate (*n* = 1 removed)	8.25	.004
		<40% accuracy rate (*n* = 2 removed)	8.59	.003
		<50% accuracy rate (*n* = 3 removed)	8.64	.003
		<63% accuracy rate (*n* = 6 removed)	7.29	.007

The results of this follow-up analyses suggest that the potential influence of poor performance in the pLDT was minimal. That is, after removing participants sequentially up to chance level performance, our analyses produced estimates for the effect of prime-target relatedness that are very similar to those reported in the main analysis. In experiment one, four participants were identified as performing below chance level. With these participants removed, priming continued to be observed for the familiar but not for the novel primes. Likewise, six participants were identified as performing below chance level in experiment 2. Priming continued to be observed for the novel but not for the familiar primes following the removal of these participants' data.

4.5 Discussion

Chapter 4 reinvestigated the research questions laid out in Chapter 3. The interpretability of the results in Chapter 3 was limited due to unexpected and null findings in our familiar 'baseline' priming condition. Chapter 4 recruited part of the design and stimuli used in TG13, where a significant semantic priming effect involving familiar prime words is reported. We therefore adopted their approach in conjunction with an experimental manipulation of SOA length.

Experiment one of Chapter 4 replicated the findings of TG13, in that recently learned novel words, with an operating SOA of 450ms in a pLDT, did not semantically prime related, existing words. Crucially, and unlike the results of Chapter 3, a significant semantic priming effect was found for familiar prime words, suggesting that the design of the priming task was sensitive enough to elicit semantic priming. Consequently, we can interpret the findings from the novel words with more confidence relative to Chapter 3.

In experiment two, we increased the SOA from 450ms to 1000ms in the pLDT. The analyses of experiment two revealed a significant priming effect in the novel pLDT but not in the familiar task. This dissociation of priming behaviour was further examined and confirmed in a combined analysis of data across both experiments.

The lack of semantic priming from the familiar primes in experiment two was again unexpected. As discussed in the interim discussion of experiment two however, the lower BAS statistics between the targets and primes in this condition could be implicated in this null effect, by reducing the effectiveness of semantic matching. For the novel words, BAS statistics were greater overall, thereby facilitating the potential use of semantic matching.

A consequence of this interpretation is that it suggests the mechanism underlying the significant novel semantic priming effect in experiment two is more likely to be semantic matching than to be expectancy generation. This isn't to say, though, that expectancy generation wasn't operating at all in experiment two. Firstly, whilst FAS - which is most heavily associated with expectancy generation - did not significantly predict priming at 1,200ms SOA[5] in Hutchison et al., (2008), numerically stronger FAS statistics were still associated with greater semantic priming. Secondly, there was a trend of semantic priming in the familiar condition in experiment two. As mentioned, the impact of semantic matching was possibly minimal in this condition. Further, the early effect of automatic spreading activation should have long faded before the presentation of the target, due to the long SOA and the propensity for activation to soon dissipate following prime onset (Collins & Loftus, 1975). Speculatively, this would mean that any effect associated with the familiar condition is most likely a result of expectancy generation, and given the equal FAS statistics between conditions, it is feasible that expectancy was also operating to an extent in the novel condition.

The key finding from this chapter however concerns the semantic priming behaviour of the novel words. Specifically, the results suggest a possible sensitivity of novel word semantic priming to the temporal delay between the prime and target. Furthermore, and to the best of our knowledge, this appears to be the first study to demonstrate significant novel word semantic priming, when measured via a pLDT. That is, when significant effects are reported in the literature, an SJT has been recruited (Bakker et al., 2015; Balass et al., 2010; Perfetti et

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[5] In fact, FAS predicted semantic priming in a lexical decision task when collapsed across short (200ms) and long (1,200ms) SOA.

al., 2005). Indeed, this is also the first study to use a 1000ms SOA with a pLDT. Possible explanations for the relationship between SOA and novel word semantic priming, as well as how the results of Chapter 4 compare to the existing literature, are discussed in the General discussion.

Another intriguing finding of Chapter 4 was the trend of novel word semantic priming in experiment one (450ms SOA). That is, whilst non-significant, response time following a related prime was numerically quicker compared to an unrelated prime, a trend that has been observed in prior work which also report non-significant effects with a similar SOA (Batterink & Neville, 2011; Borovsky et al., 2012; Tamminen & Gaskell, 2013). Indeed, given this trend, TG13 explicitly acknowledge the possibility that *some* semantic priming was present when recently learned novel words are used as primes. However, such effect was relatively weak. This may suggest that some priming mechanisms can operate at this SOA, and that novel words and their meanings are retrieved to some extent. However, perhaps the quality of these processes was halted by the SOA length, to the extent that semantic priming was hindered.

Chapter 5 – General discussion

Broadly, this thesis explored the dissociation between different forms or stages of lexical knowledge. It investigated how new words and their meanings are initially encoded, how this might differ from established word knowledge, and what consequences such encoding might have for semantic processing. Both electrophysiological (EEG) and behavioural (semantic priming) methods were recruited in this investigation.

The motivation for this research stems from claims made by at least two distinct areas of research that suggest that different kinds of lexical knowledge may be dissociable. One strand of research which makes such claim is the infant word knowledge literature, where a distinction is made between ‘associative’ and ‘semantic’ word knowledge, which may coincide in a shift from associative to referential modes of lexical acquisition (Nazzi & Bertoncini, 2003). This dichotomy in word knowledge is apparent from behavioural studies. For example, there is evidence that infants show a sensitivity towards correct word-object mappings based on looking behaviour, whilst being equally unable to explicitly identify the correct referent after hearing its label (Bannard & Tomasello, 2012; Hendrickson et al., 2015; 2017). One possibility is that the later, more explicit response requires a deeper level of symbolic understanding which may depend on social learning (Bannard & Tomasello, 2012), whilst more implicit measures such as looking time may suffice with learned associations between a word-form and its object.

The EEG infant word knowledge literature also supports the notion that there are unique aspects of word knowledge. Research by Friedrich and Friederici (2004) has implicated at least two event-related potentials (ERPs) with different strands of lexical knowledge. Firstly, there is the N400 effect, which is heavily implicated in semantic processing (Kutas & Federmeier, 2011). The cross-modal paradigm adopted by Friedrich and Friederici (2004) has also revealed another ERP effect of interest, the phonological lexical priming effect (PLPE). Rather than being implicated in semantic processing per se, it is argued that the PLPE may instead reflect an associative pathway between word-form and object representations (Friedrich & Friederici, 2015). Evidence of this associative pathway (evident by a PLPE) in the absence of semantic processing (an absent N400) has been observed in infants at risk of developing later language related disorders (Friedrich & Friedrich, 2006; Von Koss Torkildsen et al., 2007), boosting the claim that different forms of lexical knowledge may be dissociable.

The second area of research to suggest a lexical knowledge dissociation stems from models of word learning. Based on core CLS principles of knowledge acquisition, Davis and Gaskell (2009) created a theoretical framework describing the acquisition of new words and their meanings. Rather than integrating immediately into conventional language networks of the brain, it is argued that new words and their meanings are initially represented episodically via the hippocampus and surrounding, medial temporal lobe structures. Only with time and offline consolidation periods such as sleep does this novel knowledge begin to integrate with existing lexical knowledge. Thus, based on these principles, knowledge is dissociable based on an ‘episodic’ vs ‘lexical’ distinctions. The former is characterised by knowledge that is dependent on hippocampal processing, whilst the latter is characterised by the integration of knowledge into cortical language networks that is independent from the hippocampus.

These two strands of research thus make similar claims that word knowledge is not ‘all-or-nothing’. Rather, there are different ways in which words may be represented, leading to differences in how they are processed and responded to. The link between these two areas of research, however, does not appear to have been explored. For example, infant research suggests that there is a stage of lexical understanding that is non-semantic. The CLS approach to lexical acquisition similarly argues that new words are initially represented outside of language networks before integrating with existing knowledge. The question is, then, can we bridge together these respective ‘non semantic/lexical’ claims made from distinct areas of research? This was the topic of interest in Chapter 2, which measured the PLPE (N200-500 component) and N400 effect in response to recently learned words. The PLPE does not appear to have been explored in the adult word learning literature before. If knowledge takes time to integrate into language networks (indexed by the N400), perhaps learned associations between a new word-forms and objects could instead develop quite quickly, as would be suggested by a PLPE. The intention to measure this ERP effect was therefore to bridge together the non-lexical/semantic distinctions put forward by respective literatures, whilst also measuring the N400 response as a marker of integrated semantic representations.

