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# The illusion of action-specific scaling effects: action capacity does not directly influence spatial perception

Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor in Philosophy

by

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November 2017

*“Breathe in the hurricane,*

*and we can start all over again”*

- *Mesh, “Kill Your Darlings” (2016)*

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# Abstract

Whether visual perception is directly influenced by top-down cognitive processes or not is an on-going debate in vision science. Modular theories of perception claim that vision is separate from, and not affected by, cognitive processes such as emotion, intention or action (Firestone, 2013; Firestone & Scholl, 2015). However, an increasing body of evidence suggests that vision is directly influenced by action capacity. Known as the action-specific account of perception, this model of vision may challenge the idea of cognitive impenetrability and, if true, suggests that a drastic overhaul in our understanding of visual perception is required (Firestone, 2013). Proffitt and Linkenauger (2013) suggested that action-specific scaling effects occur because our bodies provide us with *perceptual rulers*, which they proposed transform visual angles into units appropriate for guiding effective action. For instance, Proffitt and Linkenauger (2013) claimed that grasping capacity provides a ruler for perceiving the size of graspable objects, and maximum reaching capacity provides a ruler for perceiving distances in near space.

In this thesis, I investigated the claims of the action-specific account, but found no evidence in its favour. In some experiments, I failed to replicate previous studies showing action-specific effects. In cases where I did find effects consistent with the action-specific account, I demonstrated that these effects reflected changes in post-perceptual judgement, or could be explained as visual illusions. In summary, this thesis provides evidence against the action-specific account of perception, and instead suggests that visual spatial perception is not directly affected by variations in action capacity. By extension, the work in this thesis supports the idea that visual spatial perception is cognitively impenetrable.

# Chapter One

## 1. Introduction and chapter overview

The first chapter of this thesis contains a short review of the relationship between action and perception, followed by a longer review of the action-specific account of perception. Although the claims of the action-specific account will be discussed in more detail at the beginning of each experimental chapter, it is worth broadly exploring the account, its development, and how it differs from other theories of visual perception here. This is because the account is relatively new, and some of its claims remain controversial in visual science. This chapter will conclude with a chapter overview, where the main hypotheses and findings reported in each empirical chapter will be summarised.

### 1.1 Introduction

A key purpose of visual perception is to guide action (Clark, 1999; Gibson, 1979; Proffitt & Linkenauger, 2013; Witt & Riley, 2014). For example, to successfully navigate a cluttered room, sighted individuals typically use visual information about the relative positions of objects and obstacles in the room in order to first choose a viable route. Then, as they move through the room, they acquire new perceptual information about the layout of the room, which may cause them to change their route several times. This on-going loop between perception and action is critical for successfully navigating the environment (Franchak, van der Zalm & Adolph, 2010; Gibson, 1979).

In the example above, the observer's opportunities for action are constrained by the relative positions of objects in the room they intended to navigate. However, their opportunities for action are also constrained by the functional morphology (size, shape, etc.) of their body (Adolph & Berger, 2006; Proffitt & Linkenauger, 2013). The functional morphology of our bodies affects our capacity to perform actions. For example, squeezing through a narrow doorway is easier for a healthy-weight than an overweight individual, reaching a mug on a high shelf is easier for a tall than a short individual, and grasping an apple with one hand is easier for an adult than a small child.

People are sensitive to the fit between the actions that their bodies afford and the spatial layout of the environment (Franchak et al., 2010; Gibson, 1979; Ishak, Lin & Adolph, 2008; Warren, 1984). They also rapidly update and recalibrate their perceived action capacity through acting (Franchak et al., 2010; Franchak & Adolph, 2014). For example, Franchak et al. (2010) showed that participants who had experience walking through apertures were more accurate when estimating whether subsequently seen apertures were passable or not. In addition, Franchak and Adolph (2014) found that pregnant participants accurately updated their estimates of the narrowest aperture they could walk through as their body size increased throughout their pregnancy. In contrast, participants who were fitted with a pregnancy prosthesis that immediately increased their girth were initially poor at estimating the narrowest aperture they could squeeze through. However, their estimates became accurate after attempting the task. Franchak and Adolph (2014) suggested that there are at least two ways in which experience walking through the apertures may have influenced participants' subsequent judgements of aperture passability. One possibility is that participants gained information about success and failure by acting. This information may have allowed them to judge aperture passability more accurately later. Another possibility is that their perceived action capacity was recalibrated by other sensory information. For instance, proprioceptive information from compressing their bodies may have provided bottom-up feedback about how easily they could fit through apertures of different width.

## The action-specific account of perception

One theory of visual perception suggests that there may be another reason that individuals can so rapidly update their perceived action capacity following a change in the functional morphology of their body. The action-specific account suggests action opportunities are the content of perception; in other words, we see the world in terms of how we can act (for reviews see Cañal-Bruland & van der Kamp, 2015; Firestone, 2013; Linkenauger, 2015; Proffitt, 2013; Proffitt & Linkenauger, 2013; Philbeck & Witt, 2015; Witt, 2011a, 2017; Witt & Riley, 2014; Witt, Linkenauger & Wickens, 2016). It is important to note that the action-specific account is separate to the literature investigating how changes in action capacity affect people's assessments of the actions their bodies afford. Instead, the action-specific account makes the strong claim that people's visual representation of spatial properties is directly affected by changes in action capacity. For the results of Franchak and Adolph (2014), for instance, the action-specific account might suggest that after experience walking through apertures while wearing a pregnancy prosthesis, participants perceived the apertures as narrower (because they were harder to walk through) and therefore reported them as unpassable. This possibility is supported by the results of Stefanucci and Geuss (2009), who reported that individuals with wider shoulders estimated the width of apertures as smaller than participants with narrower shoulders.

Proponents of the action-specific account suggest that our bodies supply us with *perceptual rulers* which scale incoming visual information (Proffitt & Linkenauger, 2013). A key aspect of the action-specific account is that relevance matters, and that different rulers are relevant for different actions. For example, Proffitt and Linkenauger (2013) suggest that the relevant ruler for traversing a long distance is the caloric cost of walking, whereas the relevant ruler for graspable objects is hand size and the accompanying grasping capacity. These perceptual rulers pertain to several aspects of action, including the bioenergetic cost of action, skill and performance variability, and the functional morphology of the body. Some evidence supporting action-specific scaling effects according to these three aspects of action is reviewed below.

**Scaling according to bioenergetics**

Proffitt and Linkenauger (2013) argued that the most relevant activity for traversing long distances on the ground is walking. By extension, the relevant unit for scaling the environment for an individual who intends to walk a given distance is the energy required to walk that distance – in other words, the bioenergetic cost of walking. One of the oldest and most famous examples of action-specific scaling according to bioenergetics is that hills were estimated as steeper by observers who wore a heavy backpack (Bhalla & Proffitt, 1999; Proffitt, Bhalla, Gossweiler, & Midgett, 1995). This effect was explained as estimates of hill slant increasing to reflect the additional bioenergetic cost of ascending the hill while wearing a backpack. It has also been reported that observers who are of low fitness, are fatigued, overweight, hungry and in ill health estimate hills as steeper (Bhalla & Proffitt, 1999; Eves, Thorpe, Lewis & Taylor-Covill, 2014; Schnall, Zadra & Proffitt, 2010; Taylor-Covill & Eves, 2013, 2014).

In another study which investigated the influence of bioenergetics in perceived distance, competitive bicycle racers estimated the distance to targets (Zadra, Schnall, Weltman & Proffitt, 2010). They completed two experimental sessions: one where they drank a calorically sweetened (sugary) drink, and another where they drank a beverage sweetened with calorie-free sweeteners. In each session, they estimated the distance to a target (pre-test estimate), consumed one of the drinks, rode a stationary bike at high intensity for 45 minutes, and then estimated the distance to the target again (post-test estimate). While they rode the stationary bike, a battery of physiological measurements was continually taken, including heart rate, blood glucose, oxygen uptake, blood lactate, and power applied to the pedals. The authors reported that distances were estimated as shorter at post-test, but only by participants who had ingested the sugary drink. In addition, they found that post-test estimates were significantly related to several physiological variables. For example, lower blood glucose levels were associated with greater distance estimates. This suggests that participants with less glucose in their blood, and therefore lower energy levels, estimated distances as greater.

**Scaling according to performance variability**

Proffitt and Linkenauger (2013) argued that, for goal-directed actions, success is dependent on the performer's skill. They defined skill as "consistency in the successful performance of a behaviour" (p. 189) and suggested that an individual's visual perception of action-relevant stimuli can be scaled according to their skill. Many studies supporting this type of action-specific scaling have investigated visual estimates of spatial properties in people with varying athletic performance. For example, more skilled swimmers estimated underwater targets as closer (Witt, Schuck & Taylor, 2011), putting holes were estimated as larger by more skilled golfers (Witt, Linkenauger, Bakdash & Proffitt, 2008) and tennis balls were estimated as slower by more successful tennis players (Witt & Sugovic, 2010).

In many studies investigating the relationship between performance and spatial perception, participants were presented with a range of different circles and asked to choose the circle which best matched the action relevant stimulus (e.g., the tennis ball, putting hole etc.) and a positive correlation between performance and circle size was obtained (e.g., Witt & Proffitt, 2005; Witt et al., 2008). However, correlational data does not provide information about the direction of the effect: did better putters see the holes as larger, or did individuals who saw the hole as larger putt more successfully? Witt and Dorsch (2009) investigated the direction of this relationship. Participants in Witt and Dorsch (2009) kicked a ball 10 times to a set of American football goals. They estimated the height of the goals both before and after attempting their kicks. The authors found no relationship between pre-kick estimates of goal height and performance, but a significant relationship between post-kick estimates and performance. The authors claimed that this demonstrated that performance influenced perception, rather than perception influencing performance.

**Scaling according to functional morphology**

The functional morphology of the body (e.g., arm length, hand size) constrains action capacity and so, according to the action-specific account, variations in the functional morphology of the body can directly affect visual spatial perception (Linkenauger, Witt & Proffitt, 2011; Linkenauger, Mohler & Proffitt, 2011). For example, observers estimated targets that were out of reach to be nearer after reaching to them with a tool which made them reachable (Witt, Proffitt & Epstein, 2005) and apertures were estimated as narrower when observers held a horizontal rod that was wider than their body (Stefanucci & Geuss, 2009). In another example, Linkenauger, Witt and Proffitt (2011) reported that right handers underestimated the size of objects they intended to grasp with their right hand relative to objects they intended to grasp with their left hand. This effect was thought to reflect the bias held by right handers that their right hand has a greater grasping capacity than their left hand (Collier & Lawson, 2017a; Gentilucci, Daprati & Gangitano, 1998; Linkenauger, Witt, Bakdash, Stefanucci, & Proffitt, 2009). This, in turn, could make objects appear more graspable, and therefore smaller, when they intend to grasp with their right hand (Linkenauger, Witt & Proffitt, 2011).

**The action-specific account of perception: theoretical implications**

The action-specific account is not the only theory of visual perception to emphasise the relationship between action and perception. However, it stands out from other theories by claiming that action capacity directly affects conscious spatial perception. Other perceptual theories which have emphasised action (e.g., Goodale & Milner, 1992; Goodale & Haffenden, 1998; Goodale, 2014) do not make the strong claim that action capacity directly influences what we see. For example, Cañal-Bruland and van der Kamp (2015) suggested that perception for what actions an environment affords and perception for spatial properties are different types of perception, with different underlying purposes. In what has become one of the most well-known models of vision to date, Goodale and Milner (1992) suggested that there exist two separate but interdependent visual pathways: one serving *vision for perception* (the ventral pathway which is involved in, for example, object recognition) and the other serving *vision for action* (the dorsal pathway which in involved in, for example, the online control of action). Behavioural evidence in favour of this account includes the finding that geometric illusions affect estimates of visual size, but not grasping behaviour (e.g., Aglioti, DeSouza & Goodale, 1995; van Doorn, van der Kamp & Savelsburgh, 2007; but see Franz et al., 2001). However, some proponents of the action-specific account (e.g., Witt, 2017) have criticised the two-stream model because processing in the dorsal stream is generally considered non-conscious (Goodale & Haffenden, 1998; Milner & Goodale, 2008) and so, they claim, action is still regarded as being outside of conscious perception. In contrast, the action-specific account claims that action capacity directly contributes to our conscious visual experience. The action-specific account therefore makes strong claims about the role of action in visual perception that go beyond those made even by other theories of vision which have emphasised action. Demonstrating whether action-specific scaling effects reflect true changes in what is perceived therefore matters because of the implications this would have for understanding how visual representations of the world are built, and how the mind is organised (Firestone & Scholl, 2015; Witt, 2017).

Action-specific scaling effects, if truly perceptual, could even be interpreted as evidence supporting *cognitive penetrability* – the idea that what we perceive is directly influenced by top-down cognitive states (Firestone & Scholl, 2015). If what we perceive is influenced by top-down cognitive factors, then this would challenge the long-held, modularist perspective that vision is *cognitively impenetrable* (Firestone & Scholl, 2015; Fodor, 1983; Pylyshyn, 1999). Exactly what counts as an example of cognitive penetrability has been fiercely debated (Deroy, 2015; Firestone & Scholl, 2015; Stokes, 2012). Firestone and Scholl (2015) suggested that researchers should instead focus on what should *not* be considered examples of cognitive penetrability. For instance, changing the sensory input by looking at a different location in the environment or a different part of an object should not be considered an example of cognitive penetrability.

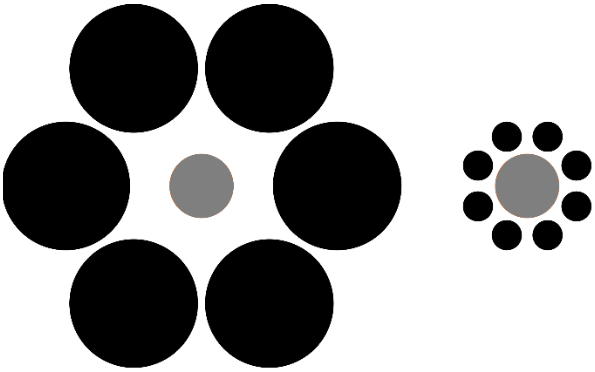

*Figure 1:* Typical configuration of the Ebbinghaus Illusion. The inner circles of both displays are the same size, yet the inner circle on the left appears smaller than the inner circle on the right.

Visual illusions are generally considered a powerful argument in favour of cognitive impenetrability (Firestone & Scholl, 2015). For example, in the Ebbinghaus Illusion, a disc surrounded by large discs appears smaller than a disc of the same size surrounded by small discs (Coren & Girgus, 1979, see Figure 1). Importantly, even when observers are aware that the perceptual effect is illusionary, this does not prevent them from reporting the inner disc as smaller when it is surrounded by larger discs. Thus, their cognitive knowledge that the effect is illusionary does not prevent them from experiencing the illusion.

Given the potential challenge to cognitive impenetrability, Firestone (2013; see also Firestone & Scholl, 2015) argued that if action-specific effects were shown to be true changes in vision due to action capacity, vision science would require a large-scale overhaul (Firestone, 2013; Firestone & Scholl, 2015). However, Witt (2017) argued that action-specific effects could be true perceptual effects which do not challenge cognitive impenetrability. This is because action-specific effects could be considered *motor effects* as opposed to examples of *explicit knowledge* influencing visual perception. Similarly, Sugovic, Turk and Witt (2016) argued that if other sensory information which may specify action capacity (e.g., proprioceptive or physiological cues) influences vision, then this would be consistent with cognitive impenetrability because the effects could be considered multisensory effects. Firestone and Scholl (2015) themselves suggested that multisensory integration does not reflect cognitive penetrability. They claimed that, as with illusions, multisensory integration occurs reflexively and regardless of any cognitive inferences made by the observer. Furthermore, multisensory integration occurs entirely within perception itself, as opposed to reflecting top-down cognitive influences on perception (Firestone & Scholl, 2015). For example, when observers hear the phoneme /ba/ at the same time as seeing lip movements showing the phoneme /ga/, they often report hearing /da/ (Barutchu, Crewther, Kiely, Murphy & Crewther, 2008). This is an example of the McGurk Effect (McGurk & MacDonald, 1976), a result of multisensory integration between vision and audition. This type of multisensory integration does not demonstrate cognitive penetrability because the effect is not driven by the observer's *explicit knowledge* about the visual input. Instead, the visual and auditory cues are integrated to give rise to a visuo-audio signal (see Deroy, 2015, for an in-depth discussion about the differences between multisensory integration and cognitive penetrability).

Therefore, action-specific scaling effects may not directly challenge cognitive impenetrability if they are considered motor effects (Witt, 2017). However, some action-specific effects have been claimed to depend on people's *beliefs* about their action capacity (Linkenauger, Witt & Proffitt, 2011). For example, Linkenauger, Witt and Proffitt (2011, Experiment 2) reported that right handers estimated objects that they intended to grasp in their right hand as smaller than objects they intended to grasp in their left hand. This was interpreted as evidence that apparent grasping capacity directly influenced perceived object size because right handers overestimate the size and grasping capacity of their right hand relative to their left hand (Collier & Lawson, 2017a; Linkenauger, Witt & Proffitt, 2011). However, there was no evidence that the mean grasping capacity of the right hand was actually greater than that of the left hand in Linkenauger, Witt and Proffitt (2011, Experiment 2) and so the only possible cause of scaling, at least according to the action-specific account, was *perceived* grasping capacity. This seems to challenge cognitive impenetrability by suggesting that higher level biases and beliefs about action capacity can directly influence perceived object size.

In summary, the action-specific account differs from other perceptual theories which emphasise action because it claims that action capacity directly influences conscious visual experience (Witt, 2017). Furthermore, some action-specific effects, e.g., Linkenauger, Witt and Proffitt (2011), seem to challenge the long-held idea that vision is not affected by cognitive factors such as belief, intention and motivation (Firestone & Scholl, 2015; Fodor, 1983; Pylyshyn, 1999). Thus, the action-specific account has important implications for how we understand the organisation of the mind, and what kinds of information is used to construct our visual representations of the environment (Firestone, 2013; Firestone & Scholl, 2015; Witt, 2017).

**The action-specific account of perception: criticisms**

Given the theoretical implications of the action-specific account, its proponents have been under pressure to demonstrate that the effects reported are truly perceptual in nature. Despite the wealth of empirical evidence supporting the action-specific account, several criticisms and concerns have been raised with this account (for reviews see Cañal-Bruland & van der Kamp, 2015; Collier & Lawson, under review; Firestone, 2013; Firestone & Scholl, 2015; Philbeck & Witt, 2015; Proffitt, 2013; Proffitt & Linkenauger, 2013; Witt, 2011a, 2017). The action-specific account has been subject to both methodological and theoretical criticisms, which are discussed below. There are also other, more general, concerns with the action-specific account, which are discussed at the end of this section.

**Methodological criticisms**

One of the most powerful methodological criticisms of the action-specific account is that the methods often used in studies which obtain effects consistent with the action-specific account could induce demand characteristics (Collier & Lawson, 2017b; Durgin et al., 2009, 2012; Firestone, 2013; Firestone & Scholl, 2015; Woods, Philbeck & Danoff, 2009). One form of demand characteristics, which Collier and Lawson (2017b) referred to as *hypothesis guessing,* occurs when participants consciously alter their responses to reflect what they believe the experimental hypothesis to be. Durgin et al. (2009) showed that one of the most famous examples of action-specific scaling could be explained by hypothesis guessing. Proffitt and colleagues (Bhalla & Proffitt, 1999; Proffitt et al., 1995) reported that hills were estimated as steeper when participants wore a heavy backpack. This was claimed to reflect the increased difficulty of ascending the hill while wearing a heavy backpack. However, Durgin et al. (2009) showed that providing participants with a cover story for why they were wearing the backpack eliminated the effect. Specifically, Durgin et al. (2009) found that slant estimates by participants who were told that the backpack contained equipment for monitoring their ankle muscles did not differ from estimates made by participants who did not wear a backpack. In contrast, participants who wore the backpack without being given an explanation showed the original scaling effect (Durgin et al., 2009).

Related to, but different from, hypothesis guessing, is poor control of easily overlooked factors in the experimental context which may produce response biases in post-perceptual judgements (Collier & Lawson, 2017b; Firestone, 2013). Unlike hypothesis guessing, biases in post-perceptual judgement may be non-conscious and sincerely held by participants (Firestone & Scholl, 2015). For example, the way a task is presented can affect whether action-specific effects are obtained or not (Collier & Lawson, 2017b). Woods et al. (2009, Experiment 5) demonstrated this experimentally after failing to replicate the results of Witt, Proffitt and Epstein (2004), who reported that participants estimated the distances to targets as greater after throwing a heavy ball than a light ball. Woods et al. (2009, Experiment 5) asked participants to throw either a light or a heavy ball to a target, and then estimate the distance to the target. Participants were assigned to one of three groups. One group estimated distance based on objective distance (how far away they thought the really target was), another estimated distance based on apparent distance (how far away the target visually appeared), and the third group based distance estimates on non-visual factors (how far away they *felt* the target was). Only participants who based their judgements on non-visual factors showed the scaling effect reported by Witt et al. (2004). This suggests that the original effect reflected what participants thought about the distance, i.e., their judgement, rather than how the distance actually visually appeared to them.

Another methodological concern with the action-specific account that is related to demand characteristics is misattribution effects (Philbeck & Witt, 2015). Such misattribution effects may occur when participants interpret a question concerning the spatial attributes of an object in terms of the actions that object affords. For example, when asked the question “how big is this object?” participants may, implicitly, respond to the associated question “could you grasp this object?" This may lead to an effect consistent with the action-specific account which does not actually reflect a change in the visual representation of the object. However, this concern is rarely discussed in the action-specific literature (Philbeck & Witt, 2015).

The action-specific account has also been criticised for overreliance on a confirmatory research strategy (Firestone & Scholl, 2014), that is predicting, and then finding, a given effect. A comprehensive account of a phenomenon should be able to predict both when an effect should occur and when it should not. Firestone and Scholl (2014) investigated whether action-specific scaling effects would be appropriately present or absent under different conditions by employing the El Greco fallacy. According to this fallacy, when both the stimulus and the means of reproduction should show the same distortion following a given manipulation, the distortions should cancel each other out and no effect should be found. This offers a disconfirmatory prediction: when a manipulation should influence both the stimulus and the means of reproduction in the same way, no action-specific effects should be detected. Firestone and Scholl (2014) applied this logic to the finding by Stefanucci and Geuss (2009) that apertures were estimated as narrower when participants held a horizontal rod that was wider than their body. Participants in Firestone and Scholl (2014) verbally guided the experimenter to alter the width of an aperture to match the width of an identical aperture, which they imagined walking through. One group of participants completed the task while holding a wide rod, while another group did not hold a rod. Applying the El Greco fallacy, no scaling effect should have occurred here because the stimulus and the means of reproduction, which were identical, should have been visually distorted in the same way. However, participants holding the rod estimated the apertures as wider than participants who did not hold the rod. Therefore, the action-specific account lacks predictive power because scaling effects occur even when they should not (see also Collier & Lawson, in press).

Some authors have also expressed concern that visual differences across conditions in an experiment may drive action-specific effects (Firestone & Scholl, 2015). Differences in the visual appearance of the body are particularly important in studies investigating the influence of grasping capacity on estimated object size (Witt, 2017) because a common manipulation in these studies has been to change visual hand size (e.g. Linkenauger, Witt & Proffitt, 2011, Experiment 3; Linkenauger et al., 2013). For example, in Linkenauger, Witt and Proffitt (2011, Experiment 3), participants visually matched the size of objects placed near their hand both while it was and was not magnified. Linkenauger, Witt and Proffitt (2011, Experiment 3) reported that objects were estimated as smaller when placed near to the magnified hand, and claimed that this demonstrated a scaling of object size by perceived grasping capacity. However, this effect could be explained by visual differences in hand size inducing a size-contrast effect. Specifically, the objects may have appeared smaller when placed next to the magnified hand through a similar mechanism that drives the Ebbinghaus Illusion (see Figure 1, above).

In addition to these specific concerns, many effects reported within the action-specific literature have not been successfully replicated (for a review see Firestone, 2013). For example, de Grave, Brenner and Smeets (2011) failed to replicate the influence of tool use on perceived distance reported by Witt et al. (2005), Woods et al. (2009) failed to replicate the influence of throwing a heavy ball on perceived distance reported by Witt et al. (2004), and Collier and Lawson (2017a) failed to replicate the influence of apparent grasping capacity on perceived object size reported by Linkenauger, Witt and Proffitt (2011). Thus, the action-specific account has several methodological short-comings which must be overcome before action-specific scaling effects can be considered truly perceptual.

## Theoretical criticisms

There are also a number of theoretical concerns with the action-specific account. First, it is not immediately clear why it would be evolutionarily beneficial for the visual representation of the environment to scale according to action capacity in the first place (Firestone, 2013). The action-specific account has its roots in the ecological approach to visual perception which suggests that the central function of perception is to guide and control action (Gibson, 1979). Proponents of the action-specific account have therefore suggested that action-specific scaling effects may assist in guiding effective action (Proffitt, 2008; Proffitt & Linkenauger, 2013). It has also been argued that a visual system which scales the environment according to action capacity may lighten the burden on decision making systems when choosing a course of action (Proffitt, 2008; Proffitt & Linkenauger, 2013). For example, individuals who are fatigued may see a hill as steeper in order to deter them from attempting the ascent.

However, it has been argued that the idea of action-specific scaling as useful for action execution is flawed (Firestone & Scholl, 2015; Durgin, 2014, 2017; Hajnal, Abdul-Malak & Durgin, 2011; Li & Durgin, 2010). Instead, action execution may be better served by stability rather than by fluctuation. This issue has been investigated regarding estimates of hill slant. People tend to overestimate the steepness of hills. For example, a 5$^{o}$ hill is often estimated as 20$^{o}$ (Li & Durgin, 2010). Durgin and colleagues (Durgin, 2014; Hajnal et al., 2011; Li & Durgin, 2010, 2013) suggested that steepness exaggeration is a systematic, functional bias which reflects greater sensitivity to functionally significant information in the environment. They called this phenomenon *perceptual scale expansion*. They argued that perceptual scale expansion is a coding strategy which allows predictable (although biased) coding of slant so that actions, e.g., walking, can be calibrated effectively. Thus, according to the perceptual scale expansion model, stability and predictability are critical in the control of action. In contrast, the action-specific account suggests that changes in action capacity can immediately affect the visual layout of the environment. However, this may introduce instability in the visual system which seems to undermine the purpose of visual perception as a guide for action.

Firestone and Scholl (2015) further argued that scaling what is perceived according to action capacity may undermine the usefulness of that percept for other purposes. For example, to again take the case of hill slant perception, we may look a hill with the in-the-moment intention of ascending it, but the hill could be viewed with other, non-walking related, purposes in mind. For example, we may intend to use it as a landmark for navigation (Firestone & Scholl, 2015) or to paint a realistic painting of the landscape. Both of these would be impeded if our perception of the hill is automatically scaled according, for example to our current energy levels.

This is related to another theoretical concern: the action specific account does not offer any explicit prediction for how visual spatial perception operates when observers do not intend to act. The account predicts that action-specific effects should not be found when people do not intend to act (e.g. Linkenauger, Witt & Proffitt, 2011a; Witt et al., 2005), but since people can estimate spatial properties in the absence of explicit intention to act, what informs what they perceive in this situation? Cañal-Bruland and van der Kamp (2015) suggested that perceiving spatial properties may be a different form of perception from perceiving action opportunities. This possibility is supported by evidence that participants' gaze patterns differ depending on whether the task at hand pertains to spatial perception or to action. For example, van Doorn, van der Kamp, de Wit and Savelsburgh (2009) used the Müller-Lyer illusion to investigate differences in gaze patterns when participants intended to grasp and pick up a rod (grasping task), and when they estimated the length of a rod by separating their thumb and index finger (perceptual task). They found that gaze fixations during the perceptual task were concentrated at the ends of the rods, while fixations during the grasping task were concentrated towards one end and the centre of the rods. This suggests that when participants viewed the rods while intending to grasp them, the visual information they picked up was different from the information used to estimate its size. However, the suggestion that perceiving spatial properties may be a different process to perceiving action opportunities was quickly rejected by proponents of the action-specific account. Specifically, Linkenauger (2015) argued that we see spatial properties only as relative to ourselves, and so absolute spatial judgements cannot exist (see General Discussion for a review of this issue). Thus, it remains for the action-specific account to explain how people make spatial estimates in the absence of intention to act.

**Other concerns**

A general concern with the action-specific account is that the critical factors claimed to drive action-specific effects sometimes appear to contradict each other. For example, Sugovic et al. (2016) claimed that heavier participants estimated the along-the-ground distance to targets as greater than lighter participants. They found this effect only for actual weight, and not for perceived weight. However, Linkenauger, Witt and Proffitt (2011, Experiment 2) found that biases in the perceived relative grasping capacity of the left and right hands influenced estimates of object size, in the absence of any actual difference in the grasping capacity between hands. These effects are contradictory: Sugovic et al. (2016) found an effect of actual, but not of perceived, body morphology, whereas Linkenauger, Witt and Proffitt (2011) found an effect of perceived, but not actual, body morphology. It is not clear how the action-specific account can resolve this discrepancy.

Sugovic et al.'s (2016) study also fails to account for individual differences in other factors that have been claimed to influence distance perception, such as fitness (Proffitt & Linkenauger, 2013; Zadra et al., 2010). For instance, what action-specific effect would be expected for "fit-but-fat" athletes e.g., sumo wrestlers? On one hand, they may estimate distances as greater because they weigh more (Sugovic et al., 2016), but on the other hand, they may estimate distances as shorter because they are physically fit (Zadra et al., 2010). The action-specific account does not seem equipped to make a clean prediction in this case[1].

It has also been claimed that action-specific effects are informationally ungrounded (Firestone, 2013). In other words, it is unclear what information vision draws upon in order to perform the scaling in the first place. As discussed above, one possibility is that information from other sensory sources interacts with vision (Sugovic et al., 2016; Witt & Riley, 2014). For example, Witt (2017) argued that action-specific effects may be motor effects, and Witt and Riley (2014) suggested that haptic (active touch), proprioceptive or interoceptive information may interact with vision to drive action-specific scaling. However, framing action-specific effects as multisensory effects cannot explain effects such as perceived grasping capacity influencing estimates of object size (Linkenauger, Witt & Proffitt, 2011) as it is unclear how proprioceptive or interoceptive signals could communicate such higher-level biases to vision. Furthermore, if proprioceptive or haptic information about grasping capacity influenced visual estimates of object size, then Collier and Lawson (2017a) should have found such an effect when both actual and perceived grasping capacity were manipulated by taping together participants' fingers. In Collier and Lawson (2017a, Experiments 4 and 5), participants actually grasped the objects with both their taped and untaped hands, and therefore received proprioceptive feedback specifying their current grasping capacity. In both of these experiments, participants reported that their grasping capacity was reduced by the taping manipulation, however this did not influence their estimates of object size. This suggestion also cannot account for the finding that participants estimated distances to targets as shorter after they imagined using a baton (Witt & Proffitt, 2008) since in this situation there is no sensory information signal inferring action capacity (Firestone, 2013).

It should be noted that these more general concerns are largely based on problems associated with the fact that the action-specific account does not specify what kinds of mechanisms underlie action-specific effects (Firestone, 2013). Proponents of the action-specific account readily accept that the account is incomplete in some areas, and research is on-going to identify an underlying mechanism that supports action-specific scaling effects (Proffitt & Linkenauger, 2013; Witt, 2011a, 2017; Witt & Riley, 2014; White et al., 2013).

## 1.2 Summary and chapter outline

In summary, action and perception are intimately linked (Adolph & Berger, 2006; Proffitt & Linkenauger, 2013; Warren, 1984), however the nature of this relationship is not yet fully understood (Cañal-Bruland & van der Kamp, 2015). The action-specific account of perception claims that the primary purpose of vision is to guide action, and that this is achieved by scaling the spatial layout of the environment according to action capacity (Proffitt & Linkenauger, 2013; Witt, 2011a, 2017). Action-specific scaling effects challenge our current view of what visual perception is for, what information it utilises, and how the mind is organised (Firestone, 2013; Firestone & Scholl, 2015; Proffitt, 2013; Witt, 2017). However, there are both methodological and theoretical concerns with the action-specific account. For example, it is not clear what the benefits of action-specific scaling effects in everyday perception are (Durgin, 2017; Firestone & Scholl, 2015), the account reports inconsistent effects which sometimes contradict each other, and action-specific scaling seems to be informationally ungrounded (Firestone, 2013). Furthermore, many effects consistent with the action-specific account could be accounted for by demand characteristics or differences resulting from changes in the visual representation of the body. It is also possible that such effects reflect changes in post-perceptual judgement rather than perception. The account has also been criticised for relying on an overly confirmatory research strategy, and many action-specific scaling effects have not been replicated (Firestone, 2013). In the current thesis, we tested several hypotheses derived from the action-specific account, and used different methodologies to investigate the claims of the account, with a focus on the criticisms outlined above.

In Chapter 2, we attempted to replicate the effect reported by Linkenauger, Witt and Proffitt (2011, Experiment 2), that apparent grasping capacity directly affects estimated object size. We tested both the manipulation of hand dominance, used in the original study, and then introduced a more powerful manipulation which directly physically restricted participants' grasping capacity. We also tested whether variation in grasping capacity would influence haptic size estimates, which has not previously been investigated by proponents of the action-specific account. We found no evidence that grasping capacity (either actual or perceived) influences estimates of object size.

In Chapter 3, we sought to understand our earlier failure to replicate Linkenauger, Witt and Proffitt (2011, Experiment 2). We investigated whether differences in demand characteristics between ours and Linkenauger, Witt and Proffitt's studies could explain this. We found no reliable evidence that providing leading instructions influenced estimates of object size. However, when participants judged both the graspability and the size of an object on every trial, as was done in Linkenauger, Witt and Proffitt, (2011, Experiment 2), we found effects consistent with the action-specific account. This suggests that the effect reported by Linkenauger, Witt and Proffitt (2011, Experiment 2) can be explained by response biases associated with completing two conceptually linked tasks on the same trial. In other words, estimating object size in a context which makes graspability seem relevant gives rise to the effect, rather than grasping capacity directly affecting estimates of object size.

In Chapter 4, we tested whether low-level differences as a result of manipulating visually perceived hand size could explain the results of Linkenauger, Witt and Proffitt (2011, Experiment 3). Linkenauger, Witt and Proffitt used magnification to manipulate visually perceived hand size, and reported that objects were estimated as smaller when placed next to the hand while it was magnified than while it was not. We replicated this finding both when participants viewed their own hand, and when they viewed a fake, plastic hand. This suggests that the effect reported by Linkenauger, Witt and Proffitt (2011, Experiment 3) can be explained by visual differences induced by magnification. Specifically, their result can be explained by size-contrast effects, possibly through a similar mechanism that gives rise to the Ebbinghaus Illusion (see Figure 1).

In Chapter 5, we explored the criticism that the action-specific account has relied on an overly confirmatory research strategy by testing a disconfirmatory prediction offered by the account. It has been claimed that action-specific scaling effects should only be found when participants intend to act (Linkenauger, Witt & Proffitt, 2011; Witt et al., 2005). We therefore tested whether scaling effects would be absent if participants did not intend to act. Our results supported the claim that the action-specific account lacks predictive power (Firestone & Scholl, 2014) as we found effects consistent with the action-specific account when participants did not intend to act, and no effects when participants did intend to act.

In Chapter 6, we investigated a potential practical application of the action-specific account. Specifically, we tested whether being hungry influenced the estimated size of food products. We found no evidence that being hungry influenced size estimates of food products. Thus, estimates of the relative size of food products do not scale in the way proposed by the action-specific account. This suggests that calls for the use of action-specific effects in everyday life (Witt et al., 2016) may be premature.

Chapter 7 provides a response to a recent review article by Witt (2017), who claimed that grasping capacity directly influences perceived object size. We critically evaluate the claims made by Witt (2017) and explain why we disagree that this is a true perceptual effect.

Finally, Chapter 8 provides a general discussion and the conclusion of this thesis. The empirical work undertaken in this thesis suggests that there are at least four major concerns with the action-specific account which demonstrate that its central claim is false. We conclude that although people are sensitive to changes in their action capacity following modifications to the functional morphology of their body, this does not modulate visual spatial perception.

## 1.3 Footnotes: Chapter 1

[1] It might be argued that heavier individuals expend more energy for a given action such as walking, since it takes more energy to move a heavier object (e.g. Sugovic et al., 2016). Thus, even a fit-but-fat individual may perceive distances as greater because distance is measured according to their “metabolic gas gauge” (Proffitt & Linkenauger, 2013). However, calorie expenditure is not dictated solely by an individual’s weight (Weigle & Brunzell, 1990; Leibel, Rosenbaum & Hirsch, 1995). In fact, it has been shown that individuals with more fat-free mass (body tissues other than fat which are non-metabolic, e.g. muscle, bones) and less body fat burn more calories during walking and running than individuals with less fat-free mass and more body fat (Pauley et al., 2016). This suggests that individuals who are muscular should expend *more* calories when walking and therefore, if energy expenditure is the driving mechanism underlying bioenergetic scaling effects, perceive the distance as greater. This means that a 90kg but mostly fit/muscular individual should see the distance to a target as greater than a 90kg but less fit/muscular individual. This undermines both Sugovic et al.’s (2016) suggestion that actual weight directly influences perceived distance, and Proffit and colleagues’ (Proffitt et al., 1995; Profitt & Linkenauger, 2013) assertion that improved fitness is associated with shorter distance estimates.

# Chapter Two

## 2. Grasping capacity does not directly influence perceived object size

***This chapter has been published as:**

**Collier, E. S., & Lawson, R. (2017). It's out of my hands! Grasping capacity may not influence perceived object size.** ***Journal of Experimental Psychology: Human Perception and Performance, 43*****(3), 749-769. DOI: 10.1037/xhp0000331**

### 2.1 Abstract

Linkenauger, Witt and Proffitt (2011) found that the perceived size of graspable objects was scaled by perceived grasping capacity. However, it is possible that this effect occurred because object size was estimated on the same trial as grasping capacity. This may have led to a conflation of estimates of perceived action capacity and spatial properties. In five experiments, we tested Linkenauger, Witt and Proffitt's claim that right-handed observers overestimate the grasping capacity of their right hand relative to their left hand, and that this, in turn, leads them to underestimate the size of objects to-be-grasped in their right hand relative to their left hand. We replicated the finding that right handers overestimate the size and grasping capacity of their right hand relative to their left hand. However, when estimates of object size and grasping capacity were made in separate tasks, objects grasped in the right hand were not underestimated relative to

those grasped in the left hand. Further, when grasping capacity was physically restricted, observers appropriately recalibrated their perception of their maximum grasp but estimates of object size were unaffected. Our results suggest that changes in action capacity may not influence perceived object size if sources of conflation are controlled for.

## 2.2 Introduction

Action capacity refers to an observer's ability to perform a given action. Physical changes to the body can alter both actual and perceived action capacity. The action-specific account of perception claims that observers perceive features of the environment as scaled according to their abilities (Proffitt, 2006a; 2006b; 2013; Proffitt & Linkenauger, 2013; Witt, 2011a). Spatial perception has been shown to scale according to energetic expenditure and effort (Bhalla & Proffitt, 1999; Proffitt et al., 1995; Proffitt, Stefanucci, Banton & Epstein, 2003; Witt et al., 2004) and performance variability (Witt et al., 2008; Witt & Dorsch, 2009). For example, proponents of the action-specific account have claimed that hills appear steeper when observers wear a heavy backpack or are fatigued (Bhalla & Proffitt, 1999), that putting holes and softballs appear larger (Witt et al., 2008; Witt & Proffitt, 2005) and that tennis balls appear to move slower (Witt & Sugovic, 2010) to more skilled players of the relevant sport. According to the action-specific account, perception is scaled in these ways in order to guide effective actions (Bhalla & Proffitt, 1999; Proffitt & Linkenauger, 2013). For example, an observer wearing a heavy backpack will find it harder to walk up a hill and so the visual slant of the hill appears steeper to them in order to deter them from attempting the ascent.

It has also been reported that perception may be influenced by action capabilities pertaining to the morphology of the body (Linkenauger, Ramenzoni & Proffitt, 2010;

Linkenauger, Witt & Proffitt, 2011). For example, observers estimate an object to be nearer when they hold a tool that increases their maximum reach (Witt et al., 2005) and apertures are estimated as narrower if observers hold a horizontal rod that is wider than their body (Stefanucci & Geuss, 2009). Further evidence for the action-specific account comes from the claim that right handed participants underestimate the size of objects they intend to grasp with their right hand relative to objects they intend to grasp with their left hand (Linkenauger, Witt & Proffitt, 2011; see also Linkenauger, Ramenzoni & Proffitt., 2010; Linkenauger, Mohler & Proffitt, 2011). Linkenauger and colleagues claim that this is because right handed observers perceive that their right hand is larger than their left hand and therefore that it can grasp larger objects (Gentilucci et al., 1998; Linkenauger, Witt & Proffitt, 2011).

Action-specific scaling effects challenge modular theories of vision, as they suggest that perception can be influenced by cognitive factors. Modular theories of perception claim that perception is *cognitively impenetrable*, that is perception is not affected by top-down, cognitive influences (for discussions see Firestone, 2013; Firestone & Scholl, 2014; 2015; Proffitt, 2013). However, Sugovic et al. (2016) recently pointed out that if action-specific scaling effects are driven by real, physical body morphology (for example, actual weight) rather than beliefs or thoughts about the body, then these effects are, in fact, compatible with the idea of cognitive impenetrability. This is because information about the physical abilities of the body - rather than conscious beliefs or thoughts - is influencing perception, possibly through multimodal processes. This information need not be specified in the visual array, but instead may, for example, be provided by other modalities or physiological cues. As Firestone and Scholl (2015, p.11) suggest, for multisensory integration, “such results are consistent with the entire process being contained within perception itself, rather than being an effect of more central cognitive processes on perception."

Interestingly, Sugovic et al. (2016) found that only actual weight, and not beliefs or perceptions about body mass, predicted action-specific scaling effects – in this case, distances were estimated as greater by heavier observers. This finding, namely that only actual, and not perceived, body morphology influenced spatial estimates contrasts to Linkenauger, Witt and Proffitt's (2011) finding that it was people's perceptions of their grasping capacity that scaled their estimates of object size, whilst their actual grasping capacity did not differ between the right and left hands.

One concern with the action-specific account is that the reported scaling effects may not reflect changes to perceived size in the strongest sense. Instead, participants' size estimates may reflect their perception of their ability to act on an object as opposed to being based on the object's spatial properties alone. A conflation of perceived action capacity and spatial perception is more likely to occur when spatial estimates are made in a context which encourages participants to consider non-visual factors, possibly including their action capacity (Firestone, 2013; Woods et al., 2009).

Woods et al. (2009) demonstrated this possibility experimentally. Participants threw either a light or a heavy ball to a target three times, and then verbally estimated the distance to the target. Participants in three different groups were asked to base their distance judgements on objective distance (how far away the target really was), apparent distance (how far away the target visually appeared to be), or nonvisual factors (how far away they 'felt' the target was). Action-specific scaling was considered to have occurred if the distance to the target appeared greater to those who threw the heavy ball, since more effort is needed to throw a heavy than a light ball (see Proffitt, Stefanucci, Banton &

Epstein, 2003; Witt et al., 2004). Woods et al. (2009) found that action-specific scaling occurred only for participants judging how far they 'felt' the target was. Only here were participants encouraged to consider non-visual factors, which may have included their throwing ability. This result suggests that the scaling effect obtained by Woods et al. (2009) arose from a difference in how easily participants could throw the ball to the target, and did not actually reflect a change in what they perceived visually.

We investigated this issue by re-examining the results of a study conducted by Linkenauger, Witt and Proffitt (2011) where right-handed participants were presented with blocks of varying size. On each trial in Linkenauger, Witt and Proffitt (2011), participants were first asked whether they thought they could grasp the block with either their left or right hand. They then visually matched the width of the block on a screen by moving two circles apart. Participants estimated the grasping ability of their dominant right hand as greater than that of their left hand. Critically, participants also underestimated the size of blocks they had imagined grasping with their right hand to a greater extent than blocks they had imagined grasping with their left hand. These findings were taken to demonstrate a scaling of perceived object size according to perceived action capacity. However, on each trial participants were explicitly asked whether they would be able to grasp the block with their thumb on one side and any finger on the other side immediately before they estimated the block's width. It is therefore possible that their estimates of object size were influenced by whether the block seemed graspable, rather than its objective size alone.

Linkenauger, Witt and Proffitt (2011) asked participants to imagine grasping the blocks because it has sometimes been argued that observers must intend to act in order for action-specific effects to be found (Witt et al., 2005; Witt & Proffitt, 2008). However, action-specific scaling effects have been found when participants performed the relevant action without being asked to consider doing it. For example, in Bhalla and Proffitt's (1999) studies with backpacks no attention was drawn to action when slopes were estimated. In a further example, Witt and Dorsch (2009) asked participants to attempt 10 kicks to a set of field goal posts and then to visually match the height of the goal posts. When they estimated height they were not encouraged to consider their previous kicks and they did not kick the ball again after making their estimate and so they were not anticipating further action.

It could be argued that this example reflects a different kind of perceptual scaling to that measured by Linkenauger, Witt and Proffitt (2011). Specifically, in Witt and Dorsch (2009), spatial properties were scaled by variability in performance, whereas in Linkenauger, Witt and Proffitt (2011) spatial properties were scaled by functional morphology (for a discussion of this issue, see Proffitt & Linkenauger, 2013). Nevertheless, the results of Witt and Dorsch (2009) suggest that action does not need to be consciously considered in order for action-specific effects to occur. Furthermore, if people know they have to perform a given action they must intend to act even if they are not consciously considering that action. Thus if intention is sufficient to influence perception, then performing the relevant action should carry the same biases as imagining doing so. In addition, actually performing an action creates a more ecologically valid context in which to test the claims of the action-specific account. Thus in our studies, participants actually grasped a block on each trial, rather than only imagining grasping a block, as in Linkenauger, Witt and Proffitt (2011).

We conducted five experiments investigating whether spatial perception is scaled by perceived action capacity. We focused on the claim made by Linkenauger, Witt and Proffitt (2011) that right handed observers estimate the size of objects they intend to grasp in their right hand as smaller than objects they intend to grasp in their left hand because they perceive the grasping capacity of their right hand as greater than that of their left hand. However, we avoided conflation effects by dissociating estimates of action capacity from estimates of object size. In Experiments 2-4 we did this by asking our participants to estimate their grasping capacity in a separate task which was completed only after they had made all of their estimates of object size. In the final experiment (5) we did this by deceiving participants by giving them a cover story that the action capacity and object size estimate tasks were unrelated and were part of two separate studies. Thus, we investigated whether a difference in either perceived or actual grasping capacity predicted a difference in perceived object size when potential sources of conflation were avoided. If perception is cognitively penetrable, and so if it is influenced by perceived action capacity, then we should replicate Linkenauger, Witt and Proffitt (2011) results when participants actually perform the relevant action, in this case grasping. In contrast, failure to replicate these effects when the action is performed and conflation effects are controlled for would support the claim that perception is cognitively impenetrable (Firestone, 2013; Firestone & Scholl, 2014).

## 2.3 Experiment 1

Linkenauger et al. (2009) reported that right-handed participants perceived that they could grasp larger objects in their right hand than in their left hand. This may reflect an asymmetry in the perceived size of the hands, such that the right hand is perceived as larger than the left, since right-handers rely on their right hand more. A similar asymmetry has been reported for arm length, where the right arm is perceived by right-handed individuals to be longer than the left arm (Linkenauger et al. 2009; Morgado, Gentaz, Guinet, Osiurak & Palluel-Germain, 2013). In order to test the robustness of the claim that right handers perceive their right hand as bigger than their left hand, in Experiment 1 we asked participants which of their hands was bigger.

### 2.3.1 Method

Ethical approval was granted for all of the experiments presented in this paper by the relevant local ethics committee at the University of Liverpool.

#### 2.3.1.1 Participants

An opportunity sample of 50 participants who self-reported as right-handed (25 females, mean age = 23.3 years) was recruited for this experiment. Thirty-nine participants were approached in person on the University of Liverpool campus and 11 were questioned online via Skype.

#### 2.3.1.2 Stimuli and procedure

The experimenter recorded the participant's age, gender and handedness then asked “Is your right hand smaller, larger or about the same size as your left hand?” If they responded that they believed their hands were about the same size, they were asked the follow-up question, “If I forced you to choose, which is bigger, your right or left hand?” Participants often looked at their hands before they made their judgement.

### 2.3.2 Results and discussion

A Chi-Square test of goodness-of-fit for the participants who responded right (n = 25) and left (n = 10) to the first question showed a significant difference, $X^2$ (1, N = 35) = 6.4, $p$ < .001. We repeated this analysis including participants who responded right (n = 14) or left (n = 1) to the second question and again found a significant difference, $X^2$ (1, N = 50) = 15.7, $p$ < .001. Thus, right handers were more likely to say their right hand was larger than their left hand than vice versa. This supports the claim made by Linkenauger et al. (2009) that most right handed observers perceive their right hand as larger than their left hand.

