# The Temporal Dynamics of Size Perception in Adults and Children

By

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# Abstract

In a series of experiments, the influence of familiar object size on the speed of processing was investigated in adults and children, using a simple reaction time (RT) approach. In chapter 2, we demonstrated that children exhibited size-constancy-like responses starting from the age of five, although this conclusion was limited by task accuracy (experiment 1). The influence of symbolic and familiar size on simple RT was explored in 3 to 6-year-olds and adults (experiment 2). The task was conducted under reduced viewing conditions to enhance the contribution of familiar size as a visual cue. Although, we were unable to observe an effect of familiar or symbolic size on RT, we attributed this result to important methodological issues. In chapter 3, we report six experiments where we tested the influence of familiar size on simple RTs, measured under regular and reduced viewing conditions. The effect of animacy on RTs was also examined. We found that RTs were affected by familiar size in a manner that reflected the level of congruency between the physical size and the stored representation of size, such that congruent stimuli were responded to faster than incongruent stimuli. We also observed an animacy effect on RT: participants reacted faster to animals than non-animals. Finally, in chapter 4 we report an ERP study that investigated the electrophysiological correlates of familiar size. Results showed that the visual system processes familiar size around 100 ms after stimulus onset. Taken together, our findings demonstrate that familiar size is an automatic property of visual processing that can affect speeded motor responses. Future research could investigate the neural mechanisms underlying familiar object size and animacy, and specifically whether these mechanisms develop with age.

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# Author’s Declaration

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others.

The research presented in Chapter 3 has been published in *The Journal of Experimental Psychology: Human Perception and Performance.*

**Poster Presentations**

Parts of this work have been presented at conferences:
The European Conference for Visual Perception (ECVP) 2015
The European Conference for Visual Perception (ECVP) 2016

Any ethical clearance for the research presented in this thesis has been approved. Approval has been sought and granted by the School of Psychology Ethics Committee at the University of East Anglia.

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Signature:

Date: 29th June 2018

# Chapter 1: General Introduction

**Glossary of terms**

Familiar size: the known size of an object

Visual angle/Retinal size /Veridical size:

the size if directly measured from the object

Perceived size: the subjective experience of the observer

Symbol: an object which represents another object

Original: the first version of an object

Symbolic size: the size denoted by the original object

Our visual perceptual experience of the world is stabilised by mechanisms of perceptual constancy. Such mechanisms are demonstrable from an observers' ability to maintain a constant visual experience of a visual scene, despite vast changes in sensation experienced within the eye. For example, if we observe a dog located far away from us on a sunny day and sat facing to the side (figure 1.1. A) and then we observe the same dog close to us, on a cloudy day and facing towards us (figure 1.1. B), the visual input generated on the retina from each of these scenes would be very different. As can be seen by comparing the two images below, numerous differences exist, including the overall shape of the figure, the colour, the quality of the image, the type and proportion of scenery and, of most relevant to the present study, the size of the figure.

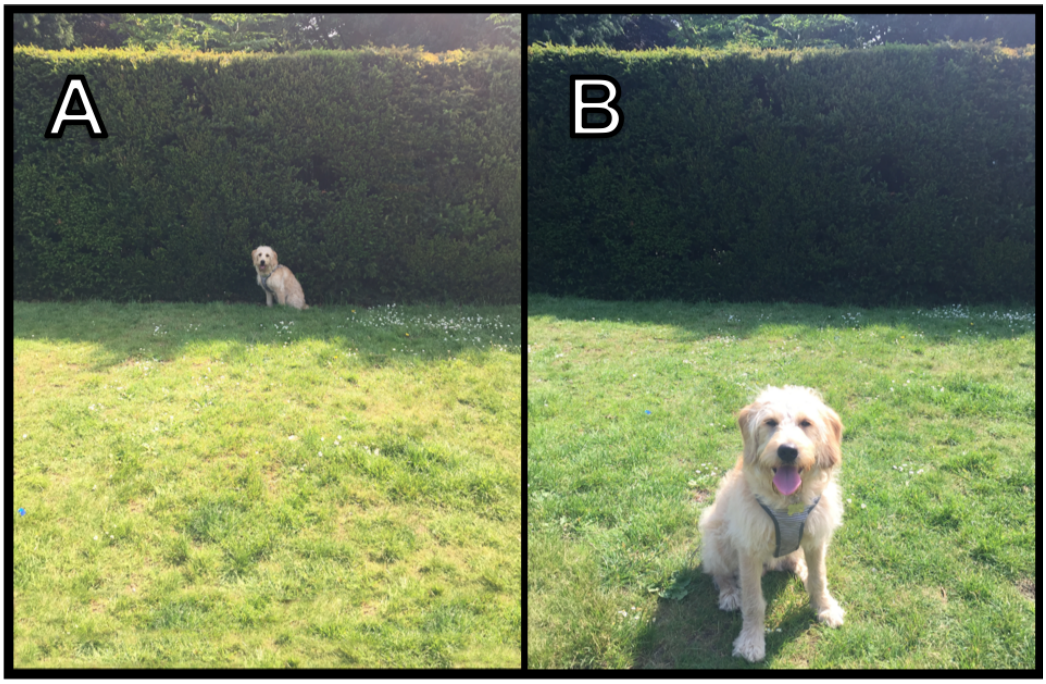


*Figure 1.1.* Perceptual constancy. The picture on the left-hand side (A) depicts a dog located further away from the observer. The picture on the right-hand side (B) depicts the same dog but located closer to the observer. The image is presented to demonstrate the difference in physical size of a familiar object across distances, along with other variations in visual experience such as luminance, colour, and resolution.

Despite all of these variations, the object in figure 1.1 would be easily identified by most observers as a dog. The mechanism that enables us to maintain stability in a visually variable world, is known as visual constancy. Although there are many useful forms of visual constancy, for example shape and colour (Hurlbert, 2007; Pizlo & Stevenson, 1999), this thesis is concerned with the mechanisms and factors responsible for *size* constancy. Size constancy can be defined as the ability of the visual system to maintain the perceived size of an objects as stable, despite changes in retinal size that occur with actual or perceived depth.

As demonstrated above, we know that the dog in figure 1.1. A is not a miniature dog, it is just located far away. Similarly, we know that the dog in figure 1.1. B is not a giant dog, it is just located relatively close.

To a large extent, cues to distance are believed to be responsible for maintaining the perception of object size in size constancy. As we can see from figure 1.1. A, the dog in the picture is not only located higher up in the visual scene, he is also surrounded by more scenery and occupies less space, than in figure 1.1. B. According to Gestalt principles (i.e. laws of perceptual organisation), the visual perceptual system integrates this kind of information in order to perceive elements within the visual scene accurately. These Gestalt grouping processes and constancy mechanisms are necessary, due to constant changes in viewing conditions that alter the visual input received by the eyes (Wagemans, Elder, et al., 2012; Wagemans, Feldman, et al., 2012). For example, if we tilt our head or reduce the ambient lighting, the visual input will be dramatically changed, as such we would rely on our visual experience in order to make sense of the incoming visual information.

Indeed, it has been argued that many visual illusions, such as those depicted in figure 1.2, are cause by the need to keep the visual experience of an object constant (Gregory, 1963; Gregory, 1998). For instance, in the Ebbinghaus illusion (see figure 1.2. B) the size of the surrounding annulus alters the perception of the size of a central circle. Specifically, an increase in the size of the surrounding annuli makes the internal annulus appear smaller, compared to the size-matched central annulus which is located within the centre of the small annuli.

According to Gregory (1963), this illusion is generated by inappropriate scaling of the target size. In this theory, perceived depth cues are proposed to cause a misapplication of size constancy mechanisms, to be applied to a target object. Such that an increase in depth cues (e.g. converging lines or surrounding object size), leads to the illusion of distance. The distance perceived by the observer is then misapplied to the retinal size of the target object, resulting in a change in the perceived size of the target. In the case of the Ebbinghaus illusion previously mentioned, the use of surrounding *small* annuli infers a far distance, since objects located far away are usually small. Whereas the use of big surrounding annuli would infer a closer distance.

A real-world demonstration of this illusion has been shown in the way people perceive the size of a portion of food on a plate (Wansink & Van Ittersum, 2013; Wansink, van Ittersum, & Painter, 2006). It was demonstrated that participants tend to place more food on a plate that has a bigger and more spread out rim, compared to when they were given a plate with a smaller and more confined rim. In other words, the misperception created by the plate affected people's behaviour, such that the inner circle was their guide, when determining how much food to place on their plates.

Similarly, in the Ponzo illusion (see figure 1.2. D), two physically identical horizontal lines located within two converging lines, are perceived as being different: the horizontal line located at the top of the image looks bigger, than the line located at the bottom of the image. The Ponzo illusion, also known as railway track illusion, is the result of the expectation that vertical lines tend to converge at the horizon. As such, the top line would be experienced as further away, compared to the bottom line (Gregory, 1963). This attribution of perceived distance leads to a misapplication of size constancy to counteract the natural shrinkage of the retinal image with distance. Hence, the top line will be rescaled according to perceived distance, resulting in a larger appearance compared to the bottom line.

In the Muller-Lyer illusion (see figure 1.2 C), two vertical shafts embedded within either inwards or outwards facing wings, are perceived as different, even if they are exactly the same size on the retina. This visual illusion can also be explained by Gregory's theory of misapplied size constancy. The Muller-Lyer illusion resembles the corner of a building. In figure 1.2 C, the left configuration (i.e. shaft with outwards wings) would represent the protruding corner of a building, making the vertical line appear closer. In contrast, the configuration on the right-hand side (i.e. shaft with inwards wings) would represent the internal corner of a room, leading the observer to perceive the shaft as further away and so longer (Gregory, 1963).

An example of a naturally occurring visual size illusion is the Moon illusion (see figure 1.2 A). In this illusion, the moon typically appears smaller when it is located at the zenith (i.e. in the sky directly ’above’ the observer), whereas it appears larger when it is located at the horizon. One explanation of this illusion is that at the zenith there are no contextual cues to indicate distance, whereas at the horizon there are many contextual cues (e.g. buildings or trees), which provide a sense of scale. This scale is generated from our experience with the familiar objects’ size and distance. As such, the visual comparison between the size of the buildings and the moon, makes the moon at the horizon appear larger, than when it is viewed at the zenith (Kaufman & Kaufman, 2000; Rock & Kaufman, 1962).

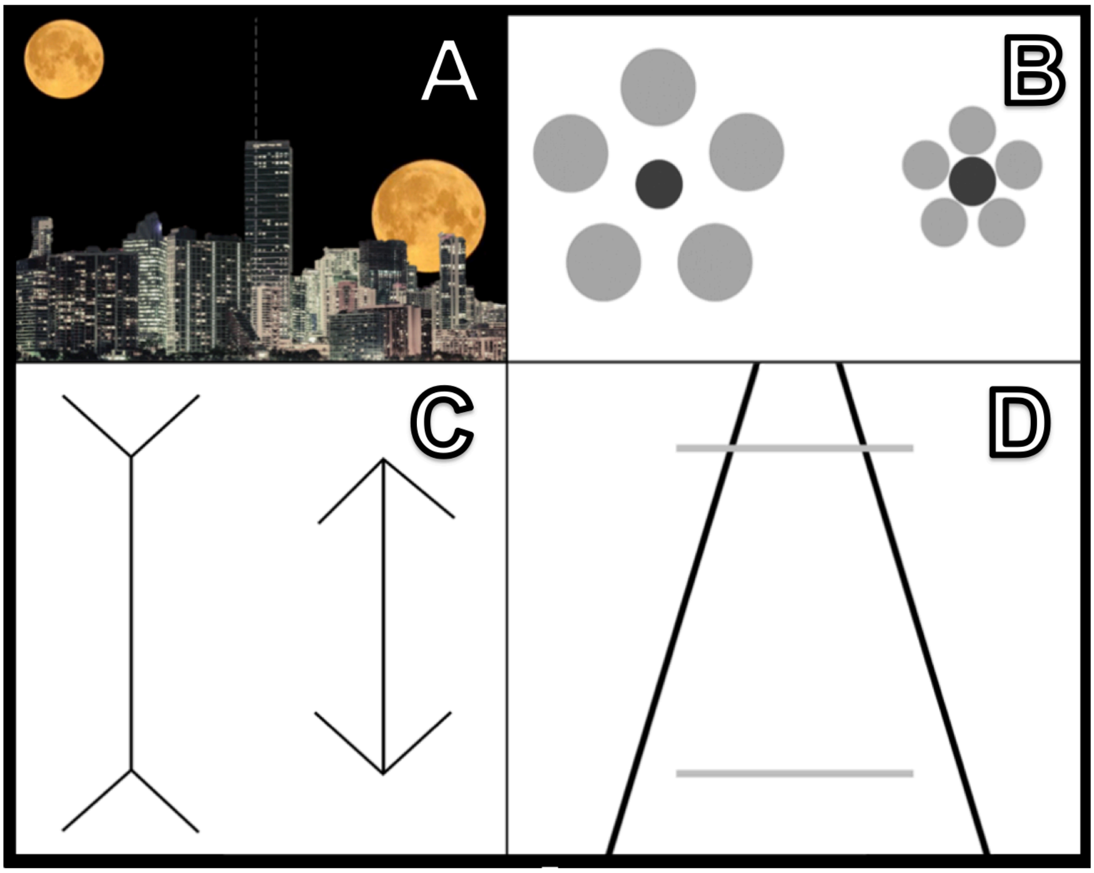


*Figure 1.2.* Visual illusions of size. (A) The moon illusion: The moon usually appears bigger at the horizon than at the zenith, note that the moons depicted in the figure are actually different sizes to demonstrate the perceptual experience. (B): The Ebbinghaus illusion: in this illusion the dark circle located within the large cluster of light grey circles is perceived to be smaller than the dark circle in the centre of the small cluster of circles, despite both circles subtending the same visual angle. (C) The Muller-Lyer illusion: the two vertical lines have the same visual angle; however, the left line appears bigger than the right line, due to the direction of the wings attached to the end of the lines. (D) The Ponzo illusion: The horizontal line at the top is perceived to be bigger than the horizontal line at the bottom, although both horizontal lines subtend the same visual angle.

Although still very influential, Gregory's theory as well as other environmentally-based arguments, are not the only explanations for these visual illusions. Alternative theories include; the relationship between the elements within the illusory display (e.g. the angles produced by the fins in the Muller-Lyer illusion) (Day & Dickinson, 1976; Todorović & Jovanović, 2018) or the variation in the degree of attention given to each element of the illusion (Coren & Porac, 1983; Fang, Boyaci, Kersten, & Murray, 2008). Therefore, there is still no consensus on how perceived size is computed in these illusions since many factors can affect the size and distance of an object.

## From Retinal Size to Perceived Size

To understand how the brain computes perceived size we need to know how the visual system works. The process of vision begins at the source of the visual input, specifically a source of light. As light waves reach the eye they are inverted by the lens and conveyed to the retina at the back of the eye. Once the light waves reach the back of the eye, they are detected by specialised cells, i.e. photoreceptors, that are concentrated in a highly sensitive area of the retina, known as the fovea (see figure 1.3).

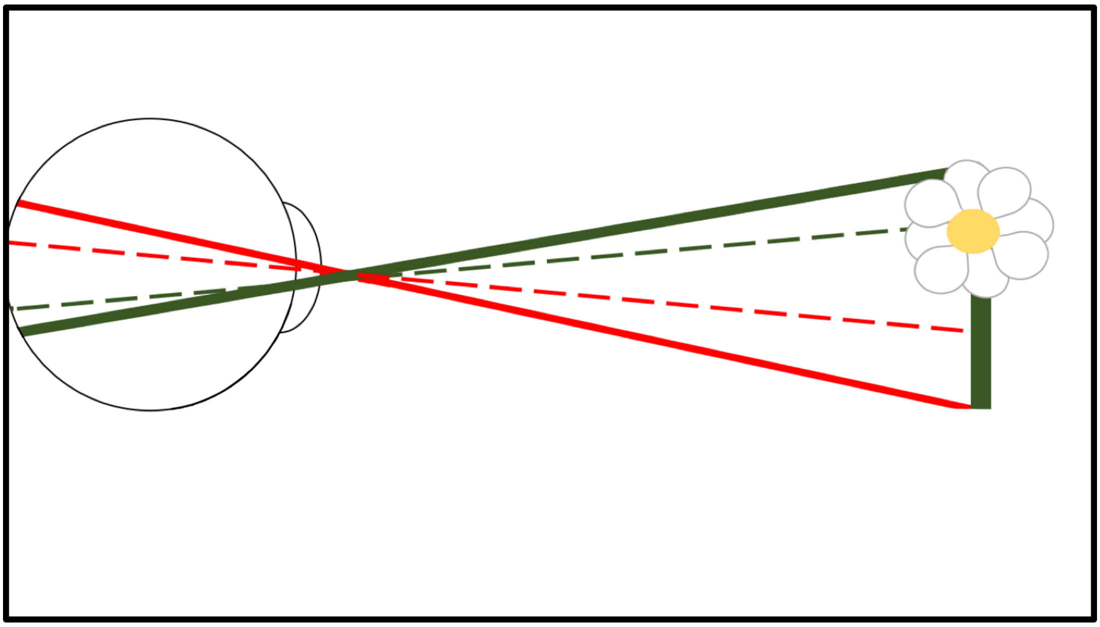


*Figure 1.3.* The relationship between the visual angle and viewing distance. Note how the image is flipped at the lens with the dark green line representing the top of the image hitting the bottom of the retina. The dotted lines give an idea about the location and proportion of image that would be received at the fovea. Note that sizes are not scaled in this diagram.

The signal from the photoreceptors is sent via the optic nerve to the lateral geniculate nuclear (LGN) and on to the back of the brain, known formally as the occipital lobe. It is well-established that the visually evoked activity in the early visual cortex corresponds to a ‘retinotopic map’ (Engel, Glover, & Wandell, 1997). This means that the activity measurable in the early visual regions of the brain, directly reflects the activity occurring within the cells located on the retina. In this fMRI study, high-contrast flickering images were used to achieve maximal activity at targeted areas of the retina, while activity in early visual areas was measured (Engel, Glover, & Wandell, 1997).

However, more recent fMRI research has challenged the idea of retinotopic mapping. Demonstrating that early visual areas, such as the primary visual cortex (V1 in particular), can also represent *perceived* size (Kreutzer, Weidner, & Fink, 2015; Murray, Boyaci, & Kersten, 2006; Schwarzkopf & Rees, 2013; Schwarzkopf, Song, & Rees, 2011; Sperandio, Chouinard, & Goodale, 2012). By using visual illusions or afterimages, these studies have shown that V1 contains a flexible map of the retinal input, that can change dynamically according to contextual information. For instance, a strong relationship was observable between the perceived size, as manipulated by the context of the Ebbinghaus and the Ponzo illusion, and the activity in V1. Results showed that an increase in perceived size corresponded to spatial shifts in peak activity. Specifically, perceived small stimuli were represented by activity more centrally located within V1, compared to perceived bigger and more eccentric stimuli, which were represented in more peripheral regions of V1 (Schwarzkopf, Song, & Rees, 2011)

Another study used afterimages projected at different viewing distances (Emmert's law) to manipulate size perception, whilst measuring corresponding neurological changes in V1 (Sperandio, Chouinard, et al., 2012). Afterimages are believed to be the result of 'bleaching' of retinal photoreceptors after looking at a strong source of light. Typically, afterimages are experienced when a camera flash is used. Immediately after the flash, the observer may report a floating cloud-like object within his/her field of vision (Gregory, 1998). The perceived size of the afterimage will depend upon its distance, as predicted by Emmert's law (Emmert, 1881).