Chapters 3 and 4 expanded on the findings of Chapter 2 and explored the ability of new words to interact with existing lexical items via (behavioural) semantic priming. A key assumption of the CLS approach to word learning is that new words cannot interact with existing words. This is because knowledge has yet to integrate with existing knowledge in language networks, and the hippocampally-mediated pathway (that regulates initial lexical knowledge) represents an indirect route of knowledge that is processed with less priority, compared to the direct cortical pathways that regulate knowledge of existing words (Davis & Gaskell, 2009).

Whilst research largely supports this claim of absent priming with new words, there is nonetheless some evidence in the literature (Bakker et al., 2015; Balass et al., 2010; Perfetti et al., 2005). Furthermore, in Chapter 2, we observed similar N400 effects between novel and familiar words, suggesting that new words can engage in semantic processes in a similar fashion to known words (see also Angwin et al., 2022; Balass et al., 2010; Batterink & Neville, 2011; Borovsky et al., 2012; Mestress-Misse et al., 2007; Perfetti et al., 2005).

One observation is that when markers of semantic processing is evident with new words, whether that be behaviour semantic priming or the N400 effect, studies have used relatively long stimulus onset asynchrony’s (SOAs) (500ms – 1000ms long), including Chapter 2 of this thesis. Since strategic priming mechanisms are more likely to feature at a longer SOA relative to a short SOA (Neely, 1977; McNamara, 2005), this could implicate a possible role of these mechanisms in novel word semantic processing (Bakker et al., 2015).

It was also argued in the introduction (Chapter 2) that the SOA could play an additional role in novel word semantic priming, which does not appear to have been explicitly considered in earlier work. Specifically, if the SOA is sufficiently long, it could also facilitate the retrieval of new words and their meanings (via the hippocampus), which, as discussed, is assumed to be relatively delayed compared to the retrieval of existing items. The reasoning for this potential role of SOA partly stems from Weighall et al. (2017), who observed significant competition effects from new words via a visual world paradigm (VWP). The authors argued that, compared to a pause-detection task which reports non-significant effects of lexical competition (e.g., Gaskell & Dumay, 2003), the VWP is better suited at incorporating information arriving slowly from the hippocampus, allowing new words to compete with existing items. Importantly, however, this temporal element of novel word processing does not appear to have been explicitly considered in prior work exploring novel word semantic priming.

We reasoned, then, that novel words could semantically prime related counterparts if the SOA is sufficiently long, because a) it would increase the likelihood of strategic priming mechanisms, and b) it would facilitate the retrieval of encoded knowledge. If true, then this would hint at a lexical knowledge dissociation between novel and familiar words since familiar words should feasibly prime related words across an SOA continuum. More specifically, familiar words should engage in priming in shorter SOA conditions due to being represented in semantic networks, and hence are exposed to automatic processing (e.g., Collins & Loftus, 1975). New words, however, may not have integrated into such networks shortly after acquisition (Davis & Gaskell, 2009). Hence, they may receive no benefit from automatic processing, but could instead be exposed to more strategic processing. Chapters 3 and 4 explored this reasoning and possible dissociation between new and familiar words by measuring novel word semantic priming as a function of SOA length.

In the following sections, the core findings of each chapter are discussed in turn. We then synthesise these key findings across chapters and discuss the broader implications and contributions of this thesis.

5.1 Chapter 2

The aim of this chapter was to investigate the electrophysiological correlates of new words. Specifically, we measured the PLPE and N400 effect in response to new words.

The presence of a PLPE can be taken to indicate the formation of associative connections between word-form and object representations, based on its functional interpretation (Friedrich & Friederici, 2015), which may be independent from the integration of words and their meanings into language networks, which may take time to develop (Davis & Gaskell, 2009).

In a cluster-based permutation analysis, a PLPE was not observed for either the novel or familiar stimuli. Given that this effect has been observed before in adults (Friedrich & Friederici, 2004), we had anticipated this effect in both the familiar and novel conditions, given that it reflects a relatively basic form of lexical knowledge that could be acquired quite swiftly. It is possible that the design of our experiment was not sensitive enough to elicit this effect. For example, Chapter 2 presented the target words within a larger carrier phrase, which could have made the activation of word-form representations more difficult, compared to previous work which presented target stimuli in isolation.

On the other hand, both the novel and familiar words appeared to elicit an N400 effect. This finding alone suggests that new words can engage with semantic processes immediately following acquisition. There were also no clear differences between the novel and familiar words concerning the spatiotemporal profile of this effect, which may suggest that new words are encoded in the same way as existing items (i.e., integrated semantic representations). Indeed, the N400 component is typically taken as a marker of relatively *automatic* semantic processing in word learning studies (e.g., Bakker et al., 2015; Liu & van Hell, 2020), and thus is often used as a marker of integrated semantic representations. These results may therefore suggest that the new words had integrated into language networks and behaved like familiar words (Borovsky et al., 2012). Importantly, given that there was no offline consolidation period in between study and test, this suggests that sleep is not necessary for this integration process to take place, as predicted by the CLS account (Davis & Gaskell, 2009).

Importantly, however, as reviewed in Lau et al., (2008), the N400 effect is similar in magnitude across short and long SOA, which may indicate that the N400 reflects both relatively automatic (short SOA) and controlled/strategic (long SOA) retrieval/semantic processing. This could thus implicate strategic mechanisms in novel N400 effects, which need not necessarily rely on integrated representations, as suggested by Bakker et al. (2015). For example, we know from existing work that participants have a good, explicit understanding of new words and their meanings shortly after acquisition, which was also evident in Chapter 2. Perhaps participants could make use of these, perhaps episodic, meanings within the context of the critical testing phase to strategically predict / integrate existing words, revealing an N400 effect. For such strategies to develop, a sufficiently long SOA would need to operate. Indeed, when significant effects are reported in the literature, the SOAs range from 500ms-1000ms (Angwin et al., 2022; Balass et al., 2010; Batterink & Neville, 2011; Borovsky et al., 2012; Mestress-Misse et al., 2007; Perfetti et al., 2005).

In Chapter 2, the SOA between the on-screen image and target word was 1506ms long, on average. This is thus well within the temporal window in which strategic mechanisms emerge (McNamara, 2005; Neely, 1977). One possibility, then, is that strategic-based mechanisms were responsible for the N400 effects in Chapter 2. Further, due to the long SOA, early automatic activity such as spreading activation should have dissipated before the onset of the target, since the effect of such activity is short-lived (Collins & Loftus, 1975). Thus, strategic processes may have been implicated in the familiar N400 effect as well, leading to similar spatiotemporal profiles. In support of this, studies which employed a 1000ms SOA (Balass et al., 2010; Perfetti et al., 2005; though see Angwin et al., 2022), similar in length to the SOA of Chapter 2, also report similar N400 effects across novel and familiar words in terms of timing and topography.

We also discussed extraneous factors which may have impacted the N400 response in our experiment. First, the stimuli were repeated several times in the form of congruous and incongruous pairings, which could have led to repetition effects on the N400 response. Second, the imbalance between the novel and familiar stimuli could have led to an odd-ball like scenario, in which the N400 signal is enhanced relative in response to deviant and unexpected stimuli (e.g., Lindborg et al., 2023). In the context of our experiments, this could have led to an enhanced response to the novel stimuli given that they were less frequent than the familiar stimuli. Finally, the passive nature of our experiment could have had an effect of the N400 response, as it has been shown that more explicit tasks tend to elicit stronger responses (Cruse et al., 2014). Again, the task was purposefully made relative passive due to planned future studies with infants. Nonetheless, it is possible that these factors may have impacted on the N400 response, and future research may wish to eliminate these factors to gain a ‘smoother’ comparison between novel and familiar words.