## 2.4 Experiment 2

Having confirmed that right handers perceive their right hand as larger than their left hand in Experiment 1, in Experiment 2 we went on investigate whether this effect would lead to the size of objects grasped by the right hand being underestimated relative to those grasped by the left hand (Linkenauger, Witt & Proffitt., 2011). The action-specific account claims that this should occur because perceived action capacity alters the perceived size of action-relevant objects. As explained by Linkenauger, Witt and Proffitt (2011, p. 1436): "Because the right hand appears larger and is deemed to be able to grasp larger objects (Linkenauger, Witt, Bakdash et al. 2009), the same object measures as smaller on the right hand’s larger ruler, and therefore, appears smaller than when it is placed on the left hand".

In addition to testing for a pre-existing bias to overestimate the grasping ability of the right hand, in Experiment 2 we tried to manipulate perceived grasping ability in a second way, by using a priming task. Franchak and Adolph (2014) showed that changes to the body are not sufficient to change perceived action capacity but that perceived action capacity may be recalibrated through acting. They demonstrated this by comparing pregnant and non-pregnant participants’ estimates of their ability to walk through apertures of different widths. Pregnant participants accurately updated their estimates of the narrowest aperture that they could squeeze through as their body size increased throughout their pregnancy. In contrast, non-pregnant participants who were fitted with a pregnancy prosthesis that immediately increased their girth were initially poor at estimating the narrowest aperture they could fit through. However, after physically attempting the task their estimates became accurate. Thus, perceived action capacity can be quickly recalibrated through acting (see also Franchak et al., 2010; Ishak et al., 2008).

We aimed to take advantage of this rapid recalibration in Experiment 2 by priming participants to feel that one of their hands had a greater grasping capacity than the other hand prior to estimating the size of objects. One group was primed to feel their right hand was able to grasp larger objects. Here, any pre-existing bias to overestimate the grasping ability of their right hand should have been enhanced. If this bias influences estimates of object size, then any scaling effects should also have been enhanced. The other group were primed to feel their left hand could grasp larger objects. Here, any priming effect should have countered a pre-existing bias to overestimate the grasping capacity of their right hand. This, in turn, should reduce or even reverse any scaling effects when estimating object size.

Finally, in Experiment 2 we also tested whether perceived grasping capacity would influence perceived object size if objects were presented haptically as well as visually. Both vision and active touch (haptics) process spatial information (Collier & Lawson, 2016; Lawson, 2009; Lawson, Ajvani & Cecchetto, 2016). Active exploration of the environment is critical to learning about the action capacity of the hands, and Gori and colleagues have shown that haptic information calibrates visual estimates of object size in young children (Gori, Del Viva, Sandini & Burr, 2008; Gori, Sciutti, Burr & Sandini, 2011). Some evidence suggests that the direction of perceptual scaling effects may reverse from vision to touch. For example, Taylor-Clarke, Jacobsen and Haggard (2004) found that magnifying the forearm led participants to estimate visual stimuli presented on the forearm as smaller. However, they found that when the forearm was again visually magnified but unseen stimuli passively touched the skin, objects were estimated as larger. Similarly, using the rubber hand illusion, Bruno and Bertamini (2010) found that when participants embodied a large hand, they estimated discs that they grasped in that hand as larger than when they embodied a small hand. This research suggests that differences in the perceived size of the relevant body parts can elicit opposite perceptual scaling effects for vision and touch. Applying this size-scaling logic to the current studies, if right-handed participants perceive their right hand to be larger than their left hand then objects they grasp in the absence of vision may be perceived as larger in the right hand, which is the opposite prediction to that of the action-specific account.

### 2.4.1 Method

#### 2.4.1.1 Participants

Thirty right handed undergraduate students from the University of Liverpool were recruited for this study (21 females, mean age = 20.6 years, mean Edinburgh Handedness Inventory score = 86, range = 25 - 100). Participants were rewarded with course credit for their participation.

#### 2.4.1.2 Apparatus, stimuli and procedure

There were four phases to this experiment. In summary, first participants were implicitly primed to perceive one of their hands as having a greater grasping capacity than the other (priming task). Second, they completed a haptic-to-vision size estimation task (HV task) where they used a visual matching response to estimate the size of haptically presented stimuli. Third, they repeated the HV task but this time the stimuli were presented visually (VV task). Finally, we measured the largest object that participants could grasp with each hand (grasping capacity task). These four phases are described in more detail below.

Participants were first told that the experiment would test their ability to estimate the size of blocks. The stimuli were 21 foamboard square blocks (0.5 cm deep) with sides varying in length from 4 to 24 cm in 1cm increments. A box (40 × 10 × 32 cm) was placed on top of a table at which participants were seated. The open end of the box facing the participant was covered by a curtain, see Figure 1A. Stimuli were presented inside the box in the priming phase and in the HV and VV tasks.

The purpose of the priming phase was to induce the feeling that one hand could grasp larger objects than the other by giving a smaller set of objects to that hand. We reasoned that if participants were able to grasp more blocks with one hand than the other, they could be led to perceive that hand as having a greater grasping capacity if they assumed that the same set of stimuli were being given to both hands. Any difference in graspability between the two hands might subsequently lead to objects seeming smaller when seen near to that hand. Participants were assigned to either the LHFeelsSmallerObjects or the RHFeelsSmallerObjects group (n = 15 per group) and were given a series of stimuli to try to pick up.

As a cover story for the priming phase, participants were told that before starting to estimate object sizes, they would do a practise phase in which they would feel objects from across the range of available sizes without making a response. In this phase participants reached behind the curtain with their left or right hand and attempted to grasp and pick up the presented block. The experimenter told the participant which hand they should use on each trial. Participants were told to always attempt to first grasp the square block with their thumb on one side and any other finger on the opposite side. They were also told that if the block was too big to grasp in this way, they should then move their hand across the block to feel its width. There were two sets of 13 stimuli, the small set (sizes = 4, 5, 6, 7, 8, 10, 12, 14, 16, 17, 18, 19 and 20 cm) and the large set (each member of which was 4cm larger than its corresponding item in the small set, so its sizes = 8, 9, 10, 11, 12, 14, 16, 18, 20, 21, 22, 23 and 24 cm). For the LHFeelsSmallerObjects group, on each trial one block from the small set was presented to the left hand and then the corresponding (4cm larger) block from the large set was presented to the right hand, and vice versa for the RHFeelsSmallerObjects group. Each pair of blocks was presented twice, giving 26 trials in total. Trial order was randomised for each participant and the hand given the small set (so being primed to have a greater grasping capacity) acted first on every trial.

The HV then VV size estimation tasks followed immediately after the priming phase, see Figure 1B. At the beginning of each trial, the experimenter told the participant which hand they should use to grasp the block. In the HV matching task, participants put their hand through the curtain to feel the block, as in the priming phase. In the VV task, participants reached through the curtain to pick up the block and placed it on the table in front of the curtain so that they could see it. In both tasks, participants always attempted the specified grasp (with the thumb on one side and any other finger on the opposite side) first. However, if the block was too big to pick up in this way then they were told to move their hand across the block to feel its width (for the HV task) or they were told to use a different grasp to pick up the block (for the VV task). Thus, in both tasks participants attempted to grasp the block in a specific way on every trial prior to estimating its size.

For the HV and VV tasks, size estimates were made on a computer monitor, which was placed on top of the box. Two 2 cm tall, 0.5 cm wide, vertical black lines, which were initially 1.75cm apart, were displayed on the screen, see Figure 1A. The participant moved the lines closer or further apart by scrolling the wheel of a wireless mouse. The mouse was fixed to the table in front of the participant, in line with their body midline. To estimate the width of each block, participants adjusted the horizontal distance between the lines until they believed it matched the width of the block they were either feeling (HV task) or seeing (VV task; here, the block was offset from the two lines, see Figure 1A. This ensured that participants could not simply line up the edges). Participants pressed the space key on a keyboard placed on top of the box in front of the monitor when they were satisfied with their response.

In the HV task, participants felt the block with one hand and used their other hand to scroll the mouse wheel. In the VV task, they used the same hand they picked the block up with to use the mouse and they were told to keep their other hand out of sight (as a cover story, participants were told that this was to ensure that their other hand did not get in the way, and so that they could clearly see the block). This ensured that the hand they had just acted with was more likely to then be used as a perceptual ruler as it was the only hand visible. Participants estimated the size of each of the blocks once for each hand in each task, thus completing 42 trials (2 hands × 21 blocks) in each task, with trial order randomised within each task.

After completing the VV task we measured the largest block that participants were able to successfully grasp with each hand (grasping capacity task). Participants attempted to grasp blocks, starting at 14 cm wide, in increasing size until the largest block they could grasp was found. Only actual, not perceived, maximum grasp was measured in Experiment 2. Participants then completed the 4-item short Edinburgh Handedness Inventory. Finally, to check for demand characteristics, participants were asked a series of questions about the experiment prior to being fully debriefed. The entire procedure lasted approximately 40 minutes.

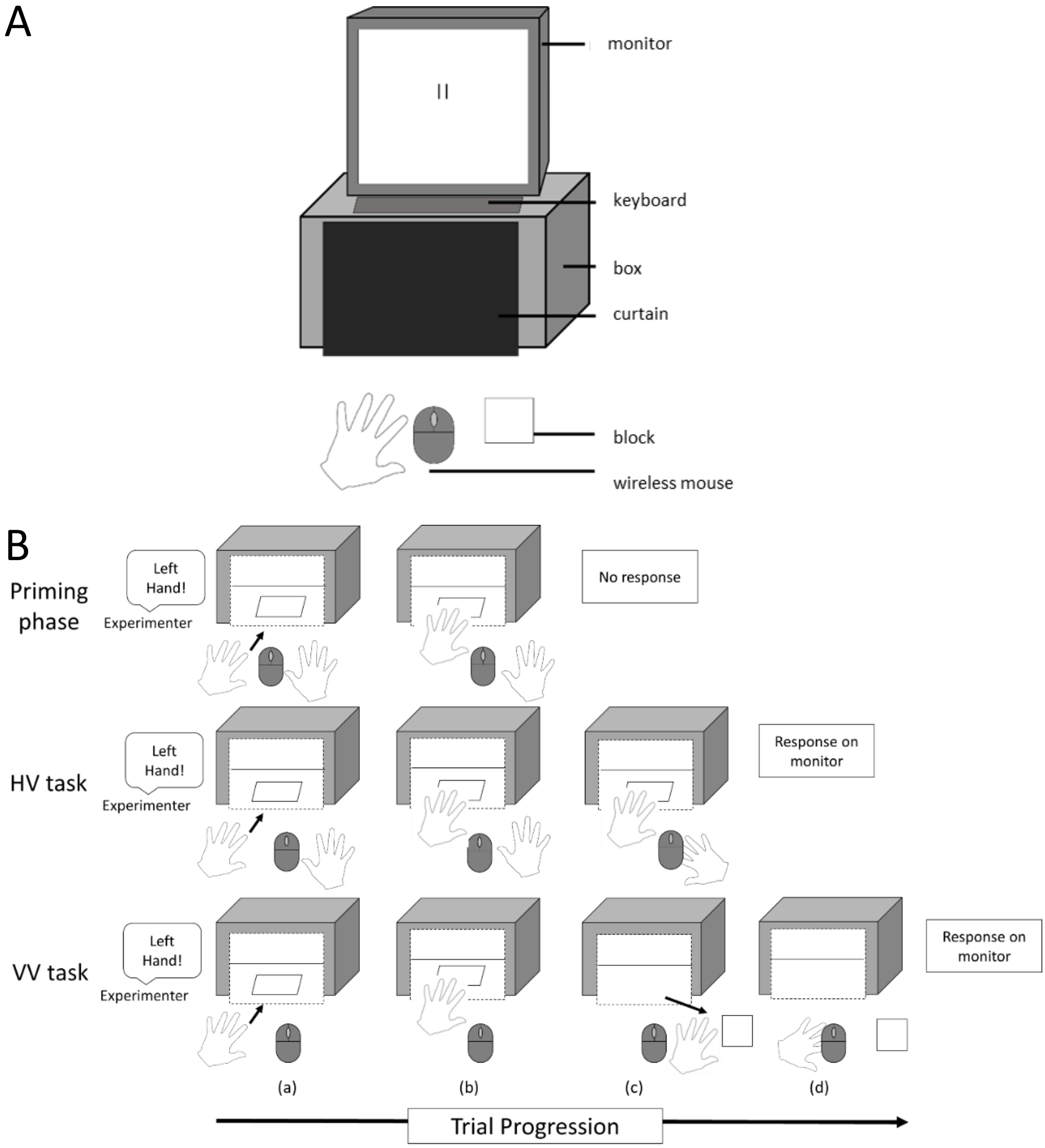


*Figure 1*: A: Diagram of the set-up of Experiment 2, showing a left hand trial in the VV task. The participant has moved the block from behind the curtain and placed it on the table in front of them, to the right of the mouse. They would then use their left hand to scroll the mouse wheel to respond. B: Diagram showing the procedure during left hand trials in Experiment 2 in the priming phase (top), the HV task (middle) and the VV task (bottom). The same procedure was used in Experiment 3 (except that the HV task was omitted), Experiment 4 (except that the priming phase was omitted). In Experiment 5 both the priming phase and HV task were omitted and changes were made to the VV task. In 1B, unlike in 1A, the curtain is drawn as transparent in order to show the block placed behind the curtain. In fact, though, participants could not see the block while it was behind the curtain (in (a) and (b) and also in (c) for the HV task). On left hand trials in the HV task, the left hand was used to feel the block, while the right hand was used to respond using the mouse. In the VV task, the right hand was not used and was kept out of sight, whilst the left hand was used to move the block from behind the curtain, to place it to the right of the mouse and then to respond using the mouse.

### 2.4.2 Results

No participant correctly guessed the main manipulation and purpose of the experiment without prompting from the experimenter. Details of the responses to the post-experimental questions can be found in Appendix J. We first discuss the results for the HV and VV tasks which measured perceived object size, followed by the results for grasping capacity.

**Perceived object size**

Fourteen individual trials were removed (2 HV-left, 2 HV-right, 6 VV-left, and 4 VV-right) where invalid responses occurred (e.g. pressing the spacebar without adjusting the distance of the lines). Ratios were then calculated for the visually estimated size of each block by dividing the estimated size by the actual size. Linkenauger, Witt and Proffitt (2011) claimed that action-specific scaling effects should only occur when the action in question is performable. Therefore, to be consistent with Linkenauger, Witt and Proffitt (2011), here we report the analysis only for the average ratio for trials where graspable stimuli were presented, based on the largest block that participants were able to grasp in the grasping capacity task (we also report results for the average ratio of all 21 sizes in Appendix A).

A mixed ANOVA was conducted where grasping hand (left/right) and task (HV/VV) were within-participants factors and prime group (LHFeelsSmallerObjects/RHFeelsSmallerObjects) was a between-participants factor (*p*-values for pairwise comparisons were Bonferroni corrected). This revealed that ratios for the left hand grasping (0.82) did not differ significantly from ratios for the right hand grasping (0.83), $F(1, 28) = 0.27$, $p = .6$, $\eta_p^2 = .01$, see Figure 2. Ratios were significantly greater in the VV task (0.89) than in the HV task (0.77), $F(1, 28) = 49.37$, $p < .001$, $\eta_p^2 =$

.64, so people underestimated size more when the blocks were perceived haptically rather than visually. There was no significant effect of prime group, $F(1, 28) = 1.42$, $p = .2$, $\eta_p^2 = .05$, of task × prime group, $F(1, 28) = 0.17$, $p = .7$, $\eta_p^2 = .01$, of grasping hand × prime group, $F(1, 28) = 2.16$, $p = .2$, $\eta_p^2 = .07$, or of grasping hand × task × prime group, $F(1, 28) = 0.16$, $p = .7$, $\eta_p^2 = .004$. The only significant interaction was for grasping hand × task, $F(1, 28) = 9.75$, $p = .004$, $\eta_p^2 = .26$. There is some evidence that for touch, contrary to the predictions of the action-specific account, objects may feel larger if the hand is perceived as larger (Bruno & Bertamini, 2010). Consistent with this proposal, pairwise comparisons showed that ratios were significantly greater for the right hand grasping in the HV task (mean difference = 0.021, $p = .011$). In the VV task, ratios for the right hand were not significantly lower, as the action-specific account would predict, though the trend was in this direction (mean difference = -0.015, $p = .08$).

We ran a Bayesian analysis to check the strength of evidence for the null effects revealed by the ANOVA, see Table 1. We used the procedure described by Masson (2011) and the descriptive terms for strength of evidence suggested by Raftery (1995).

**Table 1**

Posterior probabilities for the null [$p_{BIC}(H_0|D)$] and alternative [($p_{BIC}(H_1|D)$] hypotheses for the main effects and interactions in Experiment 2.

| Effect | $p_{BIC}(H_0\|D)$ | $p_{BIC}(H_1\|D)$ | $\eta_p^2$ |
|---|---|---|---|
| Grasping hand | .826** | .174 | .01 |
| Task | .999*** | .001 | .64 |
| Prime group | .723** | .277 | .05 |
| Grasping hand × task | .058 | .942** | .26 |
| Grasping hand × prime group | .643* | .357 | .07 |
| Task × prime group | .833** | .167 | .01 |
| Grasping hand × task × prime group | .837** | .163 | .004 |

**weak evidence, **positive evidence, *** strong evidence*

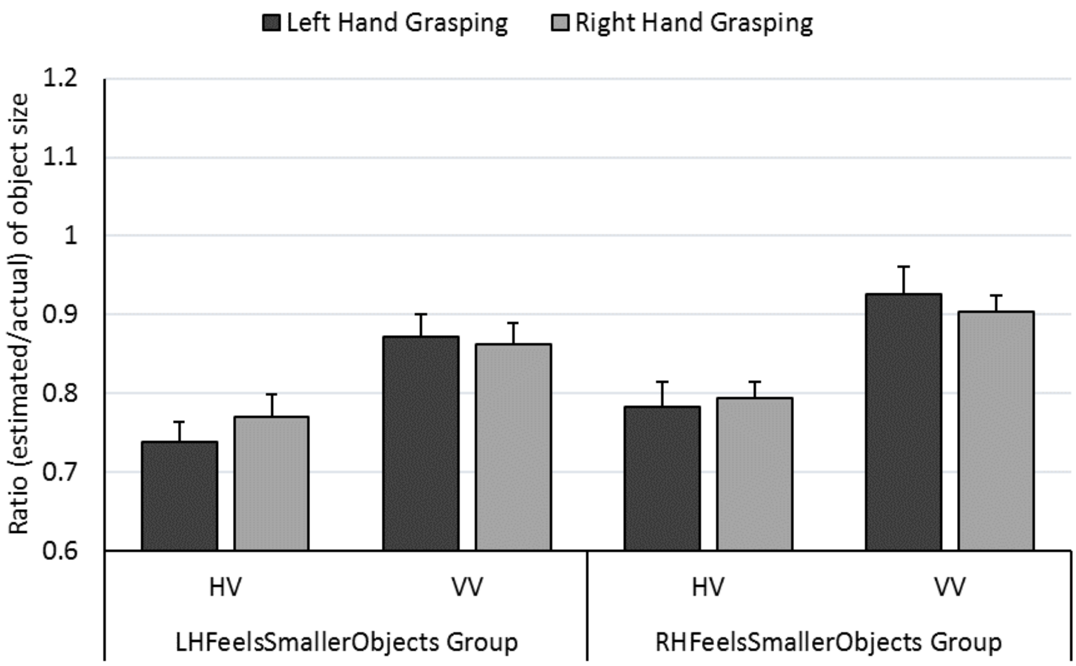


*Figure 2*: Results of the object size estimation task in Experiment 2: Size estimates of objects grasped in the left and right hands in the HV and VV tasks for the LHFeelsSmallerObjects and RHFeelsSmallerObjects prime groups. One-sample t-tests on ratios for the LHFeelsSmallerObjects prime group for the HV-left, HV-right, VV-left and VV-right conditions were all significantly lower than 1, $t(14) = -10.01$, $t(14) = -7.70$, $t(14) = -3.40$, and $t(14) = -4.02$ respectively, all $p < .001$. Similarly, for the RHFeelsSmallerObjects prime group, ratios for HV-left, HV-right, VV-left and VV-right conditions were all significantly lower than 1, $t(14) = -7.40$, $t(14) = -7.77$, $t(14) = -3.50$, and $t(14) = -4.61$ respectively, all $p < .001$. Error bars show +/- one standard error of the mean.

**Actual grasping capacity**

A mixed ANOVA analysing the maximum grasp for each grasping hand (left/right) as a within-participants factor and prime group (LHFeelsSmallerObjects/RHFeelsSmallerObjects) as a between-participants factor was conducted. This revealed no effect of grasping hand, $F(1, 28) = 0.33$, $p = .6$, $\eta_p^2 = .01$, prime group, $F(1, 28) = 1.22$, $p = .3$, $\eta_p^2 = .04$, or a grasping hand × prime group interaction, $F(1, 28) = 1.318$, $p = .3$, $\eta_p^2 = .05$. Thus although Experiment 1 found that most right handed observers think that their right hand is larger than their left, we found no evidence in Experiment 2 that the right hand actually has a greater grasping capacity than the left hand.

### 2.4.3 Discussion

In Experiment 2 we tested whether perceived differences in grasping capacity would influence the perceived size of objects presented either visually or haptically. There were two reasons why objects grasped by the right hand might be perceived as smaller than objects grasped by the left hand: first, a pre-existing tendency for right-handers to overestimate the size of their right hand (Linkenauger et al., 2009; replicated in Experiment 1 here) which could lead to them overestimating the grasping capacity of their right hand (Linkenauger, Witt & Proffitt, 2011); and, second, a priming manipulation intended to make observers feel that their right hand had a greater grasping capacity by having it grasp a set of smaller objects than the left hand before estimates were made. We also tested whether being primed to feel that the left hand had a greater grasping capacity would reduce estimates of object size for objects grasped in the left hand.

Our results suggest that neither our priming manipulation nor a pre-existing overestimation of the grasping capacity of the right hand influenced visually perceived object size. We thus found no action-specific scaling effect for visually presented stimuli. The only effect we found was that, for the HV task, objects grasped in the right hand were estimated as slightly larger than objects grasped in the left hand, regardless of priming group. This result is consistent with findings that unseen stimuli are estimated as larger if they are felt by a body part which is perceived as larger (Bruno & Bertamini, 2010; Taylor-Clarke et al., 2004). This latter, size-scaling effect was in the opposite direction to that predicted by the action-specific account, so we suggest that it does not reflect perceptual scaling based on perceived grasping capacity. Instead, this effect may reflect a difference in the perceived size of the left and right hands, consistent with the results of Experiment 1. This effect may arise from the greater representation in the somatosensory cortex of the right than the left hand for right handers (Sörös, Knecht, Imai, Gürtler, Lütkenhöner et al., 1999). This implies that the right hand may have smaller receptive fields and be more sensitive to touch than the left hand causing unseen objects held in the right hand to be estimated as larger. This suggests that the acuity of touch may influence visual estimates of object size as a result of multimodal integration. In summary, Experiment 2 suggested that perceived object size was not influenced in ways predicted by the action-specific account.

## 2.5 Experiment 3

Experiment 1 demonstrated that right-handed observers perceived their right hand as larger than their left hand whilst Experiment 2 suggested that this asymmetry in perceived hand size does not lead to differences in perceived object size when attention is not explicitly drawn to action capacity. However, we did not measure perceived maximum grasp in Experiment 2 so we could not be certain that our hand dominance and priming manipulations of perceived action capacity were effective. To address this point, in Experiment 3 we used the VV task from Experiment 2 to measure perceived object size and then, afterwards, we measured perceived maximum grasping capacity for each hand.

### 2.5.1 Method

#### 2.5.1.1 Participants

Thirty right-handed undergraduate students from the University of Liverpool (22 females, mean age = 19.9 years, mean Edinburgh Handedness Inventory score = 85, range = 37.5-100) were recruited for this experiment. Participants either volunteered or were rewarded with course credit.

#### 2.5.1.2 Apparatus, stimuli, design and procedure

The stimuli, design and procedure were identical to Experiment 2, except that there was no HV task and perceived maximum grasping capacity for each hand was measured after completion of the VV task. Here, participants were asked which block they believed was the largest they could grasp (again, using their thumb on one side and any other finger on the opposite side) in each hand. Participants saw nine foam board blocks, 0.5cm deep, which were laid out in size order on a shelf from 14 cm (on the far left) to 22 cm (on the far right), in 1cm increments. Participants pointed at the block that they believed was the biggest one they could grasp.

### 2.5.2 Results

No participant correctly guessed the main manipulation and purpose of the experiment without prompting from the experimenter. Details of the responses to the post-experimental questions can be found in Appendix J. We first discuss the results for the VV task which measured perceived object size, followed by the results for perceived and for actual grasping capacity.

**Perceived object size**

Ratios were calculated for each block as in Experiment 2. For consistency with Linkenauger, Witt and Proffitt (2011), here we report only the results for stimuli that participants perceived they could grasp (results for the full dataset are reported in

Appendix B, and results based on whether participants could actually grasp the stimuli are reported in Appendix C).

A mixed ANOVA with grasping hand (left/right) as a within-participants factor and prime group (LHFeelsSmallerObjects/RHFeelsSmallerObjects) as a between-participants factor was conducted. This revealed no significant effects of grasping hand, $F(1, 28) = 1.70$, $p = .2$, $\eta_p^2 = .06$, prime group, $F(1, 28) = 0.39$, $p = .5$, $\eta_p^2 = .01$, or of grasping hand × prime group, $F(1, 28) = 0.20$, $p = .7$, $\eta_p^2 = .004$, see Figure 3. As in Experiment 2, we ran a Bayesian analysis to check the strength of evidence for the null effects revealed by the ANOVA, see Table 2.

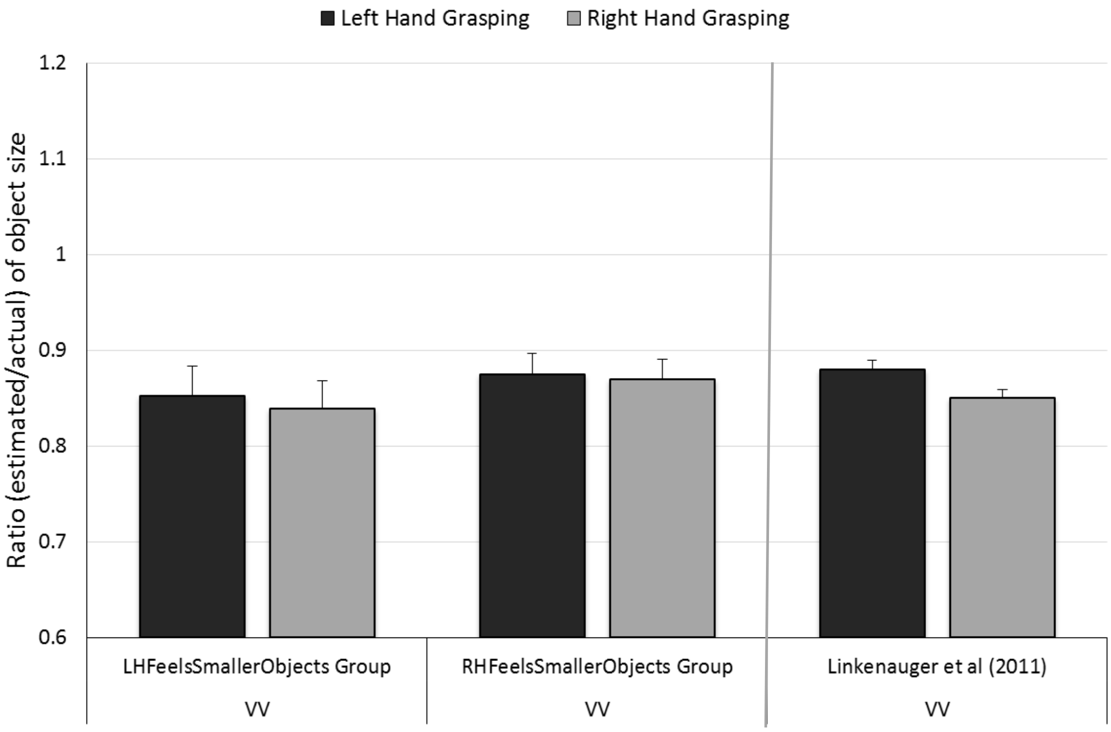


*Figure 3*: Results of the object size estimation task in Experiment 3: Size estimates of objects grasped in the left and right hands in the VV task for the LHFeelsSmallerObjects and RHFeelsSmallerObjects prime groups. For comparison, we include data from Linkenauger, Witt and Proffitt (2011). One-sample t-tests showed that ratios for the VV-left and VV-right conditions were both significantly lower than 1 for the LHFeelsSmallerObjects group ($t(14) = -4.89$, and $t(14) = -5.69$ respectively), and for the RHFeelsSmallerObjects group ($t(14) = -5.97$, and $t(14) = -6.40$ respectively), all $p < .001$. Error bars show +/- one standard error of the mean.

**Table 2**

Posterior probabilities for the null [$p_{BIC}(H_0|D)$] and alternative [($p_{BIC}(H_1|D)$] hypotheses for the main effects and interactions in Experiment 3.

| Effect | $p_{BIC}(H_0\|D)$ | $p_{BIC}(H_1\|D)$ | $\eta_p^2$ |
|---|---|---|---|
| Grasping hand | .694* | .306 | .06 |
| Prime group | .816** | .184 | .01 |
| Grasping hand × prime group | .838** | .162 | .004 |

**weak evidence*, ***positive evidence*

## Actual and perceived grasping capacity

We analysed participant's perceived and actual maximum grasp for their left and right hands in separate[1] mixed ANOVAs where hand (left/right) was a within-participants factor and prime group (LHFeelsSmallerObjects/RHFeelsSmallerObjects) was a between-subjects factor. For *perceived grasp*, maximum grasp for the right hand (18.0 cm) was greater than for the left hand (17.5 cm), $F(1, 28) = 10.85$, $p = .003$, $\eta_p^2 = .30$. There was no significant effect of prime group, $F(1, 28) = 1.15$, $p = .3$, $\eta_p^2 = .04$, or of hand × prime group, $F(1, 28) = 1.61$, $p = .2$, $\eta_p^2 = .05$. For *actual grasp*, maximum grasp for the right hand (16.2 cm) did not differ from the left hand (16.3 cm), $F(1, 28) = 1.11$, $p = .3$, $\eta_p^2 = .04$. There was no significant effect of prime group, $F(1, 28) = 1.01$, $p = .3$, $\eta_p^2 = .04$, or of hand × prime group, $F(1, 28) = 0.001$, $p = .9$, $\eta_p^2 < .001$. Together these results suggest that these right-handed participants estimated the maximum grasp of their right hand as greater than that of their left (replicating Experiment 1) but that there was no difference in the actual grasping capacities of their hands (replicating Experiment 2).

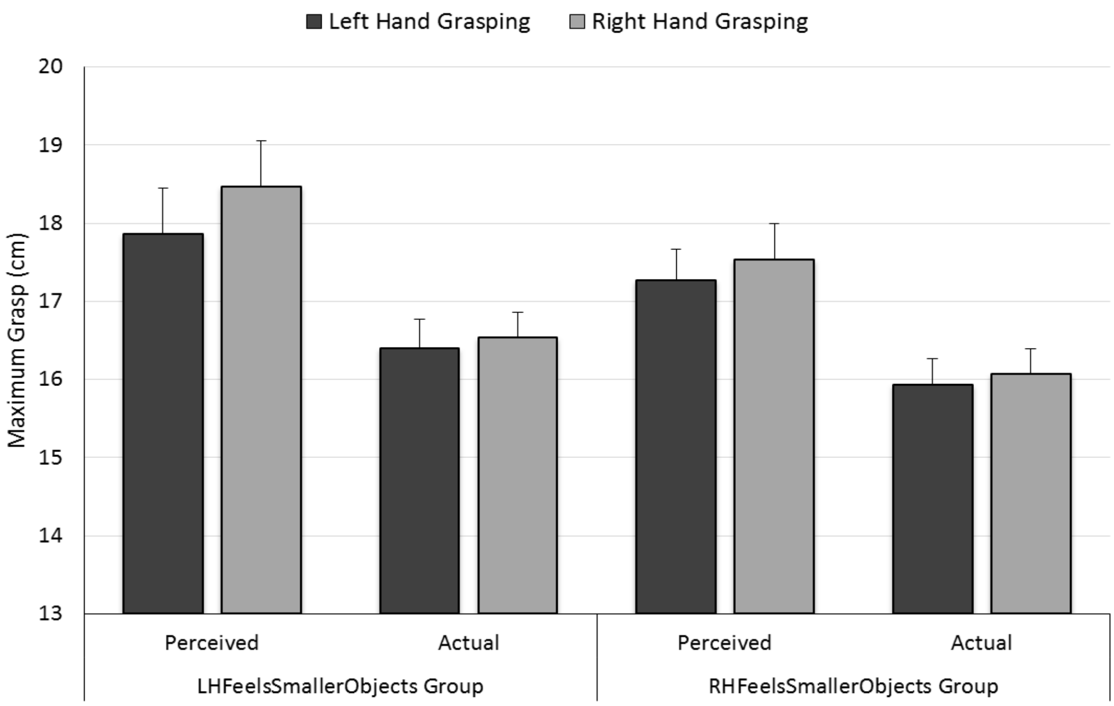


*Figure 4*: Results of the maximum grasping capacity tasks in Experiment 3: Estimates of maximum grasp for the left and right hands for the LHFeelsSmallerObjects and RHFeelsSmallerObjects groups. Perceived grasp is the largest block participants believed they could grasp. Actual grasp is the largest block that could be grasped in each hand. Error bars represent +/- one standard error of the mean.

### 2.5.3 Discussion

In Experiment 3 we showed that, regardless of prime group, participants overestimated the grasping capacity of their right hand relative to their left hand. This supports the findings of Experiment 1 which showed that right handers usually think their right hand is larger than their left hand. Nevertheless, replicating the results of Experiment 2, neither a pre-existing overestimation of the grasping capacity of the right hand, nor our priming manipulation influenced estimates of object size. Thus, although participants overestimated the grasping capacity of their right hand relative to their left hand, this did not influence their perception of object size when no attention was drawn to action. Together these results suggest that perceived object size is not directly influenced by perceived action capacity.

## 2.6 Experiment 4

In Experiments 2 and 3 we found no evidence that overestimating the grasping ability of one hand relative to the other has a direct influence on visual perceptions of object size. Consistent with Linkenauger et al. (2009; Linkenauger, Witt & Proffitt, 2011), in Experiment 1, right-handers *perceived* their right hand as larger than their left, and in Experiment 3 participants *perceived* the grasping capacity of their right hand as larger than their left hand. However, this latter effect was modest, with the right hand estimated as being able to grasp objects that were, on average, only 0.5 cm larger. Furthermore, Experiment 3 showed that there was no difference in the *actual* grasping capacity of the right and left hands, replicating Linkenauger, Witt and Proffitt (2011). Finally, our priming manipulation in Experiment 3 did not influence the relative perceived grasping capacity of the hands. This might be because the effect of priming dissipated during the size estimation task and thus was not detected in the subsequent grasping capacity task. Here, if acting rapidly recalibrates perceived action capacity (Franchak & Adolph, 2014) then grasping during the VV task may have overridden any changes in perceived grasping capacity from the priming manipulation.

Thus, it is possible that in Experiments 2 and 3 we found no scaling effects on perceived object size that were consistent with the action-specific account because there was only a modest difference in the *perceived* grasping capacity of the left and right hands, or because there was no difference in the *actual* grasping capacity of the left and right hands. Related to this second point, Sugovic et al. (2016) found that only actual differences in body size, and not people's beliefs or perceptions about their body size, affected spatial perception. To examine both of these possibilities, in Experiment 4 we used a more powerful taping manipulation which produced substantial changes in actual as well as perceived grasping capacity.

Surprisingly, comparisons between conditions where the spatial extent to be estimated is kept constant but action capacity is varied have rarely been reported in the action-specific literature, although some manipulations which alter the action boundaries of the body have been previously shown to influence spatial perception (Lessard, Creem-Regehr & Stefanucci, 2012; Witt et al., 2005). One such study was conducted by Shaffer and Flint (2011) who showed that estimated slant for an escalator did not differ to estimated slant for a set of stairs. This is inconsistent with the action-specific account which suggests that the stairs should have appeared steeper because they require effort to climb, unlike standing on an escalator. In Experiment 4 here, to directly alter participants' ability to grasp objects, we taped together the fingers of one hand to reduce its grasping capacity relative to the untaped hand. We predicted that participants would estimate their maximum grasp to be lower when their hand was taped relative to when it was untaped. Nevertheless, based on the results of Experiments 2 and 3, we predicted that even if there was a large change in perceived (and actual) action capacity following taping this would not alter estimates of object size.

### 2.6.1 Method

#### 2.6.1.1 Participants

Thirty right handed undergraduate students (26 females, mean age = 20.1 years, mean Edinburgh Handedness Quotient score = 81, range = 50-100) were recruited from the University of Liverpool. Participants either volunteered or received course credit for their time.

#### 2.6.1.2 Apparatus, stimuli and procedure

The stimuli, apparatus and procedure were identical to Experiment 3 apart from the following changes. First, we included the HV task from Experiment 2. Second, instead of the priming phase the fingers were taped on either the left hand (LHTaped group) or the right hand (RHTaped group). The middle and ring fingers were first taped together above the proximal interphalangeal (middle) finger joint, then all four fingers were taped together just under the same joint. The hand remained taped whilst participants completed the HV and then the VV tasks. After completing these two object size estimation tasks, participants' perceived maximum grasp followed by actual maximum grasp were measured for the untaped hand, then for the taped hand, and finally for the taped hand after removing the tape. The post-experimental questions were similar to those asked in Experiments 2 and 3, but were re-worded to better fit the taping manipulation.

### 2.6.2 Results

No participant correctly guessed the main manipulation and purpose of the experiment without prompting from the experimenter. Details of the responses to the post-experimental questions can be found in Appendix J. We first discuss the results for the HV and VV tasks which measured perceived object size, followed by the results for perceived and actual grasping capacity.

**Perceived object size**

Ratios were calculated for each block as in Experiments 2 and 3. For consistency with Linkenauger, Witt and Proffitt (2011), here we report only the results for stimuli that participants perceived they could grasp (results for the full dataset are reported in Appendix D, and results based on whether participants could actually grasp the stimuli are reported in Appendix E).

A mixed ANOVA with grasping hand (left/right) and task (HV/VV) as within-participants factors and tape group (LHTaped/RHTaped) as a between-participants factor was conducted, see Figure 5. Importantly, no significant effect was found for grasping hand $F(1, 28) = 0.33$, $p = .6$, $\eta_p^2 = .01$. As in Experiment 2, ratios were significantly lower for the HV task (0.84) than the VV task (0.95), $F(1, 28) = 16.28$, $p < .001$, $\eta_p^2 = .37$, so people underestimated size more when the blocks were perceived haptically rather than visually. There were no other significant effects: tape group, $F(1, 28) = 2.42$, $p = .1$, $\eta_p^2 = .08$; task × tape group, $F(1, 28) = 2.44$, $p = .1$, $\eta_p^2 = .08$; grasping hand × tape group, $F(1, 28) = 1.10$, $p = .3$, $\eta_p^2 = .04$; task × grasping hand, $F(1, 28) = 0.11$, $p = .7$, $\eta_p^2 = .01$; grasping hand × task × tape group, $F(1, 28) = 0.28$, $p = .6$, $\eta_p^2 = .01$.

As in Experiments 2 and 3, we ran a Bayesian analysis to check the strength of evidence for the null effects revealed by the ANOVA, see Table 3.

**Table 3**

Posterior probabilities for the null [$p_{BIC}(H_0|D)$] and alternative [($p_{BIC}(H_1|D)$] hypotheses for the main effects and interactions in Experiment 4.

| Effect | $p_{BIC}(H_0\|D)$ | $p_{BIC}(H_1\|D)$ | $\eta_p^2$ |
|---|---|---|---|
| Grasping hand | .812** | .179 | .01 |
| Task | .006 | .994*** | .37 |
| Tape group | .611* | .389 | .08 |
| Grasping hand × task | .838** | .162 | .004 |
| Grasping hand × tape group | .754** | .246 | .04 |
| Task × tape group | .610* | .390 | .08 |
| Grasping hand × task × tape group | .825** | .175 | .01 |

**weak evidence*, ***positive evidence*, *** *strong evidence*

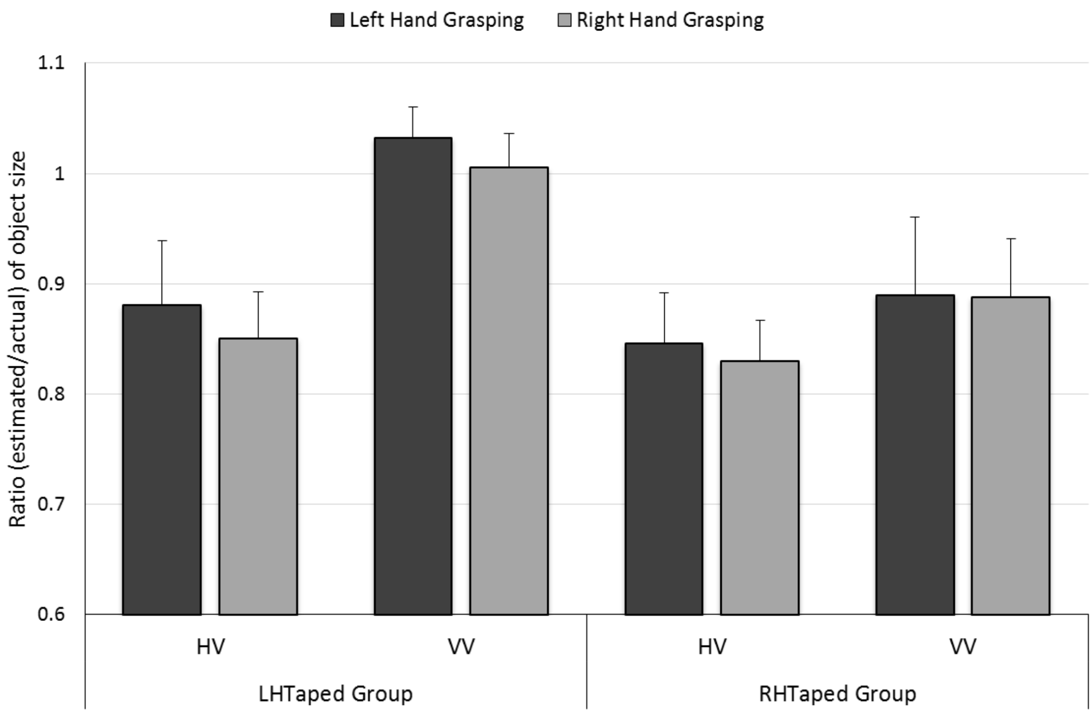


*Figure 5*: Results of the object size estimation task in Experiment 4: Size estimates of objects grasped in the left and right hands in the HV and VV tasks for the LHTaped and RHTaped tape groups. One-sample t-tests showed that for the LHTaped group, the HV-left and HV-right conditions were significantly lower than 1 ($t$(14) = -2.61, $p$ = .02, and $t$(14) = -4.03, $p$ = .001 respectively), whereas ratios for the VV-left and VV-right conditions did not differ from 1 ($t$(14) = 0.45, $p$ = .7, and $t$(14) = 0.07, $p$ = .9 respectively). For the RHTaped group, ratios for the HV-left, HV-right, VV-left and VV-right conditions were all significantly lower than 1 ($t$(14) = -4.00, $t$(14) = -3.99, $t$(14) = -3.84, and $t$(14) = -3.83 respectively, all $p$ < .001). Error bars show +/- one standard error of the mean

**Actual and perceived grasping capacity**

We analysed participants' perceived and actual maximum grasp for their left and right hands in separate[2] ANOVAs, where grasping hand (left/right) was a within-participants factor and tape group (LHTaped/RHTaped) was a between-participants factor ($p$-values for pairwise comparisons were Bonferroni corrected). For *perceived grasp* there was no significant effect of grasping hand, $F(1, 28) = 0.51$, $p = .8$, $\eta_p^2 = .02$, or of tape group, $F(1, 28) = 1.52$, $p = .2$, $\eta_p^2 = .05$, but there was a grasping hand × tape group interaction, $F(1, 28) = 118.37$, $p < .001$, $\eta_p^2 = .81$. Pairwise comparisons showed that, as expected, perceived maximum grasp was smaller for the left hand (14.9 cm) than the right hand (18.1 cm) in the LHTaped group (mean difference = -3.3 cm, $p < .001$), but was larger for the left hand (17.5 cm) than the right hand (14.4 cm) in the RHTaped group (mean difference = 3.1 cm, $p < .001$). Thus, both groups appropriately recalibrated their estimates of maximum grasp following taping of their hand.

Similarly, for *actual grasp*, there was no significant effect of grasping hand, $F(1, 28) = 0.40$, $p = 0.8$, $\eta_p^2 = .01$, or of tape group, $F(1, 28) = 0.06$, $p = .8$, $\eta_p^2 = .02$, but grasping hand × tape group was again significant, $F(1, 28) = 54.76$, $p < .001$, $\eta_p^2 = .66$. Pairwise comparisons showed that actual maximum grasp was smaller for the left hand (14.7 cm) than the right hand (15.9 cm) in the LHTaped group (mean difference = -1.3 cm, $p < .001$), but was larger for the left hand (16.0 cm) than the right hand (14.8 cm) in the RHTaped group (mean difference = 1.2 cm, $p < .001$). Thus, for both groups, taping a hand reduced the size of the biggest block it could actually grasp, with a similar, but enhanced, pattern of effects on perceived grasp, see Figure 6.

### 2.6.3 Discussion

In Experiment 4, taping one hand reduced estimates of the perceived maximum grasping capacity of that hand by, on average, 3.2cm, and actual grasp by 1.2cm, relative to the untaped hand, see Figure 6. This powerful manipulation had, though, no influence on estimates of object size, see Figure 5. Experiments 2 and 3 found no evidence that a difference in perceived grasping capacity (either due to right-hand dominance or to priming) influenced perceived object size. Experiment 4 provided direct experimental evidence supporting this finding. Participants rapidly and appropriately recalibrated their perceived action capacity when their fingers were taped together (see also Franchak & Adolph, 2014; Ishak et al., 2008). However, this recalibration had no impact on perceived object size. We also found no evidence that actual grasping capacity influences perceived object size.

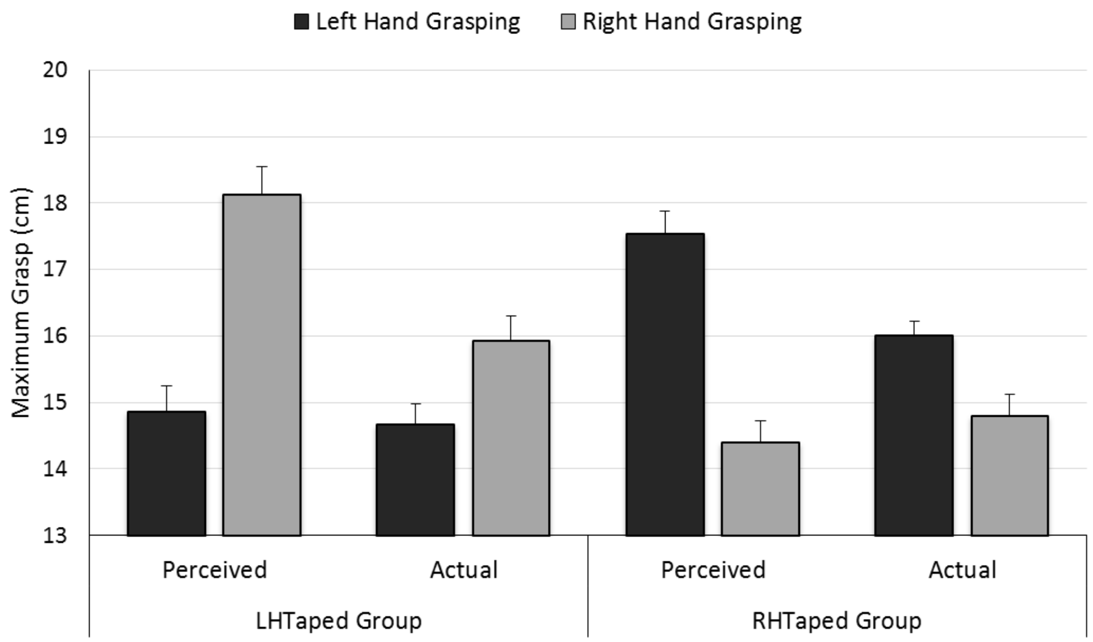


*Figure 6*: Results of the maximum grasping capacity tasks in Experiment 4: Estimates of maximum grasp for the left and right hands for the LHTaped and RHTaped groups. Perceived grasp is the largest block participants believed they could grasp. Actual grasp is the largest block that they could, in fact, grasp. Error bars represent +/- one standard error of the mean.