Emmert's law states that there is a direct relationship between the original size of the induced light source, the distance focused upon and the resulting afterimage size. The relationship between the retinal size of the light source (θ), the distance subtended (*d*) and the afterimage size (s) can be summarised as:

$$s = d \times \tan(\theta)$$

As can be seen in figure 1.4, the size of the afterimage increases with increasing distance.

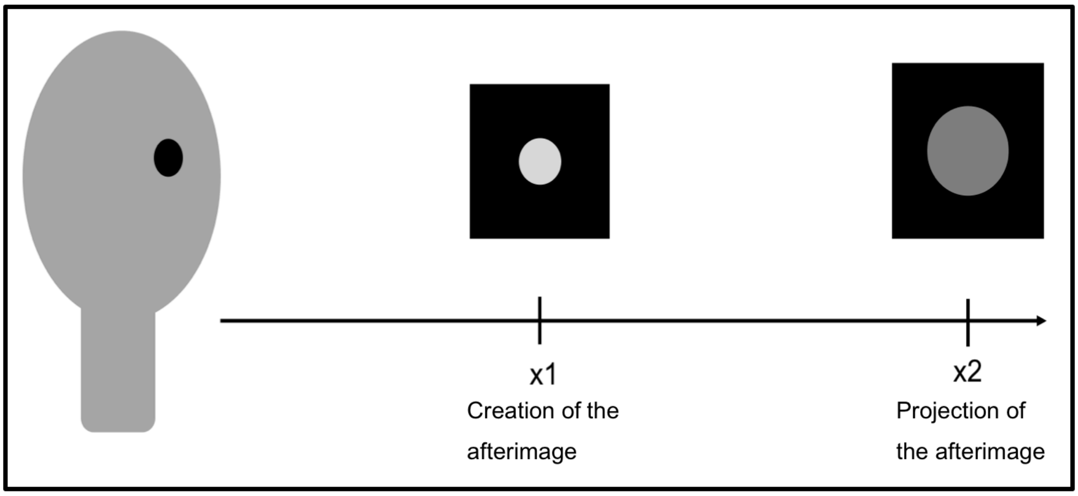


*Figure 1.4.* Emmert's law. The perceived size of the initial afterimage increases with increasing distance. Note, that whilst the amount of activity generated from the afterimage on the retina, is not altered with changes in viewing distance, the perceived size of the afterimage increases with increasing distance.

In line with the results of Murray et al (2006), Sperandio et al (2012) demonstrated that activity in V1 was once again directly and positively related to the perceptual size experience of an afterimage. Such that when participants perceived bigger afterimages at greater viewing distances, the activity in V1 was higher in more peripheral regions of V1. It is important to note that traditionally, activity within these peripheral regions is directly related to peripheral areas within the eye. In this study, these peripheral areas were not directly stimulated by the inducing light. This finding supports the theory that perception can influence veridical visual processing.

Another fMRI study found similar results using a 3D virtual reality setup of the moon illusion. Activity within V1 shared a stronger relationship with the perceptual experience of the observer. Such that, when the moon was presented at the horizon and experienced as perceptually big, there was an increase in V1 response, in comparison to when the moon was viewed at the zenith and appeared smaller in size (Weidner et al., 2014).

The temporal features of size perception have been examined in a magnetoencephalography (MEG) study. The results showed that the effects of the Muller-Lyer illusion on size perception, were observable as early as 100 ms after stimulus onset. The authors found a larger level of activity for the figure that is usually perceived as bigger (fins-out), compared to the figure that is usually perceived to be smaller (fins-in) (Weidner, Boers, Mathiak, Dammers, & Fink, 2010).

A study that measured activity from implanted electrodes in the V1 cortex, revealed that size-constancy mechanisms were observable within this area (Marg & Adams, 1970). In order to attain these measurements, patients who were being treated for epilepsy had electrodes implanted within their primary visual cortex. Participants were presented with stimuli of different physical sizes but placed at different distances, in order to subtend the same visual angle. The results showed that the activity of the V1 cells changed with perceived size (i.e. increasing with increasing perceptual size), even when the retinal image size was constant. The authors termed this effect the 'optical zoom', after the ability of the system to maintain the eccentricity of activity in early visual areas, despite the signal generated at the retina being reduced with increasing distance.

Such research demonstrates the prompt integration of size and distance information within the early stages of the visual pathway. A recent review of size constancy mechanisms supported the conclusion that this process appears to take place in V1 (Sperandio & Chouinard, 2015). Whether or not V1 is the sole determinant of perceived size is still under discussion.

Interestingly several neuroimaging studies using visual illusions, support the idea that this flexible map of the retinal input in V1 is a result of top-down modulation from higher order brain areas (Fang et al., 2008; Murray et al., 2006). For example, in Fang et al's (2008) study, they used a variant of the checkboard Ponzo illusion, previously used by Murray et al (2006). The adaption included rings instead of whole circular figures, in order to generate more refined areas of activity within the brain, than those observed previously (Murray et al., 2006). Using this method, they were able to demonstrate that the area of activity in V1 was more eccentric for the perceived larger ring located at the top of the picture, compared to the perceived smaller ring located at the bottom of the picture.

Intriguingly, they also demonstrated that by shifting the attention of the observer to a fixation point, the illusory effect was reduced, such that along with a reduction in the difference in eccentricity to the two rings in V1, activity previously observed in higher visual areas such as PPA and LOC was significantly reduced. The authors state that these findings support the idea of top-down recruitment of higher visual areas during perceptual processing since neurological illusory effects were substantially reduced when higher visual areas were disengaged.

In a behavioural study, Sperandio, Lak, & Goodale (2012a) demonstrated a perceived size effect with an afterimage version of the Ebbinghaus illusion. In this experiment, a variation of the Ebbinghaus illusion was constructed with flickering outer annuli. These flickering stimuli were shown along with a static internal annulus during an inducement phase. During this phase participants were asked to manually estimate the size of the central static annulus. A manual estimation is a perceptual measure, where participants (without looking at their hands) estimate the size of an image by adjusting the distance between their thumb and forefinger, until they believe that the distance is equal to the size observed.

After this phase the figure was removed and a plain background with a fixation cross was presented. Participants then gave another manual size estimate of the central annulus but this time estimates were made to an afterimage that was experienced. It is important to note that due to the flickering of the annuli, only the central annulus continued to be perceived as an afterimage, the surrounding annuli were *not* experienced as an afterimage. The researchers report that the typical experience of the Ebbinghaus illusion (i.e. perceiving a small central annulus with bigger outer annulus and vice versa) occurred during the inducement phase and continued on during the testing phase. For the latter condition, this was despite the absence of any online visual input. In order to clarify these findings, the experimenter also demonstrated that these effects were extinguished with a flickering central sulcus and enhanced by using a static annulus, that continued to be present through both the inducing and testing phase. Such effects demonstrate the strength of the contextual information, even in the absence of retinal information.

These findings support Gregory's (1963) theory of size distance scaling, particularly the idea of top-down influence of depth cues on the perception of the retinal size of the target. As such, these findings oppose the suggestion that this illusionary effect is driven by properties within the image itself (Day & Dickinson, 1976; Todorović & Jovanović, 2018).

A popular theory of visual processing was proposed by Goodale and Milner (1992). The 'dual route hypothesis', asserts that there are two distinct anatomical and functional routes in the brain for the processing of visual information (Goodale & Milner, 1992, see also; Milner & Goodale, 2008; Whitwell, Milner, & Goodale, 2014). The two routes proposed in this model are referred to as the 'ventral stream' and the 'dorsal stream'. The ventral stream, which originates in V1 and projects to the temporal lobe, is related to 'vision for perception' processes. The dorsal stream, which originates in V1 and projects to the parietal lobe, is responsible for 'vision for action' processes.

The model was developed through the collation of information from case studies of patients with posterior brain damage, specifically they highlight a dissociation of abilities between patients who have damage to the ventral stream (Goodale, Milner, Jakobson, & Carey, 1991; Milner et al., 1991) and patients who have damage to the dorsal stream (Perenin & Vighetto, 1988). The theory presented by Milner & Goodale honed the focus of the dual-route visual theories presented at the time (Schneider, 1969; Ungerleider & Mishkin, 1982), such that the route taken through the visual pathways was dependent on the task to be fulfilled and not the visual content itself. For instance, a task that required the observer to act upon an object would require the dorsal stream, whilst a task that required the identification of an object would require the ventral stream.

The authors concluded that when damage occurred in the region between the occipital and parietal lobe, the behavioural effects reflected difficulties in performing visually-guided actions, such as reaching and grasping, whilst sparing the patients' ability to perceive the object. In direct contrast, damage between the occipital and temporal lobe, resulted in difficulties perceiving an object, whilst retaining the ability to perform guided actions towards the same object.

Importantly, whilst the 'vision-for-action' (dorsal) pathway is believed to be an online process and solely bottom-up in nature, such that basic visual information is used to guide action. In contrast, the 'vision-for-perception' (ventral) pathway is thought to be involved in a mixture of bottom-up and top-down processes, where existing knowledge within the brain is applied to incoming information, resulting in the perceptual experience of the world.

The existence of the dual system has been supported by behavioural evidence in healthy participants, such that a dissociation between perception and action is observed (e.g. Aglioti, DeSouza, & Goodale, 1995; Haffenden, Schiff, & Goodale, 2001). In these studies, participants were presented with a 3D version of the Ebbinghaus illusion and asked to manually estimate or to reach out and grasp an inner disk. It was shown that  the grip aperture applied, when reaching to grasp the central target, was accurate with respect to the true physical size of the target and was not subject to the illusory size effects of the context. However, when participants were asked to use their thumb and forefinger to estimate the size of the disk (a commonly used perceptual lead task), the estimated size reflected the perceptual experience of the participant, and as such reflected the illusory effect on size perception. Such findings demonstrate a dissociation between the two forms of visual processing.

As this thesis is primarily interested in the examination of visual perception, the following literature will be focused on visual processing within the ventral stream. More specifically, the influence of internal representations on the perceptual experience of size. An internal representation can be defined as the information about an object that is stored within the brain and is the result of long-term experience with that object. These internal representations can vary and include basic features, like colour or shape, or more complex properties, such as functionality or purpose (Humphreys & Forde, 2001; Konkle & Oliva, 2011). These internal representations are known to influence incoming activation in a top-down fashion (Humphreys & Forde, 2001). Such processes will be revisited and expanded upon in depth at a later point.

Reflecting on the effects of visual illusions on perception, it may be reasonable to question the level of cognition necessary to experience such a phenomenon. A systematic review suggested that some species of animals, including; doves, parrots, dolphins, fish, chimpanzee's, horses and macaque's are susceptible to visual illusions, in a similar manner as humans (Feng, Chouinard, Howell, & Bennett, 2017). There is also evidence that monkeys share the same 'optical zoom' cells that are present in humans (Smith & Marg, 1975). Taken together, these findings imply that the visual system does not require complex cognitive mechanisms, in order to compute perceived size. As such, the role of development and the degree to which experience is needed for the processing of size perception will be considered in the next section. Specifically, to determine whether or not perceived size is represented early on in visual processing for both children and adults, and to establish whether or not experience is critical in size perception.

## The Development of Size Perception

Size constancy has previously been reported in many species of animals, including ducklings (Pastore, 1958), cats (Gunter, 1951), dogs (Müller, Mayer, Dörrenberg, Huber, & Range, 2011) and rats (Heller, 1951). Furthermore, using single cell recordings in monkeys, the presence of both size invariant and size variant cells in the inferior temporal cortex have been reported. These cells are suggested to be responsible for size constancy mechanisms (Humphrey & Weiskrantz, 1969;  Ungerleider, Ganz, & Pribram, 1977). Taken together, these findings support the idea that size constancy is an innate process.

Interestingly, a recent study using both the Ponzo illusion and Muller-Lyer illusion, has demonstrated that individuals who were born blind through cataracts, were susceptible to both types of illusory effects immediately after their vision was restored (Gandhi, Kalia, Ganesh, & Sinha, 2015), supporting the innate theories of size constancy.

However, another recent study countered this argument by suggesting that the results of Gandhi and colleagues could be attributed to the participants having residual vision, prior to the cataract removal (Andres, McKyton, Ben-Zion, & Zohary, 2017). In the study by Andres et al (2017), the participants' visual acuity was examined before and after the removal of the cataracts. The authors observed that prior to the surgery, the participants' vision was better than would be expected of a completely blind individual. In agreement with previous experiments involving blind individuals who had regained their sight through surgery, they also reported that these patients initially had very poor depth perception, which in turn affected their size constancy abilities (e.g. Fine et al., 2003; McKyton, Ben-Zion, Doron, & Zohary, 2015; Andres et al, 2017). Therefore, the conclusion that size constancy is an innate ability is still hotly debated.

As might be expected, the vision of a newborn baby is not as refined as in adults. In a comprehensive overview of infant vision, Slater (2002) states that when compared to that of an adult, children's visual acuity is reduced by 10% within the first year of life. Specifically, their ability to focus at a distance is poor. Slater suggests that this impairment is due to the most important cells in the eye, located in the centre of the retina (fovea), being underdeveloped. These cells are responsible for the differentiation of fine visual detail. Additionally, the structure of the eye is disproportionate for accurate vision, since the chamber of the eye is too small, and the lens is more rounded than would be optimal (Slater, 2002). Despite this lack of precision in vision, infants are believed to be able to *perceive* in a complex manner from a very young age.

A study involving newborn babies as young as 9 hrs and up to a maximum of 7 days old, showed that generally new-borns prefer to look at retinally big objects (Slater, Mattock, & Brown, 1990). The authors used a habituation looking task, where traditionally an increase in the time that an infant spends looking at an object is related to the infants perception that the object is novel, conversely a decrease indicates that the object is familiar (Fantz, 1964). Using this task, the authors found that infants were able to differentiate familiar objects, even when viewed at a new distance and, as a consequence, experienced at a different retinal size. Indeed, without size constancy the infants would have assumed that the old object placed at a different distance, would be a novel object and so looking times would be increased. These results support the hypothesis that newborns have size constancy.

A similar version of this study was conducted with 4-month-olds (Granrud, 2006). In this study, the researchers aimed to tease apart the difference between physical size, namely the size of the object if it was directly measured with a ruler, and the retinal size, which is determined by the physical size of the object and the distance placed from the observer (see figure 1.5). They established using a preferential looking paradigm, that novel physical size was the most important factor in preferential looking, with babies looking more frequently to objects of novel physical size (the object located on the right in figure 1.5), as opposed to retinal size (figure 1.5 left object). Again, supporting the theory that size constancy is an innate ability.

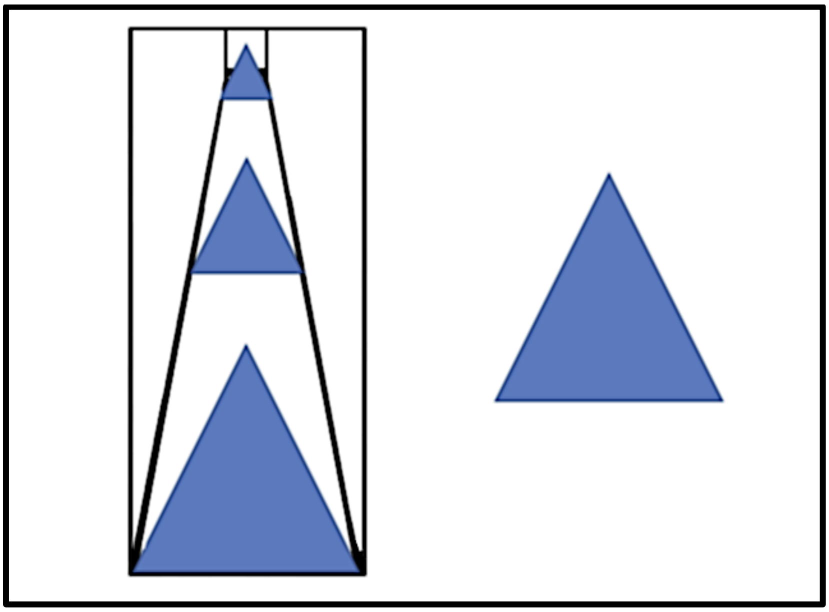


*Figure 1.5.* The relationship between retinal image size and viewing distance, whereby the visual angle of the object becomes smaller with increasing distance (left) while the physical size remains the same across the distance (right).

Granrud (2006) also suggested that the term *size constancy* is grossly used in the developmental literature. Specifically, the term size constancy is applied to any behavioural response that deviates from that which would be expected, given the retinal size of the image. Granrud estimated from his own data that infants most probably are characterised by severe under-constancy, as demonstrated by their tendency to underestimate object size. To apply this concept to the method of looking preference, this would result in less time spent looking at an object that is slightly smaller than would be expected. Although, confirmation of this theory is difficult, given the pre-verbal limit of infants (Granrud, 2006).

This idea of underconstancy in child perception has been supported by many studies with children aged between 5 and 10-years-old (Granrud, 2009a; Kavšek & Granrud, 2012; Leibowitz & Hartman, 1959; Leibowitz & Judisch, 1967; Rapoport, 1969; Tronick & Hershenson, 1979; Zeigler & Leibowitz, 1957). Typically, in these studies, children were required to perform a matching task between a target presented at a distance and a selection of stimuli of varying sizes, from which they had to choose a match, presented near to the observer. A major criticism of the initial studies conducted in the late 50's and early 60's (e.g. Leibowitz & Hartman, 1959; Zaporozhets, 1965; Zeigler & Leibowitz, 1957), is the method used to question participants. It has been argued that the level of the child's comprehension of the instructions or questions could limit the response given (Granrud, 2009; Rapoport, 1967). Granrud, a leader in this area of research, has questioned the developmental literature on size and distance perception. Stating that such findings could be explained entirely by the metacognition of children, along with their ability to understand the size-distance relationship (Granrud, 2009). Indeed, the child must understand the instructions to be able to perform the task.

An alternative way to explore size perception is to provide an implicit measure of size constancy, which has been used with adults but does not require high-level cognitive or linguistic abilities. Specifically, a more objective and indirect task for the child to complete. An example of one such measure would be the preferential looking and reaching paradigms, typically conducted in size constancy studies with infants (Granrud, 2006; Slater et al., 1990). The benefit of such an approach is that the child's implicit perceptual experience, and not their explicit knowledge, would be assessed.

Aside from the restrictions dictated by the level of language comprehension, the literature reviewed so far has also only looked at very simple stimuli and across very large distances (minimum distance of 6 metres) (e.g. Granrud & Schmechel, 2006; Kavšek & Granrud, 2012; Leibowitz, Pollard, & Dickson, 1967; Zeigler & Leibowitz, 1957). As such, the degree of familiarity with the visual stimulus and a finer difference in viewing distance will be considered in the current investigation.

## Assessing Size Perception in Children

A new direction of size-perception in children was unveiled in 2004 by DeLoache and her team (DeLoache, Uttal, & Rosengren, 2004a). The study was based on informal observation from parents, who reported that their children would  attempt to interact with objects that were too small. For instance, a child might attempt to put on a dolls jacket or to insert their hand into a miniature car.