Given similar N400 effects and the absence of a PLPE across conditions, the findings of Chapter 2 did not reveal any clear means by which knowledge can be dissociated between new and familiar words. Thus, new words appeared to behave like familiar words. In all, two possibilities were considered. First, the lack of clear differences between conditions may have indicated similar patterns of encoding, in that the novel words had integrated into language networks. Alternatively, it was possible that the design of our experiment may have reduced the scope for observable differences between the familiar and novel conditions. For example, the long SOA may have encouraged the use of strategic processing, and potentially inhibited to observability of automatic processing that the familiar words were possibly exposed to. The remaining studies of the thesis aimed to explore this possibility.

5.2 Chapter 3

Chapter 3 built on the idea, which arose in part from our findings in Chapter 2, that novel words may engage in semantic processes via controlled and strategic processes, as opposed to more automatic mechanisms that may additionally underlie the processing of familiar words. This rationale stems from the idea that new words are initially represented episodically, independently from existing knowledge, and are therefore not exposed to automatic mechanisms such as spreading activation.

Chapter 3 explored this possibility by examining novel word semantic priming across three SOA conditions (200ms, 500ms, and 1000ms). If novel word semantic priming is indeed dependent on the use of strategic mechanisms, then significant effects should be observed in the longer SOA conditions (i.e., 500ms and 1000ms) but not short (200ms). Further, it was argued that SOA length may determine the extent to which new words and their meanings are retrieved and available for strategic processes. Specifically, a long SOA may have allowed enough time for these words to be retrieved.

For the rare (novel) words, priming was detected only when a 500ms SOA was operating, However, there was no priming at 1000ms which was inconsistent with our predictions. Furthermore, there was a trend of a semantic priming effect at 200ms. This is intriguing because priming at this SOA is thought to depend more heavily on automatic processing (McNamara, 2005), which may depend on integrated semantic representations (Davis & Gaskell, 2009). Hence, just like the presence of an N400 effect in Chapter 2, this finding could argue that some integration had taken place.

An exploratory analysis was carried out to investigate these unexpected results further. This revealed a significant effect of association strength in the familiar condition, whereby targets with weaker FAS scores elicited weaker semantic priming. It was proposed that such an effect was only found in the familiar condition, as FAS statistics were more varied and slightly weaker in this condition compared to the rare/novel words. The inclusion of such targets may therefore have weakened and nullified the semantic priming effect overall. Ultimately, however, these findings limit the interpretability of the results obtained for the novel/rare words. The effect of SOA on novel word semantic priming, and how this can be used to inform us on the encoding of new words, is therefore unclear from these results alone, and it isn’t clear whether we are seeing the anticipated lexical knowledge dissociation.

5.3 Chapter 4

Chapter 4 continued the investigation of the role of SOA length on novel word semantic priming. It did so by replicating part of the design and stimuli used in TG13. We took this approach because a semantic priming effect for familiar primes was observed in this study, suggesting that the design of the task and stimuli were sensitive enough to elicit semantic priming.

Two experiments were conducted, with different SOAs used across experiments to measure semantic priming. With a 450ms SOA operating in experiment one of Chapter 4, recently learned novel words did not semantically prime existing words, whilst familiar words did. In contrast, experiment two used an increased SOA of 1000ms, which resulted in novel words semantically priming related words.

The SOA thus appeared critical in the emergence of novel word semantic priming. We believe the SOA is implicated in regulating two key factors which may influence such priming. Firstly, a sufficiently long SOA may allow for the recruitment of strategic priming mechanisms, which have been implicated in novel word processing before (e.g., Bakker et al., 2015). Since novel words are deemed incapable of priming under automatic conditions (i.e., when the SOA is relatively short – Coutanche & Thompson-Schill, 2014; Tamminen & Gaskell, 2013; van der Ven et al., 2015), this presents a potentially important role of strategic processing in novel word semantic priming, compared to familiar items which may also prime under automatic conditions due to integrated semantic representations. Secondly, a sufficiently long SOA may also allow encoded hippocampal representations to retrieve novel words and their meanings, which are processed more slowly and with less priority compared to existing words (Davis & Gaskell, 2009; Lindsay & Gaskell, 2010). Hence, whilst new words may not be integrated into language networks soon after acquisition (Davis & Gaskell, 2009), they may nonetheless still interact with semantically similar words.

5.4 Overall implications and contributions of this thesis

Most broadly, the findings of this thesis suggest that recently learned words and their meanings can contribute to semantic processing, immediately after acquisition. That is, novel words can facilitate the processing of semantically related/associated, existing words. There are two key results from this thesis which support this claim. Firstly, Chapter 2 observed a significant N400 effect with novel words; an effect that is heavily implicated in meaning processing (Kutas & Federmeier, 2011), whereby a reduced N400 component for related stimuli indicates the facilitated retrieval/integration of a target stimulus, based on preceding context. In our case, the preceding context was initiated by learned objects which were paired with their congruous, or an incongruous label. The finding of a novel N400 effect is consistent with some prior studies (Angwin et al., 2022; Balass et al., 2010; Batterink & Neville, 2011l; Borovsky et al., 2012; Mestress-Misse et al., 2007; Perfetti et al., 2005).

The second finding of interest concerns the nature of the semantic processing of novel words, and their effect on the processing of established familiar words. This finding emerges from the selective appearance of significant novel semantic priming effects, particularly those observed in Chapter 4. Semantic priming, as discussed in the introduction of this thesis, is not explained by a single, exclusive mechanism, and these mechanisms vary in terms of their explicitness (i.e., automatic versus controlled/strategic). Regardless of the exact mechanism of action (at any given time), the presence of a semantic priming effect indicates that the meaning of the prime word has affected the processing of the subsequent target item, which, depending on the mechanism of action, may be used to inform theories regarding the representation and organisation of words in semantic memory (McNamara, 2005). Semantic priming behaviour was therefore observed for novel words in this thesis (particularly in Chapter 4) and has also been observed in some prior studies (Bakker et al., 2015; Balass et al., 2010; Perfetti et al., 2005).

The finding that new words can engage in semantic processing – to the extent that they influence the processing of related words – is therefore not in itself a novel finding. What the findings of this thesis argue, though, is that such processing may be strategic in nature, as opposed to automatic which may depend on the integration of words and meaning into language networks. Hence, these findings hint as a dissociation in encoding and behaviour between new and familiar words.

This idea that new words are strategically engaged in semantic processing has been suggested before (Bakker et al., 2015). We suggest that the findings of Chapter 4 offer necessary support for this claim, and an explanation as to when and how this might occur. In this chapter, novel word semantic priming was only observed when the SOA was 1000ms long, as opposed to 450ms where non-significant effects were observed (in this chapter as well as TG13). In contrast, familiar prime words could semantically prime related words at 450ms[6]. The significance of this SOA manipulation is that strategic priming mechanisms are more likely to feature as the SOA increases (McNamara, 2005; Neely 1977), hence supporting the claim that these mechanisms can act over recently learned words.

It is possible that these mechanisms were also implicated in the N400 effects observed in Chapter 2, given the long SOA between the objects and words. Whilst Chapter 2 did not follow a typical semantic priming design, the on-screen object may nonetheless serve as a 'prime' for the corresponding label. That is, the object could have primed the corresponding label, influencing how the target word (congruous or incongruous) is subsequently processed. The spatiotemporal profile of the N400 effect between the novel and existing words was also very similar. Whilst one could argue this may reflect the immediate formation of semantic representation, another possibility is that any automatic-like activity that the familiar stimuli were exposed to, but not the novel stimuli (assuming they have not integrated into language networks), had a weaker influence at long SOA, resulting in similar N400 effects. This is because the effect of these mechanisms such as spreading activation are short-lived (Collins

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[6] The familiar stimuli however did not semantically prime at 1000ms. As discussed in Chapter 4, this could be due to lower BAS scores in this condition.

& Loftus, 1975), and thus dissipate with time. Hence, the design of Chapter 2 may have made it difficult to elicit dissociable ERP effects.