## 2.7 Experiment 5

Together, the results of Experiments 2-4 suggest that grasping capacity does not directly influence perceived object size. This conclusion is not consistent with Linkenauger, Witt and Proffitt (2011) who concluded that because right handers perceive their right hand as having a greater grasping capacity then objects grasped by the right hand are perceived as smaller than those grasped by the left hand. However, the method used in our experiments deviated in a number of ways from the experiments of Linkenauger, Witt and Proffitt (2011). For example, since the blocks were placed under the monitor, participants may have tried to use landmark matching to make their estimates (though some evidence suggests that people do not spontaneously use landmark matching, e.g. Lawson & Bertamini, 2006, Experiment 4, and note that the blocks were offset from the response lines, see Figure 1A).

Arguably the most important change made was that we did not ask participants about their grasping capacity on each size estimation trial. As discussed in the introduction, we reasoned that if intending to act is sufficient to induce action-specific scaling effects, then scaling effects should occur if participants actually grasp an object and not only when they imagine grasping it. Actual grasping preceded every size estimation trial in Experiments 2-4 and yet we found no action-specific scaling effects. We made this change due to our concern that the results reported by Linkenauger, Witt and Proffitt (2011) could have arisen because imagining grasping an object in order to verbally report its graspability may have drawn attention to action. This may have led their participants to conflate estimates of action capacity (graspability) with their subsequent estimates of object size. If so, then their participants may not have experienced a change in perceived object size in the strongest sense. However, it could be argued that, in Experiments 2-4, we not only removed this potential conflation but that we also removed participants' intention to act on the object that they were estimating the size of. This is because our participants had finished picking up and moving the object before they estimated its size, and they did not act on it again until after making their estimates. It is also possible that because grasping is such an everyday action, participants were not thinking about the action in a way which made it seem relevant to the task. We tackled these possibilities, and others, in Experiment 5 by moving to a method more similar to that used by Linkenauger, Witt and Proffitt (2011), as described below.

Importantly, though, we wanted to still ensure that any effects that we observed could not be attributed to demand characteristics, which has been a concern with the action-specific account (for reviews see Firestone, 2013; Firestone & Scholl, 2015; Philbeck & Witt, 2015), or conflation. Demand characteristics refer to participants altering their behaviour in accordance with what they believe the experimenter's hypothesis to be. A number of studies have tried to control for demand characteristics, for example by assessing individual differences (Linkenauger, Witt & Proffitt, 2011, Experiment 3) or by using indirect measures (Witt, 2011b). However, there is evidence that when demand characteristics are reduced, for example by giving participants a cover story for an otherwise unexplained manipulation, action-specific effects may disappear. For example, Durgin et al. (2009; see also Durgin, Klein, Spiefel, Strawster & Williams, 2012; Shaffer, McManama, Swank & Durgin, 2013) showed that participants wearing a heavy backpack did not estimate slant as steeper than those who did not wear a backpack when they were told that the backpack contained equipment that monitored their ankle muscles. This suggests that when no explanation is provided for wearing the backpack, participants may infer that wearing it is intended to increase their estimates of slant, and so they might adjust their estimates accordingly.

Thus, in Experiment 5, although we explicitly told participants that we were interested in graspability, and although on every trial they actually grasped the object both before and after estimating its size, we used a cover story to minimise the chances of finding an effect simply due to conflation or demand characteristics. Specifically, we told participants that, for practical reasons, we were running two separate studies simultaneously, one of which was a grasping task and the other was a size matching task. They were told that the experimenter would record how they grasped each object to provide data for a control study about grasping behaviour which was independent of the main experiment in which they estimated object size. We also provided a cover story for the post-estimation grasp by asking participants to hand the object back to the experimenter after making their size estimate. Finally, we made a number of further changes (such as removing the priming and HV tasks, blocking rather than randomising trials with each hand, and having the non-action-relevant hand make responses) to further reduce the differences between our previous experiments and those of Linkenauger, Witt and Proffitt (2011).

In Experiment 5 we manipulated perceived graspability using the same, direct manipulation of hand taping that we used in Experiment 4, as well as using the pre-existing effect of right-hand dominance used in Experiments 2-4. We minimised conflation effects using a cover story and tested whether our previous results were due to participants in Experiments 2-4 not thinking about grasping when they estimated object size. If the results of Experiment 5 show an effect of perceived grasping capacity on estimated object size, this would replicate the findings of Linkenauger, Witt and Proffitt (2011) and suggest that the lack of an immediate intention to act may be the critical difference between their studies and Experiments 2-4 here. However, if the results showed no such effect, it would suggest that having an intention to grasp is not sufficient to scale perceived object size. This, in turn, would suggest that Linkenauger, Witt and Proffitt (2011) results may have arisen because their participant's attention was drawn to the possible association between grasping capacity and object size, and not due to cognitive penetrability resulting in perceptual scaling in the strongest sense (Firestone & Scholl, 2015).

### 2.7.1 Method

#### 2.7.1.1 Participants

Thirty-two (24 females, mean age = 19.3 years, mean Edinburgh Handedness Inventory score = 91, range = 62.5-100) right handed participants were recruited for this study. Participants either volunteered or were rewarded with course credit for their time.

#### 2.7.1.2 The instructions

In Experiment 5, we ensured that participants were thinking about grasping by informing them at the beginning of the experiment that we were interested in both how they grasped the blocks and how well they could visually match the size of the blocks. They were told that they would do two separate studies during the same session, due to time constraints in data collection. We also told them that they would have to hand the blocks back to the experimenter after making their size estimates. The full instructions are given in Appendix F.

#### 2.7.1.3 Apparatus, stimuli and procedure

The apparatus, stimuli and procedure were identical to Experiment 4 apart from the following changes. We used a laptop (monitor = 27 × 35 cm) which was placed at 90$^{o}$ to the participant. The laptop was placed on the opposite side to the grasping hand used for that block and, to be consistent with Linkenauger, Witt and Proffitt (2011), participants responded with the non-grasping hand. For example, if they grasped the block with their left hand, the laptop was placed on their right hand side and they responded with their right hand. Responses were made using the up and down arrow keys on the laptop keyboard (to move the lines further apart and closer together respectively). Trials were blocked by hand. There was no HV task and, instead, participants completed three subblocks of the VV task. In one subblock, they grasped the blocks with their untaped left hand and estimated size with their untaped right hand, and in a second subblock the assignment of task to hands was reversed. In the third subblock, participants had the fingers of one hand taped as in Experiment 4 and they grasped blocks with their taped hand and responded with their untaped hand. Half of the participants completed the first two subblocks in each order and, of these, half had their left hand taped (LHTaped Group) and half had their right hand taped (RHTaped group) in the final subblock.

The box was removed so participants saw the blocks before they grasped them. The experimenter checked whether participants performed the specified grasp on each trial, see Appendix G. If participants did not initially attempt the specified grasp, they were reminded to do so by the experimenter. If the object was too big to be successfully grasped in this way, the experimenter recorded how the participant then chose to pick up the object (e.g., by the corner). Participants completed 63 VV trials (21 stimuli x 3 subblocks) and the whole procedure lasted around 30 minutes.

### 2.7.2 Results

One participant correctly guessed the aims and purpose of the experiment during the post-experimental questions (after question 3) but their data was still included in the analysis. As has been done in previous work investigating participants' beliefs (e.g. Durgin et al., 2012) we provide responses to the post-experimental questions in Appendix K. In this section, we first discuss the results for the VV task which measured perceived object size, followed by the results for perceived and actual grasping capacity.

**Perceived object size**

Ratios were calculated for each block, as in Experiments 2-4. For consistency with Linkenauger, Witt and Proffitt (2011), here we report only the results for stimuli that participants perceived they could grasp (results for the full dataset are reported in Appendix H, and results based on whether participants could actually grasp the stimuli are reported in Appendix I).

A mixed ANOVA with grasping hand (left/right/taped) as a within-participants factor and tape group (LHTaped/RHTaped) as a between-participants factor was conducted. This revealed that neither grasping hand, $F(2, 60) = 0.48$, $p = .6$, $\eta_p^2 = .02$, nor tape group, $F(1, 30) = 0.95$, $p = .4$, $\eta_p^2 = .03$, influenced estimated object size, and there was no grasping hand × tape group interaction, $F(2, 60) = 0.16$, $p = .9$, $\eta_p^2 = .01$, see Figure 7. As in Experiments 2-4, we ran a Bayesian analysis to test the strength of evidence for the null effects revealed by the ANOVA, see Table 4.

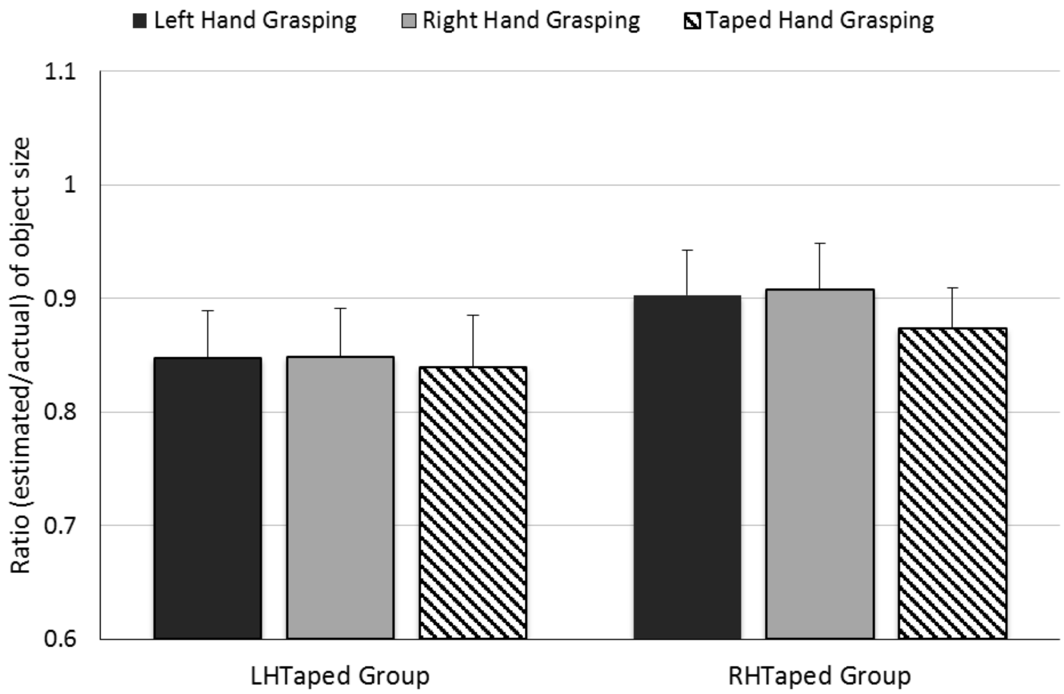


*Figure 7*: Results of the object size estimation task in Experiment 5: Size estimates of objects grasped in the left, right and taped hands for the LHtaped and RHTaped groups. One-sample t-tests showed that for the LHTaped group, estimates for the left, right and taped hands were all significantly lower than 1 ($t(15) = -3.85$, $p = .002$, $t(15) = -3.77$, $p = .002$, and $t(15) = -4.47$, $p < .001$, respectively). For the RHTaped group, estimates for the left and taped hands were significantly lower than 1 ($t(15) = -2.32$, $p = .035$, and $t(15) = -2.74$, $p = .015$, respectively) and estimates for the right hand were marginally lower than 1 ($t(15) = -2.13$, $p = .05$). Error bars show +/- one standard error of the mean.

**Table 4**

Posterior probabilities for the null [$p_{BIC}(H_0|D)$] and alternative [($p_{BIC}(H_1|D)$] hypothesis for the main effects and interactions in Experiment 5.

| Effect | $p_{BIC}(H_0\|D)$ | $p_{BIC}(H_1\|D)$ | $\eta_p^2$ |
|---|---|---|---|
| Grasping hand | .961*** | .039 | .02 |
| Tape group | .775** | .225 | .03 |
| Grasping hand × tape group | .967*** | .033 | .01 |

***positive evidence*, *** *strong evidence*

**Actual and perceived grasping capacity**

We analysed participant's perceived and actual maximum grasp for their left and right hands in separate[3] mixed ANOVAs where hand (left/right/taped) was a within-participants factor and tape group (LHTaped/RHTaped) was a between-subjects factor. For *perceived grasp*, the right hand (17.0 cm) was perceived as having a greater grasping capacity than both the left hand (16.4 cm) and the taped hand (15.8 cm), $F(2, 60) = 20.50$, $p < .001$, $\eta_p^2 = .41$, see Figure 8. There was no effect of tape group, $F(1, 30) = 0.60$, $p = .5$, $\eta_p^2 = .02$, nor a hand × tape group interaction, $F(2, 60) = 2.39$, $p = .1$, $\eta_p^2 = .07$. For *actual grasp*, the right (16.0 cm) and left (16.0 cm) hands did not differ, but the taped hand was significantly less (14.5 cm), $F(2, 60) = 73.47$, $p < .001$, $\eta_p^2 = 0.71$. There was no effect of tape group, $F(1, 30) = 0.24$, $p = .6$, $\eta_p^2 = .01$, but there was a hand × tape group interaction, $F(2, 60) = 4.306$, $p = .018$, $\eta_p^2 = .13$. For both groups, taping reduced actual maximum grasp relative to both hands, with this reduction being somewhat larger for the LHTaped group (mean 1.8 cm) than the RHTaped group (mean 1.1 cm).

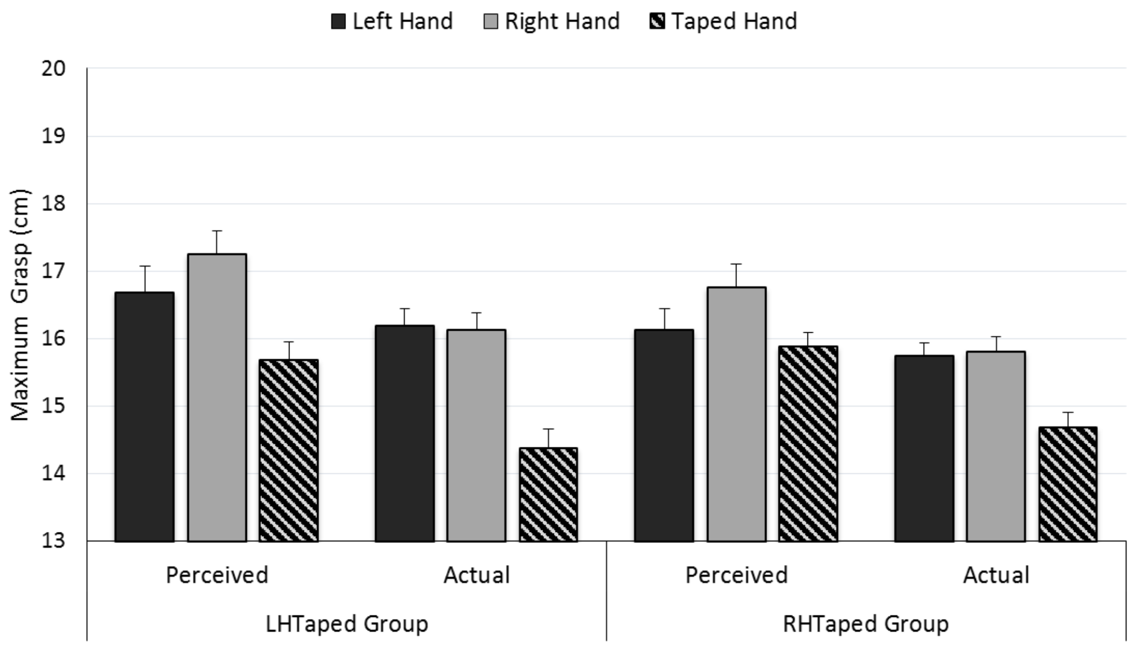


*Figure 8*: Results of the maximum grasping capacity tasks in Experiment 5: Estimates of maximum grasp for the left and right hands for the LHTaped and RHTaped groups. Perceived grasp is the largest block participants believed they could grasp. Actual grasp is the largest block that could, in fact, be grasped. Error bars represent +/- one standard error of the mean.

### 2.7.3 Discussion

In Experiment 5, we eliminated a number of methodological differences between Experiments 2-4 reported here and the experiments reported by Linkenauger, Witt and Proffitt (2011) in order to test whether these differences could explain why Linkenauger, Witt and Proffitt (2011) found an effect of grasping capacity on perceived object size but we did not. Most importantly, we changed our instructions so participants were explicitly told that we were interested in whether they could grasp each object using their thumb and finger. In addition, we changed the trial procedure so that participants always intended to act on the object when they were estimating its size, by having them pick up the object to give it back to the experimenter after making their size estimate. Nevertheless, we replicated our findings from Experiment 4. Specifically, although participants believed they could grasp larger objects with their right compared to their left hand, and with their untaped rather than their taped hand (see Figure 8), neither of these effects on perceived action capacity modulated their estimates of object size (see Figure 7).

Participants in Experiment 5 both intended to act, and did indeed act, on a given object both before and after estimating the size of that object, and they were explicitly and repeatedly told that we were assessing both their grasping capacity and their estimates of object size. However, we provided a cover story to persuade participants that there was no relation between our interest in their grasping capacity and in their object size estimates (only one participant guessed the true purpose of the study). Instead Linkenauger, Witt and Proffitt’s (2011) results may have reflected a conflation of estimates of perceived grasping capacity and of object size which arose from asking participants about both action capacity and object size on each trial without providing any explanation of why both measures were being taken (Collier & Lawson, 2017b).

## 2.8 General Discussion

The action-specific account of perception suggests that an observer’s action capacity scales how they perceive the spatial properties of the environment (Bhalla & Proffitt, 1999; Fajen, 2005; Linkenauger et al., 2009; Linkenauger, Witt & Proffitt, 2011; Linkenauger, Mohler & Proffitt, 2011; Proffitt et al., 1995; 2003; Proffitt, 2006a; 2006b; 2013; Proffitt & Linkenauger, 2013; Witt et al., 2004; 2005; Witt, 2011a; Witt & Riley, 2014). However, other evidence suggests that estimates of spatial attributes, such as distance, may only scale according to action capacity when observers are encouraged to consider non-visual factors (Woods et al., 2009; Firestone, 2013).

In five experiments, we tested whether the perceived size of graspable objects is scaled according to people's ability to pick up those objects. We began by testing the claim that right handed individuals overestimate the grasping capacity of their right hand relative to their left hand and, because of this, they underestimate the size of objects to-be-grasped in their right hand (Linkenauger et al., 2009; Linkenauger, Witt & Proffitt, 2011). We replicated the finding that right handers perceive their right hand as both larger (Experiment 1) and as having a greater grasping capacity (Experiments 3 and 5) than their left hand. In addition, when the fingers of one hand were taped together, participants appropriately reduced their estimates of the maximum grasp of that hand (Experiments 4 and 5). However, none of our three manipulations of perceived grasping capacity – right hand dominance (Experiments 2, 3 and 5), priming (Experiments 2 and 3) and restricting the grasp of the hand by taping (Experiments 4 and 5) – reliably modulated estimates of object size, whether objects were presented visually (for the VV tasks) or haptically (for the HV tasks). Thus, we did not replicate the results of Linkenauger, Witt and Proffitt (2011) since we failed to find the predicted influence of perceived action capacity on spatial perception.

The exact relationship between spatial properties and perceived action capacity is not yet fully understood (Cañal-Bruland & van der Kamp, 2015). Nevertheless, our results are consistent with previous work demonstrating that estimates of spatial features are not always predicted by perceived action capacity (e.g. de Grave et al., 2011; Woods et al., 2009). For example, Cañal-Bruland, Aertssen, Ham and Stins (2015) failed to replicate the reported finding that decreasing postural stability makes walkable beams appear narrower (Geuss, Stefanucci, de Benedictis-Kessner & Stevens, 2010). Other studies have shown that providing a cover story for otherwise unexplained task manipulations can offset action-specific scaling effects (e.g. Durgin et al., 2009; Firestone

& Scholl, 2014; we used a similar manipulation in Experiment 5 here). For example, Firestone and Scholl (2014) showed that apertures are not estimated as narrower while holding a rod that is wider than the body (as reported by Stefanucci & Geuss, 2009) if participants are given a convincing cover story for why they are holding the rod.

We suggest that our results differ from those reported by Linkenauger, Witt and Proffitt (2011) because on every trial in their experiment, participants were explicitly encouraged to consider their ability to grasp an object immediately before they estimated the size of that object. In contrast, participants in Experiments 2-4 here always estimated object size first, and in a context where attention was not drawn to action capacity, whilst in Experiment 5 participants were given a cover story to explain why we were assessing both their ability to grasp an object and their estimate of its size. Note that despite being told that the grasping and the size estimation tasks were separate and independent, the predictions of the action-specific account still hold in Experiment 5. First, participants still performed the relevant grasping action, second, they were explicitly and repeatedly told that we were interested in their grasping behaviour so their attention was drawn to grasping, and third, they knew that they would have to act on each object immediately after estimating its size so they intended to act on it when they made their estimate.

In Linkenauger, Witt and Proffitt (2011), participants were asked on each trial if they could grasp a given block so they imagined grasping the presented blocks, as opposed to actually grasping them as was done in the present studies. We did not directly test for a difference between actual and imagined grasping, and it is possible - though, we feel, unlikely - that this is a critical methodological difference. It is important to emphasise that, on every trial in Experiments 2-5 here, our participants always actually grasped the object by either feeling objects behind a curtain in the HV (haptic-to-vision) tasks or picking up and moved them in the VV (vision-to-vision) tasks. Therefore, what was removed from our tasks was only drawing participant's attention to action for no apparent reason. We did not remove the action itself. We did not replicate Linkenauger, Witt and Proffitt (2011) by testing imagined action without actual action because we do not believe that this situation occurs often in everyday life. If the action-specific account applies only when we consciously think about action, then its relevance for everyday life is severely limited. Furthermore, action-specific scaling effects have been found in previous work when participants actually acted rather than imagined doing so (e.g. Witt & Dorsch, 2009; Witt et al., 2005).

It is not entirely clear why effects consistent with the action-specific account were found in these previous experiments but not in our current work. One possibility is that spatial estimates in previous studies reflected participants' attribution of their poor performance (in the case of Witt & Dorsch, 2009) or difficulty of the task (in the case of Witt et al., 2005) to the nature of the external stimulus, rather than to their own action capacity. This has been demonstrated experimentally. For example, although Wesp, Cichello, Gracia and Davis (2004) reported that more successful dart throwers estimated targets as bigger than less successful throwers, in a later study Wesp and Gasper (2012) found that when participants were told that the darts were of poor quality, the association between success and estimated target size disappeared. In the original experiment, less successful throwers may have assumed the targets were smaller than they appeared and, because of this, they were harder to hit (Cole & Balcetis, 2011; Wesp & Gasper, 2012). In contrast, in the follow-up study participants could attribute their lack of success to the poor-quality darts, so there was no need for them to assume the targets were smaller than they appeared, and so their estimates did not change.

This account is subtly - but importantly - different from the explanation that the action specific account would provide, namely that the targets actually looked smaller to poorer dart throwers. This alternative account instead proposes that poorer throwers may have estimated the targets as smaller in order to reduce the cognitive dissonance between their expectation about how good they would be at the task and the reality of their poor performance. This explanation would not apply in our studies because our participants could explore and estimate the size of all the stimuli. Even the largest blocks could be felt by moving the hand from one side to the other so participants could always estimate block size, regardless of graspability. Our results therefore suggest that performing a task-relevant action is not sufficient for action-specific scaling effects to occur.

The present studies are not without limitations. For example, we did not include a condition including conflation of estimates of perceived action capacity and spatial properties in order to test if this allowed us to replicate the original Linkenauger, Witt and Proffitt (2011) finding that perceived grasping capacity influences perceived object size. We also did not directly test whether only imagining acting would give rise to the expected action-specific effect where actually grasping did not. We therefore do not have direct evidence to support our proposal that drawing attention to the relationship between grasping capacity and spatial perception (by asking about both on every trial) caused the results of Linkenauger, Witt and Proffitt (2011). A future study comparing their methodology with the methods used here, which were intended to dissociate action capacity and spatial perception, would be fruitful.

The results of the present experiments indicate that changes in action capacity do not affect perceived spatial properties in the strongest sense. We have suggested that there are at least two alternative explanations for previous reports of action-specific scaling effects. First, participants' spatial estimates may have changed because of a discrepancy between their expectations about how well they would perform a task and their actual performance. Second, spatial judgements may have been conflated with perceived action capacity. In conclusion, though the relationship between perceived action capacity and spatial perception is not yet fully understood, we have demonstrated that estimates of both can be dissociated. We found no evidence that perception is cognitively penetrable. Instead, our results suggest that action capacity and spatial properties can be perceived independently.

## 2.9 Appendices: Chapter 2

**Appendix A: Results of the perceived object size tasks in Chapter 2, Experiment 2 for all blocks (full dataset)**

Ratios were calculated for the visually estimated size of each block by dividing the estimated size by the actual size. These were averaged over all 21 block sizes. For the LHFeelsSmallerObjects group, one-sample t-tests showed that ratios for the HV-left (0.76), HV-right (0.77), VV-left (0.87) and VV-right (0.86) conditions were all significantly lower than 1, $t(14) = -8.99$, $t(14) = -7.12$, $t(14) = -4.39$, and $t(14) = -4.31$ respectively, all $p < .001$. Similarly, for the RHFeelsSmallerObjects group, ratios for the HV-left (0.81), HV-right (0.82), VV-left (0.92) and VV-right (0.90) conditions were all significantly lower than 1, $t(14) = -7.32$, $t(14) = -7.57$, $t(14) = -4.32$, and $t(14) = -4.87$ respectively, all $p<.001$.

A mixed ANOVA with grasping hand (left/right) and task (HV/VV) as within-participants factors and prime group (LHFeelsSmallerObjects/RHFeelsSmallerObjects) as a between-participants factor was conducted ($p$-values for all pairwise comparisons were Bonferroni corrected). This revealed that ratios for the HV task (0.79) were significantly lower than ratios for the VV task (0.89), $F(1, 28) = 40.70$, $p < .001$, $\eta_p^2 = .59$. We found no difference between ratios for the left hand (0.84) and right hand (0.84), $F(1, 28) = 0.07$, $p = .8$, $\eta_p^2 = .002$, and no effect of prime group, $F(1, 28) = 2.07$, $p = .2$, $\eta_p^2 = .07$, of task × prime group, $F(1, 28) = 0.01$, $p = .9$, $\eta_p^2 < .001$., of grasping hand × prime group, $F(1, 28) = 0.81$, $p = .4$, $\eta_p^2 = .03$, or of grasping hand × task × prime group, $F(1, 28) = 0.01$, $p = .9$, $\eta_p^2 < .001$. However, there was a significant task x grasping hand interaction, $F(1, 28) = 4.81$, $p = .037$, $\eta_p^2 = .18$. Pairwise comparisons showed that ratios were marginally smaller for the right hand than the left hand in the VV task (mean difference = -0.011, $p$ = .06), but there was no difference between the right and left hands in the HV task (mean difference = -0.009, $p$ = .2).

**Appendix B: Results of the perceived object size task in Chapter 2, Experiment 3 for all blocks (full dataset)**

Ratios were calculated for the visually estimated size of each block by dividing the estimated size by the actual size. These were averaged over all 21 block sizes. Ratios for both the left hand (0.86) and right hand (0.84) were significantly lower than 1 in the LHFeelsSmallerObjects group, $t(14) = -4.75$, and $t(14) = -5.40$ respectively, both $p < .001$. Ratios for both the left hand (0.88) and the right hand (0.87) were significantly lower than 1 in the RHFeelsSmallerObjects group, $t(14) = -6.24$, and $t(14) = -5.93$ respectively, both $p < .001$.

We conducted a mixed ANOVA, with grasping hand (left/right) as a within-participants factor and prime group (LHFeelsSmallerObjects/RHFeelsSmallerObjects) as a within-participants factor. We found no significant effect of hand, $F(1, 28) = 2.17$, $p = .2$, $\eta_p^2 = .07$, prime group, $F(1, 28) = 0.32$, $p = .5$, $\eta_p^2 = .01$, or a hand × prime group interaction, $F(1, 28) = 1.53$, $p = .2$, $\eta_p^2 = .05$.

**Appendix C: Results of the perceived object size tasks in Chapter 2, Experiment 3 for only the blocks that were actually graspable, based on participants' actual maximum grasp**

Ratios were calculated for the visually estimated size of each block by dividing the estimated size by the actual size. For stimuli that were actually graspable in Experiment 3, ratios for the left hand (0.85) and the right hand (0.84) were significantly lower than 1 in the LHFeelsSmallerObjects group ($t(14) = -4.76$, and $t(14) = -5.49$ respectively, both $p < .001$). Ratios for the left hand (0.87) and the right hand (0.87) were also significantly lower than 1 in the RHFeelsSmallerObjects group ($t(14) = -5.57$, and $t(14) = -6.29$, respectively, both $p < .001$).

We conducted a mixed ANOVA, where grasping hand (left/right) was a within-participants factor and prime group (LHFeelsSmallerObjects/RHFeelsSmallerObjects) was a between-participants factor. There was no significant effects of grasping hand, $F(1, 28) = 3.24$, $p = .08$, $\eta_p^2 = .10$, prime group, $F(1, 28) = 0.52$, $p =.5$, $\eta_p^2 = .02$, or grasping hand × prime group, $F(1, 28) = 0.64$, $p = .4$, $\eta_p^2 = .02$.

## Appendix D: Results of the perceived object size tasks in Chapter 2, Experiment 4 for all blocks (full dataset)

Ratios were calculated for the visually estimated size of each block by dividing the estimated size by the actual size. These were averaged over all 21 block sizes. For the LHTaped group, one-sample t-tests showed that ratios for the HV-left (0.85), HV-right (0.85), VV-left (0.93) and VV-right (0.94) conditions were all significantly lower than 1 ($t(14) = -4.65$, $t(14) = -4.83$, $t(14) = -2.15$, and $t(14) = -1.59$ respectively, all $p < .001$). Similarly, for the RHTaped group, ratios for the HV-left (0.84), HV-right (0.83), VV-left (0.90) and VV-right (0.89) conditions were all significantly lower than 1 ($t(14) = -3.19$, $p = 0.007$, $t(14) = -4.75$, $t(14) = -4.29$, and $t(14) = -4.03$ respectively, all $p < .001$).

A mixed ANOVA with grasping hand (left/right) and task (HV/VV) as within-participants factors and tape group (LHTaped/RHTaped) as a between-participants factor was conducted. This revealed that ratios for the HV task (0.84) were significantly lower than ratios for the VV task (0.92), $F(1, 28) = 10.37$, $p = .003$, $\eta_p^2 = .27$. There was no significant difference between ratios for the left (0.88) and right (0.88) grasping hands, $F(1, 28) = 0.09$, $p = .8$, $\eta_p^2 = .003$, and no effect of prime group, $F(1, 28) = 0.67$, $p = .4$, $\eta_p^2 = .02$, task × prime group, $F(1, 28) = 0.24$, $p = .6$, $\eta_p^2 = .01$, grasping hand × tape group, $F(1, 28) = 0.39$, $p = .6$, $\eta_p^2 = .01$, grasping hand × modality, $F(1, 28) = 0.16$, $p = .7$, $\eta_p^2 = .01$ or grasping hand × task × tape group, $F(1, 28) = 0.04$, $p = .8$, $\eta_p^2 = .002$.

**Appendix E: Results of the perceived object size tasks in Chapter 2, Experiment 4 for only the blocks that were actually graspable, based on participants' actual maximum grasp**

Ratios were calculated for the visually estimated size of each actually graspable block by dividing the estimated size by the actual size. For the LHTaped group, one-sample t-tests showed that ratios for the HV-left (0.88) and HV-right (0.86) were significantly lower than 1 ($t(14) = -2.56$ and $t(14) = -3.43$ respectively, both $p < .001$). However ratios for the VV-left (1.02) and VV-right (1.03) conditions were not significantly different from 1 ($t(14) = -0.39$, $p = .7$ and $t(14) = 0.43$, $p = .7$ respectively). For the RHTaped group, ratios for the HV-left (0.81), HV-right (0.83), VV-left (0.89) and VV-right (0.89) conditions were all significantly lower than 1 ($t(14) = -4.15$, $p = .001$, $t(14) = -4.00$, $p = .001$, $t(14) = -3.85$, $p = .002$, and $t(14) = -3.50$, $p = .004$, respectively). Marks (1978) suggested that smaller objects may appear smaller when grasped between two fingers than when seen, but this difference diminishes as object size increases.

A mixed ANOVA with grasping hand (left/right) and task (HV/VV) as within-participants factors and tape group (LHTaped/RHandTaped) as a between-participants factor was conducted. Ratios for the HV task (0.85) were significantly lower than for the VV task (0.96), $F(1, 28) = 16.62$, $p < .001$, $\eta_p^2 = .37$. There was no significant effects of grasping hand, $F(1, 28) = 0.03$, $p = .9$, $\eta_p^2 = 0.001$, tape group, $F(1, 28) = 2.43$, $p = .1$, $\eta_p^2 = .08$, task × tape group, $F(1, 28) = 2.42$, $p = .1$, $\eta_p^2 = .001$, taped hand × tape group, $F(1, 28) = 0.42$, $p = .5$, $\eta_p^2 = .02$, grasping hand × task, $F(1, 28) = 0.02$, $p = .9$, $\eta_p^2 = .01$, or grasping hand × task × tape group, $F(1, 28) = 0.86$, $p = .4$, $\eta_p^2 = .001$.

## Appendix F: Full instructions given to participants in Chapter 2, Experiment 5[4]

"Hi, so I'm coming to the end of my PhD which is all about how people use their body to perform actions and how they estimate the size of objects. Anyway, I'm getting pretty stressed because I'm running out of time to get my last bits of data so this experiment is really two separate studies rolled into one - I'm just telling you this now, because otherwise it might seem a bit strange that you'll be doing two different tasks that don't really go together.

The first thing I'm looking at is a control study for something I've already tested, where I'm checking how people grasp simple blocks with their right compared to their left hand. The second thing I'm after is your ability to match the size of objects to lines on a computer screen. I should really be testing the hand grasping task and the size matching task separately but it's hard finding participants after Easter and, like I said, I need to get this data collected really soon.

OK, so here's what I want you to do. I want you to use your right [left] hand to grasp and pick up a block that I'll put down here in front of you and then move it to here, to this marker. You should pick it up using your thumb on one side and any other finger on the other side, like this. If it is too big to grasp like this then you can pick it up in any way you wish, but you must try to grasp it with your thumb and finger first before you try anything else - is that clear? Once you've grasped the block, I want you to move it to this marker here. I will be recording how you choose to grasp the blocks that you are unable to pick up in this way so sometimes you might have to wait a few seconds whilst I write something down. So that's the first part with the grasping done.

Then, for the second task, you'll do the size matching. So for this one you will use the up and down arrow keys to move apart these two lines on the screen so that the distance between the inner sides of the black lines matches the width of the block – so that if you held the block up against the monitor you'd see the inner edges of the two black lines right up against the right and left edges of the block - is that clear? It's important that you keep your body midline aligned with the block, so please don't twist your body when you start the size matching task. In fact, if it's comfortable, you can just keep your other hand on the correct keys all the time. Once you are happy you've got the lines in the right place, press Enter on the keyboard. Please try to be as accurate as you can. Then just give me the block back and I'll set up the next trial. You should close your eyes while I put down another block. This is because we are interested in how you grasp the blocks, and if you see how I pick them up to place them on each trial, this might influence how you then choose to grasp them. So I'll tell you when to open your eyes and then you'll start all over again – is that clear?

After they completed the first block for either their left or right hand, they received further instructions before starting the second block for their other hand:

"Right, that's the first block finished. Remember that I said that one of the things I was looking at here was how you grasped simple blocks with your right compared to your left hand? Well we've finished with the trials where you pick up blocks with your right [left] hand so now I'm going to swap things around and you're going to do the same thing again except that you'll be picking up blocks with your left [right] hand. You'll also keep going with the other study, the size matching study, so this second part will be very similar to the first – on each trial you'll pick up the block with your left [right] hand then you'll do the size matching study then hand me the block back. Is that all clear?

Finally, after they had completed both left and right hand blocks, the fingers of one of their hands was taped in the same way as in Experiment 4, and they received further instructions:

> "Right, well done, that's the second block finished. Now remember that I said that one of the things I was looking at here was how you grasped simple blocks with your right compared to your left hand? Well now I'm going to tape up your right [left] hand to see how this affects your grasping behaviour. You're then going to do just what you've been doing so far except you will use your taped right [left] hand to pick up the blocks. You'll also keep going with the other study, the size matching study, so again this third part will be very similar to the first two parts – you'll pick up the block with your taped hand then you'll do the size matching study then hand me the block back. Is that all clear?"

**Appendix G: Used of specified grasp in Chapter 2, Experiment 5**

We recorded whether participants performed the specific grasp required (thumb on one side and any other finger on the opposing side) without having to be reminded by the experimenter, see Table 5. If a participant did not spontaneously use the specified grasp the experimenter stopped them and told them to do this so the specified grasp was attempted on 100% of trials. For consistency with the main results section, here we only show the results for graspable blocks.

**Table 5**

Mean (and standard deviation) of the percentage of trials performed using the specified grasp without first having to be reminded by the experimenter, for perceived and for actually graspable blocks.

| | **Before size estimation task (first grasp)** | | **After size estimation task (second grasp)** | |
|---|---|---|---|---|
| Hand | Perceived graspable | Actually graspable | Perceived graspable | Actually graspable |
| Left | 90% (6.6%) | 93% (3.7%) | 87% (7.9%) | 91% (5.8%) |
| Right | 88% (6.8%) | 92% (4.4%) | 86% (7.7%) | 91% (4.9%) |
| Taped | 86% (6.1%) | 92% (3.5%) | 83% (8.2%) | 90% (5.5%) |

## Appendix H: Results of the perceived object size tasks in Chapter 2, Experiment 5 for all blocks (full dataset)

Ratios were calculated for the visually estimated size of each block by dividing the estimated size by the actual size. These were averaged over all 21 block sizes. For the LHTaped group, one-sample t-tests showed that ratios for the left (0.83), right (0.84) and taped (0.82) hands were all significantly lower than 1, $t(15) = -4.38$, $p = .001$, $t(15) = -4.20$, $p = .001$, and $t(15) = -5.08$, $p < .001$, respectively. Similarly, for the RHTaped group, ratios for the left (0.88), right (0.87) and taped (0.85) hands were all significantly lower than 1, $t(15) = -4.80$, $t(15) = -4.72$, and $t(15) = -4.78$, all $p < .001$, respectively.

A mixed ANOVA with grasping hand (left/right/taped) as a within-participants factor and tape group (LHTaped/RHTaped) as a between-participants factor was conducted, There were no significant effects: grasping hand, $F(2, 60) = 1.42$, $p = .2$, $\eta_p^2$

= .05; tape group, $F(1, 30) = 0.73$, $p = .4$, $\eta_p^2 = .02$; interaction of grasping hand × tape group, $F(2, 60) = 0.08$, $p = .9$, $\eta_p^2 = .003$.

## Appendix I: Results of the perceived object size tasks Chapter 2, Experiment 5 for only the blocks that were actually graspable, based on participants' actual maximum grasp

Ratios were calculated for the visually estimated size of each actually graspable block by dividing the estimated size by the actual size. For the LHTaped group, one-sample t-tests showed that ratios for the left (0.85), right (0.85) and taped (0.84) hands were all significantly lower than 1, $t(15) = -3.82$, $p = 0.002$, $t(15) = -3.80$, $p = 0.002$, and $t(15) = -4.45$, $p < .001$, respectively. Similarly, for the RHTaped group, ratios for the left (0.90), right (0.91) and taped (0.88) hands were all significantly lower than 1, $t(15) = -2.30$, $p = .036$, $t(15) = -2.15$, $p = .048$ and $t(15) = -2.29$, $p = .037$, respectively.

A mixed ANOVA with grasping hand (left/right/taped) as a within-participants factor and tape group (LHTaped/RHTaped) as a between-participants factor was conducted. There were no significant effects: grasping hand, $F(2, 60) = 0.24$, $p = .8$, $\eta_p^2 = .008$; tape group, $F(1, 30) = 0.95$, $p = .3$, $\eta_p^2 = .03$; interaction of grasping hand × tape group, $F(2, 60) = 0.06$, $p = .9$, $\eta_p^2 = .002$.

## Appendix J: Post-experimental questionnaires for Chapter 2, Experiments 2, 3 and 4.

Prior to giving a formal debrief, in Experiments 2-4 all participants were asked the following three questions:

1. What did you think the experiment was testing?
2. Did you notice anything particular about the first phase of the experiment, where I gave you practice with the stimuli? (In Experiment 4, we changed this question to "What did you think the purpose of the taping was?")
3. Do you have any ideas about why the instructions for the visual matching task were so specific?

They were then asked whether they had any further comments to make about the experiment. These three questions were scored out of 5 by the first author, where a score of 0 reflected very little to no insight into the aims of the experiment, and 5 reflected complete awareness. If the participant made any spontaneous comments about the experiment, these were also recorded.

For Experiment 2, the mean score (out of 5) for Q1 was 0.5 (range = 0-4). The most commonly suggested experimental aims were that we were comparing size perception in vision and touch, and that there might be differences between the left and right hands as a result of laterality and hemispheric differences in the brain. One participant noted that they were aware that they felt that their right hand was larger than their left hand, but they did not spontaneously suggest that this may have influenced their perception of the size of objects. The mean score for Q2 was 0.1 (range = 0-1). Only three participants commented on the practice (priming) phase. They suggested that it seemed unnecessary or lengthy. The mean score for Q3 was 0 and none of our participants commented on why the instructions in the vision-to-vision (VV) task were very specific.

For Experiment 3, the mean score (out of 5) for Q1 was 0.3 (range = 0-2). The most commonly suggested experimental aims were again the comparison between size perception in vision and touch, and that estimates for the left and right hands might be different because of hemispheric differences in the brain. The mean score for Q2 was 0.1

(range = 0-4). One participant noticed that larger objects were always being presented to their right hand during the practice (priming) phase but they did not suggest that this might have influenced their perceived grasping capacity. The mean score for Q3 was 0.03 (range = 0-1). One participant suggested that the instructions in the vision-to-vision (VV) task were specific because of the shape of the visual field and another suggested that the blocks might look different depending on the side of the mouse it was placed but they did not specify why. No participants correctly identified that we were trying to ensure that the same hand they had acted with remain visible for the whole trial.

For Experiment 4, the mean score (out of 5) for Q1 was 0.4 (range = 0-3). The most commonly suggested experimental aims were comparing size estimation in vision and touch, the influence of handedness and effects of laterality in the brain. The mean score for Q2 was 0.3 (range = 0-4). Three participants suggested that the taping might influence their perception of object size, however they did not spontaneously predict the direction of the effect. After prompting from the experimenter one of these participants predicted that taping might lead to objects appearing bigger, another one proposed the opposite and the third did not suggest a direction even after prompting. The mean score for Q3 was 0 and no participants offered a reason for why the instructions in the VV task were very specific.

**Appendix K: Post-experimental questionnaires for Chapter 2, Experiment 5.**

Prior to giving a formal debrief, in Experiment 5 all participants were asked the following five questions:

In Experiment 5, participants were asked the following five questions:

1. What did you think the experiment was testing?

2. Did you notice anything particular about the instructions?
3. Why do you think I asked you to do two separate tasks at the same time?
4. Did you think that the two tasks were related?
5. Why do you think I taped your fingers together in the last part of the experiment?

The mean score (out of 5) for Q1 was 0.6 (range = 0-4). Participants rarely suggested an answer to this question, but one person suggested that the right hand would probably be better at grasping objects and so might be more accurate in the size estimation task. The mean score for Q2 was 0. Some participants commented that the specified grasp was strange, and that it was odd that they had to close their eyes. The mean score for Q3 was 0.4 (range = 0-5). One participant suggested that estimates might be lower for the right hand than the left hand because right handers are more confident with their right hand (scored 5), but most participants did not provide an answer or suggested that one of the two tasks was a distractor task. The mean score for Q4 was 1 (range = 0-5). The most common response was that the tasks were likely related but participants generally struggled to explain how. Some suggested they were related simply because the same stimuli were used in both tasks. One participant (scored 5) suggested that objects would be estimated as smaller in the right hand because right handers are more confident with their right hand. The mean score for Q5 was 1.2 (range = 0-5). Participants frequently suggested that the tape was to make the grasping task harder, and some commented that this might affect their performance in the size estimation task. Specifically, they tended to suggest that graspable blocks might be estimated more accurately than ungraspable blocks, and so they may be less accurate when their hand was taped. However, they rarely elaborated on what they meant by ‘accurate’ or mentioned size. One participant said that they noticed they had a reduced maximum grasp with their hand taped but they didn’t think this would affect their size estimates. Overall, only six participants thought we were interested in differences between the left and right hands, and four of these referred only to grasping capacity and not to estimates of object size.

## 2.10 Footnotes: Chapter 2

[1] When included in the same ANOVA, where hand (hand/right) and estimate type (perceived/actual) were within-participants factors and prime group (LHFeelsSmallerObjects/RHFeelsSmallerObjects) was a between-participants factor, there was a marginally significant grasping hand × estimate type interaction, $F(1, 28) = 3.88$, $p = .059$, $\eta_p^2 = .12$.

[2] When included in the same ANOVA, where grasping hand (left/right) and estimate type (perceived/actual) were within-participants factors and tape group (LHTaped/RHTaped) was a between-participants factor, there was a significant grasping hand × estimate type × tape group interaction, $F(1, 28) = 45.80$, $p < .001$, $\eta_p^2 = .62$. The nature of the grasping hand x tape group interaction was the same for both estimates types, see Figure 6, but the differences were greater for perceived than for actual grasping capacity.

[3] When included in the same ANOVA, where grasping hand (left/right/taped) and estimate type (perceived/actual) were within-participants factors and tape group (LHTaped/RHTaped) was a between-participants factor, there was no three-way interaction $F$ (2, 60) = 0.016, $p = .9$, $\eta_p^2 = .001$

[4] All data was collected by the first author, ESC, so variation in the verbal instructions was minimal. However, there was some deviation from this script, for example in terms of the exact words used. This was in part intentional in order to ensure that participants' suspicions were not raised by the experimenter reading from a script, but also deviation sometimes arose if participants asked questions or did not understand the original wording. Deviation also sometimes arose in terms of the order that parts of the cover story were told. However, all participants were given the same core information: that the experiment involved two separate studies being tested in the same session, the specific grasp to be used, that we were recording how they grasped the blocks if this grasp was not possible, how to complete the size matching task, to use the opposite hand on the keyboard than the hand they grasped the blocks with, to be as accurate as possible when estimating block size, that they should hand the block back to the experimenter at the end of each trial, and that they should close their eyes between trials. Particular emphasis was given to the second paragraph which described the two tasks.

# Chapter Three

## 3. Effects consistent with the action-specific account only occur under narrow conditions

***This chapter has been published as:**

**Collier, E. S., & Lawson, R. (2017). Does grasping capacity influence object size estimates? It depends on the context.** ***Attention, Perception & Psychophysics.*** **DOI: 10.3758/s13414-017-1344-3**

### 3.1 Abstract

Linkenauger, Witt and Proffitt (2011, Experiment 2) reported that right handers estimated objects as smaller if they intended to grasp them in their right rather than their left hand. Based on the action-specific account, they argued that this scaling effect occurred because participants believed their right hand could grasp larger objects. However, Collier and Lawson (2017) failed to replicate this effect. Here, we investigated whether this discrepancy in results arose from demand characteristics. We investigated two forms of demand characteristics: altering responses following conscious *hypothesis guessing* (Experiments 1 and 2), and subtle influences of the experimental *context* (Experiment 3). We found no scaling effects when participants were given instructions which implied the expected outcome of the experiment (Experiment 1), but they were obtained when we used unrealistically explicit instructions which gave the exact prediction made by the action-specific account (Experiment 2). Scaling effects were also

found using a context in which grasping capacity could seem relevant for size estimation (by asking participants about the perceived graspability of an object immediately before asking about its size on every trial, as was done in Linkenauger, Witt & Proffitt, 2011; Experiment 2). These results suggest that demand characteristics due to context effects could explain the scaling effects reported in Experiment 2 of Linkenauger, Witt and Proffitt (2011), rather than either hypothesis guessing, or, as proposed by the action-specific account, a change in the perceived size of objects.