DeLoache and her team (2004) set out to investigate this phenomenon in children aged 2 to 4-years-old, by giving them regular sized toys in an introductory play session. Before the start of the second play session, the researchers swapped these toys for miniaturised versions of the same objects. In the second session, experimenters recorded the number of interactions attempted with each of the impossible objects. The researchers aptly termed these attempts as scale-errors, as the actions attempted were the same as the actions initially performed on the correctly scaled toy objects. Interestingly, the researchers reported that overall the scale-errors were a minority of all the actions made towards the miniaturised toys.

DeLoache et al (2004) initially stated that such findings were a result of a dissociation between perception and action, with the perceptual effects of familiar size in the ventral stream, overriding the physical size information within the dorsal stream. However, in recent years the same authors have clarified that this dissociation between perception and action can be attributed to a failing in the child's ability to comprehend their own body in space. Such that they do not perceive the size of their body with respect to the toy (DeLoache et al, 2013).

Children's experiences of visual illusions have also been reported to differ from that of an adult. Children aged 4 to 5-years-old have been shown to be less susceptible to visual illusions, such as the Ebbinghaus and the Ponzo illusion. Leading researchers to conclude that children's vision is more veridical and therefore less susceptible to top-down modulation compared to adults (Doherty, Campbell, Tsuji, & Phillips, 2010; Káldy & Kovács, 2003; Leibowitz & Judisch, 1967).

In direct contradiction to these findings, several investigations have revealed that children from as young as the age of 5 years-old are either equally susceptible or even more susceptible to visual illusions than adults (Pressey & Wilson, 1978). This was true for the moon illusion (Leibowitz & Hartman, 1959), Titchner circles (variation of the Ebbinghaus illusion), Baldwin illusion (variation of the Muller-Lyer) and the Ponzo illusion (Pressey & Wilson, 1978).

However, the techniques used to measure perceived size in these studies have often been criticised. The criticisms include; the degree of freedom allowed for participants to report their perception of a targets size (e.g. giving multiple size options to match to a target, or asking a child to describe their perceptual experience), the associated risk with this kind of measure is that it could unduly increase variability in responses (Káldy & Kovács, 2003).

Yet, it could be argued that using a two-alternative forced choice task, may be too strict to accurately capture a full range of perceptual experiences. An experimenter would need to conduct numerous trials for each participant, with varying degrees of size-difference between the stimuli, in order to attain the same level of size-difference sensitivity, achieved with a more open measure. Such an approach is not feasible with children, since they have a limited ability to focus for prolonged periods of time (Greenberg & Waldman, 1993).

Beyond the specific paradigm used, the form of question can also be problematic. Three specific issues were apparent within the literature. Firstly, if the language is too complex children may not understand the concepts referred to and as such they may not be able to give a valid response. Secondly, if the researcher does not specify if the question is perceptual or objective in nature, the responses given could be either, or a combination of the two perspectives. Finally, a bias may exist with the language used, such that asking a child ‘which item is bigger?’, generally generates overestimations. Specifically, since terms like “bigger” have been found to promote larger estimates of size in children (Krahmer, Noordewier, Goudbeek, & Koolen, 2013).

Another criticism raised in the literature is that the kinds of visual stimuli used may not be adequately controlled. Specifically, that underlying features of a figure could cause the visual illusion and not the concept being investigated. For example, Doherty and colleagues (2010) propose that when using the Ebbinghaus illusion for testing, varying the distance between the central annulus and surrounding annuli across figures, could confound the effects usually observed when simply varying the surrounding annuli size.

Several implicit tasks have been developed to measure perceptual size in children. An example of such a task, involved the movement of a toy train across distances with a plain target mounted on top (Tronick & Hershenson, 1979). Initially, the participants aged between 3 and 6-years-old performed a pre-task assessment, where they were asked to identify which object in a visual illusion had a real size and which had a perceived size. Examples were given beforehand, to illustrate the kinds of perceptual experiences that constituted ‘real’ or ‘perceived’. Based on their ability to correctly identify these objects, participants were categorised as realists or phenomenalists. The participants were then asked to move a train along its tracks, until the triangle on top of the train matched the retinal size of another triangle, situated on top of a different train.

The researchers used two types of question in the task, reflecting either an ‘apparent’ or an ‘objective’ style. The aim of using these styles was to promote perceptual or physical size responses, respectively. The researchers concluded that all children in the experiment exhibited size constancy, irrespective of their ability to differentiate between real and perceived size, and irrespective of the question type. In other words, the children matched the triangles based on the retinal and not the physical size of the triangles. This finding indicates that despite the fact that some participants had knowledge of the size-distance relationship, they did not apply this information to their behaviour in the practical task (Tronick & Hershenson, 1979). Although this task was implicit in nature, it still required a degree of comprehension, in order to understand the task and the different question styles. Hence, it is possible that the lack of variation in response to instruction type was due to a miscomprehension.

In a study involving children aged between 5 and 10-years-old, size judgments were made between two target stimuli in the context of 3 photos. Each of the photos contained a different number of perceptual depth cues (i.e. i) a clear horizon, ii) lines converging to a horizon or iii) no depth cues). In this experiment, two vertical lines were used as targets and were placed in the same physical location within each picture. The participants were asked to indicate which of the vertical lines was longer. The experimenter adjusted the size of the lines between each trial.

The results showed that children from the age of 5 were generally able to determine the difference between the two vertical lines when the size difference was large. However, they made more errors in identifying the larger line, when the difference between the vertical lines was small. Interestingly, they were not aided by the contextual cues in any of the photos. A positive relationship was demonstrated between task accuracy and the child’s age, such that the older the participant, the higher their task accuracy. Interestingly, the number of cues used, as determined by the accuracy for each picture type, also increased with age, such that the performance of younger participants (7 to 8-year-olds) was not improved by the picture which had all of the cues but was improved by the picture which had just one cue. In contrast, the older participants (12 to 13-year-olds) performed equally well across all cue conditions (Shimada, 1975).

Another way of assessing perceived size in children involves the use of implicit learning (Wilcox & Teghtsoonian, 1971). In an implicit positive-reinforcement style task, 3 and 9-year-old children, along with adult participants, were presented with two buttons. The participants were told they could press the buttons in response to the stimuli presented in front of them. During the training session, if the participant pressed the button which corresponded to the side of the screen where a target had a bigger retinal size, they were awarded with a treat. The size of the targets was altered between each trial. Once participants learnt to consistently identify the retinally bigger image, they were tested in the actual experiment. In the experiment, different background images were placed behind the targets. The researchers found that 3-year-olds were unaffected by the number of contextual cues within the scene located behind the targets. Additionally, the ability to use contextual cues increased with age (Wilcox & Teghtsoonian, 1971).

Intriguingly, although participants were not given explicit instruction about the task or the target size, responses reflective of size perception were still observable. A potential cost of such an implicit technique is the possibility of differences in the personal interpretation of the task rules. It is possible that older participants may have interpreted the task to be about perceived size, whilst younger participants may have believed that the task was about physical size. Countering this explanation, the authors state that often the youngest participants informally reported that they did not know which of the objects was bigger. These remarks were made in trials where the targets had the same retinal size but a different perceived size, due to the contextual backdrop. Supporting the idea that the youngest children did not experience the same perceptual experience as the older participants and as such were not susceptible to the pictorial depth cues (Wilcox & Teghtsoonian, 1971).

Another way to measure perceived size is by means of a size-matching task. For example, Newman (1969) used a perspective illusion, where two target columns were placed within a 3-D drawing of a corridor. The column located in the foreground of the corridor was adjustable in size by the participant, via a hidden metal insert. The participants of different age groups (6, 9 or 14-years-old) were asked to adjust the column until it was the same size as the column located at the end of the corridor. Results showed that all of the participants were able to match the column at the end of the corridor according to its perceived size and that there was no difference in performance across age groups. The authors concluded that size-constancy abilities are present from the age of 6 and that even though several of the younger participants did not realise that the corridor contained depth cues, they were still able to scale the target size appropriately.

Taken together, these findings demonstrate that there is still uncertainty as to the developmental trajectories of size constancy. Whilst some researchers believe that to some extent the mechanism is already present in infants (Granrud, 2006; Slater et al., 1990), other researchers propose that this perceptual ability is not developed until the age of 12 to 13-years-old (Leibowitz & Judisch, 1967). Between these age groups, researchers have suggested that size judgments are impaired, particularly at the age of 5 to 6 (Granrud & Schmechel, 2006; Leibowitz & Hartman, 1959). Additionally, children's ability to use monocular depth cues is also underdeveloped before the age of 9 to 10 (Tronick & Hershenson, 1979). To conclude, in the literature there is currently no consensus on the age of full-development for size constancy abilities and as such further investigation is needed.

## Familiar Objects Size

In order to determine the influence of familiar object size, the process of recognising an object as familiar, must be considered. The familiarity of an object has been demonstrated to affect early visual processes in human and nonhuman primates. For instance in electrophysiological research, an increase in brain activity in response to familiar compared novel objects, is observable within the first 200 ms in monkeys (Peissig, Singer, Kawasaki, &

Sheinberg, 2007) and also in human infants (Carver, Meltzoff, & Dawson, 2006), demonstrating the primitive nature of such effects.

The theoretical mechanisms and neurological pathways behind the recognition of familiar objects are well-established. The hierarchical interactive theory (HIT) created by Humphreys and Forde (2001), views object recognition as a bi-directional hierarchy, functioning in both a bottom-up and top-down fashion. The authors propose that the spread of neurological activity is instigated within the occipital lobe, spreading across the temporal lobe, toward the inferior temporal lobe. During this flow of activity, the incoming visual information is progressively matched in terms of visible features (for example by colour or shape) to internal representations of other familiar objects. It is suggested that object categorisation can be determined easily during these early stages, as many objects within the same category possess similar image properties (e.g. most animals have eyes and many fruits are round) but identification at the individual level at this stage is more difficult, due to the degree of similarity between exemplars within the same group.

After this initial stage of visual processing, a second wave of activation occurs, which recruits more anterior regions of the ventral stream. Humphreys & Forde (2001) suggest that this top-down processing is related to the specific identification of an object. In this part of the process, activation shared by exemplars with overlapping features, is refined to the specific target object. In order to accomplish this process, the system appears to refer back to connections already established, as to hone and strengthen the choice of object identity. From this time point, the process of object naming is said to be easier for exemplars within the same category (e.g. an apple and an orange) compared to exemplars from different groups (e.g. an apple and a bicycle), since the category is already selected during the first wave of activity (Humphreys & Forde, 2001). Although many visual features are suggested to be important during object recognition (e.g. colour and shape), the size of the object is not listed as one of these features.

However, an increasing body of evidence is supporting the theory that familiar object size influences the speed of processing, leading to the conclusion that familiar object size is an automatic property in the processing of familiar visual objects (Fisher & Sperandio, 2018; Gabay, Leibovich, Henik, & Gronau, 2013; Konkle & Oliva, 2012a).

In Konkle and Oliva's (2012a) study, a Stroop-like task was used to assess if familiar object size contributes to speeded choice RTs. In this task, pairs of images of familiar object were presented on the screen at different physical sizes. The participants were asked to decide if one of the images was bigger or smaller than the other image. The authors found that the difference in familiar size between the two objects influenced the time it took to decide on the difference in physical size of the images presented on the screen. In other words, object pairs whose screen size difference was congruent to the familiar size difference (e.g. a small apple with a big elephant) produced faster choice RTs, compared to pairs of object images whose difference in screen size was incongruent to the difference in familiar size (e.g. a big apple and a small elephant). The authors attributed this benefit to familiar size being an automatic property of object recognition.

Interestingly, in a similar Stroop-like task, differences in choice RTs were also observed in response to objects of differing semantic size (Sereno at al., 2009). In this study, a singular word or non-word was presented in either lowercase letters, and as such was physically small (e.g. apple), or in uppercase letters, and as such was physically big (e.g. APPLE). The participant was asked to indicate if the text presented was a word or nonword. The authors found that when the physical size of the word matched the familiar size of the object word, choice RTs were faster (e.g. orange), compared to when the screen size of the word did not match the familiar size of the object word (e.g. ORANGE). These results show that familiar size is an automatic property of object recognition during semantic processing of words.

In a priming study involving familiar objects as stimuli, Gabay et al. (2013) found that images of familiar objects were capable of inducing priming effects on decisions made towards numerical digits. In this task an image of a familiar object was used as a prime before a target digit was presented. Participants were asked to decide if the digit was odd or even (i.e. a parity judgment). The results showed that participants were faster to make the parity judgment when the object prime matched the magnitude of the target number presented. For example, if an elephant prime was presented with the digit 9, responses would be faster than if the elephant prime was paired with the digit 3. Based on these findings the authors suggested that there is a common conceptual size, shared by numerical digits and familiar object size.

Similar results were obtained in a visual search task that required participants to find an object within a scene (Biederman, Mezzanotte, & Rabinowitz, 1982). Several factors were found to influence the speed of target detection, including; the object position, the relevance of the object to the scene, and, more importantly, the proportional size of the object. Specifically, for the latter factor, objects that were proportionately scaled in the scene were easier to find compared to those that were off-sized (e.g. an enlarged fire hydrant in a street scene was harder to find than an appropriately scaled car).

Taken together, these findings show a clear influence of familiar object size that is observable in tasks which do not explicitly require familiar size knowledge (Biederman et al., 1982; Gabay et al., 2013; Konkle & Oliva, 2012a; Sereno et al., 2009). Hence, size is hypothesised to be an automatic property of object recognition.

The effects of familiar object size on speed of processing have been also demonstrated in tasks that require object categorisation (Grill-Spector & Kanwisher, 2005).

In this study, participants were briefly presented with images of familiar objects and asked to categorise each object. The categorisation level was varied, from the basic level (e.g. animal or nonanimal) to the subordinate level (e.g. pigeon or seagull). The authors found that the RT at the basic level of categorisation of an object image was not significantly different from the RT of simply detecting the onset of the object image. However, categorisation at the subordinate level was significantly slower. This lead to the conclusion that categorisation occurs shortly after stimuli onset, making it an automatic property of object image processing.

Interestingly, familiar objects have been seen to affect the speed of processing in a simple RT task (Sperandio, Savazzi, Gregory, & Marzi, 2009). In this study, Sperandio et al explored the relationship between the speed of detection to the retinal size of an image (3°, 4.5° or 6°) when located at different distances (57 cm, 86 cm and 114 cm). In agreement with basic psychophysics principles (Osaka, 1976), the researchers found that when the retinal size of a simple circular image was small, simple RTs were slow compared to when the retinal size of the image was big. These effects can be explained by the amount of sensory stimulation at the eye, such that images with a bigger retinal image produce more stimulation, compared to smaller retinal images. As a result of this increase in activation, there is a benefit to the speed at which the brain processes such images (Osaka, 1976).

However, when the researchers replaced the plain circle stimuli with an image of a tennis ball, RTs were not only predicted by basic psychophysics principles but also according to size constancy. Specifically, when the tennis balls subtended the same visual angle (6°) across the three distances, RTs were faster to the biggest tennis balls compared to the medium or the smallest tennis balls. Interestingly, this effect of perceived size on RT was not observed when plain circles, rather than tennis balls, were presented. The authors suggested that familiarity with the size of a tennis ball induced the participants to perceive the tennis ball as off-sized (bigger than its familiar size), when it was placed at increasing distances.

The results of Sperandio et al (2009) demonstrated for the first time a relationship between simple RTs and perceived size, whereby an increase in perceived size results in a decrease in simple RT. Similar findings were obtained by presenting visual illusions, whereby illusory big objects were reacted to faster than illusory small objects (Plewan, Weidner, & Fink, 2012; Savazzi, Emanuele, Scalf, & Beck, 2012; Sperandio, Savazzi, & Marzi, 2010).

As a whole, the literature indicates that familiar size has an effect on the speed of processing (Biederman et al., 1982; Gabay et al., 2013; Konkle & Oliva, 2012a; Sereno et al., 2009) and that the familiarity of an object can affect regular size processes (Sperandio et al, 2009). Hence, it appears that information about familiar object size is easily accessed during processing of visual inputs.

In support of the idea that familiar object size information is accessed easily, research conducted with infants aged 5 to 7months demonstrated altered reaching behaviours, corresponding to changes in familiar object size (Granrud, Haake, & Yonas, 1985). In this study, infants were introduced to two novel objects of different physical size in a familiarization phase, where they were allowed to play with the object. During the testing phase, one of the recently learnt objects was replaced by a different sized version of the same object, which now matched the physical size of another recently learnt object. The two objects were now of the same retinal and physical size and located at the same distance to the infant. The results showed that infants reached significantly more often to the swapped object. The researchers concluded that the reaching behaviour represented acknowledgment of novelty and as such, the results demonstrate that the effects of object familiarity are observable in infants.

Research involving adult participants has also shown that people have a strong understanding of a range of familiar object sizes (Bolles & Bailey, 1956; Konkle & Oliva, 2011). In a study by Konkle and Oliva (2011), a series of tasks, including; size ranking, categorisation by size, size adjustment and drawing of objects were completed by participants, to assess their comprehension of familiar object size. The authors reported that all measures resulted in a positive relationship between the measure of size used and the familiar size of the object. Such that familiar big objects were consistently; ranked, categorised, drawn and adjusted to be relatively bigger than the familiar small objects. Demonstrating that participants possess an explicit understanding of familiar size (Konkle & Oliva, 2011). For example, participants reliably ranked and categorised objects like apples as small compared to objects like a van which were identified more frequently as being big. Other research investigating knowledge of familiar size, verified that participants were capable of estimating the size of familiar objects, using a linear scale (e.g. centimetres) (Bolles & Bailey, 1956). As such, the size of familiar objects appears to be well-established in adult participants.

Previous research has also demonstrated that familiar object size can aid in size judgments of objects viewed under reduced viewing conditions (Gogel & Da Silva, 1987; Gogel & Newton, 1969). In one such study, the experiment took place in a completely darkened room, in order to remove contextual cues to distance (Gogel & Newton, 1969). The participants were asked to make size estimates of familiar objects presented before them. The familiar object images were presented on illuminated colour acetates. Results showed that the size estimates reflected a direct integration of retinal image size with familiar size, such that familiar big objects (e.g. a guitar) were estimated to be smaller than the retinal size observed. Whilst familiar small objects (e.g. a key) were perceived to be bigger than the retinal size observed. In contrast, the estimates of plain shapes reflected the retinal size of the images. In a follow-up study (Gogel & Da Silva, 1987), the inclusion of a full-pictorial cue condition with monocular viewing showed that size estimates were skewed closer to the expected retinal size of the object, based on the inferred distance. This demonstrates that when making judgments of size, participants rely on existing knowledge about familiar size to shape their estimates.

In this thesis, familiar object size is hypothesised to be an automatic property of object recognition. This hypothesis is derived from the ease of access of knowledge about familiar object size (Bolles & Bailey, 1956; Konkle & Oliva, 2011) as well as the RT advantage associated with familiar object size, as demonstrated in tasks that did not explicitly require knowledge of familiar object size (Biederman et al., 1982; Gabay et al., 2013; Konkle & Oliva, 2012; Sereno et al., 2009). Moreover, it is assumed that familiar object size categorisation takes place at the point of detection, given the evidence that categorisation is an automatic property of familiar object processing (Grill-Spector & Kanwisher, 2005; Humphreys & Forde, 2001).

## The Current Investigation

The overarching goal of the current investigation was to gain a deeper understanding of the developmental, behavioural and electrophysiological mechanisms of size constancy and familiar object size, using a simple RT approach. To this end, four studies were conducted (Chapters 2-4).