This thesis also argued that the SOA in novel word semantic priming may affect the retrieval of new words and their meanings. That is, when represented via the hippocampus, new words are thought to be processed and retrieved more slowly, compared to the retrieval of existing words (Davis & Gaskell, 2009; Lindsay & Gaskell, 2010). This suggests that any task measuring novel word processing may need to accommodate this temporal deficiency. For example, work by Weighall et al. (2017) argued that novel words can compete with phonologically similar words in a VWP, but not in a pause-detection task, because the former provides a more continuous measure of competition that is better able to incorporate (slow) hippocampal information, compared to the latter which requires a one-shot, more automatic response. Tasks that are tailored towards more automatic modes of lexical access may therefore be too demanding for the hippocampus to retrieve new lexical information in time to influence processing.

It seems, then, that there could be a temporal element involved in how new words engage with existing words. In the context of semantic priming, this suggests another important role of the SOA. To the best of our knowledge, though, this idea was not explicitly considered in previous work. For example, TG13 explicitly suggest that their 450ms SOA could have allowed strategic processing to emerge, in line with McNamara’s (2005) suggestion of allowing at least 200ms between the prime and target. However, whilst non-significant effects were observed in TG13 (as well as experiment one of Chapter 4 with the same SOA), it is possible that this SOA was too short, relative to the time required for newly encoded representations to be retrieved. If the retrieval processing is impaired, then the effectiveness of any strategic mechanism that the participant can employ will also be hampered. The temporal deficiency of this early ‘lexical’ pathway, however, may have been overcome in experiment two of Chapter 4, where novel words significantly primed related words with a 1000ms SOA. Given the more than doubled SOA of experiment two from experiment one, more time may have been allowed for the participant to retrieve the meaning of a novel word, which could then have been used in conjunction with strategic priming mechanisms.

This potential process is illustrated in Figure 26. This illustration presents a semantic priming task under two SOA conditions, one that is relatively short and another that is relatively long. In both SOA conditions, the prime (novel) word appears, initiating the retrieval of this word (represented by blue horizontal arrows) and its meaning from episodic memory (i.e., from newly formed hippocampal representations). This process has the same completion time across SOA conditions. What differs instead, though, is the timing of the presentation of the target word. Under a relatively short SOA condition, the target appears *whilst the word and its meaning are still being retrieved*. As discussed, this would impair the effectiveness of strategic priming mechanisms, as one requires knowledge of the prime’s meaning. This would weaken the overall semantic priming effect. In contrast, when the SOA is relatively and sufficiently long, the meaning of the prime is retrieved *before* the presentation of the target. Having retrieved the meaning of the prime, the participant could then use this in conjunction with strategic mechanisms, such as generating expectations of possible upcoming targets, and/or perform a semantic matching strategy once the target is processed. If so, then this could and seems to allow semantic priming to ensue.

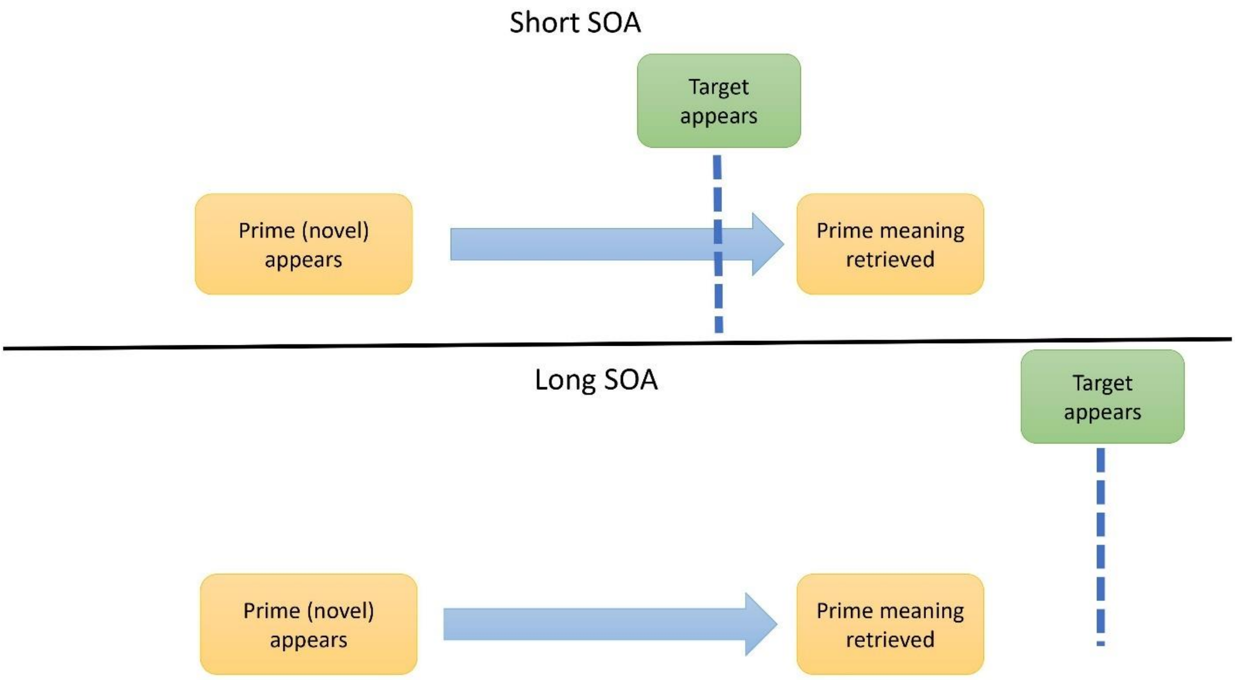

Figure 26: An illustration depicting the possible effect of SOA on novel word semantic priming.

This thesis thus contributes data to the growing consensus that newly learned words can engage and compete with other lexical items. Summarising key studies of novel word engagement and competition effects, McMurray et al. (2016) discussed factors which appear to moderate the quality of these effects that is elicited by new words. The speed of novel word processing, in particular the delay of retrieving new words and their meanings relative to existing words, was highlighted as a potentially significant factor. This was explicitly discussed in Weighall et al. (2017), who suggest that the presence of novel word competition effects is at least partly dependent on the type of task measuring competition, which must be able to incorporate (relatively slow) hippocampal information. Collectively, with the results of this thesis, it would seem that there is an important temporal element when it comes to the processing of new words. That is, new words can interact and engage with other words, but such interaction follows a longer time course to initiate compared to the interaction between familiar words. Once words begin to integrate with existing knowledge in language networks, then more automatic modes of processing begin to emerge (Tham et al., 2015).

Although Chapter 2 did not explore the possible role of SOA on novel word N400 effects, there too could be a role of timing on the quality and perhaps presence of this effect. As presented in Table 2, studies on this issue often employ relatively long SOAs. If these effects are indeed dependent on more strategic processing (Bakker et al., 2015; Mestress-Misse et al., 2007), then previous work, as well as Chapter 2, would have encouraged these effects by employing relatively long SOAs.

The results reported in this thesis provide some evidence for, and some evidence incompatible with, the claim that different kinds of lexical knowledge are dissociable. The results of Chapter 2 do not provide clear support to this idea, given the appearance of similar N400 effects across novel and familiar words. In Chapter 3, we observed somewhat different semantic priming behaviour between new and familiar words. However, as discussed and explored, it is possible that these differences were due to our method of selecting stimuli, rather than our SOA manipulation. Evidence for a possible dissociation in lexical knowledge stems from the results of Chapter 4. In their broadest terms, these results showed that semantic priming effects from respective word types (familiar and novel) seems dependent on SOA length; hence, semantic priming behaviour was dissociable across word types. This discrepancy may again relate to differences in the state of underlying neural encoding. With integrated representations and established, direct pathways between various language networks, familiar words should be exposed to *both* automatic and strategic processing streams, which possibly explains the significant priming effect in experiment one of Chapter 4 (with the familiar words). Novel words, on the other hand, are more dependent on the hippocampus, which mediates the mapping between, for example, word-form and semantic representation. Whilst this may reduce the effect of automatic processing, strategic mechanisms could nonetheless continue to have a profound role on processing. Further, processing new words is thought to be slower compared to existing words (Davis & Gaskell, 2009; Lindsay & Gaskell, 2010; McMurray et al., 2016), which we argue is also implicated in the SOA dependency.