## 3.2 Introduction

The term 'action capacity' refers to our ability to successfully perform actions. It is restricted by the morphology and capabilities of our bodies (Adolph & Berger, 2006; Proffitt & Linkenauger, 2013). Given the tight coupling between perception and action (Clark, 1999; Gibson, 1979), it has been suggested that action capacity can directly influence visual perception (Proffitt & Linkenauger, 2013; Witt, 2011a, 2017). Specifically, the action-specific account of perception suggests that our perception of the spatial properties of the environment scales according to our action capacity (Proffitt, 2006a, 2006b; Proffitt & Linkenauger, 2013). For example, reaching with a tool that increases maximum reach can influence the estimated distance to a target (Witt et al., 2005). Witt et al. (2005) found that targets which were out of reach without the tool were estimated as closer after reaching to them with the tool.

Action-specific scaling effects suggest that perception may be cognitively penetrable – so perception can be directly influenced by higher-level cognition. If action-specific scaling effects truly reflect changes in what is perceived in this strong sense, then this has major implications for standard, modular theories of vision, which hold that perception is encapsulated and separate from cognition (Pylyshyn, 1999; for a recent review see Firestone & Scholl, 2015). However, a major debate concerning the action-specific account is whether the observed scaling effects reflect judgement rather than perception (Collier & Lawson, 2017a; Durgin et al., 2009; Durgin et al., 2012; Firestone & Scholl, 2014; Zelaznik & Forney, 2016; for reviews see Firestone, 2013; Firestone & Scholl, 2015; Philbeck & Witt, 2015; Proffitt, 2013; Witt, 2011a, 2017). Specifically, participants' responses may not reflect differences in what they actually perceive; rather, their spatial estimates may be affected by non-perceptual influences such as their beliefs about the purpose of the experiment.

This possibility has been demonstrated experimentally. In a famous study supporting the action-specific account, hills were reported as steeper when observers wore a heavy backpack (Bhalla & Proffitt, 1999). However, Durgin et al. (2009) found that if participants were told that the backpack they wore contained equipment for monitoring their ankle muscles, their estimates of hill slant did not differ from participants who did not wear the backpack. This finding suggests that participants who were not given a reason for wearing the backpack may have deduced that the backpack was supposed to influence their estimates of hill slant and adjusted their responses accordingly. Similarly, Firestone and Scholl (2014) tested whether the finding that apertures were estimated as narrower when participants held a horizontal rod that was wider than their body (Stefanucci & Geuss, 2009) reflected a true perceptual change or demand characteristics. Firestone and Scholl (2014) found that when participants were given a convincing reason for holding the rod, their estimates of aperture width did not differ from participants who did not hold the rod. These results suggest that if participants are not given an explanation for a salient manipulation, they may attempt to figure out the experimental hypothesis and that this, in turn, can influence their responses.

Together, the results of Durgin et al. (2009), Firestone and Scholl (2014; see also Woods et al., 2009) suggest that demand characteristics could explain a number of action-specific scaling effects. Demand characteristics broadly refer to factors in an experimental setting which affect participants' responses (Orne, 1962). We will term the form of demand characteristics investigated by these authors *hypothesis guessing,* where participants try to work out the expected results of the experiment and consciously adjust their responses accordingly.

Such demand characteristics cannot, though, easily explain all action-specific effects (for some recent reviews see Philbeck & Witt, 2015; Witt, 2017). For example, Taylor-Covill and Eves (2016) found that overweight individuals estimated staircases as steeper than healthy-weight individuals. These results are difficult to explain in terms of hypothesis guessing (see also Witt & Sugovic, 2013). Although participants probably knew their own weight, they were unlikely to intuit that this was expected to influence what they perceived spatially, particularly given that Taylor-Covill and Eves (2016) recorded the participant's weight only after they had made their estimates of slant.

Another form of demand characteristics could, though, influence performance without participants necessarily realising it, namely *context effects* due to the experimental setting or procedure. For example, performing two tasks in quick succession could create a context which implies that the two tasks are related in some meaningful way. In an example from the action-specific literature, Linkenauger, Witt and Proffitt (2011, Experiment 2) reported that objects to-be-grasped in the right hand were estimated as smaller than objects to-be-grasped in the left hand. They claimed that this occurred because right handers perceive their right hand as larger than their left hand, and so objects appear more graspable, and therefore smaller, when they intend to grasp them with their right hand. However, participants in Experiment 2 of Linkenauger, Witt and Proffitt (2011) estimated both the graspability and size of objects on every trial. Asking participants about an object's graspability immediately before asking about its size may have created a context in which the two measures appeared related or became confused with each other. This could occur because the dimensions of graspable-to-ungraspable and small-to-big are conceptually linked. This could lead participants to estimate easily graspable objects as smaller, even if the visual representation of the object is unchanged. This possibility is supported by evidence from the literature on cross-sensory correspondences whereby properties of one perceptual domain are linked to properties in another (e.g. Walker, 2012). For example, heavy objects are rated as darker than light objects (Walker, Scallon & Francis, 2016). 'Graspability' is not a perceptual feature like those studied in the cross-sensory correspondence literature. Nevertheless, a similar issue could have arisen in Experiment 2 of Linkenauger, Witt and Proffitt (2011) if the experimental context implied a conceptual relation between grasping capacity and object size. If so, then the results of Linkenauger, Witt and Proffitt (2011, Experiment 2) could be explained by demand characteristics associated with performing two conceptually linked tasks on the same trial, as opposed to reflecting a change in what participants perceived in the strongest sense. Only the latter interpretation is consistent with the action-specific account.

We recently failed to replicate Experiment 2 of Linkenauger, Witt and Proffitt (2011). In addition to testing for an effect of hand dominance, as was done in the original study, we directly manipulated grasping capacity by taping together the fingers of one hand (Collier & Lawson, 2017). This powerful manipulation restricted both actual (by ~1.2 cm) and perceived (by ~3.2 cm) grasping capacity. According to the action-specific account taping should have influenced estimates of object size. However, although participants appropriately estimated the grasping capacity of their taped hand as less than that of their untaped hand, objects grasped in the taped hand were not estimated as larger than objects grasped in the untaped hand. We did not resolve why we failed to replicate Experiment 2 of Linkenauger, Witt and Proffitt (2011), but we suggested that this could have been due to reduced context effects in our studies. This was achieved in two ways. First, in our initial experiments, participants completed the size estimation task before starting the grasping capacity task, so their size estimates were unlikely to be biased by considering the graspability of the objects. Second, the design of our final experiment was similar to that of Linkenauger, Witt and Proffitt (2011, Experiment 2) in that participants were explicitly told that we were interested in their grasping behaviour, and the grasping task immediately preceded the size estimation task on each trial. However, our instructions emphasised that the grasping task and the size estimation task were part of two unrelated experiments.

In the present studies, we investigated whether we (Collier & Lawson, 2017) previously failed to replicate Experiment 2 of Linkenauger, Witt and Proffitt (2011) because we reduced demand characteristics. In the present studies, participants had the fingers of one of their hands taped together and we compared their estimates of object size for objects they had grasped in their taped versus their untaped hand. This taping manipulation has a number of advantages over the methods used by Linkenauger, Witt and Proffitt (2011, Experiment 2). In their second experiment, Linkenauger, Witt and Proffitt (2011) took advantage of the finding that right handers perceive the grasping capacity of their right hand as greater than that of their left hand (Collier & Lawson, 2017a; Linkenauger et al., 2009; Linkenauger, Witt & Proffitt, 2011). However, this only produces quite a small difference in *perceived* grasping capacity. Furthermore, there is no evidence for a difference in the *actual* grasping capacity of the right and left hands (Collier & Lawson, 2017a; Linkenauger, Witt & Proffitt, 2011). In contrast, our taping manipulation alters both perceived and actual maximum grasp. In their final experiment, Linkenauger, Witt and Proffitt (2011) manipulated perceived grasping capacity by magnifying the hand. However, as Linkenauger, Witt and Proffitt (2011) discussed (see also Witt, 2017), magnification could have induced a size-contrast illusion whereby objects may appear smaller next to a visually larger hand. It is therefore unclear whether the scaling effect they found in this experiment occurred because object size was scaled according to grasping capacity, or if it resulted from a size-contrast effect. In contrast, taping the hand directly reduces grasping capacity (Collier & Lawson, 2017a) while minimising the possibility of inducing a size-contrast illusion.

The action-specific account predicts that a change in grasping capacity due to taping the hand should influence perceived object size. Specifically, blocks grasped in the taped hand should be estimated as larger than blocks grasped in the untaped hand because the taped hand has a reduced grasping capacity. In Experiments 1 and 2 we tested whether previously reported effects of graspability on size estimates could instead be explained by *hypothesis guessing* by investigating whether participants were sensitive to demand characteristics arising from leading instructions. In Experiment 3, we examined the influence of demand characteristics due to *context effects* by having participants estimate both how difficult a block was to grasp and its size on every trial. We expected that this would create a context which made grasping capacity seem relevant for estimating object size.

## 3.3 Experiment 1

Experiment 1 was designed to test whether participants would figure out the predicted influence of taping on estimated object size from the instructions they were given and then change their estimates accordingly. We reasoned that, depending on their instructions, hypothesis guessing could lead to two opposite effects (see Figure 1). First, participants could be led to believe that objects grasped in their taped hand should look *larger* because taping reduces both the perceived and the actual maximum size of objects that can be grasped (Collier & Lawson, 2017a). Here, hypothesis guessing would produce an effect in the direction predicted by the action-specific account. Alternatively, participants could be led to believe that objects seen near to their taped hand should look *smaller* because taping the hand makes it look smaller, by reducing the maximum spread of the fingers (see Figure 2), and because the taped hand could be used to anchor size estimates. In the latter case, using leading instructions which imply the opposite effect to that predicted by the action-specific account provides a strong way to test whether the effect reported in Experiment 2 by Linkenauger, Witt and Proffitt (2011) was the result of hypothesis guessing. If participants are sensitive to leading instructions in this task then they would be expected to comply with their instructions regardless of the outcome they imply. We therefore tested both alternatives. In the *action capacity group*, the instructions implied that objects grasped by the taped hand should appear larger because the grasping capacity of the taped hand is reduced, consistent with the action-specific account. In the *body size group*, the instructions implied that objects near to the taped hand should appear smaller because that hand appears smaller, and this could cause the object to be scaled down in size. In the third, *objective size group*, the instructions did not suggest that taping would influence size estimation and participants were explicitly told to ignore non-visual factors when estimating object size. Here, taping was not expected to influence object size estimates due to hypothesis guessing.

In Experiment 1 participants actually grasped each object they estimated the size of. In contrast, on each trial of Linkenauger, Witt and Proffitt (2011, Experiment 2), participants only stated whether they thought they could grasp it. They did not grasp the blocks until the end of the experiment. Here, we tested actual grasping because we believe that the task used by Linkenauger, Witt and Proffitt has low ecological validity. In everyday life, we often perform simple actions without explicitly attending to them (Goodale & Haffenden, 1998) whereas we rarely repeatedly decide whether we could act without actually acting. Also, action-specific scaling effects have been reported even when, as in our experiments, participants performed a relevant action without being explicitly asked if they could do it (e.g., Witt & Dorsch, 2009). Finally, Franchak and Adolph (2014) showed that participants only updated their perceived action capacity following a change to their body after they had actually performed the action. This suggests that, for our taping manipulation to be effective, participants needed to try to grasp the objects with their taped hand.

In Experiment 1, we tested whether participants were sensitive to leading instructions which implied the desired experimental outcome. On each trial, participants first grasped and moved a block with either their taped hand or untaped hand, then placed that block next to a laptop. They then used the same hand to adjust the horizontal gap between two lines on the laptop screen to match the perceived width of the block they had just moved. If hypothesis guessing influences performance then we predicted that, relative to objects moved by the untaped hand, objects moved by the taped hand should be estimated as larger in the action capacity group, smaller in the body size group and the same size in the objective size group, see Figure 1.

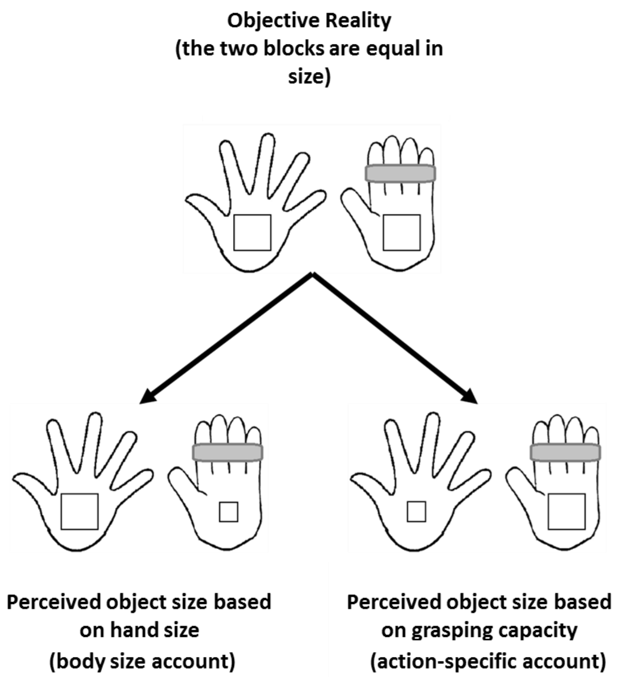


*Figure 1*: The predicted effects of instructions on perceived object size in Experiment 1. Left: Perceived object size *decreases* with a decrease in hand size due to taping (body size account). Right: Perceived object size *increases* with a decrease in perceived grasping capacity (action-specific account).

### 3.3.1 Method

Ethical approval was granted for all of the experiments presented in this paper by the relevant local ethics committee at the University of Liverpool.

#### 3.3.1.1 Participants

Fifty-four participants (mean age = 18.7 years, 7 males; n = 18 per group) were recruited for this study. Participants all self-reported as right handed, and either volunteered or were rewarded with course credit for their time.

#### 3.3.1.2 Design

Participants were allocated to one of three instruction groups (action capacity/objective size/body size). Throughout the experiment, participants had the fingers of one of their hands taped together. Half of the participants in each instruction group had their left hand taped (LHTaped group) and the remaining half had their right hand taped (RHTaped group). The middle and ring fingers were first taped together above the proximal interphalangeal (middle) finger joint, then all four fingers were taped together just underneath the same joint, see Figure 2.

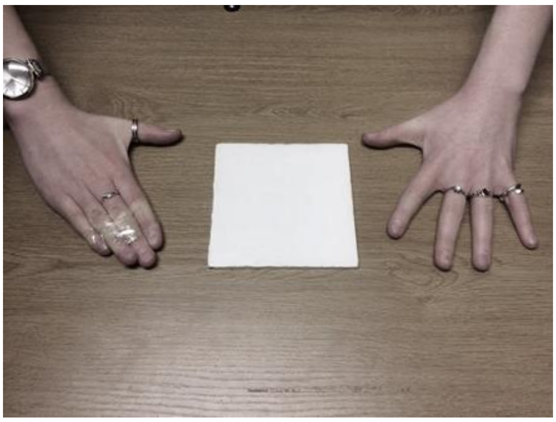

*Figure 2*: Photograph showing how the taping manipulation restricted the maximum grasp of one hand relative to the other. Image shows a participant in the RHTaped group following taping of their right hand. The hands are shown next to the largest (13 cm) block.

#### 3.3.1.3 Apparatus, stimuli and procedure

All participants received the following, general verbal instructions:

*"In this experiment, we will ask you to estimate the size of square stimuli. There are many possible interpretations of this instruction, so we want to make it clear what it is we want you to estimate. Imagine standing at one end of a road and looking at a house at the other end – the house may appear closer or further away than it really is, depending on a variety of factors. For example, if you are very tired, hungry or in a rush, the distance to the house may appear greater than it really is. In contrast, if you are feeling very energetic, the distance to the house may appear shorter than it really is. These non-visual factors have been previously suggested to influence spatial perception. The same logic applies to objects we can act on in our nearby environment. For example, if you are looking at a mug on a table, there may be things in the environment that make it visually appear closer to or further away than its actual physical distance from you (that is, the distance measured by a tape measure)."*

Following this, they received group-specific instructions. The sentences highlighted in bold differed across the groups:

**Action capacity group**

*"Similarly, this logic can be applied to the size of objects that we act on.* ***For example, being able to grasp bigger objects may affect our perception of the size of objects we intend to grasp. In this experiment, we will tape together the fingers of one of your hands. This is to restrict the grasping capacity of one of your hands.*** *You will then be presented with a series of square stimuli and asked to visually match their width on a screen. You will be asked to put either your left or right hand through the curtain to*

*pick up the stimulus, take it out from behind the curtain and place it on the table in front of you. Use the same hand you picked up the stimulus with to use the arrow keys to move the lines on the screen apart and visually match the width of the stimulus on the screen.* ***Base your answer on what size you feel the object is, taking all relevant non-visual factors into account, including whether having your fingers taped together makes it harder for you to grasp big objects.****"*

**Body size group**

*"Similarly, this logic can be applied to the size of objects that we act on. For example, thinking that* ***our hand has decreased in size may affect our perception of the size of objects which we see near or hold in our hand. In this experiment, we will tape together the fingers of one of your hands. This is to simulate a shrinkage in the size of that hand.*** *You will then be presented with a series of square stimuli and asked to visually match their width on a screen. You will be asked to put either your right or left hand through the curtain to pick up the stimulus, take it out from behind the curtain and place it on the table in front of you. Use the same hand you picked up the stimulus with to use the arrow keys to move the lines on the screen apart and visually match the width of the stimulus on the screen.* ***Base your answer on what size you feel the object is, taking all relevant non-visual factors into account, including whether having your fingers taped together makes your hand feel smaller****."*

**Objective size group**

*"Similarly, this logic can be applied to the size of objects that we act on.* ***However, if during this task you think that the objects appear to be different in size than how big you think they really are – for whatever reason – ignore these things and base your estimation only on how big you think the object really is. In this experiment, we will tape together the fingers of one of your hands.*** *You will then be presented with a series*

*of square stimuli and asked to visually match their width on a screen. You will be asked to put either your left or right hand through the curtain to pick up the stimulus, take it out from behind the curtain and place it on the table in front of you. Use the same hand you picked up the stimulus with to use the arrow keys to move the lines on the screen apart and visually match the width of the stimulus on the screen.* ***Base your answer only on how big you think the object really is – imagine there's a tape measure stretched across the object and you're reading off its size****".*

After being given their instructions, participants completed a visual size matching task. The stimuli were 10 foamboard blocks (0.5 cm thick). The blocks were square with sides ranging in size from 4 cm – 13 cm in 1 cm increments. In previous work (Collier & Lawson, 2017a) this range was found to be graspable for most participants, even when their hand was taped. We only used graspable blocks because, according to the action-specific account, scaling effects are only expected if the relevant action is actually performable (Linkenauger, Witt & Proffitt, 2011).

On each trial, one block was presented on a table behind a curtain. A laptop (screen diagonal = 25 cm) was placed in front of the curtain. Two black lines (0.2 cm x 1.3 cm) were displayed on the screen. The lines were initially 0.9 cm apart. The participant reached behind the curtain to grasp and pick up the block, see Figure 3A. The experimenter told the participant which hand they should use on each trial. The participant then moved the block onto the table in front of the curtain on the same side of the laptop as the hand they picked it up with, see Figure 3B. Participants were instructed to always first try to grasp the block with their thumb on one side and any other finger on the opposing side, see Figure 3A. If the block was too big to grasp in this way, they were then allowed to pick it up and move it in any way they wished. To maximise the likelihood of participants using the hand they had just acted with as a perceptual ruler, they pressed the response keys with the same hand they had just used to grasp the block and they kept their other hand out of sight, by their side. This ensured that they only saw the action-relevant hand while making their response. After responding, they used the same hand to place the block back behind the curtain. The experimenter then replaced the block with another block and the next trial began.

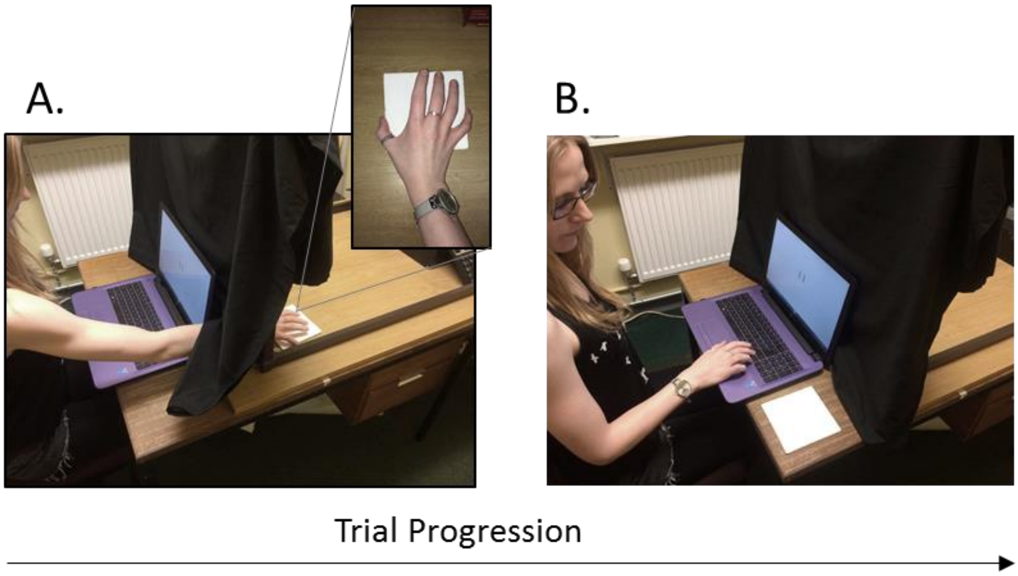


*Figure 3*: Trial procedure in Experiment 1 for an untaped right hand trial (the procedure was identical for the taped hand). A: The participant has reached behind the curtain with their right hand to grasp and move the block (size shown here = 13 cm). The inset shows that the participant has successfully grasped the block using the specified grasp – the thumb on one side and any other finger on the opposite side. B: The participant has moved the block to the right side of the laptop and placed it flat on the table. They are using their right hand to move the lines on the screen to visually match the width of the block. The experimental procedure was identical in Experiment 2. The experimental procedure was identical in Experiment 3, except that participants verbally rated how difficult the block had been to grasp before visually matching its size on the screen.

Before starting the experimental trials, all participants were given two practice trials which used the smallest (4 cm) and largest (13 cm) blocks. The 4 cm block was presented to their untaped hand, and the 13 cm block was presented to their taped hand. This was to try to highlight the difference in grasping capacity following taping. During the experimental trials participants estimated the size of each block once for each hand, giving 20 experimental trials in total (10 blocks × 2 hands). Trials were presented in a different, random order for each participant. To minimise forgetting, participants were reminded of their group specific instructions after ten trials. Specifically, the action capacity group was told to consider their grasping capacity, the body size group was told to consider whether taping made their hand feel smaller, and the objective size group was told to ignore all non-visual factors while making their estimates.

After completing the size estimation task, participants drew around their hands with their thumb and fingers spread as far apart as possible. They first drew around their taped hand (still taped), then their taped hand (with tape removed) and finally their untaped hand. They then completed a questionnaire on a computer. This asked what they believed the main manipulations of the experiment were, and whether they believed that their responses were influenced by having their fingers taped together and the experimental instructions. After this, the experimenter asked participants specifically whether they thought that having their fingers taped together had made objects appear bigger, smaller or about the same size in their taped hand relative to their untaped hand. The entire procedure took about 20 minutes.

### 3.3.2 Results

**Object size estimation task**

We excluded six trials where the participant was unable to grasp the block in the manner specified using their taped hand (one 12 cm trial and five 13 cm trials) plus the six corresponding trials for that participant for their untaped hand. In addition, a further 16 trials were excluded due to invalid responses, e.g. pressing the Enter key without adjusting the distance between the lines. To test whether size estimates differed for taped versus untaped hands, we calculated perceived block size as a proportion of actual block size then averaged these proportions for all block sizes tested for a given participant.

These ratios were used as the dependent variable in a mixed ANOVA[1] with taping (taped/untaped) as a within-participants factor and instruction group (action capacity/objective size/body size) and tape group (LHTaped/RHTaped) as between-participants factors. There were no significant effects. For the main effects: taping, $F(1, 48) = 0.416$, $p = .5$, $\eta_p^2 = .01$, instruction group, $F(2, 48) = 0.754$, $p = .5$, $\eta_p^2 = .03$, and tape group, $F(1, 48) = 2.136$, $p = .2$, $\eta_p^2 = .04$. For the interactions: taping × instruction group, $F(2, 48) = 0.517$ , $p = .5$, $\eta_p^2 = .02$, taping × tape group, $F(1, 48) = 0.037$, $p = .8$, $\eta_p^2 = .001$, instruction group × tape group, $F(2, 48) =1.817$, $p =.2$, $\eta_p^2 =.07$, and taping × instruction group × tape group, $F(2, 48) =0.309$, $p = .7$, $\eta_p^2 = .01$, see Figure 4.

We also checked whether participants estimated block size in a way that was consistent with their beliefs about their own biases on this task, based on their post-experiment responses. To do this we analysed size estimates only for participants who chose the action-specific prediction (collapsing over instruction group and tape group, n = 26, see Table 4). If their post-hoc beliefs were consistent with their experimental responses then they should have estimated blocks as larger for their taped hand. However, a paired-samples t-test for this subgroup revealed no difference between their size estimates for their taped and untaped hand, $t(25) = 1.419$, $p = .2$.

We ran Bayesian analyses to test the strength of evidence for the null effects revealed by the ANOVA, see Table 1. We used the procedure described by Masson (2011), which determines the posterior probabilities for both the null and alternative hypothesis based on the Type III Sum of Squares values for the effect. This method can provide confidence that a null effect is not simply the result of a Type II error. We used the descriptive terms for strength of evidence suggested by Raftery (1995).

**Table 1**

Posterior probabilities for the null [$p_{BIC}(H_0|D)$] and alternative [($p_{BIC}(H_1|D)$] hypotheses for the main effects and interactions in Experiment 1.

| Effect | $p_{BIC}(H_0|D)$ | $p_{BIC}(H_1|D)$ | $\eta_p^2$ |
|---|---|---|---|
| Taping | .853** | .147 | .01 |
| Instruction group | .959*** | .041 | .03 |
| Tape group | .694** | .306 | .04 |
| Taping × instruction group | .968*** | .032 | .02 |
| Taping × tape group | .878** | .122 | .001 |
| Instruction group × tape group | .883** | .117 | .07 |

*** *strong evidence*, ***positive evidence*

**Hand span as an estimate of action capacity**

We used participants' drawings around their outspread finger to estimate their maximum hand span to check whether this was reduced by taping. A mixed ANOVA was conducted with hand (still-taped / was-taped-but-tape-removed / untaped) as a within-participants factor and tape group (LHTaped / RHTaped) as a between-participants factor. Hand was significant, $F(2, 104) = 212.766$, $p < .001$, $\eta_p^2 = .80$. Maximum hand span was lower for the still-taped hand than for either the hand that was taped but with tape removed or the untaped hand, see Table 2. There was no effect of tape group, $F(1, 52) = 1.012$, $p = .3$, $\eta_p^2 = .02$, or a hand × tape group interaction, $F(2, 104) = 0.026$, $p = .9$, $\eta_p^2 < .001$. Thus, the taping manipulation significantly reduced maximum hand span by ~4 cm regardless of which hand was taped.

**Post-experiment questions**

The number of participants across all groups in Experiments 1-3 who agreed that taping or instructions influenced their estimates of object size (questions 6 and 8 in the questionnaire) is given in Table 3. The number of participants who responded that that objects appeared bigger, the same size or smaller for trials using their taped relative to their untaped hand (asked verbally by the experimenter at the end of the experiment) is given in Table 4. Detailed responses to further open-ended questions can be found in the supplementary material (available in the online publication of Collier & Lawson, 2017b).

### 3.3.3 Discussion

We did not find scaling effects on object size estimates as would be predicted by the action-specific account. In addition, estimates of object size did not differ between the taped and untaped hands in any of the three groups, so participants were not sensitive to leading instructions. We therefore found no evidence that differences in demand characteristics due to hypothesis guessing could explain why Collier and Lawson (2017a) failed to replicate Linkenauger, Witt and Proffitt (2011, Experiment 2). We re-examined this issue in Experiment 2.

**Table 2**

Mean (and standard deviation) of the maximum span of the still-taped hand, the taped hand without tape, and the untaped hand, in each group in Experiments 1, 2 and 3.

| | Action Capacity group (Expt 1, n=18) | Objective Size group (Expt 1, n=18) | Body Size group (Expt 1, n=18) | Direction Specified group (Expt 2, n=18) | Report Graspability group (Expt 3, n=18) | Grand Mean (n=90) |
|---|---|---|---|---|---|---|
| Taped hand (still taped, cm) | 13.5 (1.8) | 13.3 (1.9) | 13.5 (1.7) | 13.1 (1.6) | 13.9 (1.9) | 13.5 (1.8) |
| Taped hand (with tape removed, cm) | 17.9 (1.2) | 17.4 (1.8) | 18.0 (1.3) | 18.1 (1.2) | 17.2 (1.8) | 17.7 (1.5) |
| Untaped hand (cm) | 17.6 (1.9) | 17.0 (2.0) | 17.9 (1.3) | 17.6 (1.3) | 17.5 (1.7) | 17.5 (1.6) |

**Table 3**

The number (and %) of participants in each group in Experiments 1, 2 and 3 who agreed in a post-experiment questionnaire that taping or instructions influenced their estimates of object size.

| | Action Capacity group (Expt 1, n=18) | Objective Size group (Expt 1, n=18) | Body Size group (Expt 1, n=18) | Direction Specified group (Expt 2, n=18) | Report Graspability group (Expt 3, n=18) | Total (n=90) |
|---|---|---|---|---|---|---|
| Agreed that taping influenced size estimates | 15 (83%) | 16 (89%) | 14 (78%) | 8 (44%) | 14 (78%) | 67 (74%) |
| Agreed that instructions influenced size estimates | 9 (50%) | 14 (78%) | 8 (44%) | 15 (83%) | 9 (50%) | 55 (61%) |

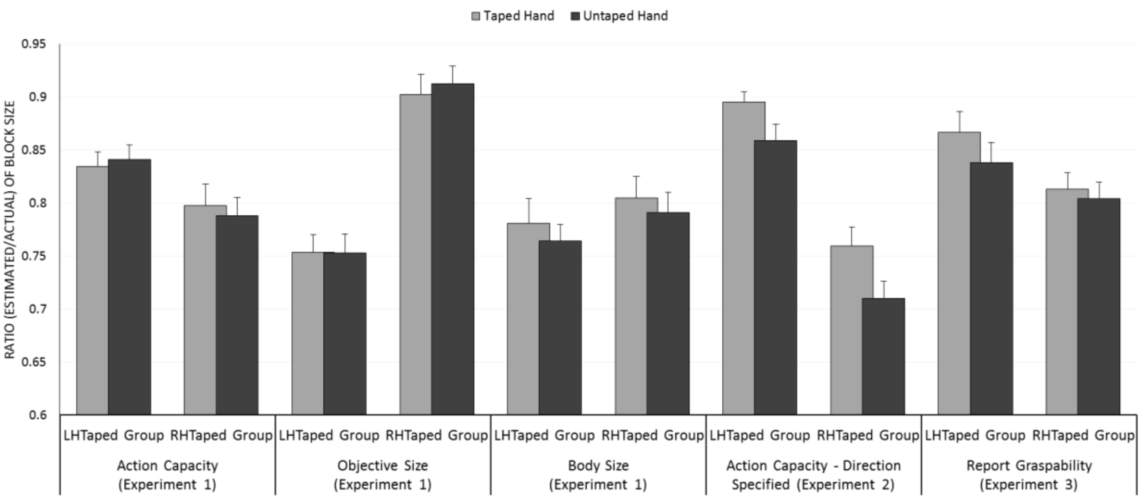


*Figure 4*: Mean estimated object size, shown as a proportion of actual object size, for the LHTaped and RHTaped groups in Experiments 1-3. Error bars show one standard error of the mean.

**Table 4**

The number (and %) of participants in each group in Experiments 1, 2 and 3 who agreed in a post-experiment questionnaire that objects appeared bigger, the same size or smaller for trials using their taped relative to their untaped hand.

| | Action Capacity group (Expt 1, n=18) | Objective Size group (Expt 1, n=18) | Body Size group (Expt 1, n=18) | Direction Specified group (Expt 2, n=18) | Report Graspability group (Expt 3, n=18) | Total (n=90) |
|---|---|---|---|---|---|---|
| Block appeared bigger in taped hand (Action-specific prediction) | 9 (50%) | 8 (44%) | 9 (50%) | 11 (61%) | 9 (50%) | 46 (51%) |
| Block appeared no different in taped hand (Objective size prediction) | 6 (33%) | 8 (44%) | 4 (22%) | 7 (39%) | 8 (44%) | 33 (37%) |
| Block appeared smaller in taped hand (Body size prediction) | 3 (17%) | 2 (11%) | 5 (28%) | 0 (0%) | 1 (6%) | 11 (12%) |

## 3.4 Experiment 2

In Experiment 1, the instructions given to the three groups may not have been sufficiently explicit to influence performance. For example, although the instructions for the action capacity group implied that grasping capacity might matter for size estimation, the expected direction of its effect still had to be inferred by participants. In Experiment 2, we investigated whether hypothesis guessing could influence performance if we directly told participants the results that we expected to obtain. We adapted the instructions from the action capacity group in Experiment 1 to explicitly tell participants that their estimates of object size were expected be greater for their taped hand than for their untaped hand.

### 3.4.1 Method

#### 3.4.1.1 Participants

Eighteen participants (mean age = 18.5 years, 0 male, mean Edinburgh Handedness Inventory score = 87.5, range = 50-100) were recruited for this study. Participants all self-reported as right handed, and either volunteered or were rewarded with course credit for their time.

#### 3.4.1.2 Apparatus, stimuli and procedure

The apparatus, stimuli and procedure were identical to Experiment 1, except for the following changes. First, participant's fingers were taped before the instructions were read to them. This was to maximise the likelihood that, as they were given their instructions, participants would consider the relationship between grasping capacity and perceived object size that was being described to them. Second, only one set of instructions was used, which was adapted from the action capacity group of Experiment 1, as follows.

**Action capacity - direction specified group**

*"In this experiment, we will ask you to estimate the size of square stimuli. There are many possible interpretations of this instruction, so we want to make it clear what it is we want you to estimate. Imagine looking at a mug on a table: there may be things in the environment that make it visually appear closer to or further away than its actual physical distance from you – that is, the distance measured by a tape measure. For example, if it appears difficult to reach, you may perceive the distance to the mug as greater than it really is.*

*Similarly, this logic can be applied to the size of objects that we act on.* ***For example, the same thing might happen when we estimate the size of objects that we are***

***going to pick up. In this experiment we have taped together the fingers of one of your hands whilst your other hand has not been taped. Previous research has suggested that taping your hand makes it harder to pick up objects and that this makes objects grasped in or seen near to your taped hand appear bigger to you. Basically, because we are clumsier when our hand is taped, objects we might pick up with it appear larger to us so that we are more careful when picking them up.***

*In this experiment, you will be asked to estimate the size of objects that you have just picked up with either your taped hand or your untaped hand.* ***Take all relevant non-visual factors into account when you estimate object size, including whether having your fingers taped together makes the objects appear bigger compared to your untaped hand."*** Participants were reminded that they should consider whether the blocks appeared larger in their taped hand after 10 trials, and the entire procedure lasted around 20 minutes.

### 3.4.2 Results

**Object size estimation task**

We excluded four trials due to invalid responses, e.g. pressing the Enter key without adjusting the distance between the lines. We calculated perceived block size ratios as in Experiment 1. These ratios were the dependent variable in a mixed ANOVA with taping (taped/untaped) as a within-participants factor and tape group (LHTaped/RHTaped) as a between-participants factor. Taped hand estimates (m = 0.83, se = 0.03) were greater than untaped hand estimates (m = 0.78, se = 0.03), $F(1, 16) = 7.282$, $p = .016$, $\eta_p^2 = .31$, see Figure 4. There was also a significant effect of tape group, $F(1, 16) = 5.977$, $p = .026$, $\eta_p^2 = .27$, where LHTaped group estimates (m = 0.88, se = 0.10) were greater than RHTaped group estimates (m = 0.73, se = 0.16). There was no taping × tape group interaction, $F(1, 16) = 0.194$, $p = .7$, $\eta_p^2 = .01$. As in Experiment 1, we ran Bayesian analyses to check the strength of evidence for the effects revealed by the ANOVA, see Table 5.

**Table 5**

Posterior probabilities for the null [$p_{BIC}(H_0|D)$] and alternative [($p_{BIC}(H_1|D)$] hypotheses for the main effects and interaction in Experiment 2.

| Effect | $p_{BIC}(H_0\|D)$ | $p_{BIC}(H_1\|D)$ | $\eta_p^2$ |
|---|---|---|---|
| Taping | .127 | .873*** | .31 |
| Tape group | .196 | .804** | .27 |
| Taping × tape group | .792** | .208 | .01 |

*** *strong evidence*, ***positive evidence*

**Hand span as an estimate of action capacity**

We used participants' drawings around their outspread finger to estimate their maximum hand span to check whether this was reduced by taping. A mixed ANOVA was conducted with hand (still-taped / was-taped-but-tape-removed / untaped) as a within-participants factor and tape group (LHTaped / RHTaped) as a between-participants factor. Hand was significant, $F(2, 32) = 102.715$, $p < .001$, $\eta_p^2 = .87$. Maximum hand span was lower for the still-taped hand than for either the hand that was taped but with tape removed or the untaped hand, see Table 2. There was no effect of tape group, $F(1, 16) = 0.037$, $p = .9$, $\eta_p^2 = .002$, or a hand × tape group interaction, $F(2, 32) = 2.912$, $p = .07$, $\eta_p^2 = .15$. Thus, the taping manipulation significantly reduced maximum hand span by ~ 4 cm regardless of which hand was taped.

### 3.4.3 Discussion

In Experiment 2, participants estimated blocks as larger when they grasped them using their taped rather than their untaped hand. Thus when, unlike in Experiment 1, the desired outcome was clearly and explicitly stated in the pre-experimental instructions, participants produced scaling effects averaging ~ 4%. This effect is modest, but is comparable to the original effect reported in Experiment 2 of Linkenauger, Witt and

Proffitt (2011), where objects to-be-grasped in the right hand were estimated as ~3% smaller than objects to-be-grasped in the left hand. More generally, Firestone noted that many effects demonstrated by the action-specific account are only modest in size. He wrote "Paternalistic perceptual effects are the wrong size for the job" (Firestone, 2013, p. 458).

Our results are consistent with previous work suggesting that hypothesis guessing can influence performance to produce the effects reported in the action-specific literature (Durgin et al., 2012; Firestone & Scholl, 2014; Woods et al., 2009). The results of Experiments 1 and 2 suggest that in the size estimation task used both here, and by Linkenauger, Witt and Proffitt (2011, Experiment 2), participants may respond to demand characteristics from hypothesis guessing. However, this required instructions to be explict and overtly biased. Such extreme demand characteristics seem unlikely to explain the perceptual scaling effects reported in Experiment 2 of Linkenauger, Witt and Proffitt (2011). In our final experiment, we tried to resolve why scaling effects were obtained in Experiment 2 of Linkenauger, Witt and Proffitt (2011) but not in Experiment 3 of Collier and Lawson (2017a). We did this by examining the influence of a different type of demand characteristics on object size, namely *context effects*.

## 3.5 Experiment 3

When action capacity and spatial properties are estimated in quick succession, and on every trial, as in Experiment 2 of Linkenauger, Witt and Proffitt (2011), the experimental context may subtly imply that the two estimates are related or the two types of estimates may be confused. Importantly, participants may not need to be aware of such context effects for them to occur, unlike explicit hypothesis guessing. Nevertheless, and importantly, scaling effects on spatial estimates arising from either type of demand characteristic are not genuine perceptual effects because the participant's visual representation of the environment is not altered (Firestone, 2013).

On every trial in Experiment 2 of Linkenauger, Witt and Proffitt (2011), participants estimated the graspability of an object immediately before estimating its apparent size. The dimensions of graspable-to-ungraspable and small-to-large may be conceptually linked, in a way similar to cross-sensory correspondences between sensory modalities (e.g. Walker, 2012; Walker et al., 2016). If so, then people may find it hard to assess them independently in a context where they are asked about both. We discussed this possibility in Collier and Lawson (2017a), and referred to it as *conflation.* However, in our previous study we did not test whether we could replicate Linkenauger, Witt and Proffitt's (2011, Experiment 2) scaling effect by introducing a context in which measures of spatial perception were likely to be combined or confused with estimates of action capacity. This was done in Experiment 3. Here, on every trial, participants rated how difficult the block had been to grasp (graspability) and then its size. Note that we were not interested in the results of this task. The purpose of this graspability task was to test whether drawing attention to the graspability of an object immediately before estimating its size would induce conflation between estimates of graspability and estimates of size. We reasoned that, in this conflation context, participants might estimate objects grasped in their taped hand as bigger than objects grasped in their untaped hand.

### 3.5.1 Method

#### 3.5.1.1 Participants

Eighteen participants (mean age = 19.6 years, 2 males) were recruited for this study. Participants all self-reported as right handed and were rewarded with course credit for their time.

### 3.5.1.2 Apparatus, stimuli and procedure

The apparatus, stimuli and procedure were identical to those of the action capacity group in Experiment 1 apart from the following change. Participants completed an additional object graspability task on each trial. For this task, participants verbally rated the difficulty of grasping each block on a scale of 1 (very easy) to 10 (very difficult) after they had picked it up and placed it on the table. They then estimated the size of the block as in Experiment 1.

## 3.5.2 Results

**Object graspability task**

We first tested whether participants rated blocks they had grasped in their taped hand as harder to grasp than blocks they had grasped in their untaped hand. Mean difficulty ratings were used as the dependent variable in a mixed ANOVA where taping (taped/untaped) was a within-participants factor and tape group (LHTaped/RHTaped) was a between-participants factor. Participants rated objects they had grasped in their taped hand (m = 3.4, sd = 1.2) as more difficult to grasp than objects they had grasped in their untaped hand (m = 2.4, sd = 0.8), $F(1, 16) = 21.519$, $p < .001$, $\eta_p^2 = .57$. There was no effect of tape group, $F(1, 16) = 0.814$, $p = .4$, $\eta_p^2 = .05$, or a taping × tape group interaction, $F(1, 16) = 1.202$, $p = .3$, $\eta_p^2 = .07$.

**Object size estimation task**

We excluded two trials where the participant was unable to grasp the block in the manner specified using their taped hand (both were 13 cm trials) plus the two corresponding trials for that participant for their untaped hand. A further three trials were excluded due to invalid responses, e.g. pressing the Enter key without adjusting the distance between the lines. Perceived block size ratios were calculated as in Experiments 1 and 2. These ratios were the dependent variable in a mixed ANOVA with taping (taped/untaped) as a within-participants factor and tape group (LHTaped/RHTaped) as a between-participants factor. Taped hand estimates (m = 0.84, se = 0.03) were greater than untaped hand estimates (m = 0.82, se = 0.03), $F(1, 16) = 4.936$, $p = .041$, $\eta_p^2 = .24$. There was no effect of tape group, $F(1, 16) = 0.771$, $p = .4$, $\eta_p^2 = .05$, or a taping × tape group interaction, $F(1, 16) = 1.208$, $p = .3$, $\eta_p^2 = .07$, see Figure 4. As in Experiments 1 and 2, we ran Bayesian analyses to check the strength of evidence for the effects revealed by the ANOVA, see Table 6.

**Table 6**

Posterior probabilities for the null [$p_{BIC}(H_0|D)$] and alternative [($p_{BIC}(H_1|D)$)] hypotheses for the main effects and interaction in Experiment 3.

| Effect | $p_{BIC}(H_0\|D)$ | $p_{BIC}(H_1\|D)$ | $\eta_p^2$ |
|---|---|---|---|
| Taping | .274 | .726** | .24 |
| Tape group | .735* | .265 | .05 |
| Taping × tape group | .688** | .312 | .07 |

***positive evidence, *weak evidence*

**Hand span as an estimate of action capacity**

We used participants' drawings around their outspread finger to estimate their maximum hand span to check whether this was reduced by taping. A mixed ANOVA was conducted with hand (still-taped / was-taped-but-tape-removed / untaped) as a within-participants factor and tape group (LHTaped / RHTaped) as a between-participants factor. Hand was significant, $F(2, 32) = 48.980$, $p < .001$, $\eta_p^2 = .75$. Maximum hand span was lower for the still-taped hand than for either the hand that was taped but with tape removed or the untaped hand, see Table 2. There was no effect of tape group, $F(1, 16) = 0.497$, $p = .5$, $\eta_p^2 = .03$, or a hand × tape group interaction, $F(2, 32) = 0.596$, $p = .5$, $\eta_p^2 = .04$. Thus the taping manipulation significantly reduced maximum hand span by ~4 cm regardless of which hand was taped.

### 3.5.3 Discussion

In Experiment 3 participants rated objects as harder to grasp in their taped hand than in their untaped hand. They then went on to estimate blocks that they had grasped in their taped hand as larger than blocks they had grasped in their untaped hand. These results provide evidence for the suggestion by Collier and Lawson (2017a) that the scaling effect reported by Linkenauger, Witt and Proffitt (2011, Experiment 2) occurred because action capacity estimates were conflated with size estimates. This likely occurred because participants were asked to estimate graspability immediately before estimating object size on every trial. This influence of context would only need to occur occasionally to produce the modest scaling effects that have been observed (~3% in both Experiment 3 here and in Experiment 2 of Linkenauger, Witt & Proffitt, 2011). In Experiment 3 here, 11 out of 18 participants estimated blocks as larger for their taped hand than their untaped hand. Furthermore, participants appear able to independently estimate object graspability and size if care is taken to distinguish between them. For example, Collier and Lawson (2017a) found that when participants were explicitly instructed that grasping and size estimates were being collected for separate, unrelated experiments, there was no influence of grasping capacity on estimated object size. Together these results indicate that the scaling effect reported by Linkenauger, Witt and Proffitt (2011, Experiment 2) was not truly perceptual.

## 3.6 General Discussion

In the present studies, we were interested in understanding the basis of biases that have previously been reported in the perception of object size and that have been interpreted as supporting the action-specific account. Specifically, Linkenauger, Witt and Proffitt (2011) argued that apparent grasping capacity can influence perceived object size. However, we subsequently found no evidence to support this claim (Collier & Lawson, 2017a). In the present studies, we sought to understand whether scaling effects were obtained by Linkenauger, Witt and Proffitt (2011, Experiment 2), but not by Collier and Lawson (2017a), because of demand characteristics.

In Experiment 1, we investigated whether leading instructions would bias estimates of object size due to participants explicitly hypothesis guessing. We reasoned that estimated object size could increase if perceived hand size increased (on a body size scaling account), or could scale in the opposite direction based on changes in perceived grasping capacity (consistent with the action-specific account), see Figure 1. Neither of these predictions were supported: we found no evidence that participants adjusted their responses after inferring the desired outcome of the experiment based on the instructions they were given. We re-examined this issue in Experiment 2 using a more powerful manipulation. Here, the instructions clearly and explicitly specified the direction of the expected effect based on the action-specific account. Now participants produced results consistent with the expectations arising from their instructions: blocks that were harder to grasp because they were picked up in the taped hand were estimated as larger than blocks that had been grasped in the untaped hand. Taken together, these results suggest that hypothesis guessing is an unlikely explanation for the results of Linkenauger, Witt and Proffitt (2011, Experiment 2) because scaling effects were only obtained in Experiment 2, when we used unrealistically directive instructions.

Orne (1962, p. 779) stated that “response to the demand characteristics is not merely conscious compliance” and that other, subtler, forms of demand characteristics can also influence participants’ responses. Based on this suggestion, and our own proposal (Collier & Lawson, 2017a) that conflation might explain Linkenauger, Witt and Proffitt’s (2011, Experiment 2) results, in Experiment 3 we investigated whether the experimental context could implicitly influence performance. This was manipulated by having participants report an object’s graspability immediately before estimating its size. Now we found the predicted scaling effect: participants estimated blocks as larger after grasping them with their taped relative to their untaped hand. This suggests that Linkenauger, Witt and Proffitt's (2011, Experiment 2) scaling effect likely arose as a result of asking participants to report graspability before object size on every trial. We propose that their task encouraged a conflation between estimates of action capacity and spatial extent, so that the scaling effects that they observed did not reflect a change in perception in the strong sense, as proposed by the action-specific account.