In Chapter 2, the developmental trajectory of size constancy mechanisms (experiment 1) and the influence of familiar object and symbolic size under reduced viewing condition (experiment 2) were investigated in children of different age groups. Although a plethora of studies on size constancy have been conducted with children and infants, there is still no consensus as to whether or not size constancy is an innate or a developed ability. Hence, experiment 1 aimed to investigate this mechanism in children in order to establish if changes in size constancy are observable with increasing age. The experiment included children between the ages of 5 to 14 years-old, as well as adults. An implicit visual task, namely a simple RT task, was used to avoid known biases produced by miscomprehension of instructions (Granrud, 2009b; Leibowitz & Harvey, 1969; Rapoport, 1967).

In this experiment, a shortened version of the simple RT task developed by Sperandio et al (2009) was used. Viewing distance was manipulated by placing a screen at two distances (i.e. 57 cm and 114 cm). The screen briefly displayed an image of a tennis ball. The physical size of the tennis ball was scaled according to the distance (4 cm and 8 cm, respectively), in order to produce the same retinal size. Importantly, average luminance was kept constant. Participants were asked to react as fast as possible to the onset of the visual stimulus, i.e. simple RT task. Based on Sperandio et al's (2009) findings, it was expected that stimuli perceived as bigger would produce faster RTs than stimuli perceived as smaller, as a result of size constancy. An absence of size constancy mechanisms would result in no difference in RTs between the small-near tennis ball and the big-far tennis ball, due to the same image size being generated on the retina by the two stimuli.

In the second experiment of Chapter 2, the influence of symbolic size on the speed of processing was investigated in 3 to 5-year-olds and adults. The visual stimuli used in this experiment consisted of pictures of familiar objects that were well-known to the children. Specifically, images of toys that possessed a symbolic representation of an object in the real-world, that would be commonly used by adults (e.g. a toy car symbolises a real car). The age range of the developmental groups, was formed by two motives: i) to establish if children as young as 3 can perform simple RTs; and ii) to expand on the finding that differences in size scaling abilities exist within this age range (DeLoache, Uttal, & Rosengren, 2004).

Two tasks were included in this study. The first task involved participants categorising 40 object images as either toys or real objects. The aim of this task was to establish if participants understood the category each object belonged to and if this process was influenced by familiar or symbolic size. In the second task, participants performed a simple RT's task under reduced viewing conditions to the 40 images previously observed in the categorisation task. Reduced viewing conditions were used, as previous research (Gogel & Da Silva, 1987; Gogel & Newton, 1969) demonstrated that the influence of familiar size on perceptual judgments is enhanced when visual cues to distance (e.g. convergence, accommodation) are reduced.

Simple RTs were predicted to be affected by familiar size in adults, such that objects that had a familiar size which matched the image size on the screen (e.g. toy apple, real apple and toy car) would be responded to more quickly than objects that were incongruent with their familiar size (e.g. real car). However, in children it is hypothesised that symbolic size may play a role in the speed of processing, leading to faster responses to both big symbolic toys (e.g. toy car) and real big objects (e.g. real car), compared to the symbolic small toy (e.g. toy apple) and small real objects (e.g. real apple). Such a difference in processing speed to these kinds of stimuli would highlight a substantial difference in perceptual processing between adults and children, where symbolic representations would shape the perceptual processing of children but not adults.

In Chapter 3, the influence of familiar object size was explored under regular viewing conditions (experiment 3) and reduced viewing conditions (experiment 4), since reduced viewing conditions are known to enhance familiar size effects (Gogel & Da Silva, 1987; Gogel & Newton, 1969). The proportionate size of familiar objects was investigated with 3 categories of objects that had been shrunken relative to their real size (experiment 5) and 3 proportionate size categories with objects that have been magnified with respect to their real size (experiment 6). Under reduced viewing conditions, a manual size estimation task was used to measure the perceptual size experience of participants (experiment 7).

In experiment 8, participants took part in a short-term cross-sensory experience phase, that was designed to allow participants to gain a sense of familiarity with the size of two novel objects. After the experience phase, a simple RT task was performed under reduced viewing conditions. The stimuli in the RT task, were images of the novel objects, presented at both the experienced and unexperienced size. It was hypothesised that the novel objects with a familiar small size (i.e. constructed out of Lego blocks) would be processed quicker than the familiar big objects (i.e. constructed out of Duplo blocks). In line with the idea that familiar object size might be an automatic property of object recognition. (Konkle & Oliva, 2012a), RTs were predicted to be faster to object images when the familiar size of the object was congruent with the physical size of the image presented on the screen.

In Chapter 4, an event-related potential (ERP) study was carried out to investigate for the first time the electrophysiological correlates of familiar object size (experiment 9). Although the functional and anatomical substrates of familiar size have already been established in recent fMRI studies (Konkle & Caramazza, 2013; Konkle & Oliva, 2012b), the temporal dynamics of familiar size are still undetermined.

In this ERP study, participants were presented with images of familiar objects, these images were the same as the stimuli used in the behavioural experiment described in Chapter 3 (experiment 5). To control for low-level properties of the stimuli, phased-scrambled versions of the familiar objects were included, as recent research suggests that familiar size effects could be caused by underlying image properties (Long & Konkle, 2017; Long et al., 2016).

In this study, participants performed a simple RT task whilst electrophysiological activity was continuously recorded from their scalp. Participants were tested in two sessions. The first was conducted under reduced viewing conditions, to enhance the effects of familiar size, whilst the second session was conducted under regular viewing conditions, to allow for comparison of the two conditions. Following the two sessions, participants were asked to categorise and rank the intact object images they had observed in the simple RT task. These measures were included to measure participants familiarity with the object size depicted in the images. The aim of the study was to establish if processing of familiar object size takes place during the early stages of visual processing, in a similar timeframe to that of object categorisation, which it has been shown to occur within the first 200 ms following stimulus offset (Proverbio, Del Zotto, & Zani, 2007; Simanova, van Gerven, Oostenveld, & Hagoort, 2010; Zhu, Drewes, Peatfield, & Melcher, 2016).

Undeniably the use of reduced viewing conditions produces an artificial situation, potentially limiting the application of findings to natural vision. Yet this technique can provide an important insight into the underlying processes of familiar size. In fact, familiar size effects are proposed to be enhanced under these viewing conditions, since the only other available cues to the objects size is the retinal size of the image (Gogel, 1969). As such, this technique provides a unique insight into processes that are not observable under regular viewing conditions.

# Chapter 2: Developmental Trajectories of Perceived Size.

This chapter explores whether or not size constancy and familiar object size develop with age, using an implicit task, i.e. simple RTs. Throughout this chapter three terms relating to size will be frequently used, these include: i) *Physical size*, which is the size of an object if directly measured, for instance the image of the aeroplane below is 6 cm wide (if shown on a 28.5 x 18 cm screen with 1440 x 900 resolution).; ii) *Familiar size*, which is our stored representation of size, for instance the familiar size of a *toy* aeroplane as depicted in figure 2.1 would be ~12 cm wide; iii) *Symbolic size*, which in this study will be the size that the familiar object represents, for instance in the image below, the toy *represents* an aeroplane, which would be +6,000 cm wide in reality. In some cases, familiar size and symbolic size information can agree with one another, for instance if a real image of an aeroplane is shown. Likewise, if an image of a crayon is shown, physical, familiar and symbolic size would all be the same.

*Figure 2.1.* An example image used to explain three different concepts of size: physical, familiar and symbolic size. The red arrow depicts the dimension of width.

In the current chapter two studies will be presented. The first experiment will investigate the influence and developmental trajectory of size constancy. In this experiment, a simplified version of the simple RT paradigm developed by Sperandio and colleagues (2009) will be used. Using this paradigm, Sperandio et al (2009) demonstrated for the first time that detection time is governed by the rules of size constancy: RTs were faster in response to stimuli perceived as bigger than those perceived as smaller, despite their fixed retinal size. Interestingly, this effect of perceived size on RTs was observed when a familiar object, a tennis ball, rather than a plain circle, was used as stimulus.

Although size constancy has been explored to a great extent in children and infants, there is still no consensus if size constancy develops with age or if it is an innate mechanism. There is evidence that a *basic* mechanism of size constancy is present from birth (Granrud, 2006; Slater et al., 1990). However, in Granrud's (2006) study, he proposes that whilst a basic size constancy mechanism is present in infants, it is possible that the complete size constancy mechanism develops later on in life. In the discussion section of this article, Granrud demonstrates that the data from infants' behaviour in his own study, reflects a slight underestimation of object size (2006). This finding supports the idea that size constancy is not completely established during infancy.

Supporting the idea that certain mechanisms of size constancy are still developing with age, several studies have demonstrated that 5-6-year-olds were impaired when making size judgments (Tronick & Hershenson, 1979; Granrud & Schmechel, 2006; Leibowitz & Hartman, 1959). Interestingly, it has also been demonstrated that the ability to use monocular contextual cues is underdeveloped in children below the age of 10 years-old. Further still, researchers have proposed that size constancy is not completely developed until the age of 13-year-old (Leibowitz & Judisch, 1967). Taken together, currently there is no general consensus as to when size-constancy is fully developed.

As such, in experiment 1 of Chapter 2, an investigation is conducted to determine if size constancy abilities change with age, using a task unrelated to the knowledge of perceived size. Specifically, visual simple RTs were made in response to a familiar object, namely an image of a tennis ball. The simple RT measure was used to assess if children ranging in age from 5-13-year-olds exhibited behaviour reflecting size constancy abilities, as previously observed in adults (Sperandio et al., 2009).

The second experiment in this chapter explored the extent to which variations in familiar object size may influence the speed of response under reduced viewing conditions. Reduced viewing conditions were used as previous research has demonstrated that when pictorial, as well as oculomotor cues to depth (e.g. eye vergence and lens accommodation) are restricted, visual perception of the image size is more influenced by the familiar size of the object (Gogel, 1969).

As research into children's perceptual experience of familiar object size is rather limited, experiment 2 was carried out to establish if familiar size is present in young children. Consideration was given to the selection of objects familiar to children and adults. Toys are objects that are highly familiar to children and many toys share a common symbolic identity to objects that are familiar to adults (e.g. a toy hammer and a real hammer). However, there are instances where the familiar size of such objects may vary considerably (i.e. a toy aeroplane and a real aeroplane). For the first time, children viewed familiar objects under reduced viewing conditions, in an attempt to enhance the influence of familiar objects size during simple RTs. Additionally, for the first time the effects of symbolic and familiar object size are measured using simple RTs.

Results from these two studies should provide us with a better understanding of the degree of development required for the mechanisms of size constancy and familiar object size to be observable.

# Experiment 1: Simple Reaction Times as a Measure of Size Constancy in School-Aged Children

The ability to determine an object's size or its distance is important in every-day life. For instance, if I see an object I intend to go to, I would probably want to know how far I would need to travel in order to get to that object. Alternatively, I might want to know how big an item is in order to avoid a collision. The ability to make such judgments is critical to maintain our own safety. As such, it should be of primary importance to assess when this ability is developed in children. For instance, if a child intends to cross the road but a car is coming, it is important that the child understands how far away that car is, in order to make the appropriate choose of whether or not it is safe to cross. From a naïve perspective, it may seem that the most appropriate way to access this knowledge is by asking the child about their perception. However, as will be outlined below, this seemingly simple task is fraught with difficulties.

Research investigating the size/distance relationship in children have predominantly examined changes in perceived size across large distances (e.g.3- 30 m), on the basis that at shorter distances (up to 3 m) size constancy would operate nearly perfectly and as such no difference in perceived size would be detected (Tronick & Hershenson, 1979). In fact, it has been shown that ocular cues such as vergence, accommodation and binocular disparity operate effectively within short distances and enable individuals to determine the correct distance of the object (Brenner & Van Damme, 1998; Hermans, 1937; Leibowitz & Moore, 1966; Leibowitz, Shiina, & Hennessy, 1972).

Although, the following presented studies tested larger distances in their methods, they still enable us to observe how size constancy mechanisms develop across a lifetime. They are also highly informative when considering methodological constraints. Measuring perceived size can be difficult, due to the subjective nature of perception. However, this is particularly true for children, whose physical and mental abilities are still developing. As such, consideration must be given to the suitability of the task to the sample used.

The majority of the research reported here used generic visual stimuli, such as plain circles or squares, with only a handful using familiar objects. In terms of the benefit of using generic stimuli, it is questionable that researchers may not have wanted familiar size to influence estimates, as has been observed before (Gogel, 1969), or if scaling familiar objects to control for visual angle was too challenging in the past. In many of the studies reviewed below, the availability of cues to distance was varied, for instance by using monocular viewing conditions (e.g. Leibowitz, Pollard, & Dickson, 1967), by removing scenic cues to distance (e.g. Tronick & Hershenson, 1979) or simply by allowing objects to be viewed in a naturalistic setting (e.g. Granrud, 2009b; Granrud & Schmechel, 2006). Such manipulations have been necessary to understand the extent to which perceived size relies on distance information. In this section, the literature concerning size constancy in children will be reviewed, highlighting several limitations in examining visual perception in young age groups, and alternative approaches of measuring children's perceptual experience will be proposed.

Two of the key researchers who have investigated size constancy in children were Carl E. Granrud and Herschel Leibowitz. Leibowitz's research in this area started in the late 50s. The first developmental study was conducted with 8 years-old boys, using a size-matching task (Zeigler & Leibowitz, 1957). The size matching task consisted of asking the participants to indicate when a comparison target, always shown at 1.5 m of distance, matched a target in height. The target was placed between 3 and 30 m away from the participant's eyes. The comparison target was a partially occluded rod that could be adjusted to match the visible height. Results showed that whilst the adults' responses fitted the expected size-distance relationship, where an increase in distance of a target of constant visual angle (VA) was perceived as increasing in size, the children's responses were better modelled by the relationship of the VA of the image with viewing distances.  In other words, children's perception was more veridical to the experienced retinal image size, particularly at viewing distances greater than 10 m. This research suggests that size constancy is not developed at age of 8.

In another study, Leibowitz and colleagues (1959) investigated the development of the moon illusion, a perceptual phenomenon whereby the moon appears to be smaller when viewed above the observer compared to when it is viewed in the horizontal plane. The authors tested the anecdotal observation that such illusion is greater in children compared to adults. Leibowitz and Hartman (1959) presented adults and children (aged between 4-11-year-old) with a 'moon-like' stimulus above them, as well as several comparison stimuli in front of them at the same distance. The task was to choose which comparison stimulus matched the 'moon' stimulus. Two versions of the experiment were conducted one outside, where the distance between the target and observer was 25 m and another indoors, where the distance between the observer and target was 10.6 m. In both cases, all participants chose the comparison stimuli that were smaller in physical size than the 'moon' stimuli. However, judgments differed according to age, such that younger participants substantially underestimated the 'moons' size, compared to adults, resulting in an enhanced illusionary experience. The authors attributed this enhanced illusion to the children's lack of experience with distant objects.

Furthermore, the authors suggest that, regardless of age, the moon illusion can be explained by the inexperience of viewing objects from the viewpoint of above, resulting in an over application of size constancy mechanisms. The illusion is a good example of size perception inaccuracy in adults, which the researchers attribute either to a lack of experience to the viewing conditions (looking up) or to the lack of familiar size for the moon itself. To put it simply, if we consider the amount of visual experience of an observer with a familiar object, like a pen, surely the observer would have experienced a pen in a myriad of visual contexts: up close, far away, in the context of background scenery, and by itself. In stark contrast, the moon is most frequently viewed within a limited context, typically a background of black, stars and possibly clouds, both of which are of an unknown size and distance to the observer. The idea that experience is behind the moon illusion, supports the hypothesis that some aspects of size perception can be learnt (Leibowitz & Hartman, 1959)

In another developmental study, Leibowitz, Pollard, and Dickson (1967), examined size constancy abilities and the role of binocular cues in children of different ages. A hundred children and adults, ranging in age between 5 and 19 years-old were asked to match the size of a generic object to a retinally stable target, whose image size subtended a constant visual angle over large distances (~ 3.81 - 60.96 m). Half of the participants from each age group viewed the stimuli under monocular conditions, whilst the remaining participants viewed the stimuli under regular binocular conditions. Under regular viewing conditions, whilst younger children tended to *underestimate* the size of stimuli at the furthest distances, the older children and adults tended to *overestimate* the size of the objects.

These effects were exaggerated under reduced viewing conditions, with all age groups apart from adults, making an increased number of under estimations. Interestingly, no differences were observed across age groups or viewing conditions when objects were viewed at the shorter distances. The authors suggested that the overestimation of object size in adults could be attributed to cognitive strategies, whereas the underestimation demonstrated by the youngest age group was ascribed to the inability to utilise monocular depth cues, such as perspective cues, which usually contribute to the estimation of objects' size.

The influence of instruction type on perceptual judgments about size was studied in adults by Leibowitz & Harvey (1969). Two types of instructions were constructed; *objective* instructions, which asked participants to use their knowledge of the objects size to make their judgment and *apparent* instructions, which instructed participants to only consider how the object appeared and to disregard any knowledge of the object size. For example, if participants were asked to judge the size of the moon, under *objective* instructions participants would judge it as big, as it is common knowledge that the moon is big, but under *apparent* instructions, it would be estimated to be small, as it appears small in the sky.

The authors found that under objective instructions size matches were relatively accurate to the physical size of the object shown, although many participants exhibited overestimation of the object size. Conversely, under apparent instruction, the matched size was close to, but not exactly matching, the retinal size of the image. Specifically, objects that were placed at further distances resulted in a decrease of perceived size, but were still perceived as relatively big, given the distance located. These findings demonstrate that participants' judgments of size can vary considerably based on the type of instructions used to collect such judgments. The influence of familiar size was also investigated in this study, with authors reporting that participants were accurate at estimating the objects size when objective instructions were given, displaying estimates more closely linked to retinal size under apparent instructions.

The effect of instructions on perceptual judgments was further investigated by Carlson and Tassone (1971), who demonstrated once again that with 'apparent' instructions, an object with a known familiar size yielded smaller size estimates at a distance than a non-familiar object of the same physical size, placed at the same distance. This effect is said to be due to the overapplication of perceived size-distance knowledge, to the known familiar size of an object. The increased size estimates of non-familiar objects size under apparent instructions has been attributed to a reduction in size constancy mechanisms with non-familiar objects, which lack a stored representation of familiar size.

Interestingly, differences between familiar and unfamiliar objects in perceived size were extinguished when the target objects were placed close to each other or another referent object was placed in the visual scene (Predebon, 1990), suggesting that the inclusion of a point of reference can aid in size judgments. Taken together, these findings highlight the importance of object familiarity in size constancy and demonstrate the permeable nature of instructions.

In summary, Leibowitz's research supports the idea that size constancy develops with age and is fully developed by the age of 11 years-old, along with other perceptual abilities, such as the use of depth cues (Leibowitz & Hartman, 1959; Leibowitz et al., 1967; Zeigler & Leibowitz, 1957). Although much of Leibowitz's work has limitations, such as the methods used to measure perceived size or small sample sizes, the findings provide an insight into the differences in perceptual experiences between adults and children.

Granrud's laboratory has also contributed greatly to the debate surrounding the development of size and distance perception. Children's metacognition of the size/distance relationship was the primary focus of their studies. In a study by Granrud & Schmechel (2006) size constancy was examined under full-viewing conditions in children aged 5-6, 9-10 years-old and adults, by means of a standard size-matching task. Findings showed that size constancy was present in all age groups. However, the youngest age group (5-6 year-olds) did not demonstrate size constancy abilities for far distances (Granrud & Schmechel, 2006).