We believe that the CLS framework offers a decent account of our results. There were, however, some findings reported in this thesis that might present challenges to this theory. In particular, we mustn't ignore the possibility that 'integration' had not taken place at all throughout our experiments. One over-arching hypothesis put forward in this thesis is that new words are more heavily reliant on strategic processing compared to the existing words. However, even if new words may benefit from hippocampal input in the initial stage of learning, it is indeed possible that some forms of integration had taken place without sleep and were a partial driver for some of our results, such as the novel N400 effect reported in Chapter 2. Indeed, other authors (e.g., Borovsky et al., 2012) have taken such effect as evidence for integrated semantic representations. Further, reports of significant competition effects in the literature (Kapnoula et al., 2015; Kapnoula & McMurray, 2016) are similarly taken as evidence for immediate lexical integration.

The integration process, therefore, may not be a 'black-and-white' process, and more recent accounts of the CLS account to lexical acquisition acknowledge this (McMurray et al., 2016) For instance, there are several factors that are thought to facilitate the integration process. When new information is consistent with pre-existing knowledge, for example, it appears to integration into cortical systems more readily (Tse et al., 2007), and does lexical information learnt via fast-mapping (Coutanche & Thompson-Schill, 2014). The repeated practice and recall of new information may also act as a mechanism of integration (Antony et al., 2017), and we reasoned that the repeated presentation of congruous stimuli in Chapter 2.

Collectively, this discussion reveals an important message: learning, whether it be in language or other domains of cognition, is a dynamic process, and there may be a myriad of intrinsic and extrinsic factors that influence the encoding, retention, and consolidation of information at any given time. While there may be multiple systems involved (Davis & Gaskell, 2009; McClelland et al., 1995), their involvement in learning does not appear uniform across different learning episodes. It is important, therefore, that future research also acknowledges conundrum.

5.5 Future directions

As has been discussed throughout this thesis, there are currently very mixed results regarding the appearance of semantic priming and N400 effects for recently learned words. Ultimately, these differences can lead to different hypotheses regarding the representation of new words and how this differs from the representation of familiar words. It is clear from the work reported that such differences are possibly related to design differences across studies. For example, different training methods have been used to train novel stimuli, with some studies adopting explicit encoding methods compared to others which present novel words within a contextual sentence or story, requiring the participant to infer the meanings of these words. Further still, some studies favour a primed lexical decision task (pLDT) to measure semantic processing whilst others opt for a semantic judgement task (SJT). The exact influence of these factors on novel word acquisition and semantic processing is therefore poorly understood.

Regarding behavioural semantic priming in particular, whilst there may be a relationship between SOA and significant effects (which is supported by results from this thesis), there is also a trend whereby the three studies to report significant effects (Bakker et al., 2015; Balass et al., 2010; Perfetti et al., 2005) recruited an SJT. Could an SJT promote novel word semantic priming more so than a pLDT? Semantic processing is viewed as more explicit in an SJT, since participants must use and compare semantics to complete the task. Whilst this exercise can facilitate performance in a pLDT (i.e., by using conscious strategies), it is not a prerequisite to complete a pLDT. Based on this, it could be argued that retrieving a new word and its meaning is facilitated (i.e., quicker) in an SJT, given that it *must* be retrieved to complete the task. If true, then the effectiveness of strategic mechanisms could be improved in an SJT, leading to an increased likelihood of significant effects. Perhaps the clearest indication for this possibility comes from Batterink and Neville (2011). Here, it was found that novel words elicited an N400 effect during an SJT but not during a pLDT. To understand the influence of these respective tasks further, and ultimately the conclusions they can draw regarding the encoding of new words, future work could compare semantic priming across these two tasks, whilst simultaneously manipulating SOA length. If semantic retrieval and processing is facilitated in an SJT, then new words should prime existing words under short SOA conditions in an SJT compared to a pLDT, which, based on our preliminary results, may require an SOA of at least 1000ms.

In previous work, the N400 component is often and explicitly employed as a neural marker for automatic semantic processing. However, as has been discussed, it seems plausible that non-automatic, controlled mechanisms may also underlie this effect (Chwilla et al., 1995; Kutas & Federmeier, 2011; Lau et al., 2008). Thus, whilst the N400 component can indeed reflect automatic processing, future work may need to take greater consideration in inhibiting the influence of strategic mechanisms, if they indeed wish to measure automatic components of processing. For example, by employing a relatively short SOA, a researcher is more likely to capture automatic components of semantic priming, which are implicated with the organisation of words in the semantic network (McNamara, 2005). With these parameters in place, one can be more confident that any resulting effect is more closely coupled with automatic processing, and hence provides a clearer investigation into the integration of words into language networks.

It was discussed in Chapter 2 that there is some evidence that novel linguistic knowledge may by-pass hippocampal representation and integrate more readily into language networks, possibly recruiting cortical learning systems (Tse et al., 2007; Warren et al., 2020). In support of this, Coutanche and Thompson-Schill (2014) present data of immediate competition effects for new words (measured via pause-detection), but only for words taught via fast-mapping compared to explicit encoding. At the same time, however, these same words failed to prime semantically related words, with an operating SOA of 200ms. These findings suggest that word-form alone could integrate relatively quickly with existing knowledge (via fast mapping). However, given the relatively short SOA of the priming task which would promote more automatic mechanisms of priming, the integration of meaning - to the extent that it is retrieved automatically - may follow a protracted time course. Nonetheless, if the integration process is facilitated via fast mapping, perhaps the meaning retrieval process is still quicker following fast mapping compared to explicit encoding. In which case, perhaps these recently learned words could semantically prime existing words under shorter SOA conditions than is required for words taught via explicit encoding. This could thus provide further support for the notion that fast-mapping may promote cortical integration relative to explicit encoding. Future work could compare novel word semantic priming across different SOA and training conditions to gather a clearer picture of the time course of word form-meaning integration across training styles.

Future research could also use our SOA manipulation to further explore the role of sleep in the consolidation process. The CLS account predicts that new information integrates with existing knowledge during sleep (Davis & Gaskell, 2009; McClelland et al., 1995). As discussed, however, behavioural findings in the literature suggest that sleep may not be necessary for lexical integration (e.g., Kapnoula et al., 2015). Nonetheless, there is a wealth of research to suggest that hippocampal replay is enhanced during sleep (Schapiro et al., 2018; Stickgold & Walker, 2005; 2013; Tamminen et al., 2010; 2013; Tukker et al., 2020), arguing that sleep may still no doubt play a facilitating role of lexical integration. Hence, one tentative hypothesis is that new words may exhibit semantic priming effects at short SOA following a sleep period, relative to priming measured shortly after acquisition.

The original aims of this PhD project were to explore lexical knowledge in the infant population, which were halted due to the COVID-19 pandemic. These aims stemmed from findings that infants appear to understand the meanings of common nouns at ever younger ages (e.g., Bergelson & Swingley, 2012). However, we have discussed and presented our own data which suggests that lexical knowledge is not an all-or-nothing phenomenon. Instead, there are multiple stages and mechanisms involved in regulating knowledge. It is therefore not clear as to the *quality* of lexical knowledge that is proposed to exist in these young infants, which this PhD originally intended to investigate. Hence, these investigations still remain outstanding and offer an exciting project for future consideration.

We also wish to finish this section with a brief summary of our experiences using online testing procedures, which have seen an increase in popularity over recent years. Overall, we had a pleasant experience using these methods and would have confidence employing online testing again in the future. We are also confident that future research, not only in language processing but experimental psychology more broadly, would benefit from online testing alongside laboratory procedures. In the context of our experiments, we are satisfied that a sufficient level of learning and attention had taken place, given the good explicit knowledge of word meaning that participants displayed in Chapter 3 and Chapter 4. Furthermore, online testing offers a swift route to data collection, given the abundance of participants on sites such as Prolific. This will undoubtedly speed up the research process compared to laboratory testing.

5.6 Limitations

The claims regarding the consequence of the speed of novel word processing are largely made through the lens of the CLS account of lexical acquisition (Davis & Gaskell, 2009; Lindsay & Gaskell, 2010). Thus, more research is required to confirm these claims, particularly neuroimaging research which can measure the speed of neural processing more directly.