Our results expand on what is already known about demand characteristics in the action-specific literature by showing that these demand characteristics can take multiple forms. In Durgin et al. (2009) and Firestone and Scholl (2014), participants produced action-specific effects if no reason for a salient experimental manipulation was given, whereas participants who were given an explanation for the manipulation showed no effect. In these studies action-specific effects seemed to occur only when participants guessed the experimental prediction. In contrast, the results of Experiment 1 here suggest that participants may not have explicitly guessed the experimental hypothesis in the object size estimation task used by Linkenauger, Witt and Proffitt (2011, Experiment 2). Nevertheless, the results of Experiment 3 here suggest that the scaling effect reported by Linkenauger, Witt and Proffitt (2011, Experiment 2) could still reflect post-perceptual demand characteristics due to an implicit context effect. The context effect, like hypothesis guessing, is inconsistent with the explanation of scaling results provided by the action-specific account, namely that participants actually see stimuli differently if their action capacity changes.

We previously demonstrated that context effects can be overridden using instructions which carefully distinguish between estimates of action capacity and estimates of spatial qualities. The final experiment reported in Collier and Lawson (2017a) was similar to Experiment 3 here in that we asked participants to first grasp and then estimate the size of blocks on the same trial. Unlike Experiment 3 here, the experimenter emphasised that they were interested in participant's grasping behaviour and said that they would record how participants grasped blocks on each trial. However, using a cover story about time constraints on data collection, participants were also told that the grasping task was producing data for a separate study to the size estimation task. In contrast to Experiment 3 here, we found no difference between size estimates made for objects grasped in taped compared to untaped hands. Thus context effects were eliminated by telling participants that the tasks were separate, similar to the way in which hypothesis guessing was controlled for by Durgin et al. (2009), by giving participants a reason for wearing the backpack while estimating hill slant.

Thus previous work has found that providing a convincing cover story can eliminate action-specific scaling effects (Collier & Lawson, 2017a; Durgin et al., 2009: 2012; Firestone & Scholl, 2014) and that the use of leading instructions can induce these scaling effects (Woods et al., 2009). In contrast, we found no evidence that explicit hypothesis guessing influenced estimated object size in Experiment 1 here. We suggest that this may have been because the experimental hypothesis was relatively hard to infer in this task, particularly since the group-specific instructions did not specify the direction of the predicted effect. Consistent with this interpretation, we did obtain scaling effects in Experiment 2, when participants were directly told the expected results of the study.

We have argued that scaling effects on estimates of object size may arise if these estimates are conflated with those of grasping capacity. Scaling effects were obtained in both Experiment 3 here and Experiment 2 of Linkenauger, Witt and Proffitt (2011), when participants were *actively and explicitly encouraged* to think about and report their grasping capacity on every trial. It is important to emphasise that this context is unusual and does not reflect everyday life. Scaling effects were not obtained in the first four experiments reported by Collier and Lawson (2017a), when participants were not encouraged to think about their grasping behaviour or capacity, even though they actually grasped blocks on every size estimation trial. Thus, scaling effects consistent with the action-specific account seem to be context-dependent, such that they only appear under narrow, non-ecological conditions.

Not all studies which have reported an influence of grasping capacity on estimated object size required participants to explicitly report their grasping capacity. For example, in Experiment 1 of Linkenauger, Witt and Proffitt (2011), a disc was placed in the palm of the left and right hands of right-handed participants and they were asked which disk appeared larger. Participants also visually matched the size of the discs. In both tasks, the disks in the right hand were estimated as smaller than the disks in the left hand. Since participants did not have to report their grasping capacity, these results cannot be explained by context effects. There is though, an alternative explanation for these results which does not assume that action-specific scaling occurred. Right handers have repeatedly been shown to believe that their right hand is larger than their left hand (Collier & Lawson, 2017a; Linkenauger, Witt & Proffitt, 2011), so the discs surrounded by a perceptually larger object (the right hand) may have appeared smaller than the discs surrounded by a perceptually smaller object (the left hand). In fact, Linkenauger, Witt and Proffitt (2011, Experiment 1) themselves suggested that such a size-contrast effect could have caused the results they obtained, rather than that perceived object size was scaled according to grasping capacity.

One reason that participants are asked to estimate their grasping capacity in studies supporting the action-specific account is to check perceived action capacity, since action-specific scaling effects are only predicted if people think that the action can be performed (Linkenauger, Witt & Proffitt, 2011; Witt, 2017). For example, only objects that people think they can grasp should be scaled; no effect should be found for objects larger than perceived maximum grasp (Linkenauger, Witt & Proffitt, 2011). One interesting issue, that has not yet been addressed, is whether scaling effects should be expected when objects are so small that they could be easily grasped regardless of whether they are grasped in the left or right hand, or indeed in a taped or untaped hand. Cañal-Bruland and van der Kamp (2015) suggested that distortions in spatial perception as a result of action capacity should be strongest at the critical boundaries for action. Investigating this hypothesis would be a valuable route for future research to pursue.

In order to produce a large, robust, yet reversible effect on both perceived and actual grasping capacity we used a taping manipulation in the experiments reported here. This differed from the manipulation of perceived grasping capacity investigated in Experiment 2 of Linkenauger, Witt and Proffitt (2011). They took advantage of the bias for right handers to overestimate both the size and the grasping capacity of their right hand relative to their left hand. This bias existed prior to the start of the experiment and may arise from a lifetime of experience using their right hand more than their left hand. There is also greater representation for the right hand than the left hand in the somatosensory cortex of right handers (Sörös et al., 1999). Such differences could be argued to explain why our results differed from those of Linkenauger, Witt and Proffitt (2011). However, we think this is unlikely. First, Experiment 3 of Linkenauger, Witt and Proffitt (2011) manipulated hand size by magnifying the hand. Like our taping manipulation, this is a short-term, within-experiment manipulation. Nevertheless, they reported differences in estimated object size when objects were placed next to the magnified, compared to the unmagnified, hand. Second, in our previous work, we found that participants rapidly updated their perceived grasping capacity after attempting to grasp objects with their taped hand (Collier & Lawson, 2017a). This suggests that, although taping is a short-term manipulation, it is effective in influencing perceived grasping capacity. Thus, although our manipulation of grasping capacity differed to that used in Experiment 2 of Linkenauger, Witt and Proffitt (2011), we believe our method is appropriate for investigating the effect they reported.

Modular theories of perception claim that perception is cognitively impenetrable, meaning that it is not affected by higher-level cognition (Firestone, 2013; Firestone & Scholl, 2015). The action-specific account challenges cognitive impenetrability by suggesting that perception can be directly influenced by action capacity. However, here we only found effects consistent with the action-specific account when the experimental instructions explicitly stated the expected outcome (consistent with hypothesis guessing), or when participants estimated object size in a context which implied that their grasping capacity was relevant (consistent with context effects). If apparent grasping capacity can directly influence perceived object size, as the action-specific account claims (e.g. Linkenauger, Witt & Proffitt, 2011), then we should also have found scaling effects when hypothesis guessing and context effects were controlled for (e.g., in Collier & Lawson, 2017a) but we did not. The effects we observed in the present studies therefore seem to reflect biases at the level of judgement as opposed to true perceptual changes. By extension, our results are consistent with the idea of cognitive impenetrability.

In conclusion, the results of the present studies do not support the strong claim of the action-specific account that what we see is directly influenced by our action capacity. Our results instead suggest that the scaling effects on estimated object size that were interpreted as supporting the action-specific account by Linkenauger, Witt and Proffitt (2011, Experiment 2) are more likely to have arisen from participants responding to subtle, easily overlooked cues within their experimental procedure. We are in agreement with Firestone and Scholl (2015) who observed: “If there is one unifying message running through our work on this topic, it is this: The details matter.” (p. 59).

### 3.7 Footnotes: Chapter 3

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[1] For each experiment reported here we also tested for the original effect reported by Linkenauger et al. (2011) that objects grasped by the right hand would be estimated as smaller than those grasped by the left hand:

In Experiment 1, a mixed ANOVA where grasping hand (left/right) was a within-participants factor and instruction group (action capacity/objective size/body size) and tape group (LHTaped/RHTaped) were between-subjects factors was conducted. There were no significant effects. For the main effects: grasping hand $F(1, 48) = 0.037$, $p = .8$, $\eta_p^2 = .001$, instruction group, $F(2, 48) = 0.754$, $p = .5$, $\eta_p^2 = .03$, and tape group, $F(1, 48) = 2.136$, $p = .2$, $\eta_p^2 = .04$. For the interactions: grasping hand × instruction group, $F(2, 48) = 0.309$, $p = .7$, $\eta_p^2 = .01$, grasping hand × tape group, $F(1, 48) = 0.416$, $p = .5$, $\eta_p^2 = .01$, instruction group × tape group, $F(2, 48) = 1.817$, $p = .2$, $\eta_p^2 = .07$, and grasping hand × instruction group × tape group, $F(2, 48) = 0.517$, $p = .6$, $\eta_p^2 = .02$.

In Experiment 2, a mixed ANOVA where grasping hand (left/right) was a within-participants factor and tape group (LHTaped/RHTaped) was a between-subjects factor was conducted. There was no effect of grasping hand, $F(1,16) = 0.194$, $p = .6$, $\eta_p^2 = .01$. There was a main effect of tape group, $F(1, 16) = 5.977$, $p = .026$, $\eta_p^2 = .27$; the LHTaped group had greater estimates (m = 0.88, se = 0.10) than the RHTaped group (m = 0.73, se = 0.16). There was also a significant grasping hand × tape group interaction, $F(1, 16) = 7.282$, $p = .016$, $\eta_p^2 = .31$. Bonferroni corrected pairwise comparisons showed that for the RHTaped group, estimates were greater for the right hand than the left hand (mean difference = 0.05, $p = .04$), whereas there was no significant difference for the LHTaped group (mean difference = 0.04, $p = .1$).

In Experiment 3, a mixed ANOVA where grasping hand (left/right) was a within-participants factor and tape group (LHTaped/RHTaped) was a between-subjects factor was conducted. There were no significant main effects: grasping hand, $F(1, 16) = 1.208$, $p = .3$, $\eta_p^2 = .07$, and tape group, $F(1, 16) = 0.771$, $p = .4$, $\eta_p^2 = .05$. There was a significant grasping hand × tape group interaction, $F(1, 16) = 4.936$, $p = .041$, $\eta_p^2 = .24$. Bonferroni corrected pairwise comparisons showed that for the LHTaped group estimates for the left hand were greater than for the right hand (mean difference = 0.26, $p = .032$) but for the RHTaped group there was no difference between estimates for the left and right hands (mean difference = -0.009, $p = .4$).

# Chapter Four

## 4. Size-contrast effects could explain at least one action-specific effect

### 4.1 Abstract

The action-specific account of perception proposes that what we see is directly affected by our action capacity. For example, Linkenauger et al. (2013, Experiment 1) used virtual reality to manipulate the apparent size of participants' right hand. They reported that objects seen near the hands were estimated as larger when the hand was rendered as smaller, and vice versa when the hand was rendered as larger. However, this effect was not found when the visual size of a virtual avatar's hands was manipulated (Linkenauger et al., 2013, Experiment 2). The authors claimed that these experiments provided evidence that perceived object size scales according to grasping capacity. Since no effect was found when the visual size of the avatar's hands was manipulated, Linkenauger et al. (2013) claimed their effect could not be due to size-contrast effects. However, in Linkenauger et al. (2013, Experiment 2), participants could see their own hand. Critically, their hand did not change apparent size across trials. This means they could have used their own hand, instead of the avatar's hands, as an anchor for object size. In the present study, we tested whether participants would estimate objects seen near their own hand (but not a fake hand) as smaller when the hand was visually enlarged using magnification. This manipulation has been used by proponents of the action-specific account in previous studies (e.g., Linkenauger, Witt & Proffitt, 2011). Participants who saw the fake hand kept their own hand out of sight so that it could not be used as an anchor

for object size. We found a magnification effect on estimated object size in both cases. This suggests that the results of studies where apparent grasping capacity was manipulated by changing visual hand size, such as Linkenauger et al. (2013), could arise from size-contrast effects.

## 4.2 Introduction

The action-specific account of perception suggests that what we perceive is scaled according to our action capacity (for some recent reviews see Collier & Lawson, under review; Firestone, 2013; Philbeck & Witt, 2015; Proffitt, 2013; Proffitt & Linkenauger, 2013; Witt, 2011a, 2017). This account proposes that we literally see the world in terms of our ability to act. Specifically, proponents of this account claim that the visual representation of the environment is scaled according to, for example, bioenergetics and energy expenditure (e.g., Bhalla & Proffitt, 1999; Schnall, Zadra & Proffitt, 2010; Zadra, Weltman & Proffitt, 2016) and performance variability (e.g., Witt & Sugovic, 2010; Witt et al., 2008). Action-specific scaling is also claimed to occur according to the functional morphology of the body (e.g., Linkenauger, Witt & Proffitt, 2011; Witt et al., 2005). For example, observers estimated targets that were out of reach to be nearer after reaching to them with a tool which expanded their maximum reach (Witt et al., 2005) and apertures were estimated as narrower when observers held a horizontal rod that was wider than their body (Stefanucci & Geuss, 2009). In another example, Linkenauger, Witt & Proffitt (2011, Experiment 2) reported that right handers underestimated the size of objects they intended to grasp with their right hand relative to objects they intended to grasp with their left hand. The authors claimed that this effect occurred because right handers perceive their right hand as having a greater grasping capacity than their left hand, and so objects appear more graspable – and therefore smaller – when they intend to grasp with their right hand.

We (Collier & Lawson, 2017a) failed to replicate Linkenauger, Witt and Proffitt (2011, Experiment 2). Although we replicated the finding that right handers estimate the grasping capacity of their right hand to be greater than that of their left hand, this did not modulate estimates of object size (Collier & Lawson, 2017a, Experiments 2 & 3). However, the bias for right handers to estimate the grasping capacity of their right hand as greater than their left hand is a relatively small effect (~0.5 cm). Furthermore, neither Linkenauger, Witt and Proffitt (2011, Experiment 2) nor Collier and Lawson (2017a, Experiments 2 and 3) found evidence that, on average, the right hand actually can grasp larger objects than the left hand. Directly manipulating grasping capacity is a stronger way to test the claim that grasping capacity causally affects perceived object size. To this end, in Collier and Lawson (2017a, Experiments 4 & 5), we taped together participants' fingers, which restricted both actual and perceived grasping capacity. In these experiments, participants estimated the size of blocks that they grasped in either their taped or untaped hands. We found that participants did not estimate objects as larger after grasping them in their taped hand than in their untaped hand, despite reporting that their grasping capacity was significantly reduced when their hand was taped. Thus, in Collier and Lawson (2017a) we found no evidence in support of the action-specific account of perception.

Linkenauger and colleagues (Linkenauger, Witt & Proffitt, 2011, Experiment 3; Linkenauger et al., 2013) have taken a different approach to manipulating apparent grasping capacity, by changing visual hand size. For example, in their third experiment, Linkenauger, Witt and Proffitt (2011) used magnification to increase the visual size of participants' right hand. On each trial, a block was placed next to the participant's right hand. Participants were first asked whether they thought they could grasp the block and then they visually matched its size on a screen. They completed one subblock of trials while their right hand was magnified, and another subblock while it was not. Blocks that were within perceived grasp were estimated as smaller when placed next to the magnified hand than the unmagnified hand. However, blocks that were beyond perceived maximum grasping capacity showed no effect. Linkenauger, Witt and Proffitt (2011) interpreted this as evidence for action-specific scaling, as the magnified hand may have been perceived as having a greater grasping capacity and so objects may have appeared smaller[1]. In a subsequent study with a similar motivation, Linkenauger et al. (2013) used virtual reality to manipulate the apparent size of participants' right hand. They found that objects seen near the hand were estimated as larger when the hand was rendered as smaller, and vice versa when the hand was rendered as larger. Linkenauger et al. (2013) argued that this result also demonstrated action-specific scaling according to grasping capacity.

However, the results of both Linkenauger, Witt and Proffitt (2011, Experiment 3) and Linkenauger et al. (2013) could have been driven by a size-contrast effect, where an object may appear smaller when placed next to a bigger object as a result of visual relativity (e.g., Obonai, 1954). To counter the possibility that their effect was driven by a size-contrast effect, Linkenauger et al. (2013) ran a series of other experiments. For example, in their second study, the hand size of a virtual avatar, which was positioned opposite the participant in the virtual environment, was manipulated. No effect was found in this experiment. The authors argued that this demonstrated that the effect they found when the size of the participants' own hand was manipulated could not have been due to a size-contrast effect. If this were the case, they argued, then the same effect should have been found when the hands of the virtual avatar were manipulated. Linkenauger et al. (2013) also argued that, consistent with the action-specific account, their result showed that scaling effects are specific to one's own body.

However, as we discussed in a recent review article (Collier & Lawson, under review), the participant's own hand was also visible in Linkenauger et al. (2013, Experiment 2). This is problematic because it is possible that participants used their own hand as an anchor for object size rather than the hands of the avatar. There are at least two reasons why participants might employ this strategy. First, their own hand is a more familiar cue for object size than the hands of a virtual avatar. Second, their own hand remained a constant size throughout the experiment, making it a more stable anchor than the avatar's hands, which changed in size on every trial. This means that Linkenauger et al.'s (2013) second experiment may not, in fact, provide strong evidence that the effect of manipulating participants' own hand size was not simply a size-contrast effect.

In the present experiment, we tested whether visual changes in hand size produce effects consistent with the action-specific account because of true scaling according to grasping capacity, or a size-contrast effect. The combined results of Linkenauger, Witt and Proffitt (2011, Experiment 3) and Linkenauger et al. (2013) suggest that there are specific conditions under which changes in visual hand size should influence estimates of object size. Linkenauger, Witt and Proffitt (2011, Experiment 3) asked participants on every trial whether they believed they could grasp the presented block before they made their size estimates. This was done because action-specific effects are only expected when participants intend to act (Linkenauger, Witt & Proffitt, 2011; Witt et al., 2005). In addition, Linkenauger et al. (2013) claimed that action-specific effects are only expected when the size of one's own hands changes. No effect is predicted when the size of another person's hands changes. This means that changes in visual hand size should only affect estimates of object size when (1) participants intend to grasp an object, and (2) the size of participants' own hand is manipulated. In the present experiment, we therefore tested four groups of participants: OwnHand-Estimate-Only, OwnHand-Graspability-and-Size, FakeHand-Estimate-Only, and FakeHand-Graspability-and-Size. The only hand visible to participants was their own right hand for the OwnHand groups and a fake, plastic hand for the FakeHand groups. On every trial, participants in all groups visually matched the width of blocks placed next to the visible hand. They completed one set of trials while the visible hand was magnified and one where it was not. The Graspability-and-Size groups additionally judged whether they thought the block could be grasped (either by their own right hand or the fake hand) before making their size estimate. The action-specific account predicts that *only* those in the OwnHand-Graspability-and-Size group should estimate blocks as smaller when the visible hand is magnified. This is because only this group satisfies both criteria for finding this effect. Obtaining the predicted effect in the other groups would be inconsistent with the action-specific account, and would instead suggest that both the results of both Linkenaguer, Witt and Proffitt (2011, Experiment 3) and Linkenauger et al. (2013) could be explained by a size-contrast effect.

## 4.3 Method

Ethical approval for this experiment was granted by the relevant local ethics committee at the University of Liverpool.

### 4.3.1 Participants

Sixty-four participants[2] (mean age = 24.6 years, 18 males) were recruited for this experiment. Participants either volunteered or were given course credit for their time. All but one self-reported as right handed. Ethical approval for this experiment was granted by the relevant local ethics committee at the University of Liverpool.

### 4.3.2 Design

Participants were assigned to one of four groups (n = 16 per group): OwnHand-Estimate-Only, OwnHand-Graspability-and-Size, FakeHand-Estimate-Only, or FakeHand-Graspability-and-Size. Those in the own hand conditions viewed their own hand, while those in the fake hand conditions kept their hands out of sight and viewed a fake, plastic hand (lifelike colour, width at widest point = 8.7 cm, length at longest point = 14.2 cm). At the start of each trial, all participants were asked to rate the similarity between the length of the presented block and the length of the visible hand in the box. This ensured that all participants looked at both the hand and the block, which in provided confidence that all participants were equally likely to use the hand in the box as an anchor for object size. We also reasoned that this task reduced demand characteristics associated with providing no explanation for why the (either own or fake) hand was visible throughout the experiment. Those in the Graspability-and-Size groups additionally judged whether they thought the block could be grasped (either by their own right hand or by the fake hand if it could move; yes/no forced choice response) after making their similarity in size ratings. They were asked to make their graspability judgements based on placing the thumb on one side of the block and any other finger on the opposite side. Finally, participants in all groups estimated the width of the block.

### 4.3.3 Apparatus and stimuli

The stimuli were 5 foamboard square blocks (0.5 cm thick) which were 5, 10, 20, 30 and 40 cm in width. This range encompassed two blocks (5 & 10 cm) that were deemed to definitely be graspable, two blocks (30 & 40 cm) which were deemed to be definitely ungraspable and one block (20 cm) which was near the threshold of perceived maximum grasping capacity for the right hand based on Collier and Lawson (2017a, Experiment 3[3]). Two boxes were constructed (dimensions = 28 × 21 × 9.8 cm). The top of one box was made from a transparent magnification sheet (which made objects placed in the box appear ~50% larger than outside the box) while the top of the second box was made from clear plastic so the visible hand was not magnified. One of the boxes was placed on the table in front of the participant, on their right side (see Figure 1).

### 4.3.4 Procedure

Participants sat at the table and placed their right hand inside one of the boxes, see Figure 1. On each trial, they closed their eyes while the experimenter placed one of the blocks flat on the table beside the box. Participants then opened their eyes to look at the block. They were asked how similar in length the block appeared relative to the visible hand as it appeared inside the box. Responses were made on a scale of 1 (very different) to 10 (the same length). The OwnHand-Graspability-and-Size and FakeHand-Graspability-and-Size groups then judged whether they thought the block could be grasped by the hand as it appeared in the box by verbally responding yes or no. Participants then estimated the width of the block. The experimenter slowly pulled out a tape measure, with the numbers facing away from the participant. The participant verbally guided them by saying “bigger” or “smaller” until they thought that the visible length of tape measure matched the width of the block. The tape measure was pulled out vertically to minimise the use of landmark matching strategies, and the experimenter looked away from the tape measure while pulling it so that they could not see participants’ estimates until the end of the trial. To ensure that responses were as accurate as possible, after the participant said “stop”, the experimenter encouraged them to make minor adjustments to their response. After any minor adjustments were made and the participant was satisfied with their response, the experimenter recorded their estimate. The participant then closed their eyes and the block was exchanged for the next block. The visible hand was not removed from the box between trials. Participants estimated the width of each block in two subblocks of trials: one with the visible hand inside the magnifying box and one with the visible hand inside the non-magnifying box, see Figure 1. Subblock order was counterbalanced across participants within each group, and block presentation order was randomised within each subblock for each participant.

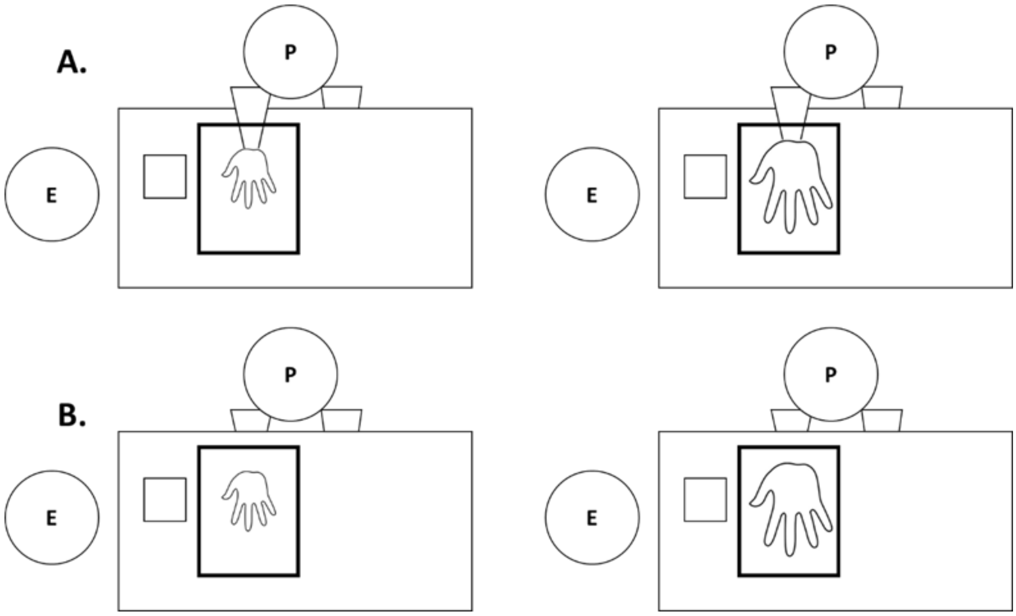



*Figure 1:* The experimental set-up for the OwnHand (A, top) and FakeHand (B, bottom) groups for a non-magnifying, control box trial (left) and a magnifying box trial (right). The experimenter (E) and participant (P) are represented by circles next to a rectangle representing the table with a square block stimulus on it and the control or magnifying box. Participants in the OwnHand conditions kept their left hand only out of sight, while participants in the FakeHand conditions kept both of their hands out of sight.

## 4.4 Results

Table 1 shows the mean width and length of the visible hand in the OwnHand and the FakeHand groups. Table 2 shows the mean estimated size of each block for each group.

**Table 1**

Actual mean (and standard deviation, for the real right hands only) for the visible hand width and length. The same fake hand was used in both FakeHand groups.

| | Unmagnified | | Magnified | |
|---|---|---|---|---|
| Group | Width (cm) | Length (cm) | Width (cm) | Length (cm) |
| OwnHand-Estimate-Only | 9.6 (0.9) | 17.1 (1.2) | 14.4 (1.4) | 25.7 (1.7) |
| Own-hand-Graspability-and-Size | 9.7 (0.7) | 17.2 (1.3) | 14.5 (1.1) | 25.8 (2.0) |
| Fake hand (both groups) | 8.7 | 14.2 | 13.1 | 21.3 |

**Table 2**

Mean (and standard deviation) estimated block width, as a ratio of actual block width, for each block in all groups. M = magnified condition, UM = unmagnified condition.

| | OwnHand Estimate-Only | | OwnHand Graspability-and-Size | | FakeHand Estimate-Only | | FakeHand Graspability-and-Size | |
|---|---|---|---|---|---|---|---|---|
| Block Width (cm) | M | UN | M | UN | M | UN | M | UN |
| 5 | 1.01 (0.14) | 1.09 (0.19) | 1.08 (0.22) | 1.14 (0.28) | 1.04 (0.11) | 1.14 (0.12) | 1.04 (0.20) | 1.11 (0.15) |
| 10 | 0.98 (0.11) | 0.99 (0.12) | 1.01 (0.16) | 1.06 (0.16) | 0.99 (0.13) | 1.07 (0.11) | 1.00 (0.16) | 1.03 (0.15) |
| 20 | 0.94 (0.11) | 1.01 (0.16) | 0.96 (0.14) | 0.96 (0.12) | 0.98 (0.10) | 0.99 (0.07) | 0.94 (0.13) | 0.98 (0.14) |
| 30 | 0.91 (0.11) | 0.93 (0.11) | 0.93 (0.11) | 0.96 (0.12) | 0.98 (0.10) | 1.01 (0.09) | 0.92 (0.14) | 0.91 (0.13) |
| 40 | 0.93 (0.12) | 0.96 (0.09) | 0.99 (0.11) | 0.94 (0.13) | 0.98 (0.14) | 1.01 (0.14) | 0.92 (0.11) | 0.92 (0.11) |

For each block for each participant, perceived block size was calculated as a ratio of actual block size by dividing estimated by actual block size. These ratios were used as the dependent variable in a repeated measures ANOVA with magnification (Magnified/Unmagnified) as a within-participants factor, and visible hand (Own/Fake) and task (SizeOnly/GraspabilityThenSize) as between-participants factors. This revealed that blocks were estimated as smaller when placed next to the magnified hand (m = 0.98, se = 0.01) than the control, unmagnified hand (m = 1.01, se = 0.01), $F(1, 60) = 16.882$, $p < .001$, $\eta_p^2 = .22$. There were no other significant effects. For the main effects: hand, $F(1, 60) = 0.347$, $p = .6$, $\eta_p^2 = .006$; task, $F(1, 60) = 0.048$, $p = .8$, $\eta_p^2 = .001$. For the interactions: magnification × hand, $F(1, 60) = 0.261$, $p = .6$, $\eta_p^2 = .004$; magnification × task, $F(1, 60) = 1.576$, $p = .2$, $\eta_p^2 = .003$; hand × task, $F(1, 60) = 2.367$, $p = .2$, $\eta_p^2 = .04$; magnification × hand × task, $F(1, 60) < 0.001$, $p = .9$, $\eta_p^2 < .001$, see Figure 2.

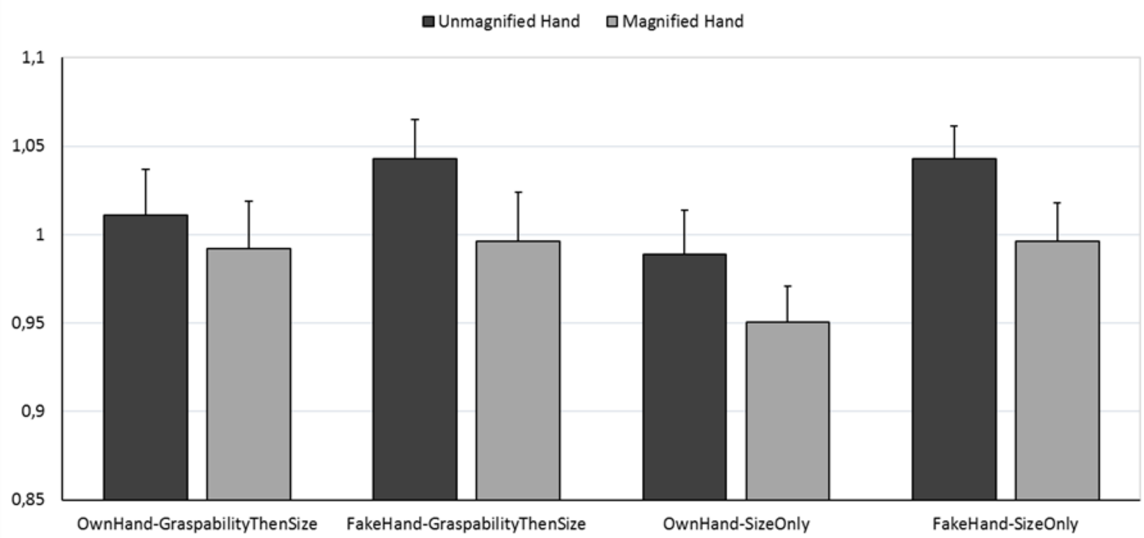



*Figure 2*: Mean ratio (estimated/actual) of block size for the unmagnified and magnified hands in each group. A ratio of 1 (highlighted in bold) represents perfect accuracy. Error bars show one standard error of the mean.

## 4.5 Discussion

Participants estimated the width of blocks placed next to a magnified hand as smaller than blocks placed next to an unmagnified hand. This effect occurred regardless of whether the hand was the participants' own hand or a fake hand, and regardless of whether or not participants were asked to report the graspability of the blocks before they estimated block width. The direction of this effect on size estimates for the OwnHand groups is consistent with the prediciton of the action-specific account of perception. However, this account cannot explain these results because it claims that magnification should only affect estimates of the size of a nearby object when the participant's own hand (and not a fake hand) appears to change size (Linkenauger et al., 2013) and when participants intend to grasp that object (Linkenauger, Witt & Proffitt, 2011). Given that we found that neither of these factors affected performance, we propose that our results and those of Linkenauger, Witt and Proffitt (2011, Experiment 3) and Linkenauger et al. (2013) may arise from a different effect, namely a  size-contrast effect. Specifically, objects may appear relatively smaller when placed next to a larger object (e.g., Obonai, 1954). The Ebbinghaus illusion (e.g., Roberts, Harris & Yates, 2005) is one example of this, where the estimated size of a central disc is affected by the size of the discs that surround it: when surrounded by larger discs, the central disc is perceived as smaller, and when surrounded by smaller discs, the central disc is perceived as larger. A similar mechanism may have caused the blocks in this experiment to appear smaller when placed next to a magnified compared to an unmagnified hand.

Linkenauger, Witt and Proffitt (2011, Experiment 3) did consider whether their results arose from a size-contrast effect. They ultimately rejected the possibility because they found an effect of magnification only for objects that were within perceived grasping capacity which, they argued, was only consistent with an action-specific account and not a size-contrast explanation. However, in our own work, we have found no evidence that the perceived graspability of objects influences whether estimates of object size show effects consistent with the action-specific account or not. For example, in Collier and Lawson (2017a), we did not find effects consistent with the action-specific account whether we analysed the data for only objects that were within perceived maximum grasp, only objects within actual maximum grasp, or for all objects including those that were too large to grasp. Thus, we are unconvinced by Linkenauger, Witt and Proffitt's (2011, Experiment 3) argument. An alternative explanation for why seeing a magnified hand reduced estimates of the size of a nearby object, but only for graspable objects, as reported by Linkenauger, Witt and Proffitt (2011, Experiment 3) is that size-contrast effects have been shown to be asymmetrical. For instance, the Ebbinghaus illusion was found to be stronger when the central disc was surrounded by larger discs than when it was surrounded by smaller discs (Ehrenstein & Hamada, 1995; see also Roberts et al., 2005). In Ehrenstein and Hamada (1995), participants estimated the size of the central disc of an Ebbinghaus illusion configuration relative to the size of a comparator disc which was equal in size to the central disc and had no surrounding discs. They found that when the surrounding discs were larger than the central disc, participants reliably estimated the central disc as smaller than the comparator disc. In contrast, when the central discs were smaller than the surrounding disc, participants often estimated the central disc as larger than the comparison disc, but less reliably and not to the same magnitude (Ehrenstein & Hamada, 1995). Applied to Linkenauger, Witt and Proffitt (2011, Experiment 3), this means that objects which were smaller than the magnified-or-not hand (which were also, presumably, more likely to be reported as graspable) may have produced a strong size-contrast effect, whereas objects which were larger than the magnified-or-not hand (which were, presumably, more likely to be reported as ungraspable) may have produced a weaker size-contrast effect.

Witt (2017) acknowledged that studies which manipulate apparent grasping capacity by changing the visual size of the hands could be problematic as they risk inducing size-contrast effects. She claimed that these methods are used because it is not straightforward to directly manipulate grasping capacity. We disagree with Witt (2017) that it is difficult to directly manipulate grasping capacity (see Collier & Lawson, under review, for a discussion). For example, we have used a simple taping manipulation to change grasping capacity. The taping manipulation is more appropriate than using magnification because unlike magnification, taping is a direct manipulation of grasping capacity and it minimises the possibility of size contrast effects since the taped hand does not, itself, shrink in size, rather maximum finger spread is reduced.

In addition, not all experiments investigating the apparent effect of grasping capacity on estimated object size which have found effects consistent with the action-specific account have manipulated visual hand size. For example, Linkenauger, Witt and Proffitt (2011, Experiment 2) instead took advantage of the bias for right handers to overestimate the grasping capacity of their right hand relative to their left hand (Collier & Lawson, 2017a; Linkenauger, Witt & Proffitt, 2011). However, this bias is relatively weak. For example, in Collier and Lawson (2017a, Experiment 3), we found that right handers believed the grasping capacity of their left hand was only, on average, 0.5 cm lower than that of their right hand. In contrast, when we taped the fingers of one hand together, the perceived reduction in grasping capacity was, on average, ~3 cm (Collier & Lawson, 2017a, Experiments 4 and 5). Furthermore, for hand dominance, neither Linkenauger, Witt and Proffitt (2011, Experiment 2) nor Collier and Lawson (2017a, Experiments 2 & 3) found a difference in the actual grasping capacity of the left and right hands. In contrast, the taping manipulation has been shown to reduce actual as well as perceived grasping capacity (Collier & Lawson, 2017a, Experiments 4 & 5). We suggest that taping, which produces a strong effect on both perceived and actual grasping capacity whilst minimising visual differences in hand size is a superior means to magnification to alter grasping capacity and investigate the claims of the action-specific account.

One limitation of the present study is that participants did few trials as it was originally designed as a pilot study to investigate whether magnification would have any effect on estimates of object size. Since effects consistent with the action-specific account have proven difficult to replicate in the past (e.g. Collier & Lawson, 2017a; de Grave et al., 2011; Woods et al., 2009; see Firestone, 2013, for a discussion), we reasoned that running a pilot study to investigate the reliability of the effect reported by Linkenauger, Witt and Proffitt (2011, Experiment 3) would be valuable. In future work, we intend to repeat this experiment with more trials per participant and a wider array of block sizes. Nevertheless, the present work provides preliminary evidence that the effects reported by Linkenauger, Witt and Proffitt (2011, Experiment 3) and Linkenauger et al. (2013) could have arisen from size-contrast effects rather than demonstrating an influence of grasping capacity on estimates of object size. Participants estimated blocks placed next to a magnified hand as smaller than blocks placed next to an unmagnified hand, regardless of whether the hand was the participants' own hand or a fake hand, and regardless of whether participants were asked to report the graspability of the blocks or not. The action-specific account cannot explain these results. Therefore, we conclude that the results of experiments manipulating grasping capacity by changing visual hand size do not provide strong evidence for the action-specific account.

## 4.6 Footnotes: Chapter 4

[1] Sixty-seven participants were tested, but the data from three participants was not analysed (two from the OwnHand-SizeOnly group and one from the OwnHand-GraspabilityThenSize group). Two of these participants correctly guessed the purpose of the study during debrief, and one was replaced because of experimenter error.

# Chapter Five:

## 5. The action-specific account lacks predictive power

***This chapter has been accepted for publication as:**

**Collier, E. S., & Lawson, R. (in press). Trapped in a tight spot: scaling effects occur when, according to the action-specific account, they should not, and fail to occur when they should. *Attention, Perception & Psychophysics*.**

### 5.1 Abstract

The action-specific account of perception claims that what we see is perceptually scaled according to our action capacity. However, it has been argued that this account has relied on an overly confirmatory research strategy – predicting the presence of, and then finding, an effect (Firestone & Scholl, 2014). A comprehensive approach should also test disconfirmatory predictions, where no effect is expected. In two experiments, we tested one such prediction based on the action-specific account, namely that scaling effects should occur only when participants intend to act (Witt et al., 2005). All participants wore asymmetric gloves, where one glove was padded with extra material so one hand was wider than the other. Participants visually estimated the width of apertures. The action-specific account predicts that apertures should be estimated as narrower for the wider hand, but only when participants intend to act. We found this scaling effect when it should not have occurred (Experiment 1, for participants who did not intend to act), and no effect when it should have occurred (Experiment 2, for participants who intended to act but who were given a cover story for the visibility and position of their hands). Thus the cover

story used in Experiment 2 eliminated the scaling effect found in Experiment 1. We suggest that the scaling effect observed in Experiment 1 likely resulted from demand characteristics associated with using a salient, unexplained manipulation (e.g., telling people which hand to use to do the task). Our results suggest that the action-specific account lacks predictive power.

## 5.2 Introduction

Given the tight coupling between action and perception (e.g., Clark, 1999; Franchak et al., 2010; Gibson, 1979), the action-specific account of perception proposes that what we perceive is scaled according to our action capacity (Proffitt, 2013; Proffitt & Linkenauger, 2013; Witt, 2011, 2016; Witt, et al., 2016). One of the earliest findings that suggested that visual perception scales according to participants' action capacity was that participants estimated hills as steeper after vigorous exercise than before exercising (Proffitt et al., 1995, Experiment 5). Subsequently, Bhalla and Proffitt (1999) reported that hills were also estimated as steeper by participants who wore a heavy backpack, were elderly or in ill health, or had low physical fitness. Many later studies have reported effects consistent with the action-specific account (for reviews, see Proffitt, 2013; Proffitt & Linkenauger, 2013; Witt, 2011a, 2017). Proffitt and Linkenauger (2013) suggested that perception can be scaled according to three components of action capacity: the bioenergetic cost of acting, performance variability and action capacity pertaining to the functional morphology of the body. For example, for bioenergetics, Witt et al., (2004) reported that distances to a target were estimated as greater after participants threw a heavy ball than a light ball. For scaling according to performance variability, Witt and Dorsch (2009) found that goalposts were estimated as higher by participants with worse kicking performance. For functional morphology, Linkenauger, Leyrer, Bülthoff and Mohler (2013) used virtual reality to alter participants' perceived hand size. They found that objects seen near the hand were estimated as larger when the hand was rendered as smaller, and vice versa when the hand was rendered as larger. In short, the action-specific account proposes that we literally perceive the world as scaled in terms of our ability to perform actions (for reviews, see Firestone, 2013; Linkenauger, 2015; Philbeck & Witt, 2015).

However, there are a number of concerns with the action-specific account (e.g., Collier & Lawson, 2017a, 2017b; Durgin et al., 2009; Firestone, 2013). For example, Firestone and Scholl (2014; see also Firestone & Scholl, 2015) argued that this account has relied on an overly confirmatory research strategy – that is predicting, and then finding, a given effect. A comprehensive account of a phenomenon should also be able to predict the absence of an effect. Firestone and Scholl (2014) suggested employing the El Greco fallacy to test disconfirmatory predictions of the action-specific account. According to this fallacy, if perception of both the stimulus and the means of reproducing the stimulus are expected to show the same distortion following some manipulation, then the two distortions should cancel each other out and no overall distortion should be perceived. Firestone and Scholl (2014) applied this logic to the finding that apertures were estimated as narrower when participants held a horizontal rod that was wider than their body (Stefanucci & Geuss, 2009). For example, participants in Stefanucci and Geuss' (2009) second experiment estimated the width of apertures by verbally guiding the experimenter to adjust the length of a tape measure until the length matched the width of an aperture that they were told to imagine walking through. There were four groups of participants. The *hold* group held a long rod horizontally in front of their body, with their arms wide apart. The *hands only* group positioned their arms in the same way as the *hold* group, but did not hold the rod. The *wear* group wore a backpack to which the rod was attached, so the rod was positioned as for the *hold* group but participants kept their arms by their sides. Finally, the *control* group kept their arms by their sides and had no rod. Participants in the *hold* and *hands only* groups estimated apertures as narrower than those in the *wear* and *control* groups. Stefanucci and Geuss (2009) interpreted this as evidence that participants who had their body widened in a functionally meaningful way perceived apertures as less passable, and therefore narrower. Participants in Firestone and Scholl's (2014) replication of this study either held or did not hold a rod and verbally guided the experimenter to make adjustments to visually match the width of apertures that they imagined walking through. However, instead of a tape measure, the experimenter adjusted the width of a second aperture (the matching aperture) that was placed perpendicular to, but was otherwise identical to, the aperture that participants imagined walking through (the stimulus aperture). Firestone and Scholl (2014) found that participants who held the rod estimated apertures as wider than participants who did not hold the rod. Importantly, holding a rod should have influenced both the stimulus aperture and the matching aperture in the same way, by making it appear less passable. Thus, according to the El Greco fallacy, this should have made it impossible to detect a scaling effect and so, although the scaling effect reported by Stefanucci and Geuss (2009) was replicated by Firestone and Scholl (2014), this in fact provides evidence against, not for, action-specific scaling.

If effects consistent with the action-specific account occur when they should not, what instead explains their occurrence? Firestone and Scholl (2014) showed that the scaling effect on apertures that they observed disappeared if participants were given a convincing cover story for holding the rod. This suggests that the effect originally reported by Stefanucci and Geuss (2009) could have resulted from demand characteristics due to being asked to hold a rod without any explanation. Demand characteristics (Orne, 1962) can also explain other scaling effects that had originally been interpreted as supporting the action-specific account (Collier & Lawson, 2017b; Durgin et al., 2009). For example, in some of the first studies to provide evidence for the action-specific account, hills were estimated as steeper when observers wore a heavy backpack (Proffitt, et al., 1995; Bhalla & Proffitt, 1999). However, Durgin et al. (2009) found that if participants were provided with a cover story for wearing the backpack, their slant estimates were no different to participants who did not wear the backpack. This suggests that participants who were not given a reason for the backpack manipulation may have figured out that it was intended to influence their slant estimates and adjusted their responses accordingly. Therefore at least some scaling effects could result from demand characteristics associated with a salient, unexplained manipulation.

The reason that action-specific researchers often ask participants to imagine performing a relevant action, as in Stefanucci and Geuss (2009) and Firestone and Scholl (2014), is that scaling effects are only expected when participants intend to act (Witt, Proffitt & Epstein, 2005). The role of intention to act in the representation of space was first investigated in electrophysiological studies on monkeys by Iriki, Tanaka and Iwamura (1996). These authors identified neurons which fired when a raisin was placed within the monkey's reach, but did not fire when the raisin was placed beyond reach. Furthermore, after the monkeys were taught to reach with a tool, these neurons adapted and now fired when raisins were placed out of arm's reach, but still within reach using the tool. However, this adaptation did not occur when the monkeys held, but never reached with, the tool (Iriki et al., 1996). This was interpreted by Witt et al. (2005) as evidence that intention to act may be critical for changes in the representation of near space to occur.

Based on Iriki et al.'s (1996) findings, Witt et al. (2005) tested whether intention to act modulated perception of near space in humans. Witt et al. (2005) found that participants estimated the distance to targets that were out of arm's reach as shorter after reaching to them with a tool which increased maximum reach and made the targets reachable. However, this effect was only found for participants who actually reached with the tool. No effect was found for participants who held the tool, but never reached with it. The authors interpreted this as support for their claim that action-specific effects only occur when people intend to act. Intention to act has been argued as critical for finding scaling effects in a number of subsequent studies (e.g., Lessard, Linkenauger & Proffitt, 2009; Linkenauger, Witt & Proffitt, 2011; Stefanucci & Geuss, 2009; Witt & Proffitt, 2008). We therefore tested here whether scaling effects due to changes in action capacity occurred if, and only if, participants intend to act.

To summarise, a comprehensive theoretical account should be able to predict both the presence and absence of an effect. Although the action-specific account has largely relied on a confirmatory research strategy (Firestone & Scholl, 2014, 2015), this account makes the disconfirmatory prediction that scaling effects should only be found when participants intend to act. In the present studies, we tested this prediction for the task of estimating aperture width.

## 5.3 Experiment 1

The passability of aperture width is a good candidate for testing the claims of the action-specific account. People's perception of whether they can walk through an aperture is dependent on their body size (Franchak, Celano & Adolph, 2012) and can rapidly be recalibrated following an increase in body girth (Franchak & Adolph, 2014). Similarly, Ishak, Adolph and Lin (2008) reported that people recalibrate whether their hand can fit through a variable-width aperture following an increase in hand width. Specifically, when participants wore a prosthesis on their hand which increased their hand width, they appropriately judged the minimum passable aperture width for that hand as wider. The results of Franchak and colleagues and of Ishak et al. (2008) demonstrate that people are sensitive to changes to their action capacity following a change in the functional morphology of their body. However, crucially, these results are not relevant to the claims of the action-specific account. This account predicts that estimates of spatial properties of action-relevant stimuli should be affected by changes in functional morphology. Specifically, here, the action-specific account predicts that people should perceive apertures that they intend to move their wider hand through as narrower, but only when they intend to act in this way (e.g., Witt et al., 2005; Linkenauger, Witt & Proffitt, 2011). No scaling effect on estimates of aperture size should be found if participants do not intend to act on the aperture.

In Experiment 1, in separate tasks, we tested both whether participants' estimates of the narrowest aperture they could fit their hand through (action capacity task) *and* their estimates of aperture width (perceptual task) were affected by wearing a padded glove. The aperture apparatus, gloves, and method for measuring perceived aperture passability in the action capacity task were closely based on the methods of Ishak et al. (2008). The visual matching method used in the perceptual task was the same as that used in other work investigating the action-specific account (e.g., Collier & Lawson, 2017a, 2017b; Linkenauger, Witt & Proffitt, 2011).

### 5.3.1 Method

Ethical approval was granted for all of the experiments presented in this paper by the relevant local ethics committee at the University of Liverpool.

#### 5.3.1.1 Participants

Thirty-six participants (23 females, mean age = 21.8 years) were recruited from the University of Liverpool. All participants self-reported as right handed and were rewarded with course credit for their participation.

#### 5.3.1.2 Design

Participants were assigned to either the Intention-To-Act group or the No-Intention group. All participants completed two tasks: a perceptual task where they estimated the width of apertures, and an action capacity task where they judged whether they could fit their hand through apertures of different widths. These tasks are described in detail below. The Intention-To-Act group (n = 18) completed the action capacity task before the perceptual task and, on each trial of the perceptual task, they were asked whether they thought they could fit their hand through the aperture before estimating its width. This is a technique used by proponents of the action-specific account to ensure that participants intend to act in the way that the experimenter is interested in (e.g., Linkenauger, Witt & Proffitt, 2011). The No-Intention group (n = 18) completed the perceptual task before the action capacity task and they were not asked whether they thought they could fit their hand through the aperture during the perceptual task. Therefore, only the Intention-To-Act group intended to act while estimating aperture width[1].