In another study, Granrud ( 2009a) examined Leibowitz's hypothesis (1967) that children under the age of 9 are unable to use monocular depth cues in judging the size of an object at different viewing distances. Participants of various ages (5-83 years-old) were asked to perform a standard size-matching task under both monocular and binocular viewing conditions. Results revealed no effect of viewing conditions on size estimates, arguing against Leibowitz's hypothesis that children rely less on monocular cues. Interestingly, in both studies (Granrud, 2009; Leibowitz et al., 1967) children aged 5-6 exhibited under-constancy, whereas over-constancy was observed in older children (10+ years-old).

Granrud developed the 'metacognitive theory' to explain the previously mentioned age differences in size-distance judgments (Granrud, 2004). The metacognitive theory relies on the idea that the ability to make an accurate judgment of size is dependent on a conscious decision and that this decision requires an understanding of the size-distance relationship. Granrud believed that this theory could account for the majority of the developmental findings related to size perception (Granrud, 2004).

To test this theory, Granrud (2004) assessed size perception through a standard size-matching task. The study included two additional size judgment tasks: in one task judgments were made toward an actual object presented in a scene, in the other task judgments were made toward an imagined object within a scene. More specifically, in the first task, children aged between 5 and 10 years-old were presented with various photos, each photo contained target objects which was located in a scene. The scenes varied in the amount of depth cues (e.g. a field or train tracks) and whether or not familiar objects (e.g. a car or apple) were also present. The second task involved the experimenter asking the child to imagine the target at different distances within each photo. During each trial, the child was asked if the target object was really big/small or just appeared bigger/smaller. They were also asked to report any strategies used during the task.

A scoring system was developed to measure the level of knowledge about the size-distance relationship. These measures were taken to determine if children's understanding of the size-distance relationship was related to their ability to make accurate size judgments at a distance (Granrud, 2009). Results showed that there was a positive relationship between the level of knowledge and the accuracy in the estimation given for the objects' physical size compared to its appearance. Such that participants who demonstrated low size/distance knowledge also exhibited under-constancy. Interestingly, this study included a pre-test assessment to check the children's understanding of the concept of 'real' and 'apparent' size, using convex and concave lenses. These lenses were used to alter the children's perceptual experience in a controlled manner, such that the experimenter could be sure that the image would appear small or bigger, respectively.

Although this study was well-designed, it could be argued that only those with high general intelligence were capable of performing the size knowledge tasks, meaning the task could have measured intelligence as opposed to actual comprehension of the size-distance relationship. In order to test this possibility, future research should consider teaching the size-distance relationship to children with low-knowledge, to see if accuracy in perceptual and physical reports is changeable (Granrud, 2004). Moreover, a more implicit measure should be considered to avoid the confounding influence of general intelligence levels.

In contrast to Leibowitz's theory, Granrud's perspective is that size constancy is innate and differences in size judgments between age groups previously reported can be attributed to differences in metacognition, rather than perceptual development (Granrud, 2004, 2009; Kavšek & Granrud, 2012). This perspective is further supported by a plethora of studies on size constancy in infants (Granrud, 2006; Granrud et al., 1985; Kavšek, Yonas, & Granrud, 2012; Yonas, Granrud, Arterberry, & Hanson, 1986; Yonas, Pettersen, & Granrud, 1982), These studies have used implicit measures, such as looking and reaching preference, to investigate size-distance scaling in infants, the findings of these studies support the theory that size constancy abilities are present early in life.

Leibowitz's perceptual learning theory (Zeigler & Leibowitz, 1957) directly opposes the suggestions that size constancy is innate (Granrud, 2006; Slater et al., 1990). According to

Leibowitz, size-distance scaling develops with age but is independent of intelligence. The following literature demonstrates support for this theory.

One of the biggest difficulties when studying size constancy is the ability to distinguish between the effects of cognitive intellect and physiological development. One study that attempted to separate general development from intellect was carried out with teenagers who had an intellectual disability (Jenkin & Feallock, 1960). The sample had a mean age of 15 years-old, but an average intellectual age of ~8 years-old. The sample with the intellectual disability was matched by chronological age with a sample of normally-developing adolescents, who had a mean age of 13-years. The sample was also matched by intellectual age with normally-developing 8-year-old participants. Healthy adults were also included as a control group. Participants were asked to perform a size-matching task similar to the one developed by Leibowitz et al (1967). A significant difference was found between the adolescents with an intellectual disability and the control group of 8-year-olds (matched by intellectual age), with the latter exhibiting under-constancy. However, no significant difference was found between the adolescents with the intellectual disability and the control group of 13-year-olds (matched by chronological age), with both groups exhibiting a slight over-constancy. As such, the authors concluded that size constancy develops over time and is not a result of the general development of intelligence.

Such findings, along with Leibowitz's research, support the idea that size constancy develops with age and experience. However, as mentioned above, considerations should be given to the methods employed, particularly the type of questions used to measure perceived size and distance.

A common issue highlighted in this area of research is related to the instructions given to participants and the difficulty of ensuring task comprehension, which may affect the responses given (Granrud, 2004; Leibowitz & Harvey, 1969; Predebon, 1992). Particularly, many studies have aimed to clarify the difference between ‘apparent’ and ‘objective’ instructions to participants, with the former being simply ‘how big the image appears’ and the latter being ‘how big the object really is’. ‘Apparent instructions’ are believed to reflect more of a response based on retinal information. Such instructions are arguably more related to the perceptual experience, whereas ‘objective instructions’ are believed to reflect more of a response based on the known size of the object and, as such, more related to a cognitive judgment. For instance; if a tennis ball is shown far away, the size of the tennis ball would be reported as being closer to its retinal size (e.g. 1 cm) under apparent instructions, whereas under objective instructions the known size of the tennis ball (e.g. 6 cm) would be reported.

However, three major criticisms still remain for this approach. Firstly, are the instructions comprehended by the child in the way that was intended by the experimenter? Secondly, having only two question types assume that perception can only be apparent or objective and not a combination of the two. Lastly, the ability to comprehend such a question must be assumed, which infers a necessity of intelligence. Indeed, most recently, it has been argued that metacognition is the determinant of accurate and objective perceptual judgments (Granrud, 2009). Furthermore, the effect of metacognition on perceptual judgments prevailed after age was partialled out of the analysis (Granrud, 2009). Supporting the theory that the ability of the child to determine the distance of an object is determined by their ability to understand and apply size-distance principles. As such, these size effects are proposed to be independent to general development, opposing the opinion of Leibowitz and colleagues (Leibowitz & Hartman, 1959; Leibowitz & Judisch, 1967; Zeigler & Leibowitz, 1957).

Additionally, the wording of the instructions can confound the results, especially in young children. It has been reported in a language-priming study (Krahmer et al., 2013), that when words related to size were used as adjectives (e.g. the big cat), 7 year-olds were prone to greater size estimation errors towards the direction of the adjective used, compared to 10 year-olds and adults. Given the issues in controlling the question type, it would be critical to utilize a more objective, implicit task in developmental studies of size constancy in order to reduce the impact of demand characteristics, level of comprehension and intelligence.

Intriguingly, Sperandio et al (2009) used a novel approach to study size constancy in adult participants, namely a simple reaction time task (RT). In this study, pictures of tennis balls were shown at various distances, but scaled in physical size according to distance, in order to control for visual angle. It was found that RTs reflected the perceived size rather than the retinal size of the stimuli, such that those stimuli that were perceived as smaller were responded to more slowly than objects that were perceived as bigger, despite a constant visual angle. This is particularly interesting as previous psychophysics studies have demonstrated that images with large visual angles are typically responded to more quickly than small visual angles (Osaka, 1976). The advantage of using such an implicit method in developmental research is that some of the methodical issues discussed above may be eliminated.

There are several studies that have examined the children's ability to perform RT tasks (e.g. Hale, 1990; Kiselev et al., 2009; Philip, 1934). The youngest recorded age for a RT task is 4-year-olds (Kiselev et al., 2009). Notably, the mean speed of response for children of this age is around half a second slower than that of the adults (Kiselev et al., 2009). Moreover, RTs tend to decrease with an increase in age and by the age of 15 the speed of response becomes comparable to that of an adult (Hale, 1990). These aspects should be taken in to account when conducting simple RT studies in children.

The current research aims to examine whether or not size constancy develops with age using for the first time a simple RT approach. Participants of different age groups will be asked to respond to visual stimuli matched in visual angle and luminance placed at different viewing distances. Five different age groups, including an adult group, were chosen for the investigation; 12-13, 9-10, 7-8 and 5-7 years-old. The 12-13 age group was chosen since, according to Leibowitz et al (1967), this is when size constancy should be fully developed. The 9-10-year-old group was selected based on the evidence that from this age, the ability to use monocular depth cues (e.g. perspective) reaches its optimal level (Tronick & Hershenson, 1979). Finally, the 5-6 age group was included because previous research has indicated that size judgments are impaired at this age (Granrud & Schmechel, 2006; Leibowitz & Hartman, 1959). Additionally, an age group of 7-8 year-olds was included to gain a more comprehensive understanding of any possible developmental changes.

An interaction between size and age was predicted, such that adults, 12-13 and 9-10 year-olds but not younger age groups would demonstrate size constancy abilities, with faster RTs to perceived bigger objects compared to perceived smaller objects. More generally, simple RTs are predicted to decrease with increasing age, while accuracy will increase with age (e.g. Lida, Miyazaki, & Uchida, 2010; Brewer & Smith, 1989).

## Method

### Design

A 2 x 5 mixed design was implemented. There was a within-group factor of Physical size, with two levels: small and big. There was a between-group factor of Age with 5 levels: 5-7, 7-8, 9-11, 12-14-years-old and adults. The dependent variables were simple RTs and accuracy.

### Participants

Testing was conducted according to guidelines and with the approval of the University of East Anglia's Psychology Ethics review board. All participants had normal or corrected to normal vision and gave informed consent prior to testing.

Adult participants were recruited via either the UEA Psychology participant panel or UEA's SONA system. Participants volunteered for the study and were awarded with either course credits or money for their time. Handedness was assessed in adults using the Edinburgh handedness questionnaire (Oldfield, 1971; see appendix B). The dominant hand was used to respond, in order to ensure quality of RTs (Peters & Ivanoffm, 1999).

Child participants were recruited from six different schools in Norfolk, with the coordination of the gatekeeper (usually the head teacher). All schools opted for opt-out consent forms, except for the youngest age group (5-6-year-olds) which were recruited via opt-in method, in line with the guidelines of the University of East Anglia Psychology Ethics board. Consent was obtained in writing from the parent/guardian of the child taking part for the youngest age group. The children whose parents did not give consent did not take part in the testing session. The final form of consent was established through verbal consent from the child at the beginning of the testing session.

After testing, children received a debrief form for their parents to read, along with a verbal debrief and a small token gift as a compensation for their time. Children were asked to report their age in years, along with their gender and handedness. Handedness was confirmed with the observation of the hand used to press the button on the keyboard. If there was a discrepancy or uncertainty about handedness, the child was additionally asked to draw a picture, so the dominant hand could be determined. Please refer to table 1.1 below for demographic information of each age group.

Table 2.1.

*Demographic information of participants of each age group.*

| Age Group | Median Age (SD) | Gender | | Handedness | | N |
|---|---|---|---|---|---|---|
| | | Female | Male | Left | Right | |
| 5 – 7 | 6 (0.45) | 17 | 22 | 6 | 33 | 39 |
| 7 – 8 | 7 (0.27) | 11 | 8 | 1 | 18 | 19 |
| 9 – 11 | 10 (0.29) | 10 | 12 | 4 | 18 | 22 |
| 12 – 14 | 13 (0.34) | 14 | 17 | 5 | 26 | 31 |
| 18 – 45 | 20 (7.64) | 17 | 4 | 2 | 19 | 21 |

Note: Group corresponds to the range of age of participants.

Age groups were defined by the minimum possible age up to the maximum possible age. The sample size of the 5-7-year-old group and 12-14-year-old group was greater than the other age groups, as several participants had to be removed from the analysis. Indeed, a poor performance in younger age groups in RT tasks was expected, based on past research (Lida et al., 2010; Van Der Meere & Stemerdink, 1999)

**Apparatus and Stimuli**

The experiment was created and presented using E-prime version 2.0 software (Psychology Software Tools, Pittsburgh, USA). Visual stimuli were displayed on a Toshiba Tecra PC laptop. The laptop screen was 16 inches in size with a resolution of 1366 x 768 pixels. Responses were collected using a customised USB keyboard, where all buttons but the spacebar had been removed, in order to simplify data collection in the younger participants. The total luminance flux of the visual stimuli was measured and matched using a LS-100 Minolta Luminance meter. Stimuli were big and small images of tennis balls, as used in Sperandio et al's (2009) study. The luminance of the tennis balls was adjusted using the photo editing software Adobe Photoshop (version 14.2). The background of the screen was set to white (RGBA: 1, 1, 1, 1) and had an average luminance of 98.6 cd/m$^2$.

There were two experimental blocks. Each block had a total of 69 trials: 60 experimental trials (30 trials per condition) and 9 catch trials. In the 'big' block, stimuli consisted of a physically 'big' tennis ball, which was 8 cm in diameter with an average luminance of 45 cd/m$^2$. In this block the laptop was always placed 114 cm away from the participant's eyes. As such, the tennis ball subtended a retinal angle of 4 degrees. In the 'small' block, stimuli consisted of a physically 'small' tennis ball, which was 4 cm in diameter and had an average luminance of 90 cd/m$^2$. In this block, the laptop was always placed at a distance of 57 cm, to attain the same retinal image size (4 degrees of visual angle) and the same overall luminance of the physically big tennis ball.

## Procedure

Adult participants were tested in the Psychophysics laboratory of the School of Psychology at the University of East Anglia. Participants were invited to sit at the table facing the laptop. The room was dimly lit with a lamp. Prior to testing, participants were asked to read carefully and fill out the necessary forms (including an information sheet, consent form, demographics form and Oldfield's (1971) handedness questionnaires: see appendix B) Participants were instructed to keep their eyes focused on a fixation cross that presented in the middle of the screen during the entire experiment. An acoustic warning, i.e. a 'beep' was then played followed by a brief presentation of the visual stimulus. Participants were asked to press the spacebar as soon as they saw an image appear on the screen. They were also advised that catch trial, consisting of a blank screen, would be presented. During catch trials, they were asked to refrain from responding.

For the practise session, the laptop was placed 85 cm from the observer. Throughout the experiment, the laptop was placed in line with the centre of the participants' line of vision. The laptop was placed upon a platform to align the laptop screen to the eye level of the participants, however, for the younger and shorter children the use of the platform was often not necessary. The participant was asked to remain seated in the same position throughout the experiment and to avoid movements with their head and body.

A brief practice session consisting of six trials in total (2 big tennis balls, 2 small tennis ball and 2 catch trials) was used, so that participants could familiarize themselves with the task. After completing the practise, the experimenter moved the laptop to the first distance and the first block was initialised. At the start of each blocks, the participant was reminded to be as quick and as accurate as possible. The experimenter remained in the room during testing and sat behind the participant. Throughout the experiment the laptop was manually moved by the experiment to each required location.

The experimental paradigm used in this experiment was an adaption of Sperandio et al's study (2009). The experiment was shortened in order to be more appealing for younger participants and in order to conform with the University of East Anglia's Psychology Ethical guidelines of developmental studies, which dictates a maximum duration of 20 minutes for each testing session. A standard trial started with a black fixation cross (Arial font and a size of 16 pixels) shown for 1000 ms. A short warning sound, i.e. a 'beep' of 1000 Hz was then played for 1 second. A random temporal window ranging between 300 and 600 ms preceded the visual stimulus. Next, the image of the tennis ball was shown for 80 ms (see figure 2.2 for example trial).

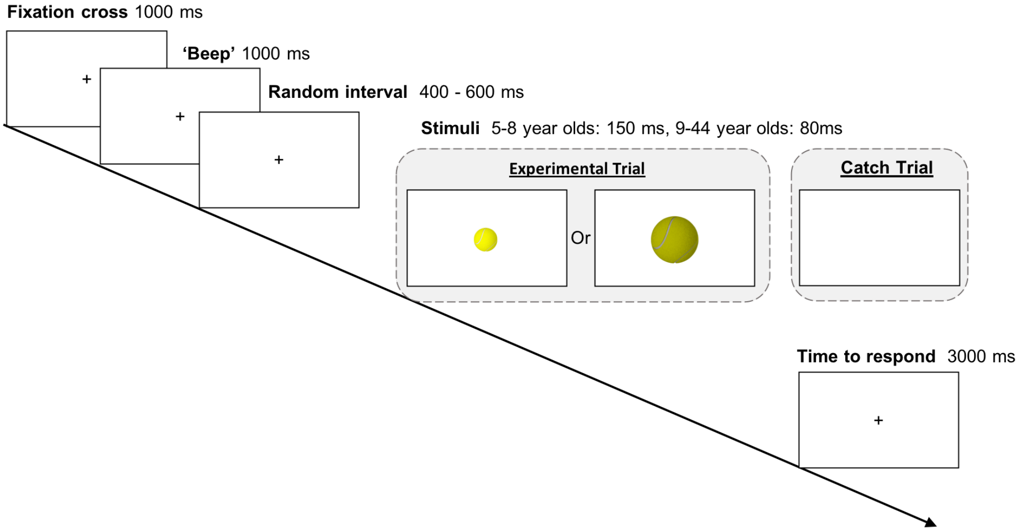


*Figure 2.2.* Example of layout of a trial. Please note while only one size of tennis ball was shown in each block, catch trials were present in both blocks.

During catch trials, no visual stimuli were shown, the screen was blank for the same duration as the experimental stimuli and participants were instructed to refrain from responding. Catch trials were included to ensure that participants were responding to the experimental stimuli and not the warning auditory cue. The following trial started either immediately after the response was made or, if no response was made, after the maximum time limit of 3 seconds was reached.

There was a short break between the two blocks. After the break, the experimenter moved the laptop to the other distance and initiated the next block. The presentation order of the two blocks was counterbalanced between participants and participants were randomly assigned to the order of each block. At the end of testing, participants were given a verbal debrief, asked if they had any questions and were given a debrief sheet. They were thanked for their time and given the appropriate compensation (credits or money).

Testing took place at the school during school hours for children. Schools provided a relatively quiet and dimly lit room with a table, chair and power source for the laptop. The final form of consent was established through verbal consent from the child at the beginning of the testing session (see the participant section for full consent details). Children were explained the procedure and asked if they would like to take part. If they did not want to take part, the aim of the study was explained to the participant, a gift was given, and the child was returned to the class. If the participant wanted to take part, the experimenter asked the child their age and gender. They were also asked about which hand they normally used to write, if the child did not know, the experimenter asked them to draw a picture and recorded the hand used to draw the picture.

After recording the demographic details, the child completed the practise session. The instructions and procedure were the same as those used with the adults, with the exception of the  inclusion of feedback.