The design of Chapter 2 was relatively simple compared to similar word learning studies with adult participants. Our training phase presented novel word-object pairings in a passive learning paradigm (i.e., no behavioural response was required), and our testing phase did not require participants to make any explicit decisions or scrutinization in response to the presented stimuli. Whilst our results nonetheless provide insight into the immediate state of novel word processing, the simplicity of the design perhaps restricts the extension of our findings to other work somewhat. As has been discussed, it is possible that the detection of any representational and/or processing differences between novel and existing items was hindered, given this simplicity. That said, we purposely designed the experiment in such a way to promote the observation of a PLPE (Friedrich & Friederici, 2004), which was one of our key measures of interest. Further, the design was intended to be replicated with infant participants and relatively passive testing measures were thus necessary.

5.7 Conclusions

This thesis set out to explore the representation and quality of initial lexical knowledge. Specifically, it investigated the processing of new words, whether such processing is dissociable from familiar words, and what such differences may tell us regarding the manner in which new words are encoded. Above all, the findings from this thesis suggest that the meaning of new words are acquired quickly and can be recruited during semantic processing to influence the recognition of existing words. This observation stems from significant N400 and behavioural semantic priming effects with new words.

We provide novel evidence that the processing of new words follows a protracted time course compared to the processing and retrieval of known words and discuss the consequences of this. The evidence for this claim is from our finding that novel words can semantically prime existing words but seem to require a sufficiently long SOA to do so. We support an account proposed by other researchers that new words can indeed interact and compete with other words soon after acquisition, but this engagement is strategic rather than automatic, and the task measuring this engagement must be able to incorporate the slower processing rate of new words. Words that are well established in language networks, however, are able to additionally interact through more automatic modes of processing. We argue that these results hint of differences in encoding between new and existing words which similarly call on separable processing mechanisms.

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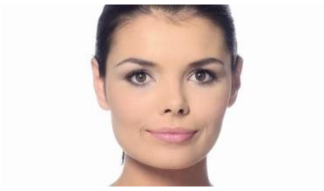
Appendices

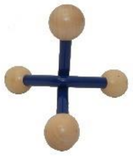
Appendix 1.1 Familiar stimuli recruited in Chapter 2

Familiar word	Familiar object	Familiar word	Familiar object
Apple		Hair	
Bike		Horse	
Bird		Juice	
Boat		Knife	

Bottle		Leg	
Bus		Milk	
Car		Monkey	
Cat		Mouth	
Chair		Nose	
Cookie		Phone	
Cow		Pig	
Cup		Plane	

Dog		Rabbit	
Door		Rocket	
Ear		Spoon	
Eyes		Table	
Face		Telly	
Fish		Train	
Foot		Van	
Fork		Yoghurt	

Appendix 1.2: Novel stimuli recruited in Chapter 2

Novel word	Novel object	Novel word	Novel object
Aker		Lep	
Blick		Manu	
Coodle		Osip	
Dite		Pabe	

Fimp		Slint	
Gloop		Toma	
Jick		Vab	
Kaki		Yok	

Appendix 2.1 Rare/novel words recruited in Chapter 3

Rare/novel word	Definition	Related target 1	Related target 2	Related target 3
Acker	*A strong or turbulent current in the sea*	Waves .85	Storm .25	Danger .25
Brammer	*An excellent, remarkable, or very attractive person*	Pretty .35	Model .35	Handsome .15
Calloo	*A kind of duck found in the Arctic*	Cold .80	Ice .30	Quack .25
Dimmet	*Another term for twilight, dusk*	Dark .45	Sunset .35	Moon .35
Dorlach	*An archer's arrow*	Bow .50	Target .40	Shoot .15
Exies	*A type of disease*	Sick .35	Virus .20	Hospital .20
Feartie	*A cowardly or timorous person*	Shy .45	Scared .35	Fear .20
Fipple	*The plug at the end of a wind-instrument*	Orchestra .25	Flute .25	Blow .20
Fossack	*A type of sea trout*	Fish .80	Salt .25	Seaweed .10
Gabbart	*A type of sailing boat*	Sea .70	Sail .50	Wind .30
Genet	*A kind of early-ripening apple*	Fruit .60	Pear .10	Juicy .10
Graddan	*A parched grain*	Seed .35	Rice .25	Oat .20
Hencote	*A small shed in which chickens are kept*	Eggs 1.0	Feathers .30	Fox .20

Hirsel	*A flock of sheep*	Lamb .45	Fluff .30	White .15
Infare	*A feast or entertainment given on entering a new house*	Welcome .30	Celebration .30	Beginning .25
Jibbons	*Spring onions*	Salad .50	Veg .25	Healthy .25
Keckle	*A short laugh or chuckle*	Fun .55	Giggle .25	Comedy .20
Linder	*A woollen waistcoat or undershirt*	Clothes .40	Old .20	Suit .15
Luvvie	*An actor or actress*	Film .45	Stage .20	Theatre .20
Morfrey	*A farm cart or wagon*	Tractor .30	Wheel .30	Wheelbarrow .15
Needler	*A person who irritates or torments others*	Annoying .65	Nuisance .15	Loud .10
Nubbling	*A small lump of coal*	Fire .65	Black .50	Burn .20
Offlet	*A channel for letting water off*	Stream .30	River .25	Pipe .25
Paidle	*A small leather bag*	Purse .40	Satchel .25	Handbag .15
Pellock	*A dolphin or similar marine animal*	Swim .50	Ocean .25	Whale .25
Rammel	*Small, stunted trees or bushes*	Garden .50	Shrub .35	Nature .30
Rivlin	*A type of shoe worn in Scotland*	Boot .40	Heel .20	Kilt .20
Soggarth	*A type of priest*	Church .65	Religion .40	Vicar .25
Stanners	*Small stones found on the bank of a river*	Pebble .85	Beach .15	Sand .10
Whitepot	*A type of milk pudding or custard*	Dessert .50	Cream .30	Pie .10

Each rare/novel word was presented with its 3 related targets in the SJT. The figure next to each target denotes its FAS score generated from the pre-rating surveys.

Appendix 2.2 Familiar primes and related targets used in Chapter 3

Familiar prime	Related target 1	Related target 2	Related target 3
Reef	Coral .45	Colour .35	Endangered .10
Beauty	Person .15	Hair .15	Woman .10
Goose	Bird .25	Duck .25	Pond .20
Dawn	Sun .80	Morning .35	Sunrise .30
Spear	War .30	Hunt .15	Battle .10
Flu	Ill .50	Cough .40	Sneeze .25
Hero	Super .65	Strong .25	Brave .20
Piano	Music .60	Notes .30	Keys .20
Salmon	Cod .10	Tuna .10	Sushi .10
Yacht	Rich .40	Wealth .25	Expensive .20

Lemon	Sour .45	Lime .30	Yellow .25
Wheat	Field .55	Breakfast .40	Bread .25
Barn	Farm .70	Animal .45	Hay .35
Herd	Cow .70	Group .15	Milk .15
Party	Friends .60	Drink .45	People .30
Carrot	Orange .70	Soup .15	Soil .15
Smile	Happy .90	Teeth .40	Joy .20
Trouser	Jeans .50	Leg .20	Pants .15
Singer	Microphone .25	Famous .15	Concert .15
Truck	Lorry .30	Road .25	Van .15
Bully	Mean .50	Nasty .20	School .20
Iron	Silver .25	Steel .25	Metal .20
Pipe	Rain .20	Sewer .15	Drain .15
Bottle	Water .80	Plastic .45	Clear .20
Seal	Clap .10	Mammal .10	Shark .10
Cactus	Green .65	Desert .60	Spike 40
Sock	Shoe .75	Warm .50	Feet .40
Bishop	Hat .20	Holy .20	Pope .15
Jewel	Diamond .65	Ruby .50	Ring .35
Biscuit	Crunch .35	Tea .30	Chocolate .20

Each familiar word was presented with its 3 related targets in the SJT. The figure next to each target denotes its FAS score generated from the pre-rating surveys. The words are ordered according to the order of their semantically matched rare word in Appendix 2.1.