#### 5.3.1.3 Apparatus, stimuli and procedure

An aperture apparatus was created using a metal frame which held two wooden boards, see Figure 1. One board was fixed and the other could move to vary the width of a diamond-shaped aperture between 0 cm (minimum) and 30 cm (maximum). A mug was placed on a small table behind the aperture apparatus, with the handle facing the participant. A laptop was placed in front of the aperture apparatus. Two black lines were displayed on its screen. The lines began at a default distance of 1.75 cm apart. Each press of the up arrow on the laptop keyboard moved the lines 1 mm further apart and each press of the down arrow moved the lines closer together by 1 mm.

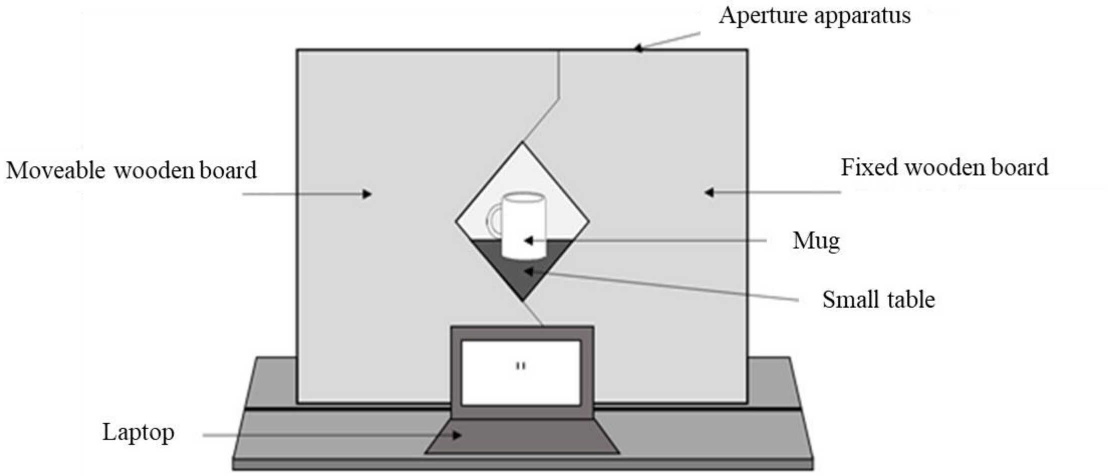



*Figure 1*: Diagram showing the aperture apparatus used in Experiment 1. The same apparatus was used in Experiment 2 except that the laptop was placed at 90$^{o}$ to the aperture.

Participants wore a pair of gloves throughout the experiment. The left (Padded) glove had additional woollen material sewn into the little finger-side of the glove[2]. The right (Unpadded) glove had no padding. Here, we refer to the hands as Padded or Unpadded but the experimenter always referred to the "left" or "right" hand when communicating with participants, and participants were not informed about the padding.

**Action capacity task**

On every trial of the action capacity task, participants were asked whether they thought they could fit their hand through the aperture in order to touch the mug on the other side, see Figure 1. If, and only if, they thought they could fit their hand though the aperture did they then attempt to actually do so. If they thought they could not fit their hand through, they verbally responded “no”. They were told to judge passability based on their hand being held flat and oriented horizontally with their fingers close together and their thumb tucked under their fingers. They were told not to twist their hand, screw their fingers into a fist or bunch their fingers together. On each trial, the experimenter told them to use either their left (Padded) or right (Unpadded) hand. Responses were coded as “success” (participant could reach through the aperture), “failure” (participants attempted to reach through but their hand did not fit) or “refusal” (participants said that their hand would not fit through the aperture), see Figure 2. Aperture width ranged from 4 cm to 14 cm in 0.5 cm increments. Participants judged whether they could fit their left (Padded) or right (Unpadded) hand through each aperture width 3 times, giving 126 trials in total (2 hands × 21 aperture widths × 3 repeats) with trials presented in a different random order for each participant.

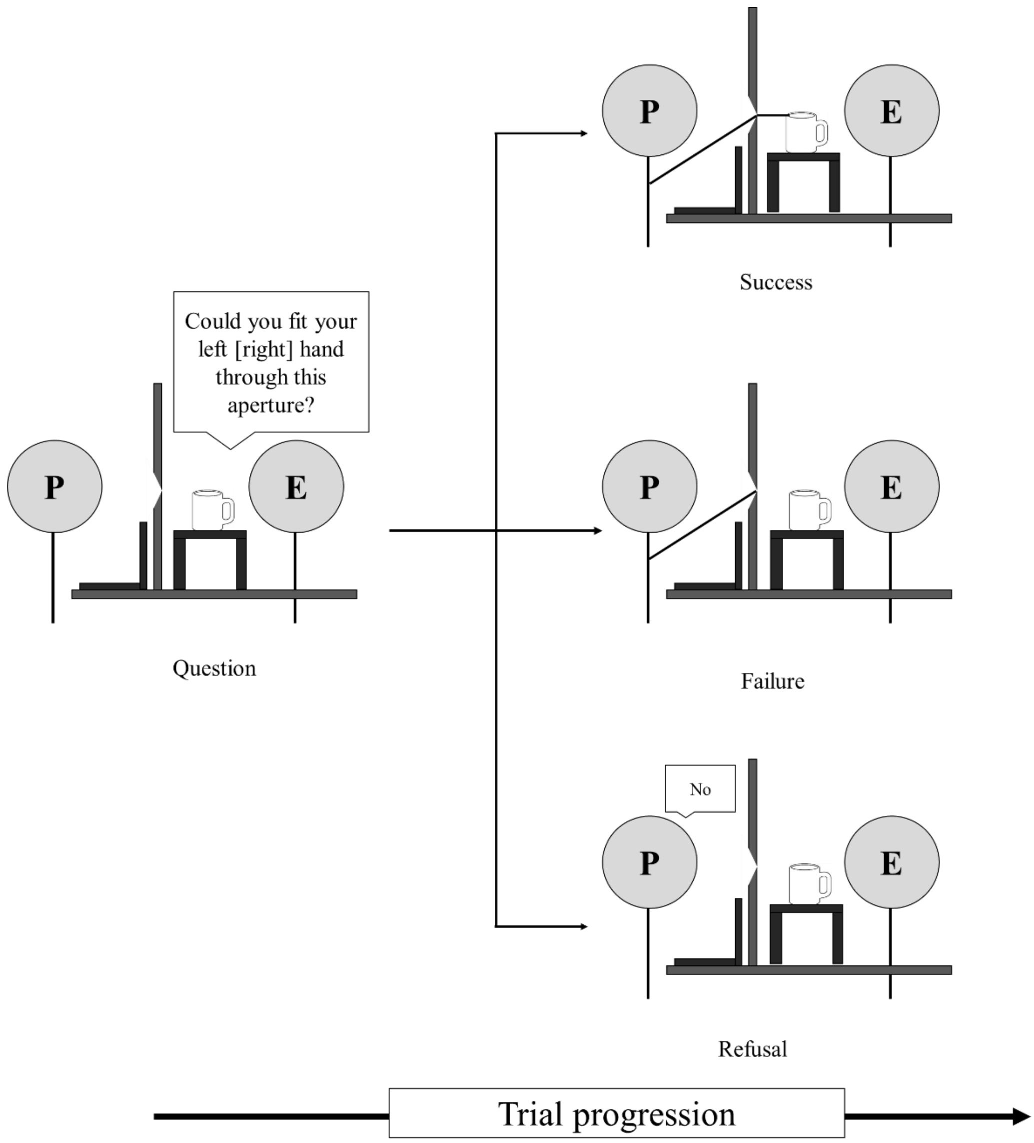



*Figure 2*: Diagram showing a participant completing the action capacity task in Experiment 1. The experimenter (E) first asked the participant (P) whether they could fit their hand through the aperture. The participant responded by either attempting the action (no verbal response given) or by verbally responding “no” and refusing to attempt. Responses were coded as “success” (participant successfully reached through the aperture, top), “failure” (participants attempted to reach through but their hand did not fit, middle) or “refusal” (participants said that their hand would not fit through the aperture, bottom).

**Perceptual task**

In this task participants were asked to use the arrow keys on the keyboard to move the lines on the screen until the distance between them matched the width of the aperture.

Participants in the No-Intention Group were only told to match the width of the aperture on each trial, see Figure 3 (top). In contrast, on every trial in the perceptual task, before matching aperture width, participants in the Intention-To-Act Group were asked whether they thought they could fit one of their hands through the aperture, see Figure 3 (bottom). Unlike in the action capacity task, here participants did not actually attempt to move their hand through the aperture.

On each trial of the perceptual task, the experimenter told the participant which hand they should use to respond. For the Intention-To-Act Group, this was always the same hand that they had just judged aperture passability for. Participants were told to keep their other hand by their side so that it was out of sight. Between trials, they kept both hands by the sides of their body and closed their eyes until the experimenter had adjusted the width of the aperture. The aperture widths used were the same as in the action capacity task. Participants matched each aperture width once using each hand, giving a total of 42 trials (2 hands × 21 aperture widths) with trials presented in a different random order for each participant.

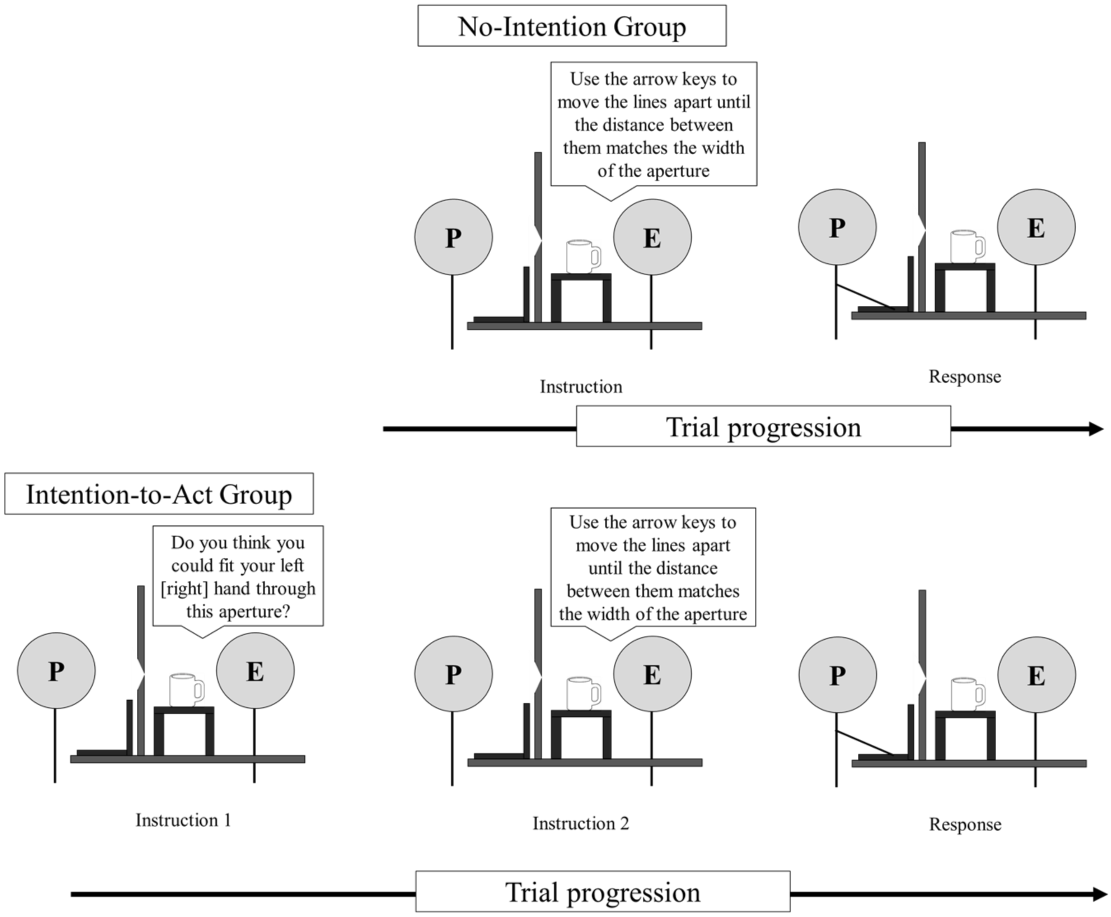



*Figure 3*: Diagram showing participants in the No-Intention group (top) and in the Intention-To-Act group (bottom) completing the perceptual task in Experiment 1. For both groups the experimenter asked the participant (P) to use the arrow keys to move the lines on the laptop screen to match the width of the aperture. In the Intention-To-Act group the participant was also asked whether they could fit their left (or right) hand through the aperture immediately before matching its width.

**Actual aperture passability task**

After participants had completed both the perceptual and action capacity tasks, the experimenter measured the actual narrowest aperture that they could fit their hands through. The experimenter opened the aperture to 15 cm and asked participants to place their hand inside it with their hand held flat and horizontally with their fingers close together and their thumb tucked under their fingers. The experimenter then closed the aperture around the participant's hand and asked the participant to move their hand in and out of the aperture. The experimenter adjusted the aperture until it was at the narrowest width that still allowed the participant to fit their hand through without getting it trapped. Participants were only told to move their hand during this task; they were not asked about aperture passability. The minimum passable aperture was measured for each hand both with and without the gloves.

### 5.3.2 Results

**Effect of wearing gloves on actual aperture passability**

To check that the glove manipulation was effective, we tested whether wearing the gloves changed the actual minimum passable aperture for each hand. We conducted a mixed ANOVA where hand (Padded/Unpadded) and gloves (With/Without) were within-participants factors and group (Intention-To-Act/No-Intention) was a between-participants factor. There was a significant main effect of gloves, $F(1, 34) = 38.351$, $p < .001$, $\eta_p^2 = .53$, which was modulated by a hand × gloves interaction, $F(1, 34) = 40.090$, $p < .001$, $\eta_p^2 = .54$. Bonferroni corrected pairwise comparisons showed that, with gloves, the minimum passable aperture was greater for the Padded hand (m = 10.4 cm, se = 0.14 cm) than the Unpadded hand (m = 9.6 cm, se = 0.15 cm), whereas there was no significant difference between the Padded and Unpadded hands without gloves (m = 9.8 cm, se = 0.12 cm; m = 9.5 cm, se = 0.13 cm, respectively). There was no effect of group, $F(1, 34) = 0.038$, $p = .8$, $\eta_p^2 = .001$. There were no other significant interactions: gloves × group, $F(1, 34) = 1.060$, $p = .3$, $\eta_p^2 = .03$; hand × group, $F(1, 34) = 0.708$, $p = .4$, $\eta_p^2 = .02$; gloves × hand × group, $F(1, 34) = 0.216$, $p = .6$, $\eta_p^2 = .01$. Wearing a padded glove therefore significantly increased hand width, as we had intended.

**Action capacity task: perceived aperture passability**

We tested whether participants appropriately recalibrated their perception of aperture passability to reflect the asymmetry in hand width caused by wearing the gloves. For each width tested, for each hand, for each participant, we calculated the proportion of times that participants said that they could not fit their hand through that aperture in the action capacity task. Cumulative Gaussians were then fitted, from which we calculated the predicted width at which participants believed they could not fit each hand through 50% of the time (the point of subjective equality, PSE; the mean Cumulative Gaussians can be found in Appendix A). These PSEs provided an estimate of the minimum aperture width participants perceived they could fit their hand through.

PSEs were used as the dependent variable in a mixed ANOVA where hand (Padded/Unpadded) was a within-participants factor and group (Intention-To-Act/No-Intention) was a between-participants factor. Participants perceived the minimum passable aperture width for their Padded gloved hand (m = 10.6 cm, se = 0.16 cm) to be greater than that for their Unpadded gloved hand (m = 9.9 cm, se = 0.14 cm), $F(1, 34) = 76.113$, $p < .001$, $\eta_p^2 = .70$. There was no effect of group, $F(1, 34) = 0.067$, $p = .8$, $\eta_p^2 = .002$, or a hand × group interaction, $F(1, 34) = 1.579$, $p = .2$, $\eta_p^2 = .04$. Thus participants appropriately recalibrated their perception of the minimum aperture width that each gloved hand could fit through during the action capacity task by increasing their estimates for the Padded hand.

**Perceptual task: estimated aperture width**

Finally, we tested the critical action-specific prediction that apertures would be estimated as narrower for the Padded hand by the Intention-To-Act group but not by the No-Intention group. Ratios were calculated by dividing estimates of aperture width by actual aperture width and then averaging over all widths for a given hand of a participant.

These ratios were used as the dependent variable in a mixed ANOVA where hand (Padded/Unpadded) was a within-participants factor and group (Intention-To-Act/No-Intention) was a between-participants factor. Ratios for the Padded hand (m = 0.68, se = 0.02) were significantly lower than for the Unpadded hand (m = 0.69, se = 0.02), $F(1, 34) = 6.557$, $p = .015$, $\eta_p^2 = .16$, see Figure 4. Although the effect we observed is small, this is common in the action-specific literature (see Firestone, 2013, for a discussion). There was no effect of group, $F(1, 34) = 0.058$, $p = .8$, $\eta_p^2 = .002$, or a hand × group interaction, $F(1, 34) = 0.027$, $p = .9$, $\eta_p^2 = .001$. Figure 5 shows the ratios for the Padded and Unpadded hand given by each individual participant.

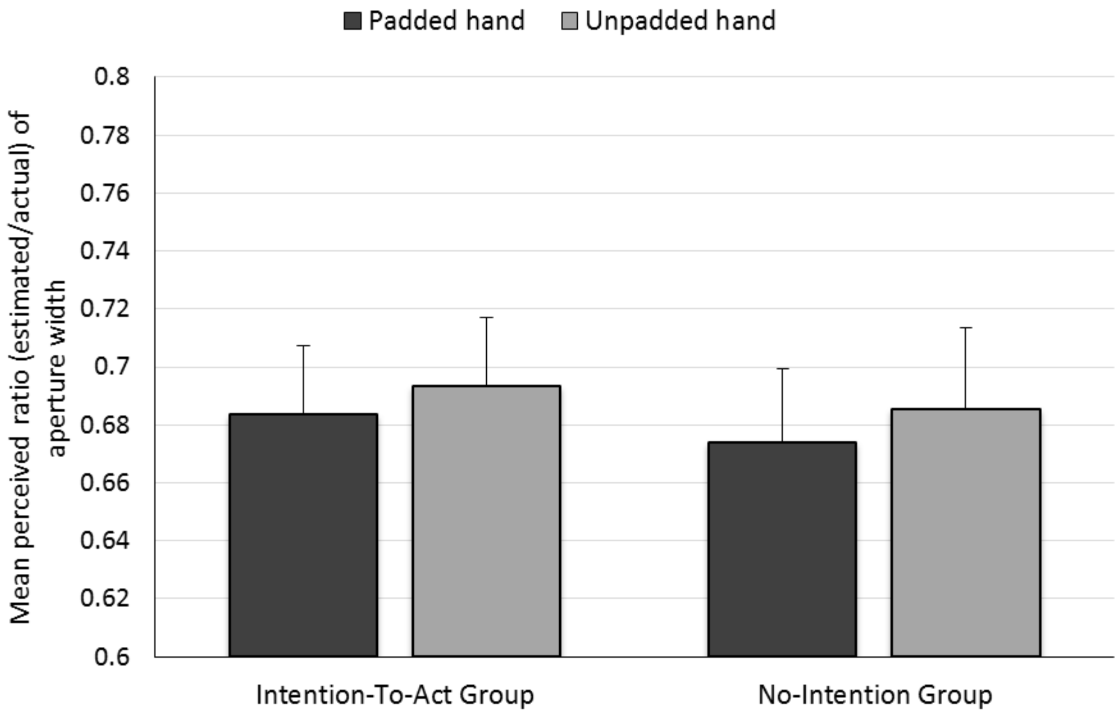



*Figure 4*: Results of the perceptual task in Experiment 1. Mean ratio of aperture size (estimated/actual) for each hand for each group. Error bars represent one standard error of the mean.

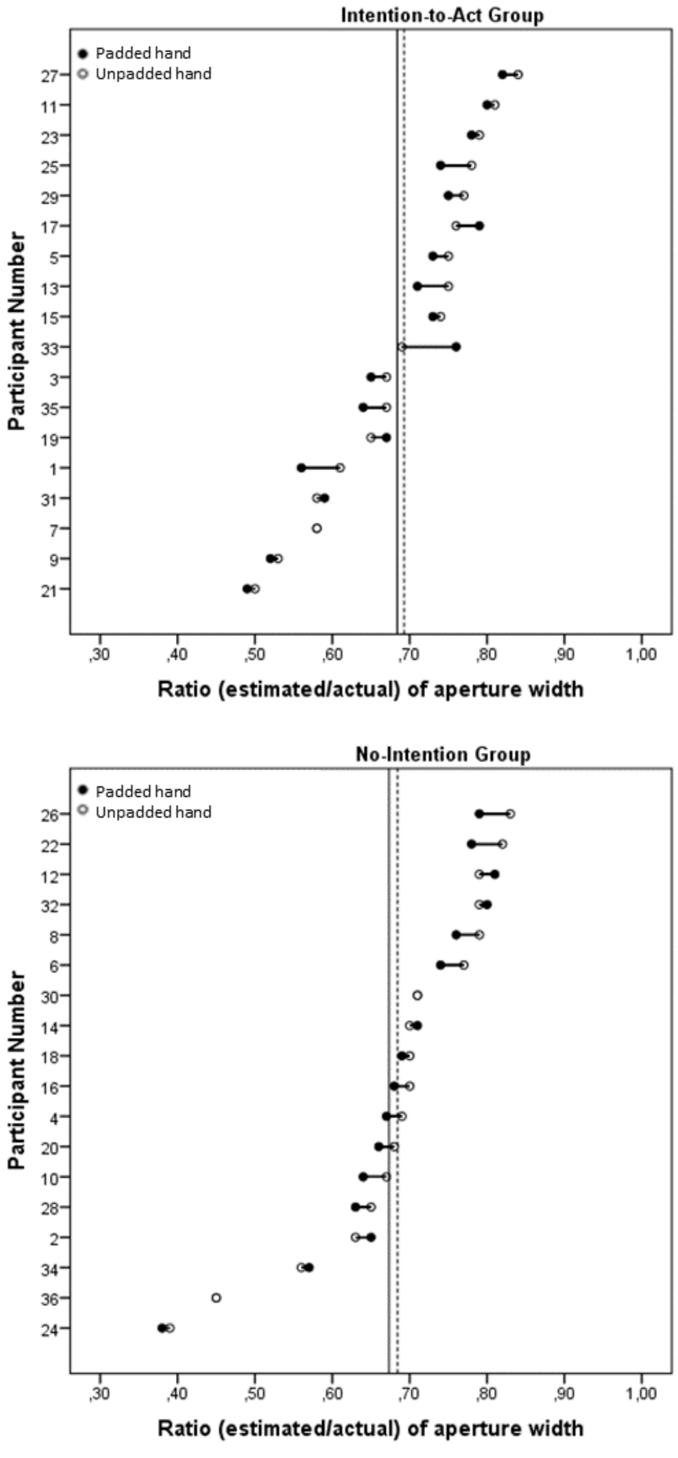



*Figure 5*: Individual estimates of aperture width (as a ratio of actual aperture width) for the Padded and Unpadded hands in the Intention-to-Act (top) and No-Intention (bottom) groups. The bold and dashed vertical lines show the mean ratios for the Padded and Unpadded hands respectively. Participants are ordered by increasing ratio of aperture width for the Unpadded hand. Cases where only one data point are shown indicate no difference between ratios for the Padded and Unpadded hand.

### 5.3.3 Discussion

Padding one hand increased the minimum passable aperture for that hand. Furthermore, this change was perceived by participants: in the action capacity task, participants estimated the minimum passable aperture for their Padded hand as wider than for their Unpadded hand. This latter result is consistent with previous results (Collier & Lawson, 2017a; Ishak et al., 2008), showing that participants appropriately recalibrate their perceived action capacity following a change in the functional morphology of their hands. Of most interest theoretically was the perceptual task. Participants estimated apertures as narrower when they estimated with their Padded compared to their Unpadded hand (see Figure 4) but, importantly, this was effect was not just due to estimates by the Intention-To-Act group. The action-specific account claims that intention is necessary for finding the scaling effects predicted by this account (e.g. Linkenauger, Witt & Proffitt, 2011; Stefanucci & Geuss, 2009; Witt, 2017; Witt et al., 2005). Therefore, this account cannot explain the results of the perceptual task since participants in the No-Intention group were not asked to report aperture passability, and therefore they did not intend to act.

An alternative explanation of our results is that demand characteristics could have arisen from explicitly telling participants whether to use either their left (Padded) or their right (Unpadded) hand to respond when they estimated aperture width. No explanation was provided for this manipulation, and participants may have deduced that we expected to find a hand-dependent effect. As a consequence some participants may, for example, have decided that they should use their visible hand as an anchor for estimating aperture width. Since right handers believe that their right hand is larger than their left hand (Collier & Lawson, 2017a; Linkenauger, Witt & Proffitt, 2011), this strategy could explain the results that we obtained.

## 5.4 Experiment 2

The action-specific account cannot explain the results of Experiment 1, since we found a scaling effect when participants did not intend to act. Instead, it is possible that this effect arose because of demand characteristics associated with telling participants whether to use the left or the right hand on each trial of the perceptual task. Previous work has suggested that demand characteristics associated with an unexplained manipulation can be reduced by using a cover story (Collier & Lawson, 2017a; Durgin et al., 2009, 2012; Firestone & Scholl, 2014). Therefore, if the effects found in Experiment 1 were the result of demand characteristics, then they might be eliminated by providing a cover story. In Experiment 2, we tested this possibility using a similar perceptual task as in Experiment 1. Participants in Experiment 2 always intended to act during the perceptual task. However, they were given a cover story for why their hand was visible near the aperture while they estimated its width. If no effect of hand padding occurs when participants are given a cover story for the presence and location of their hands, this would support the argument that the effects obtained in Experiment 1 were the result of demand characteristics.

We also made some changes to the experimental procedure in Experiment 2 to improve the design and to make it more consistent with previous studies in the action-specific literature. These changes included placing the laptop at 90$^{o}$ to the participant (as was done in Linkenauger, Witt & Proffitt, 2011, Experiment 2). This ensured that participants could not use landmark matching strategies while making their estimates. Also, half of the participants wore the padded glove on their left hand, while the other half wore it on their right hand. Finally, all participants were alerted to the difference in their hand width resulting from wearing the gloves. This was done by asking participants to squeeze their hand through a padded tube, which was hidden by a curtain, in order to reach the aperture on the other side. Since it is harder to squeeze wider hands through a tight space, we reasoned that haptic feedback from this task would alert participants to the fact that one of their hands was wider than the other. Completing this haptic feedback phase also served to motivate our cover story manipulation in the main perceptual task. Specifically, participants were told that, as a control measure, their hands should be in a similar position in the perceptual task as they were in the haptic feedback phase. The cover story did not explicitly mention the use of both the left and the right hands. This was because, when using a cover story to minimise demand characteristics, it is critical that the cover story used does not simply introduce a new set of demand characteristics (Proffitt, 2013) or further solidify demand characteristics that may already exist. Thus, we opted for a cover story which explained the position and location of the hands on each trial. We reasoned that this would alleviate any demand characteristics associated with specifying which hand to use in the task, without explicitly drawing attention to the fact that both hands were used.

In summary, in Experiment 2 we tested whether the results of Experiment 1 could be explained by demand characteristics. This was achieved by providing a cover story for why the participant's hand was visible near the aperture while they estimated its width in the perceptual task. At the start of the experiment, participants were told that we were interested in how well they could perform basic actions while wearing thick gloves and that they would first complete a haptic task involving moving their hands through tight spaces. Then, after the haptic feedback phase and before beginning the main perceptual task, participants were given a cover story for the presence and location of their hands. We predicted that hand padding would have no effect on estimates of aperture width in Experiment 2, because participants were given a cover story in the perceptual task which reduced demand characteristics.

### 5.4.1 Method

#### 5.4.1.1 Participants

Thirty-six new participants (23 females, mean age = 25.9 years) were recruited from the University of Liverpool. All participants self-reported as right handed and were rewarded with course credit or a shopping voucher for their participation.

#### 5.4.1.2 Design

Two new pairs of asymmetric gloves were made. In both pairs, the Padded glove had 1.5 cm of foam on the little finger-side and 0.5 cm of foam on the thumb-side and the Unpadded glove had 0.25 cm of foam on each side. Participants in the LHBigger group (n = 18) wore the Padded glove on their left hand and the Unpadded glove on their right hand, and vice versa for participants in the RHBigger group (n = 18).

#### 5.4.1.3 Apparatus, stimuli and procedure

All participants completed the haptic feedback phase, then the perceptual task, then the action capacity task and finally the actual aperture passability task. The stimuli and set-up were identical to Experiment 1, except where described below.

**Haptic feedback phase**

For this task, a padded plastic tube (outer circumference = 26 cm, length = 30 cm) was placed in front of the aperture. The aperture and tube were hidden from the participant by a black curtain, see Figure 6. Participants sat at the table and reached under the curtain to put on the gloves. They could not see that the gloves were different sizes but we intended that participants would believe their Padded hand was wider than their Unpadded hand as it was harder to squeeze their Padded hand through the tube. On each trial, participants were told which of their hands they were to push through the tube to the aperture. They were told to place their thumb just inside one corner of the aperture and any other finger just inside the opposite corner so that they could feel the horizontal width of the aperture between their thumb and finger. They then removed their hand from the tube[3] but kept their hands under the curtain. The experimenter then adjusted the width of the aperture for the next trial. In total, participants completed 42 trials (2 hands x 21 aperture widths). The widths were the same as those used in Experiment 1 and were presented in a random order.

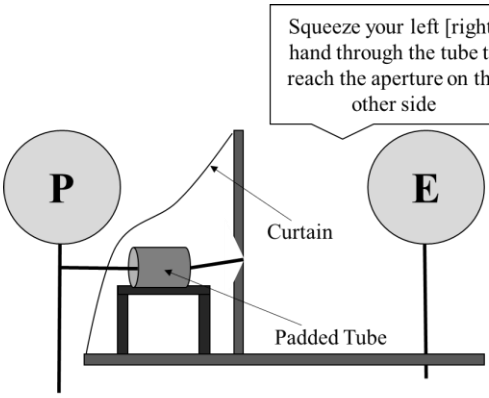



*Figure 6*: Diagram showing the setup and procedure of the haptic feedback phase in Experiment 2. The experimenter (E) has instructed the participant (P) to push their hand through the padded tube to reach the aperture on the other side.

**Perceptual task**

This task was identical to the perceptual task used in Experiment 1, except where described below. The experimenter removed the curtain and tube apparatus used in the haptic feedback phase so that the participant could see the aperture. The laptop that was used in Experiment 1 was moved so that it was at 90° to the participant. On each trial participants placed their visible hand flat on the small table in front of the aperture, see Figure 7. Critically, participants were told that placing their hand in front of the aperture was a control measure that ensured that their hands were in a similar position as in the haptic feedback phase. To ensure that they still intended to act, on every trial participants were also told to imagine moving their hand through the aperture (in the same way as in

Experiment 1) as they made their width estimates. Thus although all participants intended to act (they imagined performing the action on every trial), they were given a cover story for why they were asked to place their hand near the aperture. Width estimates were made by verbally guiding the experimenter to move the lines on the laptop screen closer or further apart. The experimenter used the mouse wheel of a wireless mouse to control the distance between the lines, see Figure 7. One click of the mouse wheel moved the lines 1 mm apart. Participants were told to say ‘stop’ when they believed the distance between the lines matched the horizontal width of the aperture. To ensure estimates were as accurate as possible, participants were encouraged to request minor adjustments to the distance between the lines even after they said ‘stop’. The experimenter stood behind the aperture apparatus so they could not see the lines on the screen, see Figure 7.

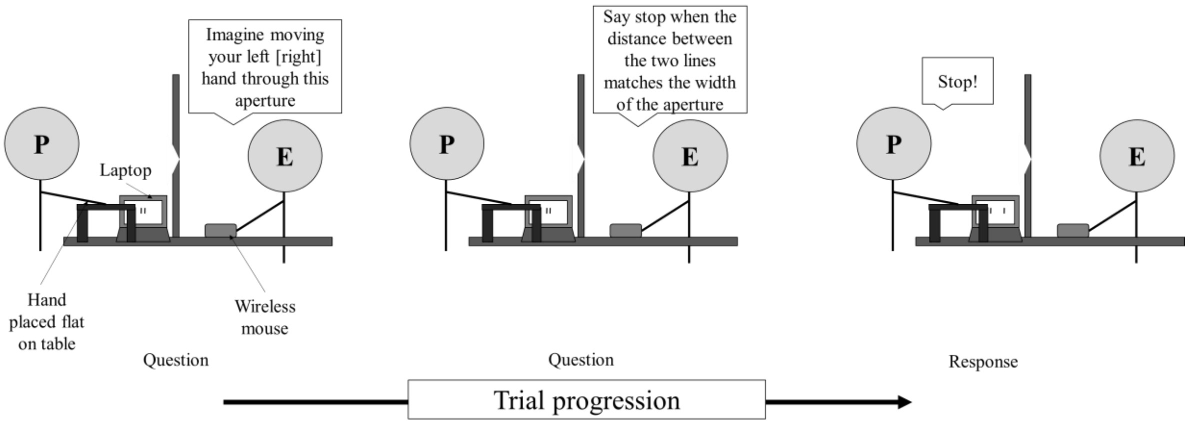



*Figure 7*: Diagram showing a participant completing the perceptual task in Experiment 2. The Experimenter (E) first told the participant (P) to imagine moving their left (or right) hand through the aperture. Then the participant verbally guided the experimenter to move the lines on the laptop screen closer or further apart until they thought the distance between the lines matched the width of the aperture.

**Action capacity task**

After completing the haptic feedback and perceptual tasks participants estimated the narrowest aperture they thought they could fit each gloved hand through. Participants were told to imagine they were going to move their left hand through the aperture in the same way as in Experiment 1. The experimenter then opened the aperture to a width of 15 cm and slowly closed the aperture. Participants were instructed to say ‘stop’ when they believed the aperture was the narrowest width they could fit their left hand through. They were not permitted to look at their hands during the task and were asked to keep them by their sides[4]. To ensure an accurate estimate, the experimenter encouraged participants to request small adjustments even after they said ‘stop’. The task was then repeated for the right hand.

**Actual aperture passability task**

Finally, the actual minimum passable aperture for each hand was measured, first with then without the gloves, as in Experiment 1.

### 5.4.2 Results

**Effect of wearing gloves on actual aperture passability**

To check that the glove manipulation was effective, we tested whether wearing the gloves changed the actual minimum passable aperture for each hand. We conducted a mixed ANOVA where hand (Padded/Unpadded) and gloves (With/Without) were within-participants factors and group (LHBigger/RHBigger) was a between-participants factor. There was a significant main effect of gloves, $F(1, 34) = 588.183$, $p < .001$, $\eta_p^2 = .95$, which was modulated by a hand × gloves interaction, $F(1, 34) = 317.151$, $p < .001$, $\eta_p^2 = .90$. Bonferroni corrected pairwise comparisons showed that, with gloves, the minimum passable aperture was greater for the Padded hand (m = 11.5 cm, se = 0.11 cm) than the Unpadded hand (m = 10.3 cm, se = 0.09 cm) whereas there was no significant difference between the Padded and Unpadded hands without gloves (m = 9.1 cm, se = 0.12 cm; m = 9.1 cm, se = 0.11 cm, respectively). There was no effect of group, $F(1, 34)$

= 0.004, *p* = .9, $\eta_p^2 < .001$. There were no other significant interactions: hand × group, *F*(1, 34) = 2.967, *p* = .09, $\eta_p^2 = .08$; gloves × group, *F*(1, 34) = 1.029, *p* = .3, $\eta_p^2 = .03$; hand × gloves × group, *F*(1, 34) = 0.912, *p* = .4, $\eta_p^2 = .03$. Wearing the padded glove therefore significantly increased hand width relative to the unpadded, gloved hand, as we had intended.

**Action capacity task: perceived aperture passability**

We tested whether participants appropriately recalibrated their perception of aperture passability to reflect the asymmetry in hand width caused by wearing the gloves. Perceived minimum passable aperture by the gloved hand was calculated as in Experiment 1. This was used as the dependent variable in a mixed ANOVA where hand (Padded/Unpadded) was a within-participants factor and group (LHBigger/RHBigger) was a between-participants factor. Participants perceived the minimum passable aperture for their Padded gloved hand (m = 11.1 cm, se = 0.19 cm) to be greater than that for their Unpadded gloved hand (m = 10.8 cm, sd = 0.20 cm), *F*(1, 34) = 9.523, *p* = .005, $\eta_p^2 = .22$. Also the perceived minimum passable aperture was greater for the RHBigger group (m = 11.4 cm, se = 0.26 cm) than for the LHBigger group (m = 10.5 cm, se = 0.26 cm), *F*(1, 34) = 5.912, *p* = .02, $\eta_p^2 = .15$. There was no hand × group interaction, *F*(1, 34) = 0.135, *p* = .7, $\eta_p^2 = .004$.

**Perceptual task: estimated aperture width**

Finally, we tested the critical action-specific prediction that apertures would be estimated as narrower for the Padded hand. Ratios were calculated as in Experiment 1 and used as the dependent variable in a mixed ANOVA where hand (Padded/Unpadded) was a within-participants factor and group (LHBigger/RHBigger) was a between-participants factor. There were no significant effects: hand, *F*(1, 34) = 0.690, *p* = .4, $\eta_p^2$

= .02; group, $F(1, 34) = 0.082$, $p = .8$, $\eta_p^2 = .002$; hand × group, $F(1, 34) = 0.180$, $p = 0.7$, $\eta_p^2 = .01$, see Figure 8. Thus, unlike Experiment 1, participants in Experiment 2 did not estimate apertures as narrower for their Padded hand than their Unpadded hand. Figure 9 shows the ratios for the Padded and Unpadded hand given by each individual participant.

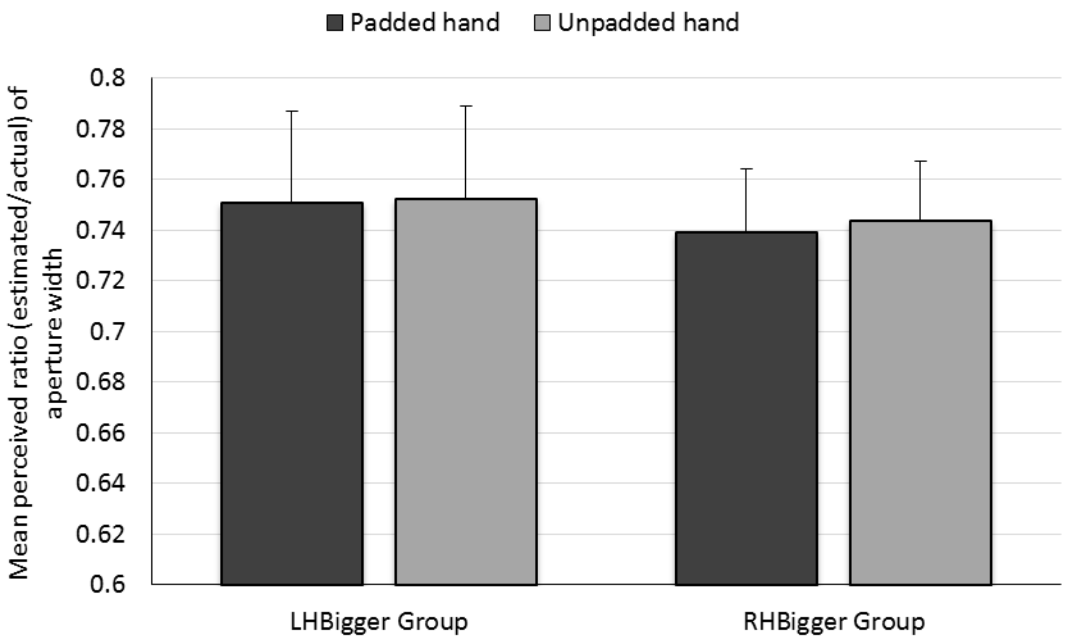



*Figure 8*: Results of the perceptual task in Experiment 2. Mean ratio of aperture size (estimated/actual) for each hand for each group. Error bars represent one standard error of the mean.

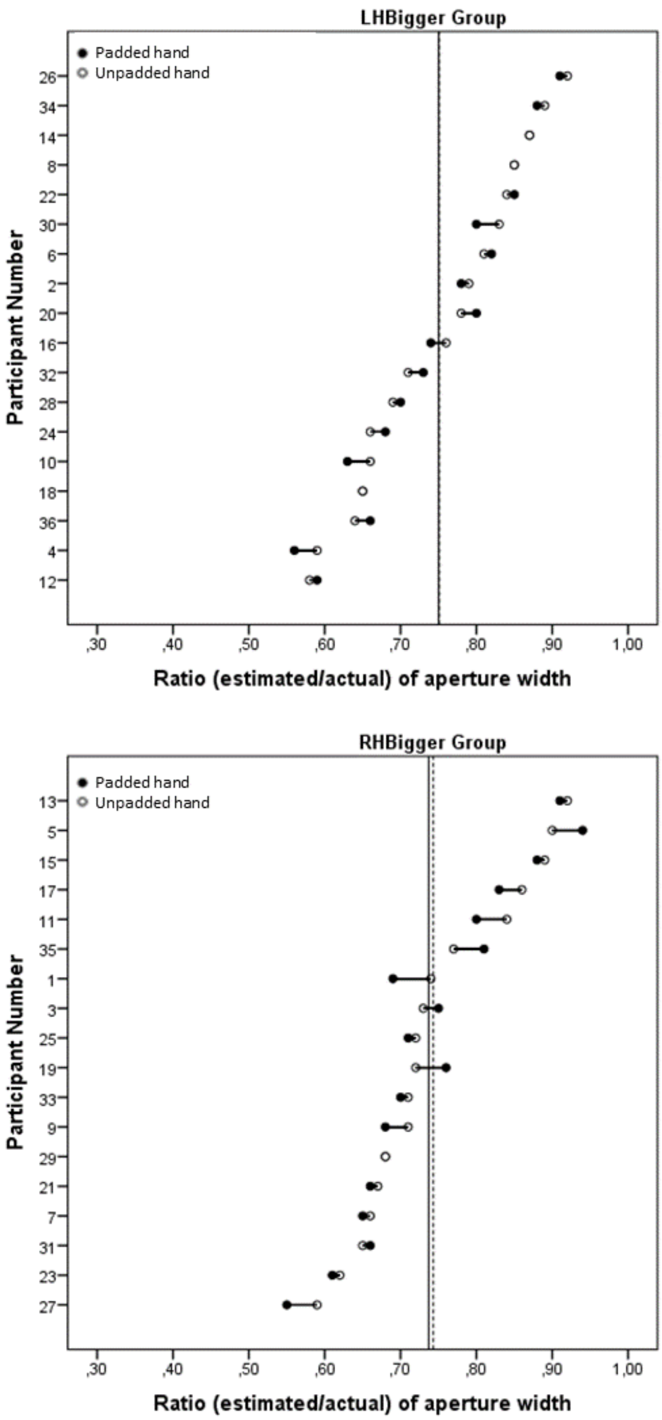



*Figure 9*: Individual estimates of aperture width (as a ratio of actual aperture width) for the Padded and Unpadded hands in the LHBigger (top) and RHBigger (bottom) groups. The bold and dashed vertical lines show the mean ratios for the Padded and Unpadded hands respectively. Participants are ordered by increasing ratio of aperture width for the Unpadded hand. Cases where only one data point are shown indicate no difference between ratios for the Padded and Unpadded hand.

### 5.4.3 Discussion

Replicating Experiment 1, padding one hand increased the minimum passable aperture for that hand. This change was perceived by participants: in the action capacity task, participants estimated the minimum passable aperture for their Padded hand as wider than for their Unpadded hand. Most importantly, using a cover story in the perceptual task eliminated the effect of altering action capacity on perceived aperture width which we had found in Experiment 1. Participants in Experiment 2 were told that their hands had to be placed near the aperture in the perceptual task as a control measure to ensure that their hands were in a similar position as in the haptic feedback phase. Our results are consistent with previous findings that have demonstrated that, even when participants intend to act, providing a cover story for a salient experimental manipulation can eliminate effects that appeared consistent with the action-specific account (Firestone & Scholl, 2014). Our present results suggest that the scaling effects found in Experiment 1 were not true perceptual changes, as proposed by the action-specific account, but were instead more likely due to demand characteristics (Orne, 1962).

It is important to emphasise that the action-specific account predicts a scaling effect in the perceptual task in Experiment 2 despite the use of a cover story. This is because, on every trial of the perceptual task, we asked participants to imagine whether they could fit their hand through the aperture before they made their width estimates. If action capacity directly influences what is perceived, as proposed by the action-specific account, then scaling should have occurred since we directly manipulated both actual and perceived action capacity, and participants intended to act on every trial.

## 5.5 General Discussion

In the present studies we were interested in biases in size perception and the role of intention to act in producing these biases. We investigated whether visual estimates of aperture width would be influenced by increases in hand size which altered action capacity. The action-specific account predicts that if a participant intends to move a wider hand through an aperture they should perceive the aperture as narrower, but that this scaling effect should not occur when participants do not intend to move their hand through the aperture (i.e. when they intend to act, Witt et al., 2005). However, we found that participants estimated apertures as narrower when the width of their hand was increased by wearing a padded glove even when they did not intend to act (Experiment 1)[5]. We then successfully eliminated this effect by providing a cover story for the presence of the hand near to the aperture, even though participants intended to act (Experiment 2). Both of these results suggest that the scaling effects that we observed were not true perceptual changes, as the action-specific account claims. Our results suggest that intention to act does not influence biases in spatial perception in the way predicted by the action-specific account. Instead our results support previous work that has shown that the action-specific account lacks predictive power (Firestone & Scholl, 2014).

Providing a cover story can reduce the demand characteristics associated with an otherwise unexplained manipulation (Collier & Lawson, 2017a; Durgin et al., 2009; Firestone & Scholl, 2014). Bhalla and Proffitt (1999; see also Proffitt et al., 1995) reported that hills were reported as steeper when observers wore a heavy backpack. However, Durgin et al. (2009) found that if participants were told that the backpack contained equipment for monitoring their ankle muscles, their slant estimates did not differ from estimates made by participants who did not wear a backpack. This finding suggests that participants who were not given a reason for wearing the backpack deduced that the backpack was supposed to influence their estimates of slant and changed their responses accordingly. Proponents of the action-specific account have rejected claims that their effects can be explained by demand characteristics (e.g. Witt & Sugovic, 2013; Linkenauger, Witt & Proffitt, 2013; Taylor-Covill & Eves, 2014). For example, Proffitt (2009; see also Proffitt & Linkenauger, 2013) argued that Durgin et al.'s (2009) study was not comparable to the original backpack studies because it used a 2 m ramp instead of a real hill and the energy required to ascend such a small ramp may not be sufficient to influence perception. However, Durgin, Klein, Spiegel, Strawster and Williams (2012) subsequently reproduced the results of Durgin et al. (2009) using a real hill, consistent with the claim that demand characteristics, rather than differences in energy requirements, produced the scaling effect on estimating hill slopes. In Experiment 1, we found an effect consistent with the action-specific account for participants who did not intend to act. Thus, our results suggest that intention to act is not critical in producing effects consistent with the action-specific account. Intention to act has been claimed as central to obtaining the scaling effects predicted by the action-specific account. For example, Witt et al. (2005) reported that increasing participants' maximum reach by providing them with a tool (a baton) influenced distance estimates, but only for participants who intended to reach with the tool. There is, however, an alternative interpretation of Witt et al.'s (2005) results. Franchak and Adolph (2014) showed that changes to the body are not necessarily sufficient to recalibrate perceived action capacity. They reported that pregnant women were able to accurately estimate the narrowest aperture they could walk through as this increased throughout their pregnancy. In contrast, participants who were temporarily fitted with a pregnancy prosthesis were initially inaccurate in estimating the narrowest aperture they could walk through, but after attempting the task their estimates were appropriately recalibrated. Thus, short-term changes to the body may not be sufficient to change observers' perceived action capacity, but it can be rapidly recalibrated through acting. Based on this conclusion, distance estimates by participants who held - but never reached with - a tool in Experiment 3 of Witt et al. (2005) may not have been affected by holding the tool because they had not yet recalibrated their perception of their maximum reach through acting. Thus Witt et al.'s (2005) results may not have been driven by intention to act. Instead their results may have arisen because only participants who acted with the tool recalibrated their perceived reaching capacity. Note, furthermore, that this does not mean that their perception of distances changed. Instead it may only have been their *judgements* of the distances that changed because they were aware that targets were easier to reach with the tool than without it (see Firestone, 2013; Firestone & Scholl, 2015, for discussions of whether action-specific effects reflect changes in visual perception or in post-perceptual judgement).