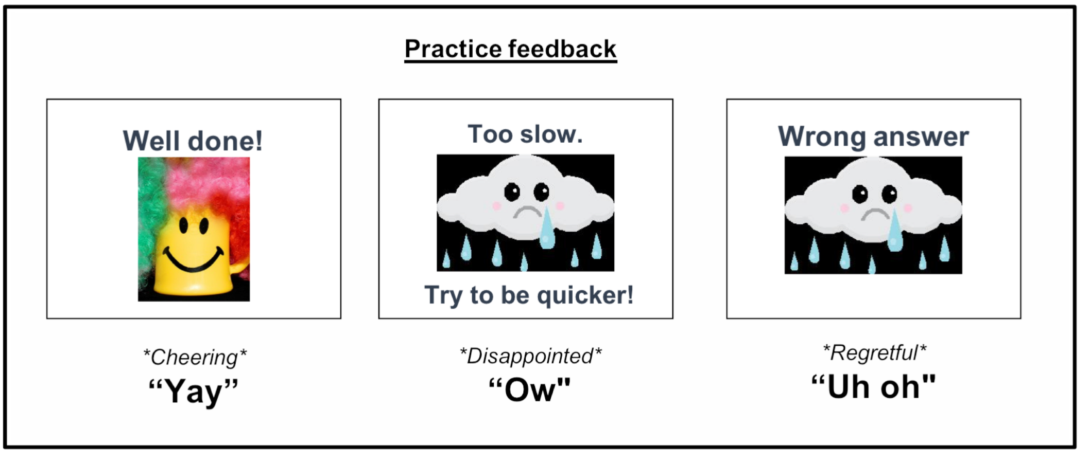


*Figure 2.3.* Example feedback screens viewed by the child participants (aged 5-14-years-old). Participants received a 'well done' (left image) feedback for responding to the tennis balls within the time limit of 3000 ms and for refraining from responding on catch trials. Participants received the "too slow" feedback (middle image) if it took them longer than 3000 ms to respond, after stimulus onset. The 'wrong answer' (right image) slide was shown if the participant responded on a catch trial.

The practise block for children consisted of 9 trials in total: 3 big tennis balls, 3 small tennis balls and 3 catch trials. The children were also provided with feedback of their performance after each trial. Three types of feedback were given: an audible cheer and a smiley face for correct responses to experimental (responding) and catch trials (not responding), a disappointed “aw” sound and sad cloud face for slow responses and an “uh oh” sound along with a sad cloud face for incorrect responses (i.e. either forgetting to respond in an experimental trial or responding during a catch trial) (see figure 2.3).

The main experiment was the same as that used for adult participants, with the exception that for younger participants (7-5-year-olds), the stimuli were displayed for a longer period of time, namely 150 ms, to allow for the additional time required by their visual system to process the visual stimuli. Specifically, as electrophysiological research has demonstrated that the latency required to process visual stimuli is longer at components P1 and N1 for children under the age of 9-years-old compared to older children and adults (Henderson, McCulloch, & Herbert, 2003; Taylor & Khan, 2000).

During the break, the experimenter checked the child was happy to continue before starting the next block. If the child did not want to continue they were returned to class and their data was excluded from the analysis. After completing the task, the experimenter gave a verbal debrief, followed by a written debrief, which was addressed to the parent/guardian. At this time any questions were answered.

## Statistical Analysis

A 2 x 5 mixed ANOVA was conducted on both RTs and accuracy with the Physical size of the tennis ball and the Age group. As previous research has suggested that accuracy may be reduced in RT studies with young children (Kiselev et al., 2009; Lida et al., 2010), the influence of accuracy on speed of response was considered. Therefore, an additional analysis was conducted, namely the inverse efficiency index (Townsend & Ashby, 1978), where task accuracy levels were incorporated in to RT performance, to account for any speed-accuracy trade-off that may have occured (for a review see: Heitz, 2014). In order to incorporate accuracy levels in to RT performance, the mean RT of each participant was divided by the accuracy for that condition. For example; if a participant achieved a mean RT of 220 ms in the small tennis ball condition but only achieved 65% accuracy during that block, the inverse efficiency score for that participant in the small tennis ball condition would be 338.

## Results

### Task Accuracy

Accuracy was measured as the percentage of correct responses for each block, considering all of the catch and experimental trials. As can be seen in table 2.2, on average children's performance (5-14-year-olds) was reasonably good (*M* = 84%, *SD* = 10.18), whereas the accuracy for adults was very high, as would be expected (see table 2.2).

Table 2.2.

*Mean accuracy (%) for each age group, along with the standard deviation (SD), range and number of participants (N).*

| Age (years) | Mean (%) | SD | Range (%) | N |
|---|---|---|---|---|
| 5-7 | 81.86 | 7.64 | 60.00 – 97.10 | 32 |
| 7-8 | 81.69 | 13.65 | 51.45 – 94.93 | 19 |
| 9-11 | 89.28 | 7.15 | 71.74 - 98.55 | 20 |
| 12-14 | 85.40 | 10.87 | 65.94 - 98.55 | 27 |
| 18+ | 95.98 | 4.85 | 84.78 – 100 | 20 |

Note. Only the data from participants who completed both blocks and performed better than chance (50%) are included in these statistics.

In terms of the accuracy criteria, a correct response to a catch trial was no response. A correct response to an experimental trial was classified as responses made between 140 ms and 650 ms for adults (Sperandio et al, 2009), therefore anticipations and delays were classified as errors. For younger children, an upper cut-off was determined by taking into account the mean RT +2 SD of the age group, as is frequently used in the literature (e.g. Dye, Green, & Bavelier, 2009; Field, 2006; Kiselev et al., 2009). The resulting cut-offs were as follows: 945 ms for 5-7-year-old and 824 ms for 7-8-year-olds. The calculated cut-off for the older age groups (i.e. 9-11-year-olds and 12-14-year-olds) were comparable to the adult upper cut-off (i.e. 602 ms and 635 ms, respectively), so the same upper cut-off of 650 ms was used for these groups.

For all child groups, the lower cut-off was the same as that of the adults (140 ms). After applying the cut-off, several participants were excluded from the analysis due to poor task performance, where accuracy fell below chance level (50%). Based on this criterion, two participants from the 5-7-year-old age group, one from the 9-11-year-old group, and four from 12-14-year-old group, were rejected. Additionally, Grubb's test (Grubbs, 1969) was used to check for outliers within each age group, resulting in the following additional removals: one participant from the 5-7-year-old group, one from the 9-11-year-old group and one from the 18-44-year-old age group.

A 2 x 5 mixed ANOVA was conducted on task accuracy. The within-groups factor was the Physical size of the tennis ball (small vs big) and the between-groups factor was the Age group (5-7, 7-8, 9-11, 12-14 and 18-44-year-olds). There was no main effect of Physical size on task accuracy ($F(1, 113)= 0.04$, $p = .851$, $\eta p^2 = .00$). As might be expected, there was a main effect of age on task accuracy ($F(4, 113)= 9.24$, $p < .001$, $\eta p^2 = .25$). Pairwise comparisons with Bonferroni correction revealed a significant difference between 5-7 and 9-10-year=olds ($p = .034$), there was also a significant difference between 18-44-year-old and all of the other age groups (all p < .01). Finally, there was an interaction between Age and Physical size ($F(4, 113)= 2.74$, $p = .032$, $\eta p^2 = .09$). Planned comparisons revealed that there was a significant difference in accuracy for 5-7-year-olds between small and big tennis ball ($t(31)= 2.91$, $p = .007$), as can be seen in figure 2.4, the 5-7-year-olds were significantly more accurate on the small physical size stimulus compared to the big physical size stimulus, while there was no significant difference between the two physical size stimuli for the adult group ($t(19)= -0.16$, $p = .878$).

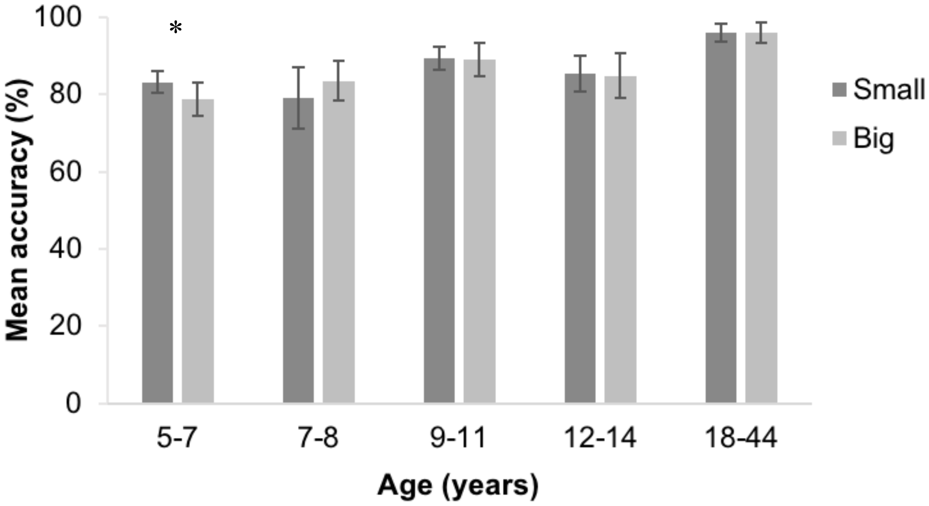


*Figure 2.4.* Mean accuracy (%) as a function of object Physical size (small vs big) and Age (5-7, 7-8, 9-11, 12-14 and 18-44-year-olds). Error bars represent +/-95% CIs. Asterisks denotes significant differences ($p < .05$).

### Simple Reaction Times

RTs were cleaned from anticipations and delays (please see previous paragraph for specific cut-offs). A mixed 2 x 5 ANOVA was conducted on RTs. The within-groups factor was Physical size (small vs big) and the between-groups factor was Age group (5-7, 7-8, 9-11, 12-14 and 18-44-year-olds). There was a main effect of Physical size on simple RT

(*F*(1, 113 = 14.54, $p < .001$, $\eta p^2 = .114$); as previously reported (Sperandio et al, 2009) RTs were faster in response to large than small tennis balls.

As might be expected, there was also a main effect of Age on simple RT (*F*(4, 113) = 19.03, $p < .001$, $\eta p^2 = .403$). Pairwise comparisons with Bonferroni correction revealed that 5-7-year-olds were significantly slower compared to 9-10-year-olds, 12-13-year-olds and 18-44-year-olds (all comparisons: $p < .001$). Interestingly, 7-8-year-olds were only significantly slower than 12-13-year-olds ($p < .001$) and 18-44-year-olds ($p = .012$) but not 9-10-year-olds ($p = .532$). All other comparisons were not significant ($p < .05$). In general, younger participants (5-10-years-olds) were slower than the other age groups, as can be seen from figure 2.5 below. Contrary to our expectations, there was no significant interaction between Physical size and Age (*F*(4,113) = 0.24, $p = .918$, $\eta p^2 = .008$).

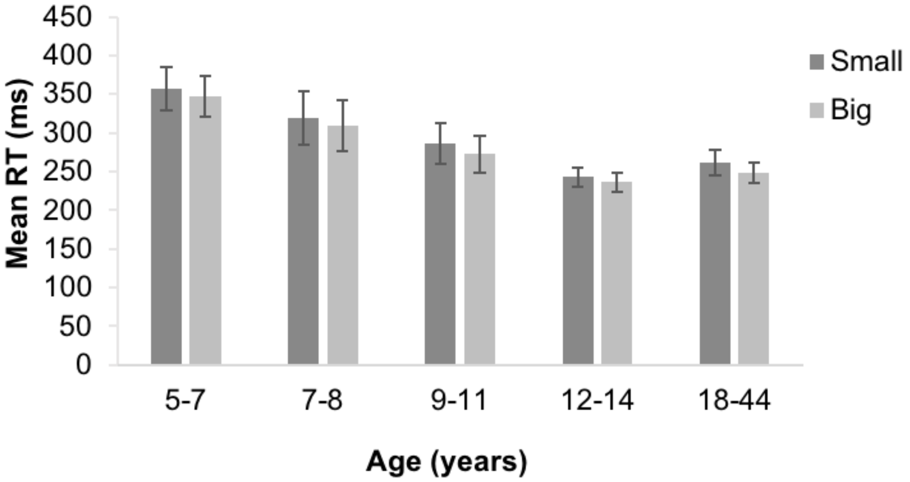


*Figure 2.5.* Mean simple RTs for each age group and physical size. Error bars represent +/- 95% CIs.

**Inverse Efficiency Index**

Due to the effects of age on accuracy and speed of response observed in the current study as well as elsewhere (Hale, 1990; Kiselev et al., 2009), an additional analysis was carried out to take into account speed and accuracy. The benefit of this analysis is that it should remove any speed-accuracy trade-off that might occur within the data (for a review see; Heitz, 2014). The statistical approach used was the Inverse Efficiency Index (Bruyer & Brysbaert, 2011), whereby the mean RT of each condition is divided by the percentage of accuracy for that condition, resulting in an inverse efficiency score (IES).

A 2 x 5 mixed ANOVA was conducted on the mean IES with Physical size and Age group as main factors There was a main effect of Physical size on IES (*F*(1, 113 = 4.46, *p* = .037, η$p^2$ = .038); the IES were significantly slower for the small (*M* = 352, *SD* = 106) compared to the big stimuli (*M* = 344, *SD* = 105). There was also a significant main effect of Age on IES (*F*(4, 113 = 27.15, *p* < .001, η$p^2$ = .490). Pairwise comparisons with Bonferroni correction revealed a significant difference in IES between 5-7-year-olds and all the other age groups (all *p* < .001) except for the 7-8-year-olds (*p* = .690). Also, the 7-8-year-olds group was significantly different from the older age groups (all p < .01). The rest of the comparisons were not significant (all *p* < .05). As can be seen in figure 2.6, 5-7-year-olds and 7-8-year-olds generally generated larger IES values compared to the other age groups.

Interestingly, there was a significant interaction between Physical size and Age on the IES (*F*(4, 113 = 3.54, *p* = .009, η$p^2$ = .111). Planned comparisons revealed that while there was no significant difference between small and big tennis ball for 5-7-year-olds (*t*(31)= -1.26, *p* = .217), 9-10 (*t*(19)= 1.69, *p* = .107), and 12-13-year-olds (*t*(26)= 0.11, *p* = .988), such comparison was significant for 7-8-years-old (*t*(18)= 2.80, *p* = .012) and the adult group (*t*(19)= 3.32, *p* = .004) (see figure 2.6).

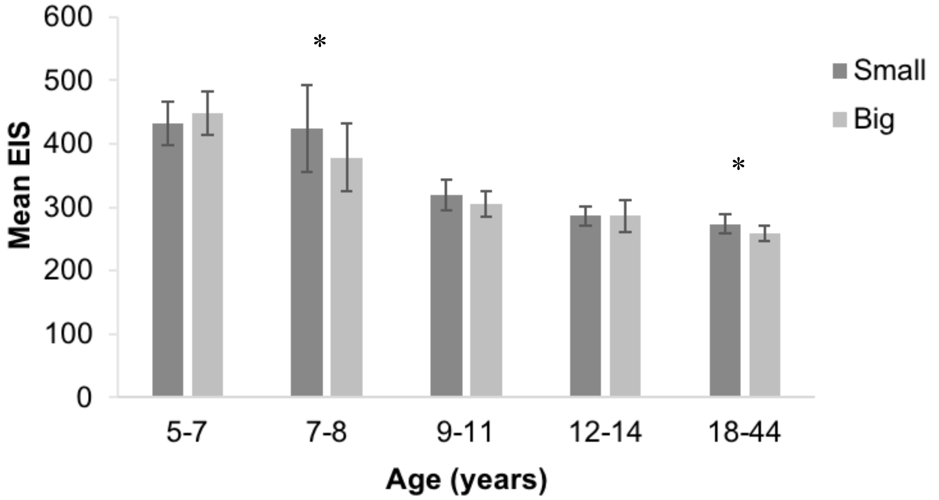


*Figure 2.6.* Mean EIS for each Age group (5-7-year-olds, 7-8- year-olds, 9-11-year-olds, 12-14-year-olds and 18-44-year-olds) and each object size (small vs big). Error bars represent +/- 95% CIs. Asterisks denotes significant differences ($p < .05$).

## Discussion

The aim of this study was to examine whether or not size constancy develops with age using for the first time a simple RT approach, using familiar object stimuli of matched luminance and visual angle placed at different viewing distances. Five different age groups were tested, including 18-44, 12-13, 9-10, 7-8 and 5-7-years-old. Simple RT results showed an effect of size, such that the bigger tennis balls were responded to more quickly than the small tennis balls of matched retinal size, replicating previous research (Sperandio et al, 2009). As one might expect (Hale, 1990; Kail, 1991; Kiselev et al., 2009; Lida et al., 2010), RT was affected by age: younger age groups were slower to react to the stimuli than older age groups. However, contrary to our expectations, there was no significant interaction between age and size, suggesting that size constancy was present in all age groups which leads to the conclusion that this mechanism does not develop with age. Importantly, findings also revealed an effect of age on accuracy, whereby younger participants were less accurate at performing the task than older participants, confirming previous findings (Lida et al., 2010).

Given this effect of age on accuracy, the Inverse Efficiency scores (IES) were calculated to assess if accuracy had an influence on task performance. In agreement with the simple RTs, the IES analysis revealed a main effect of size, where IES was larger for small compared to big objects, as well as a main effect of age, where IES values decreased with increasing age. In contrast to the simple RT finding, there was an interaction between age and size, which was driven by a significant difference between small and big stimuli for 7-8-year-olds and adult participants. However, there was a lack of significant difference for the 5-7, 9-11 and 12-14-year-olds. In the ensuing discussion, the accuracy, simple RTs and IES results are discussed in more detail, along with the contrasting findings of the simple RT and IES analyses.

**Task Accuracy**

As suggested elsewhere (Lida et al., 2010), an effect of age on accuracy was expected. In line with this expectation, younger participants tended to be less accurate at performing the task than older participants.

Specifically, adults performed better than all of the other age groups. When considering the data from the children alone, it is interesting that the only significant difference was between 5-7 and 9-10-year-olds. Intriguingly, research revealed that 9-10 years-olds outperform 7-8-year-olds but do not significantly differ in accuracy level when compared to 11-12-year-olds (Van Der Meere & Stemerdink, 1999), perhaps indicating a distinct milestone for the ability to control responses around that age. In agreement with this idea, Brewer and Smith (1989) also found that the ability to self-monitor errors in RT tasks is fully developed after the age of 9. As such, the age range of 9-10 appears to be an important timepoint in the performance of simple RT tasks.

The fact that an interaction was observed between Physical size and Age for accuracy on the task, could be due to difficulty in performing the task by young children. In a study investigating the factors involved in children's ability to perform RT tasks, the ability to self-identify errors made during task performance was the biggest contributing factor in the level of performance accuracy (Brewer & Smith, 1989). The authors suggested that younger participants (e.g. 5-year-olds) often fail to identify the cause of their errors. Typically, adult participants realize when they have missed the onset of a stimulus and adjust their behaviour accordingly. In contrast, children continue to make anticipatory errors, as they are unable to identify that they have responded incorrectly, or they realize they have made a mistake, but they are not sure how to correct their behaviour.

As such, future developmental experiments should be designed to promote self-identification of errors and children should be given strategies to improve performance (e.g. slowing down the speed of their response, to ensure they have observed the stimuli before responding). Amendments to the existing paradigm could include; the extension of the inter-trial interval, to allow participants to recover from the last trial and get ready to the next one. Alternatively, an intensive training session could be implemented in order to teach participants to self-identify their task performance. Although, a practise session with feedback was included in this study, future research could make this practise longer or more frequent (e.g. see Brewer & Smith, 1989).

### Simple Reaction Time Task

In agreement with Sperandio et al's (2009) study, all age groups responded to the physically big tennis balls more quickly compared to the physically small tennis balls.