Appendix 2.3 Data trimming results as a function of condition in Chapter 3

Values represent the mean (± SD) number of trials retained for each condition across participants. The total possible number of retained trials is 30 trials for each condition.

	Rare Related	Rare Unrelated	Familiar Related	Familiar Unrelated
200ms	18.05 (± 6.37)	22.68 (± 5.90)	21.70 (± 6.81)	25.31 (± 5.77)
500ms	19.27 (± 5.66)	23.54 (± 6.65)	22.41 (± 5.99)	25.99 (± 5.31)
100ms	18.32 (±6.82)	23 (± 7.39)	20.88 (± 5.78)	24.54 (± 7.05)

Appendix 3.1 Novel words and their meanings used in Chapter 4

Word	Meaning
agglem	is a type of baby that is premature and underweight
ardoff	is a type of beef that is British and comes from calves
blontack	is a type of cat that has stripes and is blue-ish grey
chebbor	is a type of skirt that is flowery and made of silk
chisdow	is a type of prison that is for murderers and is located in the U.S.
dawtatt	is a type of neck that is short and freckled

dobbir	is a type of knife that is often used by butchers and is very sharp
entelem	is a type of cream that is organic and low in fat
eritriff	is a type of meadow that buffalo graze in and that was created by Native Americans
feckton	is a type of knight that carries a banner and protects the helpless
flimmir	is a type of sheep that lives in Scotland and has soft hair
gahoon	is a type of candle that has a fragrance and has an especially bright flame
glain	is a type of leg that is long and very muscly
heprit	is a type of face that has had plastic surgery and looks completely different
hoddar	is a type of ring that is silver and engraved
jabbary	is a type of fog that happens in equatorial areas and appears very quickly
kerple	is a type of pan that is battery-heated and used for camping
konrith	is a type of maid that comes in once a day and takes care of pets
loodit	is a type of pistol that carries 20 bullets and can fire very quickly

lupitat	is a type of lemon that is seedless and imported from Mexico
meckalen	is a type of fist made with the thumb on top and a bent wrist
merdut	is a type of bread that is dark brown and has nuts in it
ospont	is a type of path that is paved and occurs in parks
peckolet	is a type of drawing that is a portrait and is in neon colours
poffren	is a type of shoe that has a strap and is made of plastic
quammish	is a type of book that has pictures and is oversize
quemmer	is a type of tooth that is weak and is discoloured
slethy	is a type of ear that belongs to a mammal and is folded
speth	is a type of cow that has a hairy tail and has giant horns
tobbin	is a type of mirror that is circular and is convex
uvar	is a type of monk that lives in Tibet and fasts for seven days at a time
vilchy	is a type of pill that lowers cholesterol and blood pressure

vorent	is a type of needle that is made of platinum and can make very small
waba	is a type of crown that is worn by monarchs and is made of rubies

Appendix 3.2 Related target words for the novel (prime) words used in Chapter 4 and nonword targets

Word	Real word target 1	Real word target 2	Real word target 3	Nonword target 1	Nonword target 2	Nonword target 3
agglem	child	cry	infant	chyld	cro	Inlant
ardoff	steak	meat	roast	steat	veat	poast
blontack	dog	mouse	kitten	dox	wouse	kitgen
chebbor	dress	blouse	shirt	driss	blousa	shirf
chisdow	jail	bar	cell	jais	ber	rell
dawtatt	shoulder	throat	tie	shounder	throad	kie
dobbir	fork	cut	blade	fosk	vut	blada
entelem	whip	coffee	cheese	whis	coftee	cheete
eritriff	field	grass	flower	fielm	prass	flowen
feckton	armor	soldier	sword	arhor	solpier	swort

flimmir	wool	lamb	herd	woot	pamb	hird
gahoon	light	wax	flame	jight	wex	flome
glain	arm	body	walk	arn	sody	walp
heprit	eyes	nose	smile	oyes	nosa	smige
hoddar	finger	wedding	diamond	cinger	wodding	diawond
jabbary	mist	smog	thick	misp	swog	theck
kerple	pot	cook	fry	pog	wook	bry
konrith	clean	servant	butler	cleah	sermant	bunler
loodit	gun	shoot	rifle	gug	shoog	rikle
lupitat	lime	sour	orange	limi	rour	orenge
meckalen	fight	hand	punch	feght	hond	ponch
merdut	butter	dough	loaf	vutter	mough	loat
ospont	road	trail	way	roat	truil	woy
peckolet	art	picture	sketch	ast	pictere	skitch
poffren	foot	sock	lace	foet	seck	labe
quammish	read	school	study	pead	schood	stidy
quemmer	decay	ache	brush	debay	uche	bresh
slethy	hear	sound	head	vear	soind	heax
speth	milk	calf	bull	rilk	calt	jull
tobbin	reflection	image	glass	seflection	umage	gless
uvar	priest	monastery	religion	proest	modastery	teligion
vilchy	medicine	drug	aspirin	tedicine	drig	asmirin
vorent	thread	sew	pin	threal	gew	pid
waba	king	jewel	queen	fing	jefel	queel

Appendix 3.3 Related target words for the familiar (prime) words used in Chapter 4 and nonword targets

Word	Real word target 1	Real word target 2	Real word target 3	Nonword target 1	Nonword target 2	Nonword target 3
ambulance	emergency	siren	accident	emermency	giren	accicent
balloon	air	helium	float	oir	hesium	flood
binder	folder	notebook	paper	volder	notegook	waper
bruise	hurt	pain	hit	hurp	pait	hib
burglar	thief	robber	steal	thiel	tobber	steab
cannon	ball	fire	weapon	byll	fite	weanon
circus	clown	animal	carnival	clewn	animad	carpival
clinic	doctor	sick	health	hoctor	bick	heamth
coffin	dead	burial	grave	sead	butial	frave
dart	board	game	throw	boarf	gamu	thriw
eraser	pencil	mistake	rubber	pencid	misvake	subber
flask	wine	bottle	whiskey	wina	bittle	whilkey
flour	cake	bake	sugar	cace	dake	sutar
frog	toad	hop	jump	toak	kop	fump
herb	spice	tea	garden	spoce	toa	larden
ketchup	mustard	red	tomato	muskard	rer	togato

lizard	reptile	snake	green	reppile	sneke	dreen
medal	gold	award	honor	golp	awarn	hosor
nun	convent	church	sister	lonvent	chorch	tister
oyster	clam	shell	pearl	claf	shull	pearn
paddle	row	oar	canoe	rop	oad	casoe
parcel	package	post	box	dackage	posk	jox
pebble	rock	stone	beach	vock	stine	neach
raisin	grape	prune	fruit	grare	prane	frait
salad	lettuce	dressing	bowl	lettace	bressing	bewl
sausage	breakfast	pork	bacon	breamfast	porl	gacon
slug	worm	slow	snail	worb	sfow	snoil
termite	bug	wood	pest	byg	bood	mest
tiger	lion	jungle	stripe	liot	dungle	strepe
towel	cloth	wet	wash	clath	det	wosh
vampire	blood	bat	fangs	bloot	baf	nangs
vinegar	oil	bitter	salt	oid	vitter	sall
wallet	money	purse	leather	momey	pursa	leathen
wasp	sting	bee	nest	stong	kee	nesk

Appendix 3.4 Sentences used in the sentence plausibility task of Chapter 4

Novel word	Sentence	Plausibility
Agglem	The doctor was happy to announce the survival of the agglem.	Plausible
	The midwife carefully picked up the agglem.	Plausible
	The doctor was astounded by the growth of the agglem.	Plausible
	The train was packed with commuters on their way to agglem.	Implausible
Ardoff	The man didn't care for vegetarian food so he chose a burger with ardoff.	Plausible
	The experienced chef was very helpful and recommended. the ardoff.	Plausible
	The guest examined the menu and was torn between the chicken and ardoff.	Plausible
	The child's favourite game was ardoff.	Implausible
Blontack	The woman liked to listen to the purring of her blontack.	Plausible
	The vet was pleased by the recovery of the blontack.	Plausible
	The woman was woken by the paws of her hungry blontack.	Plausible
	The monkey was too frightened to climb the blontack.	Implausible
Chebbor	The fashion designer was pleased with the design of the new chebbor.	Plausible
	The woman went to the party wearing her new chebbor.	Plausible