A further point is that, although intention to act is often argued to be necessary for the scaling effects predicted by the action-specific account to occur (e.g. Linkenauger, Witt & Proffitt, 2011; Witt, 2017; Witt et al., 2005), intention was not present in several studies that have been argued to support the action-specific account. For example, Bhalla and Proffitt (1999) did not mention walking up the slope to their participants, and Linkenauger et al., (2013) did not ask participants to consider or estimate the graspability of objects they estimated the size of. Therefore, even proponents of the action-specific account are not consistent about whether intention to act is needed to induce scaling effects. Given this, one possible critique of the present work is that we focused on intention to act as a test of when scaling effects should be found and when they should not. However, countering this critique, note that the action-specific account predicts an effect for the perceptual task in Experiment 2 even if participants did not intend to act. Linkenauger and colleagues (Linkenauger et al., 2010; Linkenauger, Mohler & Proffitt, 2011; Linkenauger, Witt and Proffitt, 2013) have reported that just placing the participant's hand next to an object can influence estimates of that object's size. For example, Linkenauger, Witt and Proffitt (2013) used virtual reality to manipulate perceived hand size. Participants were not asked to imagine grasping the object in this study, yet the authors reported that objects that appeared near the apparently larger hand were estimated as smaller (because, on the action-specific account, the objects were easier to grasp), and vice versa when the hand appeared smaller.

Another possible limitation of the present work is that, by providing a cover story in Experiment 2, we may have reduced not only demand characteristics, but also reduced participants' intention to act. However, on every trial in the perceptual task, participants were told to imagine moving their hand through the aperture while making their width estimates. This manipulation has been used in studies which have been claimed to show evidence for the action-specific account based on scaling effects (e.g. Linkenauger, Witt & Proffitt, 2011; Stefanucci & Geuss, 2009). Thus we would argue that there was no less intention to act in Experiment 2 than in other action-specific studies.

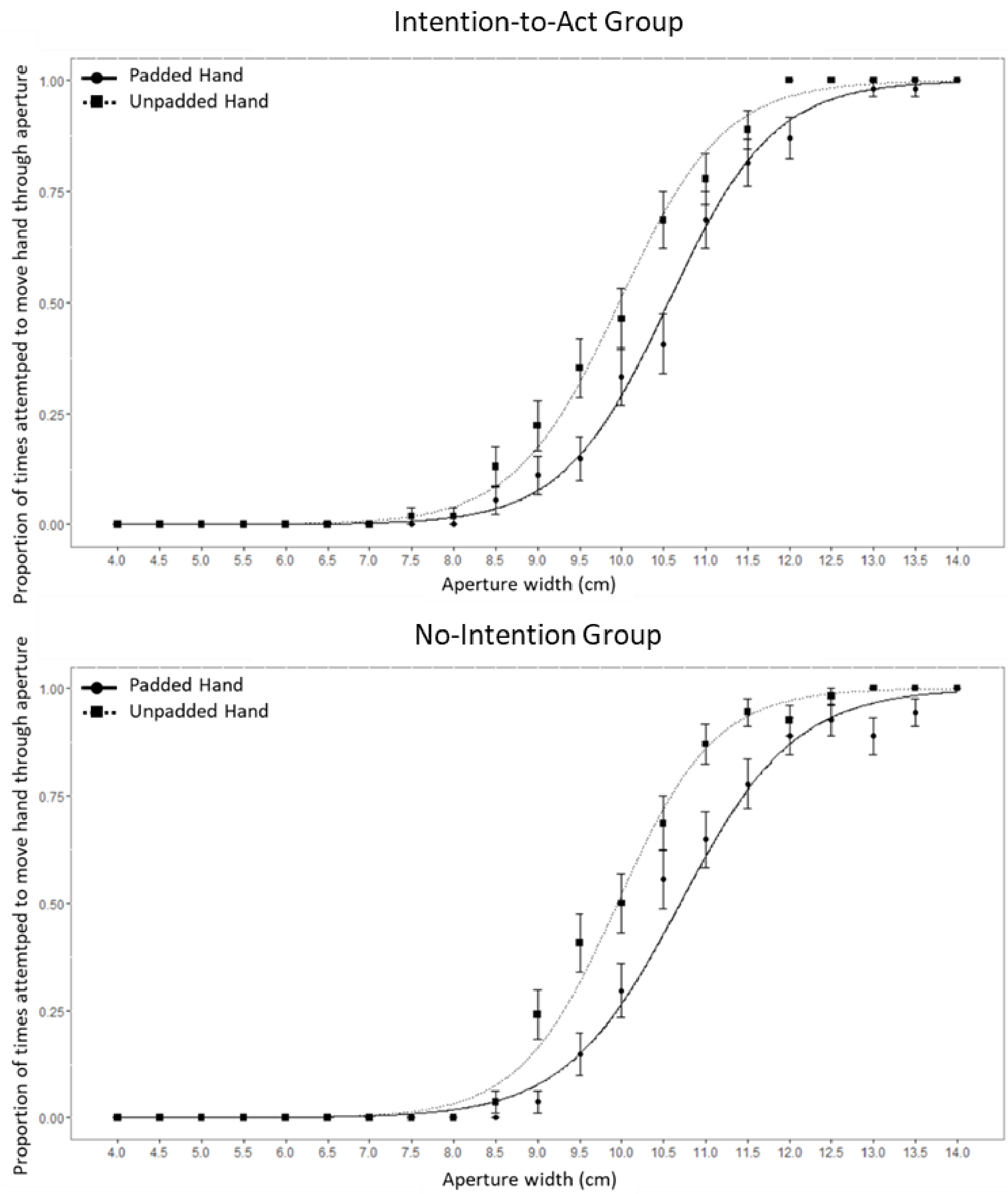
Our results suggest that intention to act is not critical in finding scaling effects. This is important because, if intention to act induces scaling effects, as the action-specific account proposes, this would suggest that visual perception is cognitively penetrable (Firestone & Scholl, 2015). This, in turn, would be inconsistent with modular theories of vision, which assume that perception cannot be influenced by higher-level cognitive factors such as intention, emotion or motivation (e.g. Pylyshyn, 1999; Firestone & Scholl, 2015). If we had found that intention to act was a driving factor in eliciting biases consistent with the action specific account, this would challenge cognitive impenetrability and it would necessitate a drastic change in our understanding of how perception works

(Firestone, 2013; Firestone & Scholl, 2015). Our results instead support cognitive impenetrability.

In conclusion, the results of the present studies suggest that the action-specific account of perception lacks predictive power. We found a scaling effect consistent with the action-specific account when one should not have been found (Experiment 1, when participants did not intend to act) and we failed to find this scaling effect when it should have been present (Experiment 2, when participants did intend to act). In Experiment 2 we were able to eliminate effects found in Experiment 1 that appeared to be consistent with the action-specific account by using a cover story, suggesting that these effects were likely the result of demand characteristics rather than true perceptual changes. Our observers were sensitive to changes in their action capacity to act following changes in their hand size due to wearing padded gloves. However, changes in both their actual and perceived action capacity did not affect their visual spatial perception in the strong sense proposed by the action-specific account.

## 5.6 Appendices: Chapter 5

**Appendix A: Mean Cumulative Gaussian curves for the Padded and Unpadded hands in the Intention-To-Act (top) and No-Intention (bottom) groups in Chapter 5, Experiment 1. Error bars show +/- one standard error of the mean.**



## 5.7 Footnotes: Chapter 5

[1] It is possible that at least some of the No-Intention group intended to act on the aperture given that they were seated directly in front of it. However, this group was not explicitly asked about their action capacity and they never acted on the aperture during the perceptual task. Thus few of them were likely to have explicitly considered acting by moving their hand through the aperture and any intention to act in this way in this group would likely to be weak, implicit and infrequent. In summary, an intention to put their hand through the aperture should have been stronger, explicit and universal in the Intention-To-Act group even if intention was not entirely absent in the No-Intention group.

[2] All participants wore the Padded glove on their left hand because right handers have been shown to believe that their right hand is larger than their left hand (Collier & Lawson, 2017a; Linkenauger, Witt & Proffitt, 2011) so if participants estimated apertures as narrower while wearing the glove on their right hand, this could be because their judgements were affected by the change in hand size caused by the glove, or because of the underlying bias in perceived hand size. Having participants always wearing the Padded glove on the left hand avoided this confound. However, it introduced a second confound, namely that the same hand always wore the Padded glove, so in Experiment 2 we counterbalanced which hand wore the Padded glove.

[3] During the haptic feedback phase participants estimated the width of the apertures they felt between their fingers. This was done in the same way as described for the main perceptual task. These results are not reported here because participants actually acted in this task but not in the perceptual task, making it difficult to compare the results of the two tasks. In addition, the action-specific account does not offer specific predictions for haptic spatial perception (though see Collier & Lawson, 2017a, and Linkenauger, Witt & Proffitt, 2011, for a discussion of the different biases that might be expected for visual and haptic perception). The main purpose of this task was to alert participants to the difference in the width of their Padded and Unpadded hands through haptic feedback, and to ensure that the cover story used in the subsequent perceptual task was persuasive.

[4] Most participants did, though, look at their hands before the task began, while the experimenter was explaining the task.

[5] It might be argued that our results in Experiment 1 arose from a confound. The Padded glove was always worn on the left hand and our right-handed participants might, for example, have been less confident about their ability to pass their non-dominant hand through the aperture. However, in other, similar, studies (e.g., Collier & Lawson, 2017a), we have found no evidence for a baseline difference in spatial estimates depending on whether participants intended to use their dominant versus their non-dominant hand. Furthermore, in Experiment 2 here this confound was removed and there was no effect of whether our right-handed participants wore the Padded glove on their left or their right hand. Instead, we suggest the critical difference between the design of Experiments 1 and 2 was the use of a cover story.

# Chapter Six

## 6. Hunger does not affect perceived size of food products

### 6.1 Abstract

The action-specific account of perception suggests that we see the world in terms of our ability to act. Although most of the research in this area has focussed on the implications of action-specific scaling effects for theories of visual perception, recently Witt et al. (2016) suggested that such effects could have important real-world applications. One possibility they discussed was the role of action-specific scaling effects in perpetuating unhealthy behaviours which may contribute to obesity. For example, heavier individuals tend to estimate staircases as steeper than healthy weight individuals (Taylor-Covill & Eves, 2014). As a result, they may be less likely to take the stairs, despite the health benefits of doing so. Here, we investigated another prediction, based on the action-specific account, in this area. Namely, we tested whether hungry participants would perceive food items as smaller because they believe they can eat more than satiated individuals. This may explain why people who have fasted, and are hungry, tend to eat more than people who have not fasted when food becomes available (Wansink, Tal & Shimizu, 2012). Hungry people may eat more because the same amount of food seems like a smaller portion to them. We compared hungry and satiated participant's verbal estimates of the width and height of food and non-food products. Both groups of participants estimated food products as taller than non-food products, but there was no

effect of hunger on size estimates. Our results provide no support for the idea that the action-specific account can provide insights into understanding why people overeat.

## 6.2 Introduction

The action-specific account of perception suggests that perceivers see the world in terms of their ability to act (for reviews see Collier & Lawson, under review; Firestone, 2013; Philbeck & Witt, 2015; Linkenauger, 2015; Proffitt & Linkenauger, 2013; Witt, 2011a, 2016). Evidence claimed to support this account includes the finding that participants who drank a sugary beverage estimated distances as shorter than participants who drank an artificially sweetened drink (Schnall, Zadra & Proffitt, 2010). In addition, hills were estimated as steeper by participants who were fatigued, had poor physical fitness, or wore a heavy backpack (Bhalla & Proffitt, 1999; Eves, Thorpe, Lewis & Taylor-Covill, 2014; Taylor-Covill & Eves, 2013), and stairs were estimated as steeper (Taylor-Covill & Eves, 2014) and distances to targets were estimated as greater (Sugovic et al., 2016) by heavier participants.

By suggesting that what we see is directly influenced by our action capacity, the action-specific account of perception may challenge the long-held, modular perspective that vision is cognitively impenetrable (Firestone & Scholl, 2015). As a result, most research in this area has focussed on the theoretical implications of the action-specific account for our understanding of how visual perception works (e.g., Bhalla & Proffitt, 1999; Collier & Lawson, 2017a, 2017b, in press; Firestone & Scholl, 2014, 2015; Linkenauger, Witt & Proffitt, 2011; Taylor-Covill & Eves, 2014; Witt, 2017). Recently, though, Witt et al. (2016) suggested that action-specific effects may impact our everyday life because changes in our action capacity may influence our behavioural decisions, as these are largely based on visual information from the environment. For example, Taylor-

Covill and Eves (2014) found that overweight individuals estimated staircases as steeper than healthy-weight individuals and Eves et al. (2014) reported that people who estimated staircases as steeper were more likely to use an escalator than take the stairs. Taken together, these results imply that overweight and obese individuals may be less likely to choose energetically demanding options, such as taking the stairs, despite the health benefits of doing so (Witt et al., 2016). This could create a positive feedback loop whereby unhealthy lifestyle choices are repeated.

In the present work, we investigated another possible application of the action-specific account, namely whether hunger affects the perceived size of food products. This may provide important insight into whether people sometimes overeat because food appears smaller to them when they are hungry. It has been suggested that repeated dieting to lose weight often results in long-term weight gain (Dulloo, Jacquet, Montani & Schutz, 2015), and dietary restraint is associated with increased food intake in the long-term (Hawkins & Clement, 1980; Polivy & Herman, 1985). Similar effects are found for short-term fasting. For example, people who have fasted, and are therefore hungry, tend to eat more than people who have not fasted when food becomes available. Wansink, Tal and Shimizu (2012) compared the calorie intake from a buffet of participants who had fasted for 18 hours and participants who had not fasted. During the experiment, participants selected foods to eat from a buffet. Participants who had fasted ate ~47% more calories than those who had not fasted. According to the action-specific account, increased food consumption following fasting could occur because hungry people may also believe they can eat more and, in turn, may perceive food items as smaller. This could lead them to eating more, since – to them – it appears that there is less on their plate.

Evidence from anorexia nervosa patients also suggests that estimates of food size may be affected by how much people think they can eat. For example, Yellowlees, Roe, Walker and Ben-Tovim (1988) found that anorexia patients estimated food products as larger than healthy individuals. In addition, Milos et al. (2013) found that anorexia nervosa patients estimated the size of prepared meals (presented as images on a screen) as larger than healthy controls (though see Vinai et al., 2007, who found no difference in food volume perception between anorexia nervosa patients and healthy controls). The action-specific account suggests that these effects may have arisen because anorexia patients do not think they can, or should, eat a lot of food and so food products appear larger to them to deter them from eating. If this were the case, then the action-specific account may provide important insight into why the recovery rates for anorexia nervosa are so poor (e.g., Herzog, Deter, Fiehn & Petzold, 1997).

However, there is an alternative account for these effects, namely a bias in visual attention. It has been shown that attended items appear closer (Cole, Riccio & Balcetis, 2014) and larger (Anton-Erxleben, Henrich & Treue, 2007) than non-attended items. A characteristic of anorexia nervosa is the tendency to obsess over food (Garner & Garfinkel, 1980; Hesse-Biber, Marino & Watts-Roy, 1999; Hesse-Biber, Leavy, Quinn & Zoino, 2006) and these patients also show an attentional bias towards food- and eating-related stimuli (Channon, Hemsley & Silva, 1988; Shafran, Lee, Cooper, Palmer & Fairburn, 2007). Thus, anorexia patients' overestimations of food size could instead reflect their increased attention to food stimuli. Such an attentional bias would be consistent with the modular account of perception that proposes that vision is cognitively impenetrable, whereas an influence of thoughts or beliefs on perception would not (Firestone & Scholl, 2015).

In the present study, we were interested in whether healthy, but hungry, individuals would show biases in estimated food product size similar to those found for anorexia nervosa patients. Analogous to the two competing explanations for the perceptual biases found for anorexia nervosa patients, there are two competing predictions for the present experiment. On the one hand, hungry participants may estimate food products as *smaller* than satiated participants, since they may think they can eat more. This is the prediction made based on the *action-specific* account. On the other hand, hungry participants may estimate food products as *larger* than satiated participants, because their increased attentional focus to food products may make them appear larger. This is the prediction made based on a *visual attention* account. This experiment is among the first to investigate whether hunger directly affects estimates of food product size in healthy individuals, and it may also shed light on the nature of the biases found for anorexia nervosa patients. If healthy, but hungry, individuals estimate food products as smaller than satiated individuals, this would provide evidence for an action-specific account of the clinical data. In contrast, if healthy, but hungry, individuals estimate food products as larger than satiated individuals, this would provide evidence for a visual attention account of the clinical data.

In the present experiment, we tested whether hungry individuals showed biases in the perceived size of food relative to non-food products. We tested one group of participants who were tested in the morning and who were asked to miss breakfast, and another group who were tested in the afternoon and who were asked to eat a meal one hour before being tested. All participants verbally estimated the height and width of food and control, non-food products. Neither the action-specific nor the visual attention account predict a main effect of product type (food versus non-food). However, the action-specific account predicts that the Hungry group should estimate food products as smaller than the Not-Hungry group, with no difference for the non-food products. The visual attention account also predicts an effect only for the food products, but in the opposite direction – the Hungry group should estimate food products as larger than the Not-Hungry group.

## 6.3 Method

Ethical approval for this experiment was granted by the relevant local ethics committee at the University of Liverpool.

### 6.3.1 Participants

Thirty-two participants (mean age = 18.9 years, 5 males) were recruited from the University of Liverpool. Participants self-reported as being non-dieters and having no history of eating disorders.

### 6.3.2 Design

Half of the participants were tested in the morning and were told to miss breakfast that morning (Hungry group, n = 16), whilst the other half were tested in the afternoon and were told to ensure that they ate a meal within an hour before arriving at the lab (Not-Hungry group, n = 16).

### 6.3.3 Apparatus, stimuli and procedure

Upon arrival, participants confirmed that they had adhered to their instructions about eating before the experiment. They then completed a verbal object size estimation task. Fifty-six real objects were used as stimuli. Half of the stimuli were containers of food, and the other half were non-food products (e.g., cleaning and skincare products). The mean height and width (at the product's widest point) for the food and non-food products are given in Table 1[1]. Each food product was paired with a non-food product that was matched in size, shape and colour, see Figure 1.

**Table 1**

Mean (standard deviation) and range (below) of the height and width of the food and non-food products used.

| Measure | Food products (n = 28) | Non-food products (n = 28) |
|---|---|---|
| Height (cm) | 15.4 (5.6) | 16.1 (5.8) |
| | 5.5 – 31.9 | 5.8 – 32.1 |
| Width (cm) | 8.9 (4.0) | 8.9 (3.7) |
| | 4.5 – 23.3 | 4.9 – 22.5 |

Participants sat at a table, in front of a curtain, see Figure 2. The experimenter stayed behind the curtain, and presented the objects, one at a time, by placing them on the table in front of the participant through the curtain. Participants verbally estimated the height and then the width of each object in centimetres (cm). After they had made both estimates, participants closed their eyes, and the object was replaced with the next object. The experimenter told the participant when to open their eyes for the next trial.

Not all objects could be placed upright so all the objects were placed flat on the table with the base nearest the participant and the top furthest away from them, as shown in Figure 2. This ensured that that the terms “height” and “width” were constant across objects. Before the experimental trials began, the experimenter visually demonstrated what was meant by height and width using a foamboard cube. The height of the object referred to the length from the edge of the bottom of the object (nearest the participant) to the top of the object (nearest the curtain), see Figure 2. The width referred to the widest part of the object from one side to the opposite side. The experimenter asked whether participants understood what they had to estimate, and checked this in two practice trials using foamboard cubes (dimensions = $16cm^2$ and $24cm^2$). Participants were told the actual dimensions of these cubes after both trials were complete. Once the experimenter was satisfied that the participant understood the task, the experimental trials began.

Objects were presented in a fixed, quasi-random order to half of the participants, and in the reverse order to the remaining half of participants. There were no more than two successive food or non-food items, no feedback was given and participants were not allowed to touch the objects.

Participants then completed a series of visual analogue scales which measured anxiety, happiness, sadness, hunger and how much participants believed they could eat (on a scale of 0 (not at all/none) to 100 (very much/a lot). Participants also reported when they last ate and what they had eaten.


*Figure 1*: The matched pairs of food and non-food containers that were used as stimuli. The pairs were rated for visual similarity by five independent raters, who scored each pair on a scale from 1 (not at all similar) to 5 (extremely similar). The average similarly rating was 3.44, with a range of 2 – 5. The mean similarity ratings for each pair can be found in Appendix A.

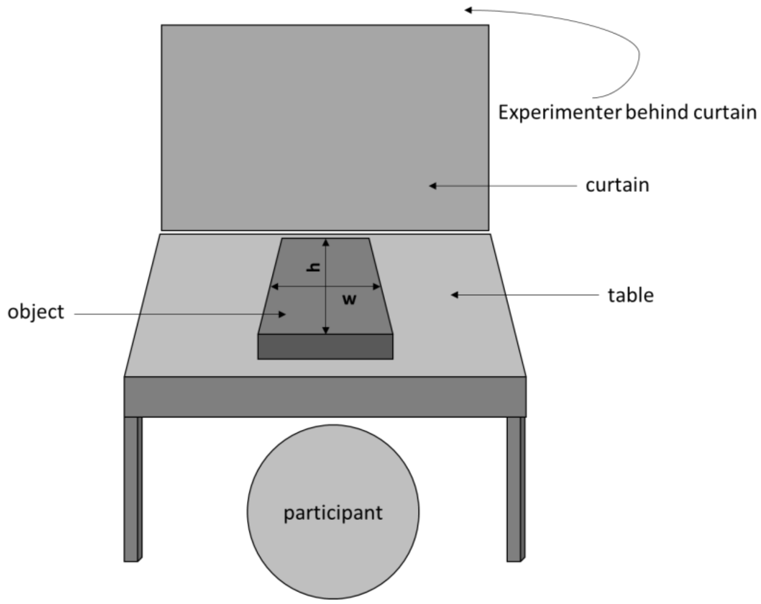



*Figure 2*: Experimental setup. The participant sat at a table in front of a curtain. On each trial, the experimenter lifted the curtain, placed the object on the table in front of the participant, and put the curtain back in place until the participant made their verbal estimates of height (h) and width (w) in centimetres. After the participant made both estimates, the object was removed and replaced with the next object.

## 6.4 Results

Table 1 shows the number of mean weight, height and body mass index (BMI) of participants in the Hungry and Not-Hungry groups. Table 1 also shows the amount of time since participants in each group reported eating a meal.

**Subjective ratings using the visual analogue scales (VAS)**

Participants in the Hungry group reported feeling significantly hungrier than those in the Not-Hungry group, $t(30) = 8.557$, $p < .001$, see Table 3. They also reported that they could eat significantly more than the Not-Hungry group, $t(30) = 5.978$, $p < .001$. There were no differences between the Hungry and Not-Hungry groups on any other scale: anxiety, $t(30) = -0.818$, $p = .4$; happiness, $t(30) = -0.149$, $p = .8$; sadness, $t(30) = -0.447$, $p = .6$.

**Table 2**

Mean (and standard deviation) of the height, weight and BMI of participants in each group and the time since their last meal.

| Measure | Hungry Group (n = 16) | Not-Hungry Group (n = 16) |
|---|---|---|
| Height (cm) | 168.1 (11.4) | 168.4 (11.8) |
| Weight (kg) | 54.6 (8.3) | 58.8 (9.6) |
| BMI | 19.4 (2.9) | 20.7 (2.8) |
| Time since last meal | 11 hrs (4.0 hrs) | 52 mins (34 mins) |

**Table 3**

Mean (and standard deviation) of visual analogue scale scores for measures of hunger, how much could be eaten, anxiety, happiness and sadness in the Hungry and Not-Hungry groups. Ratings were made on a scale of 0 (not at all/none) to 100 (very much/a lot).

| Measure | Hungry Group (n = 16) | Not-Hungry Group (n = 16) |
|---|---|---|
| Hunger | 74.0 (16.8) | 19.8 (19.3) |
| How much could you eat? | 64.0 (15.0) | 28.1 (19.0) |
| Anxiety | 12.9 (15.3) | 19.4 (25.7) |
| Happiness | 66.0 (18.7) | 67.4 (20.0) |
| Sadness | 9.8 (8.8) | 12.3 (19.0) |

**Object height and width estimation**

Perceived object height and width were calculated as a ratio (estimated/actual) of actual height and width respectively. These ratios were then used as the dependent variable in two separate mixed ANOVAs (one for width estimates and one for height estimates)[2], where product type (Food/Non-Food) was a within-participants factor and group (Hungry/Not-Hungry) was a between-participants factor, see Figure 3.

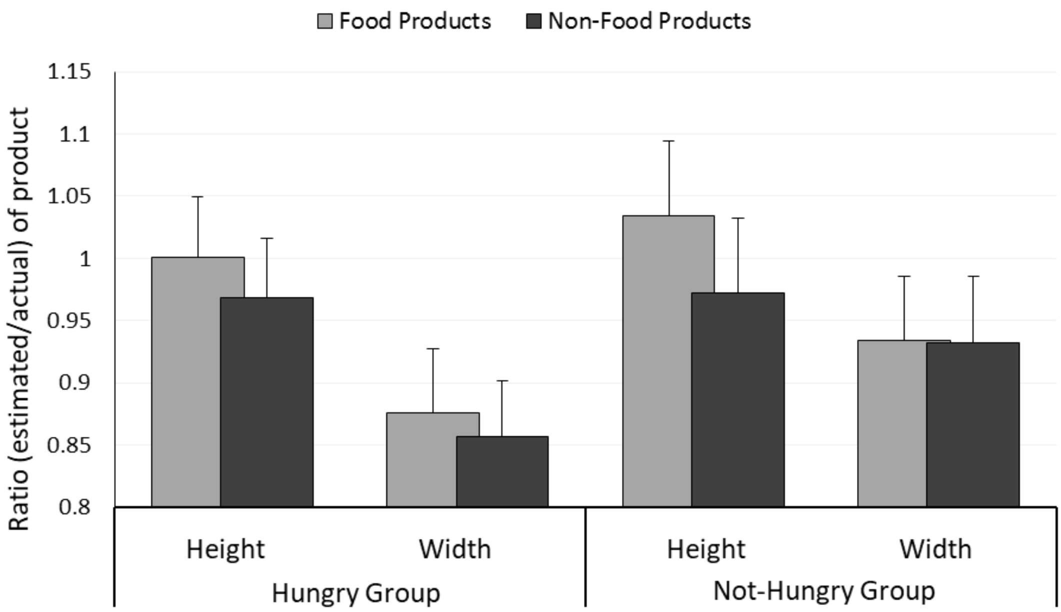



*Figure 3:* Mean ratio (estimated/actual) of the height and width of food and non-food products in the Hungry and Not-Hungry groups. Error bars show one standard error of the mean.

For *perceived width* there were no significant effects: product type, $F(1, 30) = 1.503$, $p = .2$, $\eta_p^2 = .05$; group, $F(1, 30) = 0.875$, $p = .4$, $\eta_p^2 = .03$; product type × group, $F(1, 30) = 1.076$, $p = .3$, $\eta_p^2 = .04$. For *perceived height*, food products (m = 1.01, se = 0.04) were estimated as taller than non-food products (m = 0.98, se = 0.04), $F(1, 30) = 16.959$, $p < .001$, $\eta_p^2 = .36$. However, group was not significant, $F(1, 30) = 0.062$, $p = .8$, $\eta_p^2 = .002$, and, most importantly, product type × group was not significant, $F(1, 30) = 1.621$, $p = .2$, $\eta_p^2 = .05$. Thus, the only significant difference that we found was that, for both groups, height estimates for food products were greater than height estimates for non-food products. This finding suggests that the non-significant interaction which tested the main prediction of this experiment was not due to a lack of power.

## 6.5 Discussion

In this experiment, we were interested in testing whether the action-specific account of perception could provide insight into why people sometimes overeat.

Specifically, we tested whether being hungry affected the estimated size of food products but not visually matched control (non-food) products. The action-specific account claims that hungry individuals may perceive food products as smaller than satiated individuals because they may believe they can eat more. This may, in turn, lead them to actually eat more. Our hungry participants did report both feeling hungrier than our satiated participants, and believing that they could eat more than them. However, this did not modulate their estimates of the size of food products. Therefore, our results did not support our prediction based on the action-specific account. Interestingly, our results also did not support our prediction based on a visual attention account, which predicts that hungry individuals should estimate food products as larger than satiated individuals. Instead, we found that both groups estimated food products as slightly taller than non-food products. However, this unexpected effect was small and occurred only for height and not for width.

In summary, although we found no evidence that hunger affects estimates of food products in the way predicted by the action-specific account, we also found no evidence that attention affected size estimates. Thus, our results do not provide evidence for either an action-specific or a visual attention account of previous findings that anorexia nervosa patients estimate food as larger than healthy controls (Milos et al., 2013; Yellowlees et al., 1988). However, there is a third explanation for the biases reported for anorexia nervosa patients that does not require appealing to changes in perception. Specifically, the overestimation of food products could reflect a cognitive strategy arising from anorexia nervosa patients' belief that they should restrict the amount of food that they eat. Exaggerating the size of food products may reflect a self-justification for eating less ("there's just too much food here, I really can't finish it all"). This possibility is supported by evidence showing that biases in perceptual estimates can serve to justify a given behaviour (Wesp & Gasper, 2012). In one experiment, Wesp et al. (2004) reported that less successful dart throwers estimated targets as smaller than more successful throwers. However, in a later study, Wesp and Gasper (2012) found that this association between success and estimated target size disappeared if participants were told that they were using low quality darts. This suggests that less successful throwers in the original Wesp et al. (2004) study may have estimated the targets as smaller to justify their poorer performance. In contrast, in Wesp and Gasper (2012), participants could attribute their poorer performance to the low-quality darts, so their size estimates were unaffected by performance because they did not need a further explanation of why they were failing to throw well. Consistent with this account, Vinai et al. (2007) found that when references to food intake were minimised, anorexia nervosa patients showed no difference to healthy controls in their estimation of the number of candies on a plate.

The present experiment was motivated by the suggestion that action-specific effects could have applications in real life which affect behaviour (Witt et al., 2016). Observers make action decisions based on visual information from the environment and, according to the action-specific account, what they see is affected by their action capacity. However, Witt et al.'s (2016) reasoning may be problematic. In a commentary on Witt et al. (2016), Gray (2016) suggested that many of the examples given by Witt et al. (2016) did not, in fact, represent action-specific effects at all. For example, Witt et al. (2016) discussed the finding that using the Ebbinghaus illusion to change the apparent size of golf holes improved golfing performance (Chauvel, Wulf & Maquestiaux, 2015) and claimed that this provides evidence for the action-specific account and its application in real life. However, this in fact provides evidence for the reverse direction of effect that that proposed by the action-specific account. Specifically, in Chauvel et al. (2015), people's perception of the layout of the environment (hole size) affected their golfing performance rather than vice versa. Gray (2016) further argued that little is known about the mechanisms underlying action-specific effects and that, without this understanding, it is too early to try to apply the action-specific account in practice. Based on the results of the current study, we agree with Gray (2016), as we found no evidence that the action-specific account can provide insight into behaviours such as overeating.

This experiment was not without limitations. One important caveat to note is that the foods used were contained within packages, rather than being prepared and ready to eat. This may have limited the salience of these items as food products, although these results do replicate the experiences of choosing what to cook in a kitchen or supermarket shopping[3]. It might be expected that hunger would affect the estimated size of prepared meals more than packaged foods[4]. This possibility is supported by the findings of Milos et al. (2013) who reported that anorexia nervosa patients overestimated the size of images of prepared meals to a greater extent when they imagined eating the meals. Thus, it would be fruitful to retest the hypotheses investigated here using prepared meals which afford immediate eating rather than packaged food products which do not. It is worth noting that this limitation is not unique to the present study. For example, studies investigating the relationship between estimates of food size and diet success (e.g., van Koningsbruggen, Stroebe & Aarts, 2011) and studies comparing the estimates of meal size between anorexia nervosa patients and healthy controls (e.g., Milos et al., 2013) used images of food products or prepared meals instead of real objects or meals. One exception is Chandon and Wansink (2007), who investigated whether individuals with a higher body mass index (BMI) underestimated the calorie content of fast food meals more than individuals with a lower BMI. In this study, participants were presented with real fast food meals of varying portion size. It was found that, regardless of BMI, people underestimated the calorie content of large meals more than small meals (Chandon &

Wansink, 2007). However, as the authors acknowledged, calorie content is not a perceptual property and so this study did not directly test the relationship between body size and the visual perception of food.

In conclusion, in this experiment, hunger did not directly affect people's estimates of the size of food products. We agree with Gray's (2016) comment that calls for the action-specific account to be applied in everyday life (Witt et al., 2016) are premature. First, as discussed by Gray (2016), some examples given by Witt et al. (2016) do not in fact reflect action-specific scaling. Second, it has not yet been established that action-specific effects are true perceptual effects (Durgin et al., 2009, 2012; Collier & Lawson, 2017a, 2017b, in press; Firestone, 2013; Firestone & Scholl, 2014; Woods et al., 2009). For example, it has been argued that several action-specific effects can be explained by demand characteristics resulting from participants guessing the experimental hypothesis (Durgin et al., 2009; 2012; Firestone & Scholl, 2014), or response biases associated with conflating estimations of action capacity and spatial properties (Collier & Lawson, 2017b; Woods et al., 2009). Therefore, the action-specific account faces both theoretical (Durgin, 2016; Firestone, 2013; Gray, 2016) and methodological (Collier & Lawson, 2017a, 2017b; Durgin et al., 2009; Firestone & Scholl, 2014; Woods et al., 2009) hurdles which it must overcome before attempts at employing its findings in real life are seriously considered.

## 6.6 Appendices: Chapter 6

**Appendix A: Similarity ratings for the pairs of food and non-food stimuli in chapter 6.**

| Pair | Food item | Non-Food item | Average rating (/5) | Minimum rating | Maximum rating |
|---|---|---|---|---|---|
| 1 | Kellogg's Frosties | Bold Washing Powder | 4 | 3 | 5 |
| 2 | Rice cakes (white pack) | Kitchen roll | 3.2 | 2 | 4 |
| 3 | Rice cakes (blue pack) | Cloths | 3.6 | 3 | 4 |
| 4 | Walkers crackers | Soda crystals | 4.4 | 4 | 5 |
| 5 | Ritz | Daz washing powder | 4.6 | 4 | 5 |
| 6 | Brunch bar | Cura-heat pain relief pads | 3 | 2 | 4 |
| 7 | Dolmio lasagne mix | Scented candle | 3.2 | 2 | 4 |
| 8 | Cadburys Fingers | Purple pillow case | 2.8 | 2 | 4 |
| 9 | Oreos | Sanex anti-persperant | 3.2 | 2 | 4 |
| 10 | Chocolate digestives | Fresh bin powder | 3.8 | 3 | 4 |
| 11 | Poppets | 2 in 1 mop refill (green) | 2.6 | 2 | 4 |
| 12 | Salt 'n' Shake crisps | Nivea face wipes | 3.6 | 2 | 5 |
| 13 | Rowse honey | Garnier hair oil | 4 | 3 | 5 |
| 14 | Milky -Way chocolate spread | V05 styling gel | 4 | 3 | 5 |
| 15 | Mini mint matchmakers | Green scourer | 3.2 | 2 | 4 |

| | | | | | |
|---|---|---|---|---|---|
| 16 | Mushy peas (can) | Air-Wick air freshener spray | 4 | 3 | 5 |
| 17 | M&Ms Peanut | Flash cleaning wipes | 3 | 2 | 4 |
| 18 | Fox's crunchy-cream ginger nuts | Vaseline spray moisturiser | 3.4 | 3 | 4 |
| 19 | Glenrick's Pilchards can | Imperial Leather soap bar | 2.6 | 2 | 4 |
| 20 | Cup Shotz Tomato & Herb | Flash Wipe 'n go wipes | 4 | 3 | 5 |
| 21 | Hellmann's mayonnaise | Pukka labels | 2.6 | 2 | 3 |
| 22 | Hartlet's raspberry jelly cubes | Vanish stain remover bar | 3.4 | 2 | 4 |
| 23 | Anchovy fillets (can) | Asda brand stain remover bar | 2.6 | 1 | 5 |
| 24 | Pink Panther wafers | Felight cat litter tray wipes | 3.2 | 2 | 4 |
| 25 | Rich Tea biscuit (single) | George pressed face powder | 3.2 | 2 | 5 |
| 26 | Shortbread | Yankee melter (small candle) | 4 | 3 | 5 |
| 27 | Shreddies (small box) | Duck fresh toilet discs | 3.2 | 2 | 4 |
| 28 | Red leicester cheese block | Postit notes | 4 | 3 | 5 |

## 6.7 Footnotes: Chapter 6

[1] The food products were not significantly wider than their matched non-food pairs, $t(27) = -0.118$, $p = .9$, but they were significantly shorter, $t(27) = -2.256$, $p = .03$.

[2] When included in the same ANOVA, there was a three-way interaction of product type (food/non-food) × group (Hungry/Not-Hungry) × dimension (height/width), $F(1, 30) = 7.7178$, $p = .012$, $\eta_p^2 = .19$.

[3] For example, our results suggest that the anecdotal idea of not shopping while hungry because we may buy more food than we need is unlikely to be motivated by perceptual factors such as changes in the perceived size of food products on the supermarket shelf.

[4] Though note that both Yellowlees et al. (1988) and Milos et al. (2013) reported that anorexia nervosa patients overestimated the size of food stimuli relative to healthy controls, despite the former using packaged foods and the latter using images of prepared meals. This suggests that stimulus choice may not be a critical consideration.

# Chapter Seven

## 7. The influence of grasping capacity on estimates of object size is not a true perceptual effect

***This chapter has been submitted for publication as:**

**Collier, E. S., & Lawson, R. Getting a grasp on action-specific scaling: A response to Witt (2017). (under review).**

### 7.1 Abstract

Can higher level cognition directly influence visual spatial perception? Many recent studies have claimed so, on the basis that manipulating cognitive factors (e.g., morality, emotion or action capacity) seems to directly affect perception. However, Firestone and Scholl (2015) argued that such studies often fall prey to at least one of six pitfalls. They further argued that if an effect could be accounted for by any of these pitfalls, it is not a true demonstration of a top-down influence of cognition on perception. In response to Firestone and Scholl (2015), Witt (2017) discussed four action-specific scaling effects which, she argued, withstand all six pitfalls and thus demonstrate true perceptual changes caused by differences in action capacity. One of these effects was the influence of apparent grasping capacity on perceived object size. In this article, we provide new interpretations of previous findings and assess recent data which suggest that this effect is not, in fact, perceptual. Instead, we believe that many earlier studies showing this effect are subject to one or more of the pitfalls outlined by Firestone and Scholl (2015). We

substantiate our claims with recent empirical evidence from our laboratory which suggests that neither actual nor perceived grasping capacity directly influence perceived object size. We conclude that studies manipulating grasping capacity do not provide evidence for the action-specific account because variation in this factor does not directly influence perception.

## 7.2 Introduction

Understanding how the mind is organised is central to theories of spatial perception, and this involves understanding what factors contribute to what is perceived (Firestone & Scholl, 2015; Witt, 2017). In this article, we provide an independent contribution to the on-going debate concerning whether action capacity directly influences visual perception (for reviews see Firestone, 2013; Philbeck & Witt, 2015; Proffitt, 2013; Proffitt & Linkenauger, 2013; Witt, 2011, 2017; Witt & Riley, 2014). First, we would like to outline our position in the action-specific debate. When we began investigating the claims of the action-specific account, we were not active in the wider debate. Rather, we found the idea that action capacity could influence visual perception intriguing. We therefore investigated the mechanism purported to underlie these effects, and whether comparable effects to those obtained for vision would be found for our sense of active touch (haptics). In pursuit of this, we ran a series of studies (Collier & Lawson, 2017a) based on the findings of Linkenauger, Witt and Proffitt (2011), which suggested that apparent grasping capacity directly influenced perceived object size. We failed to replicate the effect reported by Linkenauger, Witt and Proffitt (2011, Experiment 2) and we sought to understand why. As we further investigated the apparent influence of grasping capacity and hand size on perceived object size (Collier & Lawson, 2017b, 2018), we became increasingly convinced that these effects are not caused by a true perceptual change as the action specific account claims. Instead, we now believe that this effect can be explained by other factors including experimental demand characteristics, strategies such as using the size of familiar objects to anchor estimates, and visual illusions. These alternative explanations are not compatible with the action-specific account (Firestone, 2013).

The present paper is a direct response to a recent review paper by Witt (2017), a proponent of the action-specific account. In her review Witt provides a detailed discussion of four empirical case studies. She claimed that each case provided evidence for action-specific effects that did not fall prey to any of the pitfalls outlined by Firestone and Scholl (2015) which could provide an alternative explanation of action-specific effects. Her third case study focussed on the claim that grasping capacity exerts a direct influence on perceived object size. In our response here, we discuss our own empirical data which provides evidence against this claim. We also offer a critical evaluation of the arguments made by Witt (2017) and new interpretations of previous results claiming to support the action-specific account. We conclude that this portion of the evidence that Witt (2017) used to support the action-specific account of perception is not reliable.

## Cognition and perception

What is meant by *perceiving* something? Phenomenologically, this is relatively clear: we can *see* the yellowness of a banana, *hear* the melody in our favourite song, and *feel* a breeze against our skin. In each of these cases, incoming signals from external stimulation of the relevant sensory system give rise to a perceptual experience. These experiences seem distinct from, for example, *knowing* the price of a banana in your local shop, *recalling* when you first heard your favourite song, or *imagining* how pleasant a breeze might be on a warm day, all of which could be considered examples of cognition.

To borrow from Firestone and Scholl (2015), the distinction between perception and cognition usually seems “natural and robust” (p. 1).

Despite the phenomenologically simple distinction between perception and cognition, there has been fierce debate as to whether our perceptual experiences are truly independent of cognitive influence (Firestone & Scholl, 2015; Proffitt & Linkenauger, 2013; Pylyshyn, 1999; Vetter & Newen, 2014). Some evidence appears to support the idea that perception is directly influenced by cognitive factors in a non-trivial way. For example, it has been suggested that desires (e.g., Balcetis & Dunning, 2010; Stokes, 2012), morality (e.g., Gantman & van Bavel, 2014) and emotions (e.g., Stefanucci & Proffitt, 2009) can literally change what is perceived. Such effects would indicate *cognitive penetrability* – the notion that what we perceive can be directly altered, top-down, by cognitive states. This, in turn, would challenge the claim that perception is *cognitively impenetrable* (Pylyshyn, 1999; Firestone & Scholl, 2015). If cognition was found to be penetrable by cognitive factors then our current understanding of perception would need a drastic overhaul (Firestone, 2013; Firestone & Scholl, 2015) so this is an important issue to address.

What kinds of effects count as examples of cognitive penetrability has also been debated (Firestone & Scholl, 2015; Stokes, 2012; Witt, 2017). Since it is difficult to convincingly state whether an effect demonstrates cognitive penetrability, Firestone and Scholl (2015) proposed that, instead, we should consider what does *not* constitute cognitive penetrability. They outlined six *pitfalls* which, they claimed, explained nearly all apparent examples of cognitive penetrability. They argued that if an effect could be explained by one or more of these pitfalls then it should not be considered to provide evidence for cognitive penetrability in its strongest sense. The pitfalls are:

1. Only confirmatory predictions were tested; no attempt was made to produce disconfirmatory evidence.

2. Post-perceptual judgements were measured, rather than online perception.

3. Effects could be explained by experimental demand and response bias.

4. Effects could be explained by variation in low level perceptual features.

5. Effects could be caused by changes in the focus of attention.

6. Effects could be due to changes in memory and recognition.

**The action-specific account of perception**

An increasing body of evidence has been claimed to support the hypothesis that what we see is scaled according to the action capabilities of our body. Proffitt and Linkenauger (2013) argued that this scaling may relate to variation in energetic expenditure and effort, as well as differences in performance success. Examples relating to energy expenditure and effort include the findings that hills were estimated as steeper when observers were fatigued or wore a heavy backpack (Bhalla & Proffitt, 1999; Proffitt, Bhalla, Gossweiler and Midgett, 1995), and after participants consumed a sugar-free compared to a sugary beverage (Schnall, Zadra & Proffitt, 2010). In addition, underwater targets were estimated as closer when people wore flippers which made swimming easier (Witt, Schuck & Taylor, 2011). Examples resulting from differences in performance ability include the findings that putting holes and softballs were estimated as larger (Witt et al., 2008; Witt & Proffitt, 2005) and tennis balls were estimated as slower (Witt & Sugovic, 2010) by more successful players of the relevant sport.

It has also been suggested that what we see may scale according to the functional morphology of our body (Linkenauger, Ramenzoni & Proffitt, 2010; Linkenauger, Witt & Proffitt, 2011; Proffitt & Linkenauger, 2013). For example, observers estimated targets to be nearer after reaching to them with a tool which increased their maximum reach and hence made the targets reachable (Witt, Proffitt & Epstein, 2005). Also, door-like apertures were estimated as narrower when observers held a horizontal rod that was wider than their body (Stefanucci & Geuss, 2009). In a final example that we will consider in depth in the present paper, Linkenauger, Witt and Proffitt (2011, Experiment 2) reported that right handers underestimated the size of objects they intended to grasp with their right hand relative to objects they intended to grasp with their left hand. Right handers perceive their right hand as larger than their left hand, and they also believe that it can grasp larger objects (Collier & Lawson, 2017a; Linkenauger, Witt, Bakdash, Stefanucci & Proffitt, 2009; Linkenauger, Witt & Proffitt, 2011). Based on this finding, Linkenauger, Witt and Proffitt (2011, Experiment 2) argued that the bias in size estimates that they found occurred because objects appeared more graspable, and therefore smaller, when observers intended to grasp them with their right hand.

**The action-specific account: truly a challenge to cognitive impenetrability?**

As discussed by Firestone and Scholl (2015), the question of what constitutes a cognitive process is not straightforward to answer, making it difficult to determine whether action capacity should be considered truly cognitive in nature. Nevertheless, these authors suggested that action-specific effects do indeed challenge cognitive impenetrability. However, Witt (2017) argued that it is possible to accept that action-specific effects are truly perceptual without rejecting cognitive impenetrability because action-specific effects may not necessarily arise from cognitive processes. Witt (2017) also noted that Firestone and Scholl (2015) themselves rejected the strictest definition of cognitive impenetrability, which would entail that any influence on what is perceived visually by non-visual information constitutes cognitive penetrability. For example, Firestone and Scholl (2015) suggested that multimodal effects should not be considered examples of cognitive penetrability.

Witt (2017) claimed that if top-down, cognitive influences on perception are restricted to those involving explicit knowledge affecting the visual representation of the environment, then action-specific effects should not be considered a challenge to cognitive impenetrability because these effects could be based on motor processes (Sugovic, Turk & Witt, 2016; Witt, 2017). Similarly, Sugovic et al. (2016) suggested that "an effect based on unconscious physical abilities rather than on conscious beliefs would preserve the idea that spatial vision is cognitively impenetrable because what is known (or thought or believed) would not exert an influence on vision" (p. 1). Although it is not clear exactly what these *unconscious physical abilities* might refer to, it seems reasonable to interpret this as referring to feedback from kinaesthetic, proprioceptive or interoceptive cues which may unconsciously specify information about the current action capabilities of the body (see Witt & Riley, 2014, for a discussion about the possible role of other sensory cues in driving action-specific effects). On this interpretation, action-specific effects may not be considered to directly challenge cognitive impenetrability.

There is evidence for the reverse relation, namely that motor feedback from acting, such as kinaesthetic/proprioceptive cues, can affect perceived action capacity. For example, Franchak and colleagues have shown that we update and recalibrate our perceived action capacity through acting (Franchak, van der Zalm & Adolph, 2010; Franchak & Adolph, 2014). Franchak et al. (2010) showed that participants who had prior experience of walking through apertures were subsequently more accurate at estimating whether apertures were passable. They suggested that motor feedback from performing the relevant action made participants more aware of the fit between the spatial properties of their body and that of the apertures. Extending this, it is possible that action-specific effects may result from an interaction between motor information, which may specify action capacity[1], and vision. This, in turn, could mean that at least some action-specific effects may be compatible with cognitive impenetrability, since they are not necessarily driven by explicit knowledge or beliefs about the action capabilities of the body (Sugovic, et al., 2016; Witt, 2017; see also Witt & Riley, 2014).

However, critically, some action-specific effects are argued to result from observers' *beliefs* about their action capacity rather than from their actual action capacity. For example, Linkenauger, Witt and Proffitt (2011, Experiment 2) claimed that perceived object size was scaled according to the *perceived* grasping capacity of the left and right hands. Given that they reported no *actual* difference in the grasping capacity of the hands, the only available source of the scaling effect they reported, at least according to the action-specific account, was in participant's beliefs about their grasping capacity. This claim seems to challenge cognitive impenetrability by suggesting that the critical factor in producing the reported effect was the observer's beliefs about the action capacity of their body. The focus of this article is the reported influence of grasping capacity on perceived object size. Notwithstanding the debate as to whether action capacity itself is a cognitive factor (Firestone & Scholl, 2015) we believe that testing the claims of the action-specific account is relevant for investigating the issue of cognitive impenetrability.