As might be expected, simple RTs were affected by age and tended to decrease with increasing age. The effect of age on RT is well-documented in the literature (Hale, 1990; Kail, 1991; Kiselev et al., 2009; Lida et al., 2010). It is also known that children have lowered ability to inhibit responses on catch trials (Lida et al., 2010) and are characterised by a decreased speed of processing for basic stimuli, such as lights or sounds (Philip, 1934). Contrary to expectation, however, there was no interaction between Physical size and Age, which is suggestive of size constancy abilities being present in all age groups. These findings disagree with the developmental theories of size constancy (Leibowitz & Hartman, 1959; Zeigler & Leibowitz, 1957) and supports the hypothesis that size constancy is an innate ability, already present at a high-level from a young age (Andres et al., 2017; Granrud, 2006; Granrud et al., 1985; Granrud & Schmechel, 2006; Kavšek et al., 2012; A Slater et al., 1990; Yonas et al., 1986, 1982).

## The Inverse Efficiency Index

The inverse efficiency analysis was included to take in to account the impact of task accuracy on the speed of response. A common problem that can occur with RT tasks is a speed-accuracy trade-off, this is when participants focus on responding quickly but not at the appropriate time. This results in fast RTs but increased errors (for a review see: Heitz, 2014). Therefore, an inverse efficiency analysis was carried out to incorporate this cost into the RTs (Townsend & Ashby, 1978). The most interesting outcome from this analysis, was the interaction between Age and Physical size. The interaction supported the possibility that the size constancy effect observed in the original analysis in the youngest age group, could be confounded by an increased error level. In fact, the IES results show that the effect of perceived size on simple RTs tended to be in the opposite direction for the youngest age group,

When interpreting these findings, two perspectives can be considered. Firstly, it is possible that size constancy is not present in the youngest age group (as shown in the IES analysis and in agreement with the developmental theories of size constancy), but instead, high levels of inaccuracy confound the findings. Alternatively, size constancy is present in young children as shown in the RT results and in agreement with the innate theories of size constancy, but participants are unable to give manual responses in line with their perception.

Although visual acuity develops quickly after birth (Slater, 2002), and is comparable with that of an adult by the age of 5, contrast sensitivity continues to develop until the age of 8 years-old (Leat, Yadav, & Irving, 2009). Whilst visual acuity is the ability to differentiate between two physically small points, contrast sensitivity involves the detection of different wavelengths, which are responsible for the generation of colour perception. Therefore, it is possible that a child’s ability to detect the presence of the tennis ball stimuli is diminished compared to that of an adult, based on their immature contrast sensitivity.

Specifically, the contrast level between the colours yellow and white is particularly low. This decrease in contrast could be attributed to the manner in which the eye processes white and yellow wavelengths, with both colours being detected by photoreceptor cells that are sensitive to the wavelengths of red and green light. The colour yellow is the absence of activation in the blue light sensitive photoreceptor. In contrast, white light stimulates all three classes of cone photoreceptors (R, G and B), along with rod photoreceptor cells (Gregory, 1998; Hurvich & Jameson, 1951, 1957).

Traditionally, the colour yellow is frequently used to visually alert observers (e.g. a wet floor sign or ambulance). Interestingly, research involving adult participants found that the ability to differentiate within shades of yellow was easier, compared to the ability to differentiate between shades of white and black, when controlling for levels of contrast and luminance (Rabin & Wiley, 1996), supporting the idea of yellow being an easily detectable colour. However, when considering the contrast levels of the stimuli used in the current study, specifically a white background (R=255, G=255, B=255) and a yellow tennis ball (R=255, G=255, B=0), the level of contrast was low. Hence, given the differences between children and adults in contrast sensitivity, as well as the way that the colour yellow is processed by the human brain, one should carefully consider these potential issues when developing the visual stimuli. Future research should incorporate a background colour , e.g.  a standard grey (RGB: 128, 128, 128) or black (RGB: 0, 0, 0) that highly contrasts the target stimuli. Such amendments could potentially counteract any confounding influences of contrast sensitivity abilities since the contrast between the background and stimuli would be high. Finally, training for object detection over a series of sessions with feedback, would ensure children can perform the task to a high standard before testing (e.g. as in Brewer & Smith, 1989).

## Future Directions

An alternative approach to testing size constancy is with the use of virtual reality. One such study investigated the perceptual experience of size in a virtual environment, using simple RTs to capture size constancy (Plewan & Rinkenauer, 2017). In this study, a 3D version of the Ebbinghaus illusion was presented, with the inducer circles placed at different virtual depths, surrounding a target stimulus that could also be displayed at different virtual depths. The researchers did not find an effect of perceived size on RTs, contrary to previous findings (Sperandio et al., 2010). A major criticism presented by the authors, is that the virtual environment lacks naturalistic cues to distance and the absence of these cues could cause a reduction the illusionary effect. Despite this issue, future research could use a virtual reality setting to display images of familiar real object as targets, in the context of a more naturalistic style VR environment.

The advantages of using VR headsets in developmental studies is mainly the ability to control the environment across school and laboratory settings.  Specifically, schools are usually visually ‘noisy’ environments. The rooms used are often classrooms and as such sub-optimal for testing (e.g. extraneous cues to distance are often present, such as wall decoration or furniture, along with changes in the overall luminance, due to the presence of windows).

Although, the researcher will do their best to minimise the effect of these factors, they are still problematic. As such VR headsets would be particularly useful in controlling this variability.

The role of familiar size on perceived size may be further examined in future research. Previous studies has shown that performing a hobby at a professional level that requires a high level of inhibition, such as baseball, increases task performance in go no-go experiments (Kida, Oda, & Matsumura, 2005; Nakamoto & Mori, 2008). Specifically, baseball players with two years of experience of batting a baseball were better at inhibiting responses in no-go trials, compared to beginner baseball players and non-baseball players (Kida, Oda, & Matsumura, 2005; Nakamoto & Mori, 2008). Interestingly, tennis ball players perceive a tennis ball to be of a different size depending on how well they are performing, with those performing better perceiving the ball to be bigger (Witt & Proffitt, 2005). Considering these stimulating findings, it would be interesting to investigate the influence of sport experience with a specific object on task performance, using a simple RT paradigm. In future studies, it may be beneficial to measure the perceptual experience of tennis ball players to the visual stimulus (e.g. tennis ball), in order to relate the perceived size of the object with the participants match performance.

To further examine the developmental extent of these findings, it would be interesting to consider objects that are more familiar to the children, for example images of toys. Finally, to better understand the developmental trajectory of size-distance scaling, younger samples of children could be included in future studies.

## Conclusion

Our study demonstrates for the first time that simple RTs can be used as an indirect measure of size constancy to objects within a relatively near distance to the observer (< 200 cm), as participants within all age groups exhibited the size constancy effect observed in

Sperandio et al’s (2009) study. As such, it could be concluded that size constancy does not develop with age but is present at least from the age of 5 years-old. However, caution should be given when using this method with younger participants, due to the high levels of errors produced, which may confound such findings. The effect of such errors is highlighted by the IES analysis, where an interaction between age and IES score was observed. Specifically, only adults and 7-8-year-olds exhibited a difference in IES scores for the big compared to small stimuli in the expected direction. As such, future studies using this measure should implement extended training sessions, in order to improve young children’s ability to perform the RT task and increase accuracy (e.g. as in Brewer & Smith, 1989).

## Experiment 2: Does the Symbolic Size of a Toy Influence 3-6-year-olds Simple Reaction Time Performance?

**Glossary of terms**

Symbol: an object which represents another object

Symbolic size: the size denoted by the original object

Original: the first version of an object

Real size: the size of the object if directly measured

Perceived size: the subjective experience of the observer

Toys are a special kind of object, often they can symbolise another object or being. This means that although toys are typically small, they are capable of symbolising very big objects. For instance, a toy car maybe a few centimetres in length, whilst symbolising an original object which is over one-hundred times as big. The interactions a child has with these toys will usually be representative of the functions of the object. The functions of the original object will usually be constrained by other elements in the environment. For example, a car can only go down a street and cannot fit through the doorway of a house. However, these functionalities can be manipulated by children during play, where the scale of a variety of objects often differs. For instance, a child might offer a cup of tea to a dolly, who is proportionately too small to drink from such a cup. Yet, many children try to interact themselves with inappropriately sized objects. Attempting to enter doorways that are too small or climb in to cars that are too big (DeLoache et al., 2004). Such behaviour brings in to question not only the ability for a child to represent themselves in space but also their representation of the objects size. In such instances, would a child hold the representation of the object as 'big', leading them to believe that the object affords the ability to be interacted with or is it because the child is unable to consider themselves with respect to the visual scene in front of them? This study aims to address the former theory; if the semantic size inferred by an object can influence perceptual processes. Since relatively little research has been conducted on the perceptual experience of familiar object size. As such, this study will investigate the perceptual experience of children and adults, in order to establish if a semantic overlap between the symbolic toy size and the familiar object size exists and if these size related factors, differentially effect the speed of processing.

## Scale Errors

Scale errors are infrequent behaviours, that are appropriate for the type of object but inappropriate for the size of the object. This phenomenon was first formally investigated and reported by DeLoache, Uttal, & Rosengren (2004). Typically, the task would involve the child interacting with a toy at its correct size, then the child would leave the room and the toy would be replaced by a miniature replica. Even though the object was too small to be interacted with by a child, researchers observed that children still made object appropriate but size inappropriate actions toward the object. For instance, a child would attempt to sit on a miniature slide, despite their not being enough room on the slide.

The authors attributed these findings to an inability of the child to scale their movements to the size currently being experienced and instead actions reflected more of the internal representation held by the object. The authors suggest that this is a good example of a perception/ action dissociation. Opposing Goodale & Milner’s dual-route hypothesis (1992) that actions are made online, in accordance with the physical retinal sensation and not with the perceptual experience. Scale errors are mostly commonly reported in young children aged around 1 1/2 years to 4 year-olds, peaking by the age of 2 and reducing by the age of 4 (for a novel scale errors finding in adult participants, see; Casler, Hoffman, & Eshleman, 2014).

Almost a decade later, following numerous replications and extensions of the study (e.g. Boyer, Carlson, & Pasnak, 2012; Brownell, Zerwas, & Ramani, 2007; Casler, Eshleman, Greene, & Terziyan, 2011), the original research team re-investigated the phenomenon. The authors led with the theory that the size effect originally observed could be attributed to a lack of inhibition and general errors in the child’s body self-awareness (DeLoache, LoBue, Vanderborght, & Chiong, 2013). They then go on to investigate if the effects observed previously could be attributed to the child play acting or pretending with the item. Interestingly, the children would not perform scale errors, when asked to ‘pretend’ to interact with the miniature replicas. Additionally, attempts to reduce errors with a size prompt (e.g. play with the small car) or attempt to increase the scale errors, by experiencing other sized versions of the object, did not change the results originally found. Interestingly, when asked to ‘pretend’ to interact with the object, several children referred to their body size in order to justify the lack of interaction with the item (for example saying that they are too big to sit on the chair). Yet verbal prompts to the size of the object did not reduce the number of errors made. As such, the researchers conclude that the errors must *only* be made in the moment of the execution of the action and not as a part of the conscious pre-planning.

Other researchers have proposed different theories for the cause of these scale errors. One research group proposed that it was the overriding influence of the object's function that caused the effect (Casler, Eshleman, Greene, & Terziyan, 2011). In this task children aged 1.5-3.5 years-old performed children were offered different options of tools in different size with which to perform a task. Authors reported that the children always chose the object based on the associated function of the object, whilst disregarding the degree of compatibility between the tool size and the task. For example, when asked to remove a toy fish from a tank, they would opt for a fishing net, even if the net was too small to catch the fish. When a scoop was provided that was theoretically big enough to capture the fish, the child still chose the unusable fishing net. Although, when various sizes of the same tool were presented, the majority of children chose the correct size tool. Researchers conclude that errors should not be attributed to a lack in perceptual abilities but a prioritisation of action schema over size, in action judgments.

Brownell, Zerwas, & Ramani (2007) proposed that the effects could be attributed to the child's underdeveloped perception of themselves in the content of their environment. In this experiment, 17-30 months olds infants experienced multiple versions of the traditional error tasks.  The tasks consisted of the classic self-related task, involving miniaturised versions of regular toys. Less commonly used and non-size related tasks were also implemented. An example of one of these tasks, including a cloth tied to a trolley. The error would involve the child attempting to push the trolley, whilst standing on the cloth. Additional measures included the age the infant first walks, their ability to perform size variant tasks on other subjects (real or unreal) and other mood related factors (e.g. asking for help and frustration levels).

The authors conclude that traditional size related error effects, such as those exhibited in DeLoache et al's classic task (2004), can be attributed to errors in the child's self-awareness of their body and not errors in size reasoning. Particularly as they found that the number of errors made in the object-related size tasks did not significantly differ, compared to the number of errors made in the other tasks (e.g. the person-related tasks). However, there is a considerable amount of variation in the mean number of size errors made, when comparing the different object-related tasks. Perhaps such variation is an indication that the 3 tasks do not measure the same thing. Interestingly, the other-referent task, in which the children made on average the greatest number of errors, is arguably closer in nature to the classic task. In the other-referent task, the child is given clothes that are too-small to place on a doll, in the self-referent task the child is given clothes that are too small to put on themselves. As such, the idea that children inaccurately perceive the size of objects within their environment is still open for debate.

Boyer, Carlson, & Pasnak (2012) expanded on DeLoache et al's (2004) experiment by including children aged 3-4 years-old. They found that whilst performance on all tasks was generally better, errors were still made in self-referent and other-referent tasks. The authors conclude that children's ability to perceive the size of their own body *and* the size of objects in their environment is still developing at this age.

One of the more recent studies in this area, concluded that a child's ability to understand size concepts (e.g. big and small or wide and narrow), is strongly related to the frequency of scale errors (Ishibashi & Moriguchi, 2017). In this study a questionnaire was completed by the parents of the child to assess the child's ability to understand size concepts. The children also completed the standard task created by DeLoache et al (2004), plus 2 other tasks; one assessing their ability to inhibit behaviour and another to assess the ability to plan actions. Regression analysis revealed that size comprehension alone significantly predicted the number of scale errors. Although this experiment rules out several alternative influences, it is important to consider the limitations. For instance, this study used the mother's response to a questionnaire known as the "kinder inventory development scale (KIDS)", to assess the child's comprehension of size. This questionnaire has only been used in a handful of experiments and is currently only available in Japanese. As such, the extent to which these questions directly capture the ability of the child to understand size is unknown. It could be that the child's behaviour and not the intended cognitive understanding, is actually informing the mothers' responses on the task. As such additional measures would be needed in order to establish if a lack of size understanding causes scale-errors.

## Toys as Symbols

Behaviour related to the understanding of the object's symbolic category or identity is important because it shows the child understands the symbolic nature of the toy. In a preferential looking task, infants just over a year-old were able to match symbolic toys with their real object counterpart (Younger & Johnson, 2004). However, this could be interpreted as being the ability to match pictorial properties such as shape.

Adding to this finding, by the age of 20 months this ability has extended to other exemplars within the objects category. There is a possibility that visual similarities at the groups level could cause this effect (i.e. lots of animals have 4 legs). However, children at this age exhibited this behaviour across various formats of the object, including; a model and a picture of the exemplar. Different formats of the object would result in a different retinal representation, making the ability to match an object based on shape alone more difficult (Younger & Johnson, 2006).

Aside from looking tasks, there is a limited selection of behavioural evidence to suggest that children play in a categorical way, such that they are able to categorise objects based on semantic details (e.g. they would not play with both animals and vehicles at the same time). One such study investigated the natural play of children between the ages of 1 ½ - 4 ½ years-old. The toys used were miniature versions of original objects (e.g. a toy spoon) and the researchers observed the children's interaction both with and between the items (Egan & Brown, 1986). The majority of children under the age of 2 were unable to name the miniature versions of the real objects but 4-year-olds were able to name and use the toys in a semantically relevant manner (e.g. putting the spoon in a cup). Unprompted, around half of the children at this age placed the larger miniaturised objects (e.g. toy planes and ships) away from the household objects, indicative of a deeper semantic understanding. Interestingly, there is a substantial difference in symbolic size between the two object categories, as such either size or scale could have also played a role in the decision to separate these objects.

Within the first few years of life infants looking preference reflects an understanding of object categorisation. Infants not only display the ability to differentiate objects based on whether or not they are a toys, they also demonstrate an understanding certain toys belongs to certain categories (e.g. animals or vehicles) (Younger & Johnson, 2004, 2006). By the age of 4-years-old, children can play in a way that reflects the symbolic nature of the toy (e.g. using milk bottle with a dolly) (Egan & Brown, 1986). However, they are prone to make size scaling errors when interacting with toys, especially between the ages of 2 and 5 years-old (DeLoache et al., 2004).

In order to gain a deeper understanding of the perceptual system for object size, the following study will investigate the influence of familiar, symbolic & real size of an object image on participants perception. Familiar size being the size we know the object to be (e.g. a toy elephant is *small*). The symbolic size being the size represented by an object (e.g. a toy elephant represents an elephant which is *big*) and the physical size being the size of the image presented on the screen. To our knowledge this is the first experiment to investigate size in this manner.

## Hypothesis and Justification

Based on the previously mentioned research, the time required to process objects of different semantic size is not well understood, particularly in children. As such, it is possible that children may identify symbolic size before familiar or real size. From an early age children's looking preference has been demonstrated to reflect a category understanding, seen across multiple formats. Similarly, familiar object size has been demonstrated to be an automatic property of object images in adults (see Chapter 2). As such, it is possible that the categorisation of size is also automated in children. In the present study, the symbolic size of familiar objects is explored, in order to determine if symbolic size is also an automatic property of familiar object images. Further to this point, this study explores the possibility that differences between those individuals with a current learning experience of symbolic objects (children) may differ, compared to those individuals (adults) who have passed this intensive developmental stage.

Children around the age of 3-6 years-old are frequently in contact with miniature items (i.e. toys). As such, this age range is ideal to test this theory. It is proposed that adults will be faster to physically small objects (all toys and real-small objects) but not physically big objects (real-big objects only). For 5-6-year-olds, the influence of the symbolic size of the object will dominate the categorical size factor, in a similar manner to the familiar size effects observed in adults (Fisher & Sperandio, 2018). Such that objects that are symbolically big (e.g. a house) are responded to more slowly than objects that are symbolically small (e.g. a hammer). Additionally, it is proposed that size effects will not be present for 3-4-year-olds, since their perceptual system is not as sensitive to size changes, compared to older children and adults. Such insensitivity is demonstrated by their susceptible to errors in perceptually guided actions, when a target object size is altered (DeLoache et al., 2004; Ware, Uttal, & DeLoache, 2010).

It is essential that the children understand both the real and symbolic nature of the toys in our study, in order for the hypothesis to be testable. For example, if a toy ship is only ever seen as a toy and nothing else, then it would share no conceptual properties with that of a real ship. So, the possibility of any semantic overlap would not occur. Mirroring this requirement, the participants must also be able to distinguish between toys and real objects, otherwise responses will be biased to the size of the perceived category. For example, if the observer believes all the images are toys, there will be no difference in RTs because there is little variation in toy size. Research suggests that children are able to distinguish between toy or real objects (Bunce & Harris, 2013) and are able to appreciate the symbolic nature of a toy by the age of 3 (DeLoache, 2004). As such, the minimum age of participants in this study will be 3 and a short categorisation task will be performed, in order to confirm the observer's understanding of the toys category.