	The mannequin was wearing the new chebbor.	Plausible
	The man's car broke down and was taken to the chebbor.	Implausible
Chisdow	The judge sentenced the criminal to two years in chisdow.	Plausible
	The guard protected the tall walls of the chisdow.	Plausible
	The criminals prepared a plan to escape from the chisdow.	Plausible
	The book was written in 18-century chisdow.	Implausible
Dawtatt	The man found the shirt otherwise comfortable but the collar was too tight around his dawtatt.	Plausible
	The fast car put a lot of strain on the driver's dawtatt.	Plausible
	The man wore a scarf around his dawtatt.	Plausible
	The paramedic rushed to the scene of the dawtatt.	Implausible
Dobbir	The cook sliced the lamb with his dobbir.	Plausible
	The man sliced his finger on the dobbir.	Plausible
	The cutlery drawer had only one dobbir.	Plausible
	The boat alerted the coast guard when it began to take on dobbir.	Implausible
Entelem	The child asked the waiter for cookies and entelem.	Plausible
	The baker was pleased by the taste of the entelem.	Plausible
	The chef served the trifle with entelem.	Plausible
	The student erased their work using their entelem.	Implausible
Eritriff	The children ran out and rolled in the dewy eritriff.	Plausible
	The sun quickly set over the green plains of the eritriff.	Plausible
	The horse ran happily through the eritriff.	Plausible
	The politician delivered a strong and powerful eritriff.	Implausible
Feckton	The maiden locked in the tower was rescued by a handsome feckton.	Plausible
	The medieval banquet was attended by the brave feckton.	Plausible
	The village was saved thanks to the heroics of the feckton.	Plausible
	The accountant was shocked after reading the latest figures in the feckton.	Implausible
Flimmir	The owner of the farm was horrified when she saw in the field only one flimmir.	Plausible
	The farmer set out to round up of all the flimmir.	Plausible

	The farmer began shearing the flimmir.	Plausible
	The volcano erupted and caused disruption on the flimmir.	Implausible
Gahoon	The man was mindful of fire safety and put out the gahoon.	Plausible
	The restaurant prepared for dinner by lighting the gahoon.	Plausible
	The room had a pleasant smell from the fumes of the gahoon.	Plausible
	The students danced together at the gahoon.	Implausible
Glain	The athlete couldn't run after breaking his glain.	Plausible
	The personal trainer explained that squating helps train muscles in the glain.	Plausible
	The rugby player went to the gym to train her glain.	Plausible
	The printer required attention after it ran out of glain.	Implausible
Heprit	The man felt confident for the first time because of his heprit.	Plausible
	The ball struck the person's heprit.	Plausible
	The surgeon was pleased with the result of the heprit.	Plausible
	The receptionist blew their nose into a heprit.	Implausible
Hoddar	The man asked her to marry him and gave her an expensive hoddar.	Plausible
	The diver took no risks and removed their expensive hoddar.	Plausible
	The marriage ceremony finished after the bride and groom each received their hoddar.	Plausible
	The driver explained that the journey will take longer due to the closure of the hoddar.	Implausible
Jabbary	The plane could not land due to a heavy jabbary.	Plausible
	The driver had trouble seeing through the jabbary.	Plausible
	The referee cancelled the game as they could not see the other end of the pitch due to the jabbary.	Plausible
	The priest was pleased by the attendence at this morning's jabbary.	Implausible
Kerple	The wife made an omelette on her non-stick kerple.	Plausible
	The child burnt their hand on the hot kerple.	Plausible
	The ingreditents were placed into the kerple.	Plausible
	The zoo began to release animals back into the kerple.	Implausible

Konrith	The man didn't have time to take care of his guinea pigs so he hired a professional konrith.	Plausible
	The woman's dog was fed by the konrith.	Plausible
	The cat was looked after by the konrith.	Plausible
	The man broke the computer after spilling his konrith.	Implausible
Loodit	The sheriff threatened the highwayman with his loodit.	Plausible
	The silence was quickly broken by the shooting of the loodit.	Plausible
	The race commenced after the firing of the loodit.	Plausible
	The athlete was nervous at the prospect of competing in the loodit.	Implausible
Lupitat	The man preferred his iced tea with a fresh slice of lupitat.	Plausible
	The chef squeezed the juicy lupitat.	Plausible
	The baby pulled a disgusted face after biting into the lupitat.	Plausible
	The opera singer was forced to sing louder when they broke their lupitat.	Implausible
Meckalen	The man was furious and hit the table with his meckalen.	Plausible
	The patient was asked to open and close their meckalen.	Plausible
	The boxer clenched their meckalen.	Plausible
	The guest complained to the manager after finding a hair in their meckalen.	Implausible
Merdut	The woman living next to a bakery loved the smell of fresh merdut.	Plausible
	The jam was spread over the merdut.	Plausible
	The man made a sandwich with the merdut.	Plausible
	The student went to the library to return a merdut.	Implausible
Ospont	The old man got lost after following the wrong ospont.	Plausible
	The engineers installed floodlights to light up the ospont.	Plausible
	The runners ran along the ospont.	Plausible
	The house was placed on the market for a cheap ospont.	Implausible
Peckolet	The parents were impressed when the child painted a lovely peckolet.	Plausible
	The artist made a lot of money after selling their peckolet.	Plausible
	The man bought pencils and pens to begin their peckolet.	Plausible

	The woman sold her phone to the peckolet.	Implausible
Poffren	The woman broke one of her heels and needed to buy a new poffren.	Plausible
	The friends queued up all night for a chance to buy the latest poffren.	Plausible
	The girl ran to school wearing her new poffren.	Plausible
	The computer began to overheat and caused a poffren.	Implausible
Quammish	The librarian could not find the quammish.	Plausible
	The blurb explained the contents of the quammish.	Plausible
	The author began writing their new quammish.	Plausible
	The cafe was busy thanks to its tasty quammish.	Implausible
Quemmer	The dentist pulled out the patient's quemmer.	Plausible
	The woman took painkillers to ease the pain of her quemmer.	Plausible
	The woman took great care to clean her quemmer.	Plausible
	The dusty track descends to a quemmer.	Implausible
Slethy	The doctor told the old lady the loud music had damaged the drum of her cat's slethy.	Plausible
	The rabbit had an ache in their slethy.	Plausible
	The music quickly entered the DJ's slethy.	Plausible
	The man went into the kitchen to wash the slethy.	Implausible
Speth	The vet inspected the hooves of the speth.	Plausible
	The car stopped when crossing the road was a black and white speth.	Plausible
	The farmer had a great affection for their speth.	Plausible
	The bartender poured the guest a pint of speth.	Implausible
Tobbin	The girl enjoyed watching herself in the tobbin.	Plausible
	The child accidently pushed over and cracked the tobbin.	Plausible
	The wall was covered by a large tobbin.	Plausible
	The woman took her dog for a walk in the tobbin.	Implausible
Uvar	The man enjoyed meditating so much that he became a deeply religious uvar.	Plausible
	The church procession was led by the uvar.	Plausible
	The religious person decided to become an uvar.	Plausible

	The professor demonstrated the laws of physics using his uvar.	Implausible
Vilchy	The patient needed a glass of water to swallow the vilchy.	Plausible
	The doctor prescribed the patient a vilchy.	Plausible
	The man's knee pain improved after swallowing a vilchy.	Plausible
	The teacher was quick to find fault in the student's vilchy.	Implausible
Vorent	The man fixed a hole in his child's clothing with the vorent.	Plausible
	The child accidently pricked their finger with the vorent.	Plausible
	The sewing class began with a demonstration of how to use a vorent.	Plausible
	The mechanic shook hands with the vorent.	Implausible
Waba	The princess hoped that one day she could carry on her head the waba.	Plausible
	The burglars sneaked into the palace with the intention of stealing the waba.	Plausible
	The museum unveiled the new 16th century waba.	Plausible
	The women typed on her waba.	Implausible