**The present article: a response to Witt (2017)**

1. **The present article: a response to Witt (2017)**

Witt (2017) responded to Firestone and Scholl's (2015) challenge by identifying four action-specific scaling effects within the existing literature and arguing that each defied all six of their pitfalls. Here, we consider in detail one of the examples that she provided, namely that one's "ability to grasp an object affects perceived size" (p. 13). Before discussing the reasons why we believe that grasping capacity does not, in fact, directly influence estimates of object size, we will briefly address some broader concerns with the evidence in favour of this idea.

First, we believe that the way in which grasping capacity has been manipulated in studies supporting the action-specific account is problematic. Witt (2017) claimed that it is difficult to directly manipulate grasping capacity. We disagree. From our everyday experience, it is clear that it is more difficult to grasp objects when we have cold hands, or when we wear thick gloves. Furthermore, grasping capacity can be directly manipulated in a controlled way, for example by taping together participants' fingers. We have employed this simple, yet effective, manipulation in our own work (Collier & Lawson, 2017a, 2017b) and, in several of our experiments, we used it to reliably reduce both perceived and actual grasping capacity, by ~2-3cm and by ~1-2cm respectively.

Some of the methods used by proponents of the action-specific account to try to alter grasping capacity may be weak or unreliable. For example, Witt (2017) suggested that changing apparent hand size is a viable alternative to directly manipulating grasping capacity. However, as acknowledged by Linkenauger, Witt and Proffitt (2011, see also Linkenauger et al., 2013), changing visually perceived hand size risks inducing a size-contrast effect whereby objects may appear smaller when placed next to a larger hand than when placed next to a smaller hand due to visual relativity (Obonai, 1954). Any such size-contrast effect would mean that the scaling effect on perceived object size could be explained by Firestone and Scholl's (2015) fourth pitfall, namely variation in visual features. In contrast, the visual change in hand size following taping is minimal, and so the chances of inducing a size-contrast effect is also minimised. Other studies reporting evidence in support of the action-specific account action-specific account have taken advantage of the fact that right handers both perceive their right hand as larger than their left hand, and believe that it can grasp larger objects (e.g., Linkenauger, Witt & Proffitt, 2011). However, this effect of handedness on perceived grasping capacity is small and it does not necessarily influence actual grasping capacity (Collier & Lawson, 2017a; Linkenauger, Witt & Proffitt, 2011).

Second, there are concerns with the issue of replicability and reliability within the action-specific literature. Firestone (2013) noted that many of the frequently cited findings from the action-specific account have proven difficult to replicate (e.g., De Grave, Brenner & Smeets, 2011; Hutchison & Loomis, 2006; Woods, Philbeck & Danoff, 2009). Indeed, our investigation into the reported effect of grasping capacity on object size began when we (Collier & Lawson, 2017a) failed to replicate Linkenauger, Witt and Proffitt (2011, Experiment 2). Furthermore, the size of action-specific effects reported are sometimes inconsistent. For example, in Linkenauger et al. (2014) it was argued that the dominant (right) hand is less susceptible to visual changes in hand size, and the authors suggested that “the stability of perceived hand size suggests that the hand is a natural perceptual metric that is used to scale nearby graspable objects.” (p.7). However, perceived hand size was not constant across experiments. In Experiments 1, 2 and 4, participants always had their hand magnified by 18% but participants estimated that their hand was magnified by 26%, 3% and 19% respectively. Thus, even when the same researchers use the same experimental paradigm, the size of the effect is both variable and unrelated to the size of the manipulation (Firestone, 2013).

A further example of the poor replicability of the effects reported by the action-specific account comes from the evidence used by Witt (2017) to respond to Firestone and Scholl's (2015) first pitfall, namely testing disconfirmatory predictions. Witt (2017) argued that if an object is too big to be grasped, it would be nonsensical for its perceived size to scale according to grasping capacity. This provides a disconfirmatory prediction for the action-specific account: the apparent size of objects that are too big to be grasped should not alter following a change in grasping capacity. In support of this claim, Witt (2017) highlighted Linkenauger, Witt and Proffitt (2011, Experiments 2 & 3). They reported that, as expected, size estimates for objects that were perceived to be graspable seemed to scale according to perceived grasping capacity. However, objects that were too big to be grasped showed no such effect. In Collier and Lawson (2017a), we attempted to replicate the findings of Linkenauger, Witt and Proffitt (2011, Experiment 2). In that paper, our analysis focussed on the confirmatory prediction that only objects within perceived maximum grasp would show effects consistent with the action-specific account. However, we also tested some blocks that were too big to be grasped. In Figure 1 here, we provide the size estimates for all of the blocks that we tested in Experiment 3, along with the percentage of our right-handed participants who thought they could grasp each block size. The action-specific account predicts that size estimates for objects to be grasped by the right (rather than the left) hand would be smaller for right-handers, but only for blocks perceived to be small enough to be grasped. Instead, we found no clear scaling effects regardless of block graspability. Thus, the evidence provided by Witt (2017) regarding the first pitfall may not be reliable.

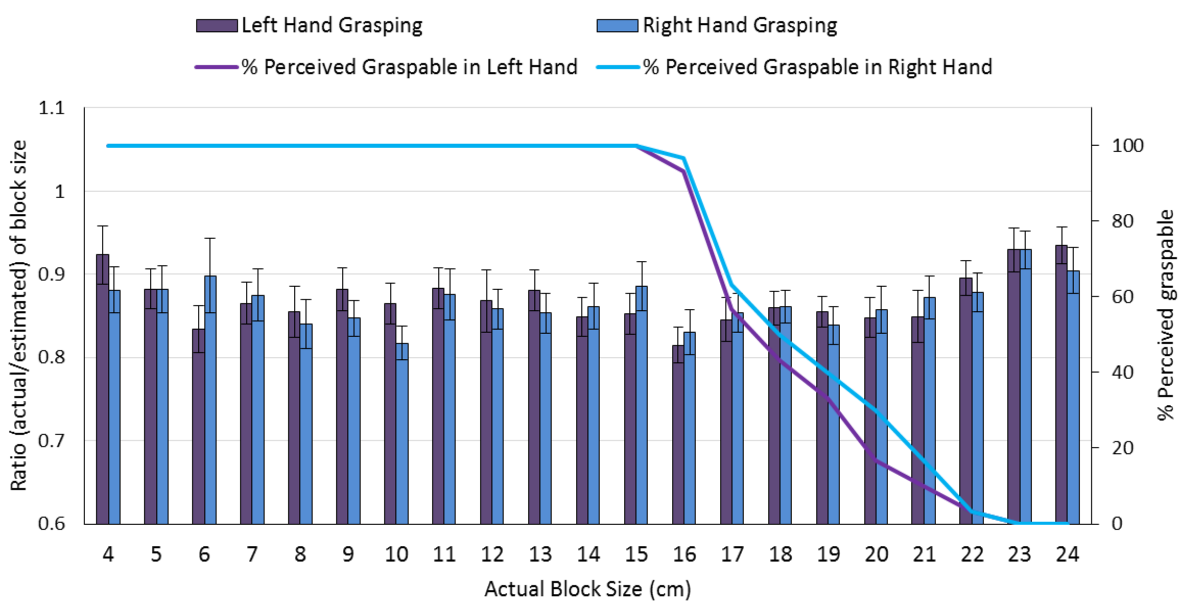



Figure 1: Data from Experiment 3 of Collier and Lawson (2017a), showing estimates of block size (estimated/actual, left axis) and % of participants who thought the blocks were graspable at each block size (right axis). Error bars show +/-one standard error of the mean.

In the following sections, we provide evidence and arguments as to why we believe that grasping capacity does not directly influence perceived object size. We explain in detail why we disagree with the arguments given by Witt (2017). To do so, we provide examples from our own work to illustrate how many studies claiming to show that grasping capacity directly affects perceived object size could have an alternative explanation because they fall into at least one of three out of the six possible pitfalls outlined by Firestone and Scholl (2015). Specifically, we suggest that the results of several studies could be explained by experimental demand and response bias (pitfall #3). We suggest that two further pitfalls, effects arising from offline judgement rather than online perception (pitfall #2) and low-level visual differences (pitfall #4), could account for other effects reported in the literature. We discussed pitfall #1 (disconfirmatory predictions) above, but we have not included it in the following sections as we have not directly tested the disconfirmatory claim that objects too large to grasp should not show scaling effects. We agree with Witt (2017) that studies investigating grasping capacity and perceived object size do not generally fall into Firestone and Scholl's (2015) pitfall #5 (attentional effects) or #6 (memory and recognition effects). On the basis of our own findings, we conclude by arguing that perceived grasping ability does not influence perception of object size. By extension, this portion of the literature does not provide support for the action-specific account.

### 7.3 Pitfall #2: Perception versus judgement

Firestone (2013) noted that in many experiments that have been used to support the action-specific account, it is not clear whether an effect has occurred at the level of perception (a literal change in what a person sees) or the level of judgement (an inference based on what they see). The use of indirect measures can be valuable in disentangling effects of perception from other effects. As an example of this approach, Witt (2017) cited a study where Linkenauger, Mohler and Proffitt (2011) found an effect consistent with the action-specific account using estimated weight to indirectly assess whether differences in hand size led to differences in perceived, as opposed to simply judged, object size.

However, the devil is in the detail when distinguishing perception from judgement, and this conclusion relied on a complex chain of assumptions. The predictions in Linkenauger, Mohler and Proffitt (2011) relied on a previous finding that, when participants wore magnifying goggles which globally enlarged the environment, they estimated objects as smaller when objects were seen next to their right hand (Linkenauger, Ramenzoni & Proffitt, 2010). Based on the size-weight illusion, where small objects are estimated as heavier than larger objects of equal weight (Buckingham, 2014), Linkenauger, Mohler and Proffitt (2011) predicted that objects would therefore also be estimated as heavier when seen near their right hand. Their participants used a pulley system to lift a reference object (a beanbag) and a test object (a basket). Right-handed participants verbally instructed the experimenter to add or remove weight from the basket to match the weight of the beanbag. Participants in the visible-hand condition placed their right hand next to the beanbag, and estimated the beanbags to be *heavier* than participants in the non-visible hand condition who kept their right hand out of sight. Hand size alone was not manipulated in this study, either across groups or on a trial-by-trial basis. Instead, all participants wore goggles that globally enlarged the whole environment.

Linkenauger, Mohler and Proffitt (2011) predicted that objects should be perceived as *smaller* when the right hand was present based on the following logic. In this study the magnifying goggles should have made all objects appear larger to all participants. However, according to the action-specific account, when the right hand was visible this should have directly indicated to the participant how large the beanbag was with respect to their hand's known grasping capabilities. This effect should have negated the influence of the magnifying goggles and so the beanbag should have been perceived as smaller to the visible-hand group than the non-visible-hand group. This, in turn, due to the size-weight illusion, should have made the beanbag feel heavier.

This was, indeed, what Linkenauger, Mohler and Proffitt (2011) reported. However, there is a simpler explanation of their effect. Participants who could see their right hand had a salient and familiar cue to object size. They could have used this as a reference to infer – in other words, judge – beanbag size, unlike participants who could not see their hand. Participants might not have had an accurate sense of the effect of the magnifying goggles unless they could see something of known size. If so, then placing a different, familiar object next to the beanbag (such as a glove) might have been just as effective here. Linkenauger, Mohler and Proffitt (2011) did not run this control.

Linkenauger, Mohler and Proffitt (2011) argued that their results could not have arisen from using a familiar object as a size reference based on the findings of Linkenauger et al. (2010). The results of Linkenauger et al. (2010) have rarely been discussed in detail in the literature, so we think it is worth doing so here. In Experiment 1 of Linkenauger et al. (2010), participants wore magnifying goggles which globally enlarged the environment. Participants verbally estimated the size of three familiar and three unfamiliar objects, once while keeping their hand out of sight and then again with their hand next to the objects. One group saw their right hand and the other group saw their left hand. Objects were estimated as smaller when the hand was present, and this effect was stronger for the group who saw their right hand. Experiment 2 repeated Experiment 1 except that minification goggles were used, and only the right hand was viewed. Minified objects were estimated as larger when the right hand was visible. Linkenauger et al. (2010) argued that these effects of hand visibility could not have been driven by familiarity with the size of one's own hand because otherwise reduced scaling effects should have been found for the familiar objects (because these were of known size so could, themselves, have been used as size references). However, all six of their objects were spheres and it is not clear that participants would have considered some to be familiar (e.g., a ping-pong ball) and others not (e.g., a styrofoam ball). Their argument that familiarity could not explain these effects would be more compelling had they measured it, for example, by having participants rate the familiarity of each object.

Familiarity effects are also relevant to the interpretation of Experiment 4 of Linkenauger et al. (2010). Here, participants estimated the size of the same six objects as in Experiment 1 except that, instead of their right hand, a pair of tongs was either present, or not, next to the objects. Before putting on the magnifying goggles, one group of participants gained experience at lifting and moving objects with the tongs (practice group) whilst a second group did not (no-practice group). The practice group subsequently estimated objects as smaller when the tongs were present than when they were not, whilst no effect was found for the no-practice group. Since tools are embodied after experience using them (e.g., Berti & Frassinetti, 2000), Linkenauger et al. (2010) interpreted this finding as showing that perceived object size was rescaled to tool size only after the tool was embodied. There is, though, once again, an alternative explanation for this finding. Before they made their size judgements, the practice group in Experiment 4 of Linkenauger et al. (2010) gained experience using the *exact pair of tongs* in the *same environment* that they were about to be tested with. Although the no-practice group had probably used kitchen tongs in their everyday lives, kitchen tongs come in different shapes and sizes and this group did not use the exact tongs that they would be tested with. Thus, in Experiment 4 only the practice group gained familiarity with the unmagnified size of the tongs before they made their size judgements. The different results for the two groups could, again, have been driven by the presence of a familiar reference of known size rather than by action-specific scaling.

In Linkenauger et al. (2010) familiarity with the participant's hand size or of tong size could explain the results of Experiments 1, 2 and 4 (and also Experiment 5 which repeated Experiment 1 but used a visual matching task instead of verbal report). In all of these experiments participants were familiar with the size of the comparator *before* they wore the goggles. However, Experiment 3 appears to provide evidence against this account of scaling effects being modulated by using references of known size. This experiment replicated Experiment 1 except that, when a hand was visible, it belonged to the experimenter rather than the participant. Unlike Experiment 1, estimates in Experiment 3 were not influenced by hand visibility. Results of both experiments are consistent with the action-specific account because scaling effects are only predicted to occur for actions of one’s own body. However, hands vary in shape and size and participants would probably have had little opportunity to see the unmagnified experimenter's hand before they were tested in Experiment 3. Thus, the experimenter’s hand would not have been as effective as that of the participant's hand in providing a reference of known size. This could explain why size estimates in Experiment 3 were not affected by hand visibility without relying on the action-specific account. Importantly, note too that we failed to replicate this finding from Experiment 3 of Linkenauger et al. (2010) in a recent, unpublished study that we report below (section 6.3) so the results of Experiment 3 may not be reliable.

Firestone (2013) suggested that the results of Linkenauger et al. (2010) could be accommodated by a modularist perspective but he did not specifically outline how. Here, we offer a new interpretation of these results which suggests that the reported effects can be explained without appealing to action capacity. We suggest that neither the results of Linkenauger et al. (2010) or of Linkenauger, Mohler and Proffitt (2011) rule out the possibility that judgements, and not perception, of object size are affected by the presence of the hand.

In summary, we do not believe that the use of estimated weight as an indirect measure for perceived size has provided convincing evidence in favour of the argument that grasping capacity influences perceived object size. This is because the scaling effects found in Linkenauger et al. (2010) and Linkenauger, Mohler and Proffitt (2011) could, instead, arise from providing a salient and familiar cue of known size (such as the participant's hand) which participants then use to anchor their object size estimates.

## 7.4 Pitfall #3: Demand and response bias

The action-specific account has recently been under pressure to demonstrate that effects consistent with it are not the result of experimental demand characteristics (e.g., Collier & Lawson, 2017a, 2017b; Durgin et al., 2009; Firestone, 2013; Firestone & Scholl, 2015, 2017). For example, Witt (2017) noted that Linkenauger Leyrer, Bülthoff and Mohler (2013) tested whether estimated object size would scale in ways predicted by the action-specific account if the size of another person's hand, as opposed to the participant's own hand, was manipulated. This is a good test for demand characteristics, since the action-specific account predicts that object size should only scale when the size of one's own hand is manipulated, and participants seem unlikely to guess this prediction (Linkenauger et al., 2010). Linkenauger et al. (2013, Experiment 1) used virtual reality to manipulate the apparent size of the participant's hand. Objects were estimated as smaller when placed next to a large compared to a small hand and vice versa when placed next to a large hand. However, no effect was found when either a virtual avatar's hand size was manipulated (Experiment 2) or when the size of a familiar object was manipulated (Experiment 3). Witt (2017) claims this as evidence that the results of Experiment 1 were not driven by experimental demand.

However, this does not mean that the results of Experiment 1 can only be explained by the action-specific account. The results of Linkenauger et al. (2013) can be interpreted in a different way. For instance, in Experiment 3, participants saw both a virtual, familiar object (a pen) and their own hand. The pen changed size on each trial while the participant's hand remained constant. Here, participants may simply have preferred to use their own hand as an anchor for size estimates because it was more stable and more familiar than the pen. A control condition where the participants' hand was removed entirely from sight and the size of a familiar object was manipulated could address this concern. Without this control, Linkenauger et al. (2013) cannot rule out the possibility that the hand provided a convenient anchor, from which the size of other objects could be inferred, when other objects that could have been used as an anchor were less reliable, less salient and/or less familiar.

In our own work, we have shown that at least some studies claiming to show an influence of grasping capacity on perceived object size can be explained by experimental demand and response bias. After we (Collier & Lawson, 2017a) failed to replicate Linkenauger, Witt and Proffitt (2011, Experiment 2), we sought to understand why. We (Collier & Lawson, 2017b) tested whether a critical difference between their study and ours was that, on every trial in Linkenauger, Witt and Proffitt (2011, Experiment 2), participants were first asked whether they thought they would be able to grasp the block placed in front of them before estimating its size. We reasoned that the dimensions of graspable-to-ungraspable and small-to-large could be conceptually linked or conflated (e.g., Walker, 2012). We therefore hypothesised that judging graspability immediately before estimating size on every trial could have led to size estimates being biased by the immediately preceding graspability judgements in Linkenauger, Witt and Proffitt (2011, Experiment 2). This conflation could have led to graspable blocks being estimated as smaller. To test this, on each trial we, too, asked participants to rate the difficulty of grasping a block before estimating its size. In contrast to the null results that we reported in Collier and Lawson (2017a), where such context or conflation effects were controlled for, now, in Collier and Lawson (2017b), participants estimated objects they grasped in their taped hand as larger than objects they grasped in their untaped hand. This suggests that the scaling effect reported by Linkenauger, Witt and Proffitt (2011, Experiment 2) likely reflected a response bias arising from asking participants about two conceptually linked dimensions in quick succession. If so, then the scaling effect was not a true perceptual change.

In a different experiment, we used a cover story to try to reduce the experimental demand involved with grasping in this size estimation task (Collier & Lawson, 2017a, Experiment 5). The inspiration for this manipulation came from previous studies showing that action-specific effects are often not found when experimental demand is minimised by using a cover story (e.g., Durgin et al., 2009; Firestone & Scholl, 2014). Here, we asked participants to visually match the size of blocks they had just grasped with their left hand, their right hand and after the fingers of one of their hands were taped together. To ensure that participants intended to act, and knew that we were interested in their grasping behaviour, we told them repeatedly and explicitly that we were recording whether they could grasp the blocks. In addition, on each trial, they had to grasp the block both before and after estimating its size. Critically, though, to control for demand characteristics associated with doing these two tasks on the same trial, we also told them a cover story that the grasping task and the size estimation task were providing data for separate studies, and that they were only doing both tasks together because of time constraints. Perceived action capacity changed as expected: our right-handed participants believed that they could grasp bigger objects in their right hand than their left hand, and bigger objects in their untaped hand than their taped hand. However, crucially, we found no differences in their estimates of object size depending on which hand they intended to grasp the block with, and whether that hand was taped. If the influence of grasping capacity was truly perceptual, our cover story manipulation should not have worked and, according to the action-specific account, objects should have been estimated as larger for the left hand and larger still for the taped hand. These results demonstrate that scaling effects in object grasping studies can be eliminated when experimental task demands are minimised.

## 7.5 Pitfall #4: Visual differences

Many studies investigating the influence of grasping capacity on estimates of object size manipulate apparent grasping capacity by changing the visually perceived size of the hand (e.g., Linkenauger, Witt & Proffitt, 2011, Experiment 3; Linkenauger et al., 2013). Witt (2017) acknowledges the possibility that the effects obtained in such studies could be caused by visual differences between conditions because “visual differences in hand size are key to obtaining these effects” (p. 15). Manipulations such as taping, which alter participants’ grasping capacity with little effect on hand size, should help to rule out explanations in terms of visual differences because they largely avoid this fourth pitfall. However, when we have used a taping manipulation, we have found no influence of grasping capacity on estimated object size when we have controlled for conflation (Collier & Lawson, 2017a, 2017b). This means that it is possible that visual differences could account for at least some of the scaling effects reported in other studies which manipulated hand size using magnification and minification in order to vary grasping capacity (e.g., Linkenauger, Witt & Proffitt, 2011; Linkenauger et al., 2013).

For example, in Linkenauger, Witt and Proffitt (2011, Experiment 3), participants estimated the grasping capacity of their dominant hand while it was, and was not, magnified and they also estimated the size of objects placed near their hand. Objects were estimated as smaller when placed near to the magnified hand. Linkenauger, Witt and Proffitt (2011, Experiment 3) claimed that this demonstrated a scaling of object size by perceived grasping capacity. They discussed, but ultimately rejected, the explanation that visual differences, in the form of size-contrast effects, could explain their result because they found that only objects that were perceived as graspable showed the predicted scaling effect. They claimed that a size-contrast explanation would produce contrast effects across all stimulus sizes, regardless of perceived graspability.

Linkenauger et al. (2013) also tested whether size-contrast effects could explain their finding, in their first experiment, that objects were estimated as smaller when participants' hands were enlarged using virtual reality. In their second experiment they manipulated the size of the hands of a virtual avatar and found no effect on estimated object size. Thus, the combined results of Linkenauger, Witt and Proffitt (2011, Experiment 3) and Linkenauger et al. (2013, Experiments 1 and 2) seem to suggest that size-contrast effects cannot explain action-specific scaling effects.

However, this may not be the case. For example, in a recent study, we used the same magnification manipulation as Linkenauger, Witt and Proffitt (2011, Experiment 3). We tested four groups of 16 participants. The first group decided whether their right hand could grasp a block that was placed next to it and then they visually matched the size of the block. A second group did the same two tasks but a fake, plastic right hand replaced their own right hand and they were asked if it could grasp the block if it could move. A third and fourth group were matched to these two groups, but they only did the size matching task. All groups made estimates while the visible hand, whether their own or fake, was both magnified and unmagnified (in separate subblocks with a counterbalanced order). We tested whether, as predicted by the action-specific account (Linkenauger, Witt & Proffitt, 2011; Linkenauger et al., 2013), scaling effects would occur only for the first, OwnHand-GraspabilityThenSize group since only here did participants both make estimates when their own hand was visible (rather than a fake hand) and intend to act on the block (as they were asked about grasping it). Contrary to these predictions, we instead found that blocks were estimated to be smaller when they were seen next to a magnified (compared to an unmagnified) hand in all four groups, see Figure 2.

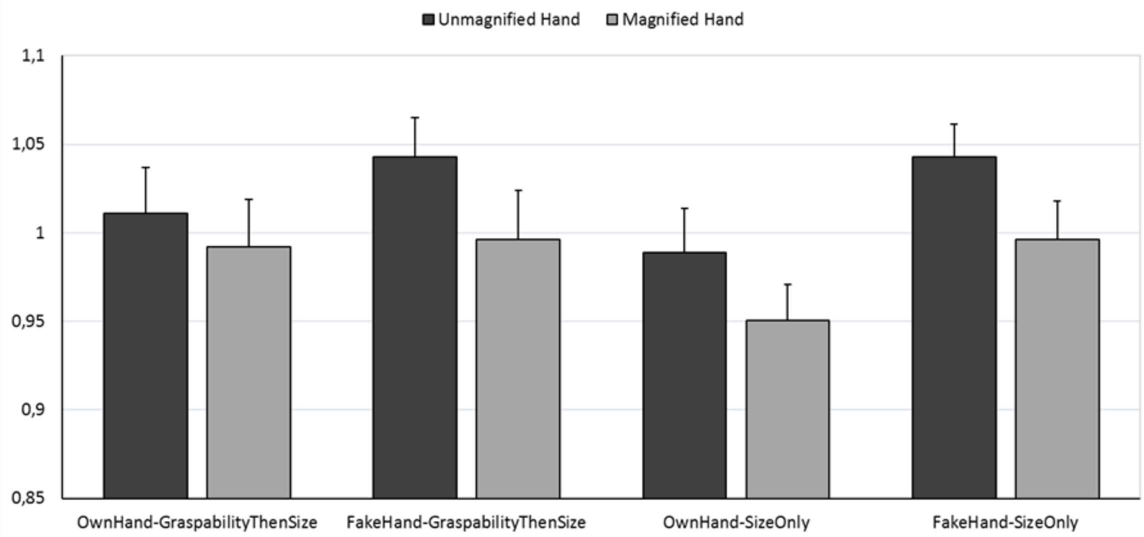



*Figure 2*: Mean ratio (estimated/actual) of block size for the unmagnified and magnified hands in each of the four groups. A ratio of 1 represents perfect accuracy. Error bars show one standard error of the mean.

## 7.6 General Discussion

Firestone and Scholl (2015) outlined six pitfalls which, they claimed, can explain nearly all effects which claim to demonstrate a direct, top-down influence of cognition on perception. They argued that if an effect falls into just one of these pitfalls, it should not be considered a true demonstration of cognitive penetrability. An important test of this approach are the results used to support the action-specific account, which claims that what we perceive is scaled according to our action capacity (Proffitt & Linkenauger, 2013; Witt, 2011, 2017).

Witt (2017) responded to Firestone and Scholl (2015) by claiming that at least four action-specific effects withstand all six of their pitfalls. One of the four effects that Witt (2017) discussed in detail was the influence of apparent grasping capacity on perceived object size. In this article we have challenged Witt's claim with respect to this effect. We argued that grasping capacity (whether actual or perceived) does not directly influence perceived object size. To this end, we critically examined the claims Witt (2017) made, and we provided new interpretations of previous results claiming to support the action-specific account. We noted that many of the studies cited by Witt (2017) did not directly manipulate grasping capacity but, instead, altered perceived hand size using, for example, handedness effects, magnification or virtual reality. We also noted that many action-specific effects, including the purported effect of grasping capacity on estimates of object size, have been difficult to replicate. Then we provided empirical evidence from our own work which suggests that studies claiming to demonstrate this effect in fact appear to fall prey to at least one, and possibly several, of the pitfalls outlined by Firestone and Scholl (2015). To summarise our findings across several experiments:

1. We failed to replicate the finding that the greater perceived grasping capacity of the right compared to the left hand for right-handers increases estimates of the size of objects that are intended to be grasped by the right hand (Collier & Lawson, 2017a, Experiments 2 & 3).
2. We found no effect of directly manipulating perceived grasping capacity, by taping together the fingers of a hand, on estimates of the size of objects to be grasped by the taped hand (Collier & Lawson, 2017a, Experiments 4 & 5; 2017b).
3. We only found scaling effects consistent with the action-specific account under restricted, non-ecological circumstances, namely when estimates of perceived object size could be conflated with perceived action capacity because participants were asked to estimate their ability to grasp an object immediately before being asked to estimate its size (Collier & Lawson, 2017b).

4. We found that using a convincing cover story to minimise experimental demand characteristics and conflation effects eliminated the effect of grasping capacity on estimates of object size (Collier & Lawson, 2017a, Experiment 5).
5. We found that visual differences resulting from, for example, magnification, could explain the apparent influence of grasping capacity on estimates of object size (new data reported in this paper; see also supplementary materials).

In conclusion, many studies claiming to show an effect of grasping capacity on perceived object size fall into at least one of the pitfalls outlined by Firestone and Scholl (2015). Furthermore, the results from our own studies do not suggest that grasping capacity influences perceived object size. We argue that the scaling effects that have been reported in this case need not be interpreted as revealing a true perceptual change caused by altering action capacity and therefore that these effects do not challenge cognitive impenetrability.

## 7.7 Footnotes: Chapter 7

[1] However, there is some evidence against this alternative account. For example, in our studies (Collier & Lawson, 2017a, 2017b; see also Collier & Lawson, 2018) we taped together the fingers of one hand, restricting both actual and perceived grasping capacity. Since participants actually acted in our experiments, they received motor feedback about the restricted grasping capacity of their taped hand relative to their untaped hand. If action-specific effects were driven by such motor feedback, we should have found effects consistent with the action-specific account in our experiments. However, we found no indication that changes in either actual or perceived grasping capacity influenced estimates of object size. Thus, for this action-specific effect we found no evidence that it was driven by motor processes.

# Chapter Eight

## 8. General Discussion and conclusion

This final section offers a summary of the empirical work presented, a general discussion of the results and the concluding message of this thesis.

### 8.1 Summary of the findings of this thesis

According to the action-specific account of perception, action capacity directly affects visual perception. Collectively, the empirical work undertaken in this thesis demonstrates that there are at least four concerns with this claim. These concerns challenge the idea that visual perception is directly influenced by variations in action capacity. They are listed here, and discussed in detail below:

Poor replicability: it is difficult to replicate effects previously reported as consistent with the action-specific account

Poor predictive power: changes in functional morphology reliably affected perceived action capacity, but this did not modulate visual size estimates in the ways predicted by the action-specific account.

Visual differences: changing the visual properties of the body can lead to changes in visual estimates of the size of nearby objects without appealing to action capacity

Judgement, not perception: when we did find effects consistent with the action-specific account, these could be explained as changes in post-perceptual judgement rather than online perception.

## Poor replicability

Although replicability is a concern across many domains within psychology (Open Science Collaboration, 2015), Firestone (2013) noted that many frequently cited and prominent findings from the action-specific literature have proven difficult to replicate (e.g., de Grave et al., 2011; Hutchison & Loomis, 2006; Woods et al., 2009). In Chapter 2 (Experiments 2 & 3), we failed to replicate Linkenauger, Witt and Proffitt (2011, Experiment 2) who claimed that apparent grasping capacity influences perceived object size. Although we replicated the finding that right handers believe that their right hand is larger than and can grasp larger objects than their left hand, this did not modulate estimates of the size of objects grasped in the left and right hand. This difficulty in replicating effects is problematic, as it casts doubt on the reliability and strength of the original effect (Firestone, 2013).

## Poor predictive power

Firestone and Scholl (2014, 2015) argued that the action-specific account has relied on an overly confirmatory research strategy. Specifically, researchers often predict the presence of, and then find some effect. However, a theory with strong predictive power should also be able to predict the absence of an effect. A disconfirmatory prediction from the action-specific account is that action-specific scaling effects should be found if, and only if, people intend to act (Witt et al., 2005). We used this disconfirmatory prediction to test the predictive strength of the action-specific account. In Chapter 5 (Experiment 1), participants wore asymmetrical gloves which made one hand wider relative to the other. They then visually matched the width of apertures on a laptop screen. One group were asked on each trial if they thought they could fit their hand through the aperture (Intention-to-Act group) and a second group simply performed the visual matching task (No-Intention group). Both groups showed the expected effect: apertures were estimated as narrower for the wider hand. Then in Chapter 5 (Experiment 2), we provided a cover story for why participants were asked to place their hand next to the aperture while estimating aperture width. To ensure they still intended to act, we asked them, on every trial, to imagine moving their hand through the aperture. Here we found no effect. Therefore, we found effects consistent with the action-specific account when no effect was predicted (when participant did not intend to act) and failed to find such effects when the account called for them to occur (when participants did intend to act). This suggests that intention to act is not critical for obtaining effects consistent with the action-specific account, and therefore the account lacks predictive power.

A second example of the poor predictive power of the action-specific account highlighted by the work in this thesis is that our novel taping manipulation, used to directly alter grasping capacity, did not influence estimates of object size. Having failed to replicate Linkenauger, Witt and Proffitt (2011, Experiment 2) in Chapter 2 (Experiments 2 & 3), we introduced a stronger manipulation, namely taping together the fingers of one hand. The action-specific account predicts that objects grasped in taped hands should be estimated as larger than the same objects grasped in untaped hands. This is because it is harder to grasp objects in taped hands. Our taping manipulation reduced both perceived and actual grasping capacity, however we, again, found no effect of grasping capacity on estimates of object size (Chapter 2, Experiments 4 & 5). A final example showing that the action-specific account lacks predictive power from the work in this thesis is that hunger did not affect size estimates of food products. Based on the action-specific account, hungry people who believe they could eat a lot of food might estimate food products as smaller in order to facilitate eating more. In Chapter 7, participants were split into either the Hungry or Not-Hungry group. The Hungry group were always tested in the morning and were asked to skip breakfast. The Not-Hungry group were asked to eat a meal at least an hour before coming to the lab. All participants then completed an object size estimation task where they verbally estimated the height and width of food and non-food products. Although the Hungry group reported feeling significantly hungrier than, and believed that they could eat more food than, the Not-Hungry group, there was no difference in their estimates of the size of food objects. We therefore found no evidence that being hungry influenced size estimates of food products. Both of these examples demonstrate that the action-specific account lacks predictive power, since we found no evidence that these manipulations, based closely on the claims of the account, produced effects consistent with the account.

**Visual differences**

Witt (2017) acknowledged that changing visual hand size in studies investigating whether grasping capacity influences estimates of object size could be problematic. For instance, changing the size of the hand could alter estimates of the size of nearby objects through size-contrast effects. We investigated this in Chapter 4. Linkenauger, Witt and Proffitt (2011, Experiment 3) reported that participants estimated objects seen near to their hand as smaller while their hand was magnified than while it was not. However, this effect was only reported for objects which were perceived as graspable – there was no effect for objects beyond grasp. Linkenauger, Witt and Proffitt (2011, Experiment 3) claimed this was evidence against a size-contrast explanation, as this does not predict a difference between graspable and ungraspable objects. However, we replicated Linkenauger, Witt and Proffitt (2011, Experiment 3) both when participants viewed their own hand, and when they viewed a fake, plastic hand. Since the fake hand had no ability to grasp the objects, this effect could not be driven by perceived grasping capacity. This suggests that the original effect can be explained by visual differences induced by magnification. Specifically, their result can be explained by size-contrast effects.

**Judgement not perception**

Firestone (2013; Firestone & Scholl, 2015) emphasised the importance of disentangling post-perceptual *judgements* from online *perception*. This is not always simple, since it is not possible to measure perception directly (Witt, 2017) and some visual properties can be both perceived and judged, e.g., colour (Firestone & Scholl, 2015). Several methods have been employed to tease judgement and perception apart, for example the use of highly specific instructions (e.g., Woods et al., 2009), and the use of a cover story (Collier & Lawson, 2017a, Experiment 5; Durgin et al., 2009, 2012).

In this thesis, both of these techniques were employed to demonstrate that the results of Linkenauger, Witt and Proffitt (2011, Experiment 2) could be explained as changes in judgement, rather than online perception. First, in Chapter 2 (Experiment 5), we used a cover story. Since there were a number of methodological differences between Experiments 2-4 in Chapter 2 and Linkenauger, Witt and Proffitt (2011, Experiment 2), we ran a fifth study which was more similar in design to the original experiment. In order to ensure that participants intended to act, we told them repeatedly that we were recording whether or not they could grasp the blocks and that on each trial they would have to grasp the blocks both before and after estimating block size. Critically, we also provided a cover story where we told participants that the grasping task and the size estimation task were providing data for separate studies, but that they were doing both tasks together because of time constraints. This meant that spatial estimates of size were made in a context where participants intended to act, but which did not explicitly draw their attention to grasping capacity. We found that right handers believed that they could grasp bigger objects in their right hand than their left hand, and bigger objects in their untaped hand than their taped hand, so perceived action capacity differed as expected across the conditions. However, we found no differences in their estimates of object size depending on which hand they intended to grasp the block with, or whether that hand was taped. We suggested that when participants make spatial estimates in a context which does not draw attention to grasping capacity, effects consistent with the action-specific account are not obtained.

To test this possibility, in Chapter 3 we tested whether estimates of object size were sensitive to the context in which those estimates were made. Again, participants had the fingers of one hand taped together and grasped and estimated the size of objects for both their taped and untaped hands. When participants were explicitly told that we expected them to estimate objects they grasped in their taped hand as larger than objects they grasped in their untaped hand, they conformed to the experimental demand and the predicted effect was obtained (Chapter 3, Experiment 2). Critically, we also found the predicted effect of taping when, as in Linkenauger, Witt and Proffitt (2011), participants estimated both the graspability and size of objects on the same trial (Chapter 3, Experiment 3). This supported our suggestion that whether or not grasping capacity affects estimates of object size is dependent on the experimental context. In other words, if it appears that grasping capacity is relevant for estimating object size, then participants' estimates of object size are biased by their judgements of graspability. This is incompatible with the action-specific account as it suggests that the effect occurs at the level of judgement, rather than perception (Firestone, 2013).

Thus, the collective results of Chapters 2 and 3 support the idea that effects consistent with the action-specific effect can be explained by whether or not action capacity seems relevant while completing a spatial task. This is consistent with the notion that action-specific-type scaling effects obtained under this condition arise from changes in judgement, rather than perception. It has recently been argued by proponents of the action-specific account that attempts to distinguish between judgement and perception are fruitless (Schnall, 2017). Specifically, Schnall (2017) appealed to the argument that observers often infer their feelings from several environmental cues but that once they are made aware of the true underlying sources and reasons for feeling a certain way, their responses change accordingly (Schachter & Singer, 1962). For example, in one study, participants evaluated themselves as having greater overall quality of life on warm and sunny days than on cold and rainy days. However, this effect disappeared when their feelings about the weather were made salient (Schwarz & Clore, 1983). In contrast, their evaluation of their current mood remained unaffected by being reminded about the weather. Schnall (2017) argued:

> "Stated differently, participants' subjective feelings remained the same, what changed was the relevance of these feelings to the judgement" (p. 332).

She argued that the same process occurs when vision researchers apply methods such as specific instructions and cover stories to tease apart judgement and perception: if action capacity is seemingly no longer relevant for a spatial judgement, then it should not be expected to influence that spatial judgement. However, this seems to undermine the central claim of the action-specific account, and instead suggests that such effects are simply changes in post-perceptual judgement after all! The results of Chapters 2, 3 and 5 are entirely consistent with Schnall's (2017) suggestion. In fact, one can summarise the take-home message of Chapters 2 and 3 by changing only a couple of words in Schnall's argument: *participants' perceptions of object size remained the same, what changed was the relevance of their grasping capacity to the judgement.*

## 8.2 General discussion

The empirical work presented in this thesis highlights several concerns with the action-specific account and suggests that action capacity does not directly affect visual spatial perception. It is important, however, to emphasise that we do not wish to suggest that we believe that action and perception are not intimately linked. Instead, the results of the work in this thesis suggest that they are not linked in the way claimed by the action-specific account. There is strong evidence that perception influences our action choices. For example, van Doorn et al. (2007) presented participants with aluminium rods of varying length that had either inward or outward facing arrows at each end (the Müller-Lyer illusion). Van Doorn et al. (2007) found the expected effect that rods with outward facing arrows at each end were perceived as longer than rods with inward facing arrows (Coren & Girgus, 1979). In addition, they found that participants switched from using a one- or two-handed grasp earlier when rods with outward facing arrows were presented. Although a demonstration that perception influences action choices, this does not suggest that action capacity affects the visual representation of the environment.

Furthermore, many researchers who are critical of the action-specific account do not deny that cognitive factors affect *action choices*. For example, Firestone and Scholl (2015) wrote: “Our object-directed actions can and do incorporate what we think, know, and judge” (p. 59), and Durgin (2017) suggested: “Energetic considerations must affect choices, but they probably contribute directly rather than by affecting the perception of spatial layout” (p. 344). In a similar vein, the results of the current thesis do not imply that spatial perception does not affect action choices or perceived action capacity. Indeed, we consistently found that manipulating the functional morphology of the body influenced participants’ perceptions of their own action capacity. Rather, our results contribute to a growing literature which suggest that the reverse relation – that perceived action capacity affects spatial perception – does not withstand empirical scrutiny (de Grave et al., 2011; Durgin et al., 2009, 2012; Firestone, 2013; Firestone & Scholl, 2014, 2015; Woods et al., 2009).

## 8.3 Limitations

The work presented in this thesis identified several weaknesses in the action-specific model of perception, however we do not intend to claim that the entire account is incorrect. The majority of the work here focussed on claims that the functional morphology of the body affects visual spatial perception. Thus, we have not tackled action-specific effects pertaining to energetic expenditure or performance variability (Proffitt & Linkenauger, 2013). In addition, there remain several unresolved issues within the action-specific literature that should be addressed in future work. We did not directly tackle these questions in the work presented here, but some are outlined below.

**Intention to act and cognitive impenetrability**

As discussed throughout this thesis, some action-specific scaling effects have been argued to be driven by *intention to act* (Witt et al., 2005). For example, Witt et al. (2005) found that participants estimated the distance to unreachable targets as shorter after reaching to those targets with a tool which increased their maximum reach, and made the targets reachable. However, they only found this effect for participants who actually reached with the tool. No effect was found for participants who held, but never reached with, the tool. This was interpreted as showing that intention to act is critical to producing action-specific scaling effects (Witt et al., 2005). The importance of intention to act has been emphasised in many subsequent studies showing action-specific scaling effects (e.g., Lessard et al., 2009; Linkenguer, Witt & Proffitt., 2011; Linkenauger, Bülthoff &

Mohler, 2015). Firestone and Scholl (2015) claimed that intention is cognitive, and so if intention can directly produce changes in what is perceived then this would challenge cognitive impenetrability.

Recently, however, Witt (2017) argued that the action-specific account does not claim that intention affects perception directly and so Firestone and Scholl's (2015) argument is flawed. She argued that rather than directly influence was is perceived, intention can "change the information that is processed by perception" (p. 19). Interestingly, it has been shown that participants' gaze patterns are different depending on whether the task at hand pertains to spatial perception or to action. For example, van Doorn et al. (2009) used the Müller-Lyer illusion to investigate differences in gaze patterns when participants considered whether to use a one- or two-handed grasp to pick up a rod, and a perceptual size estimation task where they estimated the length of a rod by separating their thumb and index finger. They found that the perceptual size estimations of rod length were affected by the arrowheads that surrounded the rod, but grip aperture when reaching to grasp the same rods was not affected by the arrowheads. Van Doorn et al. (2009) also found that gaze fixations during the perceptual task were concentrated towards both ends of the rods, while fixations during the grasping task were concentrated towards one end of the rod and the centre of the line. This suggests that when participants viewed the rods while intending to grasp them, the visual information they used to decide which grasp to use was different from the information used to estimate its size. However, as discussed by Firestone and Scholl (2015), changing the visual input should not be considered evidence of a true top-down influence on perception. In short, how intention to act fits both in the action-specific literature itself and in the wider argument concerning cognitive impenetrability is, currently, not fully understood. The work presented in Chapter 5 of this thesis suggests that intention to act is not critical for obtaining effects consistent with the action-specific account, however further work is required to resolve this issue.

**Individual differences**

Schnall (2017) claimed that critics of the action-specific account have failed to explain effects consistent with the action-specific account that appear to occur according to individual differences in action capacity. For example, Stefanucci and Geuss (2009, Experiment 1) found that participants with wider shoulders estimated apertures that they imagined walking through as narrower than participants with narrower shoulders. We suggest there are two possible explanations for the results of Stefanucci and Geuss (2009, Experiment 1). The first is misattribution effects. As discussed in Section 1.1., it is possible that whenever participants are asked to report on some spatial property, they may misinterpret the question as an estimate concerning their action capacity. In this instance, some participants may have responded to the question "how difficult would it be to walk through this aperture" rather than "what is the physical width of this aperture?" A second, and in our opinion, more likely possibility is that the effect can be explained by context effects. In Stefanucci and Geuss (2009, Experiment 1), participants were asked to imagine walking through the apertures while making their width estimates. As we showed in Chapter 2 (Experiment 3), effects consistent with the action-specific account can occur when the experimental context implies that action and perception are linked in a meaningful way. In this case, participants with wider shoulders may have given narrower estimates of aperture width than participants with narrower shoulders, without there being any true difference in the underlying visual representation. Thus, the effect could have been a difference in judgement, rather than perception. However, in the experiments presented in this thesis, we did not explicitly test for whether individual differences in action capacity affected estimates of spatial properties. Future work investigating whether context effects can influence spatial estimates in experiments investigating individual differences in the same way as in experiments with a clear manipulation of action capacity would be fruitful.

## 8.4 Conclusion

In conclusion, the action-specific account of perception (Proffitt, 2006a, 2006b, 2008; Proffitt & Linkenauger, 2013; Witt, 2011a, 2016) suggests that we see the world as scaled according to our action capacity. According to the action-specific account, the body provides *perceptual rulers* by which angular visual information is scaled. Different rulers are used in different contexts, depending on the perceiver's goals. For example, for walking across a field or ascending a hill, the relevant ruler is the caloric (energetic) cost of walking, and for grasping objects the relevant ruler is grasping capacity (Proffitt & Linkenauger, 2013). However, many theoretical (e.g., Durgin, 2017; Firestone, 2013) and methodological (e.g., Collier & Lawson, 2017a, 2017b; Durgin et al., 2009, 2012; Firestone & Scholl, 2014, 2015) concerns have been raised with this account. The aim of this thesis was to investigate whether action capacity directly influences visual perception, as suggested by the action-specific account. The work presented in this thesis provides evidence against the action-specific account of perception, and suggests that variations in action capacity do not directly affect visual spatial perception

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# Notes

This thesis is dedicated to my beloved grandparents Peter and Christine Reynolds.

Special thanks go to my mother, Samantha Reynolds, and my grandmother, Wendy Pickering, both of whom have loved, respected and supported me through all my endeavours. Special thanks also go to my supervisor Rebecca Lawson, whose guidance and insight has inspired and motivated me throughout this project. I also wish to give special thanks to Victor Hörlin, who has brought such happiness into my life. Finally, I would like to thank Stefano Cecchetto, Alexis Makin, Mike Jecks, and all my other friends and colleagues at University of Liverpool who have supported me, and laughed with me, over the past few years.

The empirical work in this thesis was funded by a grant from the Economic and Social Research Council [ES/J500094] to Elizabeth Sarah Collier. The research reported in this thesis was conducted in the Perception Lab at the School of Psychology of the University of Liverpool (UK). Some of the work presented in this thesis has been accepted or submitted for publication, and/or has been presented at international conferences.

*Chapter 2 has been published as:*

Collier, E. S., & Lawson, R. (2017). It's out of my hands! Grasping capacity may not influence estimated object size. *Journal of Experimental Psychology: Human Perception and Performance, 43*(3), 749-769.

*Chapter 3 has been published as:*

Collier, E. S., & Lawson, R. (2017). Does grasping capacity influence object size estimates? It's a matter of context. *Attention, Perception & Psychophysics, 79*(7), 2117-2131.

*Chapter 5 has been accepted for publication as:*

Collier, E. S., & Lawson, R. (in press). Trapped in a tight spot: scaling effects occur when, according to the action-specific account, they should not, and fail to occur when they should. *Attention, Perception & Psychophysics.*

*Chapter 7 has been submitted for publication as:*

Collier, E. S., & Lawson, R. Getting a grasp on action-specific scaling: A response to Witt (2017). (under review)

*Findings from the research presented in this thesis have been presented at the following conferences:*

Collier, E. S., & Lawson, R. (2017, August). Action capacity does not directly influence visual perception: evidence for the cognitive impenetrability of vision. *European Conference of Visual Perception (ECVP),* Berlin, Germany.

Collier, E. S., & Lawson, R. (2017, January). Thinking but not perceiving: apparent

grasping capacity does not directly influence perceived object size. *Experimental Psychology Society Meeting (EPS),* London, UK.

Collier, E. S., & Lawson, R. (2015, August). The role of action capacity in perceiving affordances and spatial properties. *European Conference of Visual Perception (ECVP).* Liverpool, UK.

Collier, E. S., & Lawson, R. (2015, June). Your hand is not a perceptual ruler: changes in action capacity influence affordances but not spatial properties. *(16th International Multisensory Research Forum (IMRF),* Pisa, Italy.