Under reduced viewing conditions, the perceived size of an object is more heavily influenced by familiar size (Gogel & Da Silva, 1987; Gogel & Newton, 1969). Additionally, simple RTs have been seen to reflect the commonly perceived size of an object, in both children (Experiment 1: Chapter 2) and adults (Sperandio, Savazzi, Gregory, & Marzi, 2009). A proportionate familiar size relationship was also observable in simple RT's, under reduced viewing conditions in adults (experiment 4 and 5: Chapter 3).

A simple reaction paradigm was created and images for the simple RT task were observed through reduced viewing conditions, in order to enhance the effect of familiar object size during perceptual processing. Whilst there is evidence to suggest 5-year-olds can perform speeded response time tasks (Cantor & Cantor, 1965; Simmons, Wass, Thomas, & Riley, 2002; Thomas & Nelson, 2001), there is no evidence to suggest that 3-year-olds can perform simple or choice RTs. Additionally, although monocular conditions have been used with children in the past (Granrud et al., 1985; Leibowitz et al., 1967), to our knowledge no study has attempted to use restrictive viewing conditions with 3-6-year-old children.

The current study will investigate the effect of familiar size in both real and toy objects. Performance in a categorisation task and in a simple RTs will be used as measures. It is important to note that the toys will be categorised in to two groups based on the equivalent size of the real object. For example, although a toy carrot and a toy car are around the same *physical* size, there *symbolic* size categories would be small and big respectively, due to their real-world size.

In terms of hypothesis, a significant difference in RT's based on the categorisation of symbolic size is predicted for 5-6-year-olds participants. This hypothesis is suggested, since this age groups would have lots of experience with the objects both in a symbolic and physical manner. Specifically, 5-6-year-old participants are predicted to respond faster to objects that symbolise small original objects (such as a spoon), compared to those objects that symbolise big original objects (e.g. a ship). For adults, RT's are expected to reflect the real familiar size of the objects. Specifically, adult participants will be faster in the toy-small, toy-big & real-small categories, compared to the real-big category. Since the former categories are all around the same real familiar size. In terms of developmental differences, it is predicted that there will be no significant difference in terms of categorisation accuracy between any of the age groups, as previous research has indicated that children as young as 3 can correctly categorise object images as either toys or real objects (Bunce & Harris, 2013) .

In terms of the speed to categorise the object images, no prediction will be made for the differences between adults and children, since the method of data collection was different across the groups. Ultimately, the present study aims to determine if 3-4-year-olds are capable of performing speeded responses, since limited research on the youngest age group is available. As such, it is logical to suggest that 5-6-year-olds, who are capable of performing choice RTs (Cantor & Cantor, 1965; Kiselev et al., 2009), might display faster RT's compared to 3-4-year-olds.

Generally, in the simple RT task adults are expected to be more accurate compared to both 3-4 and 5-6-year-olds, in line with general developmental trends in speeded response task performance (Cantor & Cantor, 1965; Kiselev et al., 2009). The current review of the literature, revealed an absence of speeded response research involving 3-4-year-olds. As such it is possible that this age group will not be able to make 'speeded' responses. Overall, adult participants are expected to be faster in the simple RT task compared to both 3-4 and 5-6-year-olds (Cantor & Cantor, 1965; Kiselev et al., 2009).

## Method

### Design

A 3 x 2 x 2 mixed design was used. There was a between-groups factor of Age group with 3 levels: 3-4, 5-6 or 18-21 years-old. There were 2 within-group factors. The first was the Familiar size of the object, with two levels: small and big. The Familiar size of the object was based on the *real* object size. The second within-groups factor was the Type of object, with two levels: toy and real objects (see figure 2.7. for examples). There were two dependent variables the mean RT and accuracy, as measured in both the choice and simple RT tasks.

### Participants

All testing was conducted in accordance with the guidelines and approval of the University of East Anglia's Psychology Ethics review board. All participants had normal or corrected to normal vision and gave informed consent.

Child participants were recruited from a school and nursery in the local area, via a gatekeeper at the school e.g. a head teacher or nursery manager. Opt-in or out forms were used based on the discretion of the head teacher, except for the youngest children, who all had permission granted from their parent/guardians via opt-in forms, in agreement with the UEA Psychology Ethics board. For the child participants, the experiment took place in the schools/nursery. All children were asked if they would like to take part before the study began. Age was established by asking the teacher and confirming where possible with the child. Handedness was established by the researcher by asking the child and by seeing which hand they used when asked to draw something. The eye dominance was the same as the process used with adults. All children were given a certificate of participation and a sticker for taking part.

For the adult participants, the experiment took place in a psychophysics laboratory at the University of East Anglia. Adult participants were undergraduate Psychology students recruited from UEA's SONA system. Participants volunteered their time and received course credits for participation. All adult participants gave written informed consent before testing commenced.

The participants were from 3 age groups. The first age group consisted of ten 3-4-year-olds ($M_{age}$= 4 years, SD= 6 months, 3-year-olds: N=5, 4-year-olds: N=5), three were male and 2 were left handed. Half of the participants wore the glasses for the whole session. For those participants who wore the glasses, 1 was left eye dominant, 1 was unconfirmed and the rest were right eye dominant. For any unconfirmed eye dominance, the researcher always defaulted to the right eye for consistency.

The second group consisted of twenty-eight 5-6-year-olds ($M_{age}$= 6 years, SD= 5 months, 5-year-olds: N= 11, 6-year-olds: N= 17), 16 were male, 6 were left handed. Eleven participants wore the glasses throughout the task, 3 were left eye dominant and the rest were right eye dominant. All children were typically developing. The third group consisted of 14 adults, ranging in age from 18–21-years-old ($M_{age}$= 19 years, SD= 0.84), 1 participant was male and 1 was left handed. All adult participants were right-eye dominant.

**Apparatus and Stimuli**

A hole in a piece of card was used to determine the dominant eye, using Dolman's method. Participants were given pinhole glasses to see through to do both of the computer tasks. The glasses had one central pin-size hole to see through (1 mm x 1 mm) for the dominant eye only. A mounted tube was used that led to the screen and the screen was covered by the material to prevent additional extra-retinal cues, such as external light. A Toshiba (Tecra) PC laptop was used to present the experiment. The screen size was 16 inches with resolution of 1366 x 768 pixels. The laptop had standard internal speakers to play the beep tone. An external button response box made by Black Box Toolkit Ltd, was used to record simple RT responses. A standard keyboard was used to record the questionnaire responses.

The experiment was programmed using E-Prime version 2.0 software (Psychology Software Tools, Pittsburgh, USA). A Konica Minolta LS-100 luminance photometer was used to make sure all stimuli were equated to the same average luminance (30 cd/m$^2$). All images were presented at the same size on the screen (6 cm), roughly the same distance (57 cm) from the participants and equated for the same mean luminance of 30 cd/m$^2$. A tape measure was used to ensure a standard distance. A laptop raiser was also used to bring the laptop to eye level. The background throughout the experiment was black with a mean luminance of 0.5 cd/m$^2$. In the RT task, a white cross (font Arial, size 16 pt.) was presented at the centre of the screen. In the categorisation task the buttons were grey (RGB: 128, 128, 128) with black writing (font Arial, size 16 pt.). Size and luminance of the stimuli were adjusted using GNU image manipulation program, version 2.8.6 (available at: www.GIMP.com).

Experimental stimuli were colour images of real objects. A cartoon monster was used in catch trials (see figure 2.8 for example). Children responded well to the catch trial image and generally reacted positively. All objects, including the catch trial image, were adjusted to keep within a 6 x 6 cm frame whilst maintain aspect ratio to prevent distortion, resulting in an approximate visual angle of 6° when viewed at the set distance of 57 cm. Objects had to meet 2 requirements, the type of object being either a toy or real object and the familiar size of the real object being either small or big.

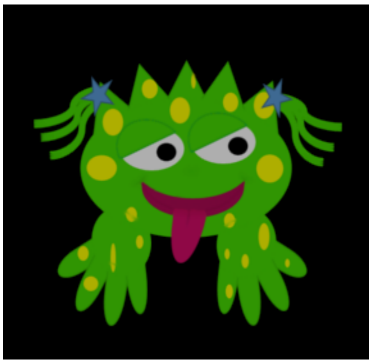


*Figure 2.7.* An example of the catch trial monster. The monster was shown to participants at the beginning of the session. Participants were told that when they see the monster they must not press the button. In the practise session feedback was provided. An ‘uh oh’ noise was made if the response was incorrect and cheering noise was made if the response was correct.

Objects were defined as being small if the real object was between 10 - 170 centimetres and big if the real object was between 300 - 2,000 centimetres. The toy objects were around the same size in real-life for both the small and the big categories (see table 2.3 for more details on size). For example, with the objects depicted below, there would be a big difference in actual size between the real tractor and real carrot but not between the toy tractor and toy carrot. Forty images were used in total (10 for each condition). The stimuli were the same in both the categorisation task and the simple RT task. Some images where purchased from dreams time (dreamstime.com), other were found online from various sources and internet searches and some were created by the researcher. See figure 2.7 for example stimuli.

Table 2.3.

*An overview of the size of the objects in the real-world. The categories of small of big are determined by the real object size.*

| Object Type | Real Object Size | |
|---|---|---|
| | Small | Big |
| Real | | |
| *Mean (SD)* | 55.06 (*49.00*) | 728.47 (*494.82*) |
| *Range* | 12.01 – 167.64 | 304 – 1828.8 |
| Toy | | |
| *Mean (SD)* | 20.98 (21.80) | 18.57 (19.04) |
| *Range* | 3 – 71.12 | 3.99 – 58.01 |

*Note.* Measurements are shown in centimetres.

*Figure 2.8.* Example image for each of the four stimuli types, as determined by the real object size. From left to right: a tractor (toy followed by real), a carrot (toy followed by real).

## Procedure

Children were taken out of the classroom by an assistant or the experimenter. The sessions took place in a quiet area located close to the classroom. The task was explained to the participant and they were asked if they would like to take part. If the child did not agree to take part they were debriefed verbally, presented with the debrief letter and returned to the class. However, if the child did agree, then the study continued, and demographic details were collected. A classification block viewed under regular binocular viewing conditions was included. In the classification block, participants classified each object image as either a ‘toy’ or ‘real’ object. The block was included to check that the objects were easily associated with the intended category

A practise was given to make sure the participant was happy with the task. Two keys were assigned, the left arrow key was to choose ‘toy’ object and the right arrow key was to choose ‘real’ object. Images were presented on the screen until a decision was made. The experimenter asked the child participant whether they thought the image was a toy or a real object, the experimenter then manually keyed in their response (see example below). The adults were asked to indicate if the object was a ‘toy’ or ‘real’ by pressing the relevant key. The response along with the time taken to respond were recorded.

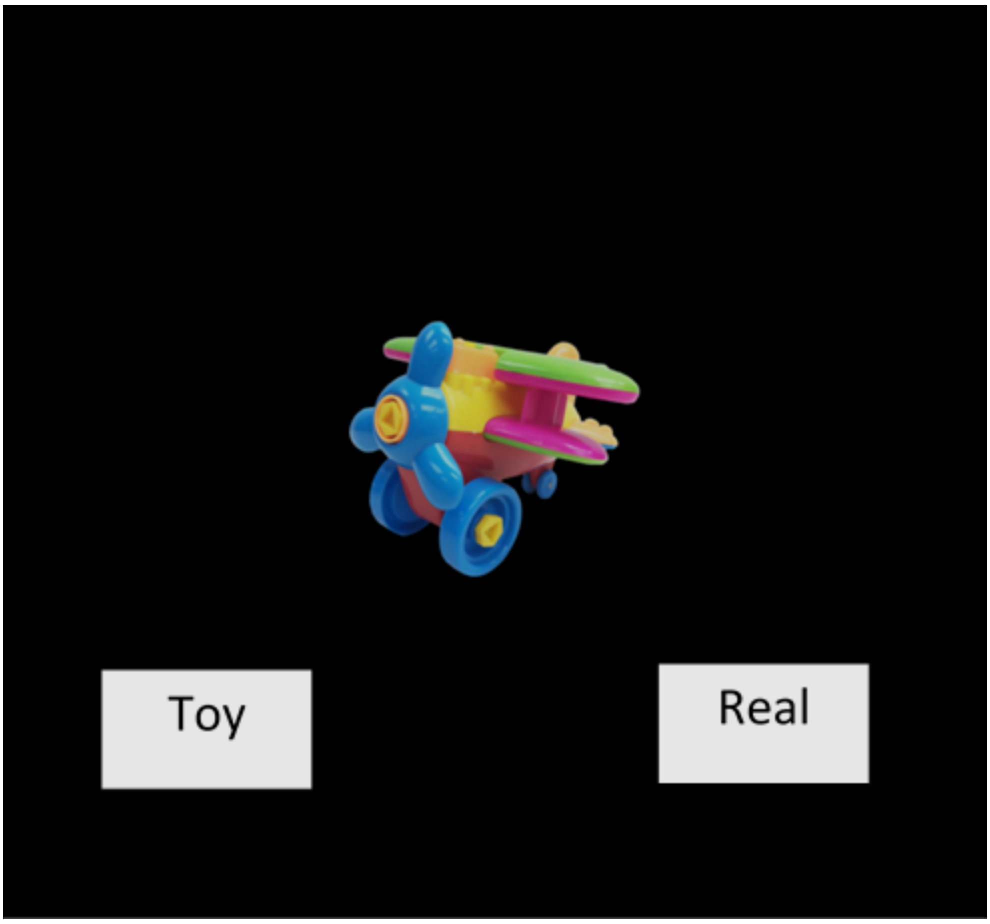


*Figure 2.9.* An example trial from the categorisation task. Here the correct answer would be ‘Toy’.

The RT task then followed. The same paradigm for the RT task was used here, as described in study, with the exception that a ‘monster’ cartoon was shown in the catch trials instead of a blank screen. First of all, a fixation cross appeared on screen (1000 ms), followed by a ‘beep’ of 1000 Hz (1000 ms), a random interval followed (400-600 ms) and then the target image was shown for 80 ms for the adults and 130 ms for the children. The additional 50 ms exposure time was given to allow for child responses, based on previous electrophysiological research findings that suggested children require more time to process visual images, compared to adults (Henderson et al., 2003; Taylor & Khan, 2000). The participant was told to press the button as soon as they observed the stimuli. A blank screen was shown, and participants had a total of 2000 ms to make their response, before the start of the next trial. Participants were told to be quick but to make sure they avoided pressing the button when the monster appeared.

The monster image was introduced at the beginning of the simple RT experiment before the task started. A practise was given and then the participants started. There were 80 experimental trials shown across 2 blocks. Each of the 40 experimental stimuli were shown once in the first block and again in the second block. There were a total 92 trials including 12 catch trials. Stimuli were presented randomly with a break between each block.

## Results

### Categorization task

**Accuracy.** The 3-4-year-old participants (N = 10) accuracy was generally quite low, ranging from 50 to 85% (*M* = 69% , *SD* = 12.75), in particular 2 participants failed to do better than chance (50%), so were removed from the analysis. After the removal of these 2 participants the accuracy within this group was still poor (*range* = 60-85%, *M* = 74%, *SD* = 8.76). For the 5-6-year-olds, accuracy for all 30 participants of this group was a slightly better, ranging from 60% - 95% (*M* = 80%, *SD* = 9.67). Accuracy for the 15 adult participants was much better, ranging from 80 - 97.5% (*M* = 89%, *SD* = 5.50).

As the responses for the children were made via a researcher, the analysis for children was separated from that of the adults, who made the responses themselves. Additionally, as the two child groups did not significantly differ in accuracy ($t(36) = -1.46$, $p = .153$), the two groups were merged in the following analysis.

The first analysis was for the child data, consisting of a 2 x 2 within-groups ANOVA, consisting of Size (big vs small) and Object type (toy vs real objects). There was a significant main effect of Object type on categorisation accuracy ($F(1, 37) = 17.04$, $p < .001$, $\eta p^2 = .315$), Toys were categorised more accurately (*M* = 86%, *SD* = 11.07), compared to images of Real Objects (*M* = 71%, *SD* = 18.48). There was not a significant main effect of

Size ($F(1, 37) = 0.1$, $p = .752$, $\eta p^2 = .003$). However, there was a significant interaction between Object Size and type ($F(1, 37) = 39.46$, $p < .001$, $\eta p^2 = .516$).

Planned comparisons revealed that there was no significant difference in categorisation accuracy between Real-Small and Toy-Small objects ($t(37) = - .06$, $p = .952$), however there was a significant difference between Real-Big and Toy Big ($t(37) = -6.58$, $p < .001$). As can be seen from figure 2.10 below, people where least accurate at categorising the Real-Big objects but most accurate at categorising the Toy-Big objects.

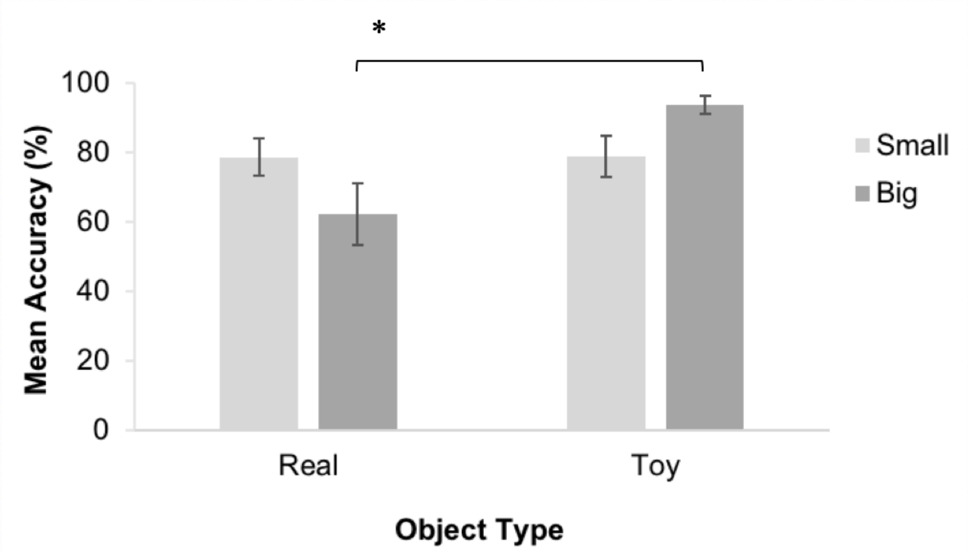


*Figure 2.10.* Mean accuracy on the categorisation task (ms) for 3-6-year-old participants, as a function of Size (small vs big), Object type (small vs big). Error bars represent +/- 95% CI's. Asterisks denotes significant difference ($p < .05$).

The same 2 x 2 within-groups ANOVA was conducted with the adult data. A similar pattern was observed within this group; there was a significant main effect of Object type on categorisation accuracy ($F(1, 14) = 28.74$, $p < .001$, $\eta p^2 = .672$), Toys were categorised more accurately ($M = 97\%$, $SD = 4.5$), compared to images of Real objects ($M = 81\%$, $SD = 10.21$). There was not a significant main effect of Size ($F(1, 14) = 3.09$, $p = .101$,

$\eta p^2 = .181$) but again, there was a significant interaction between Size and Object type ($F$(1, 14) = 7.18, $p = .018$, $\eta p^2 = .339$).

Planned comparisons were conducted and the difference between Real-Small and Toy-Small was significant ($t$(14) = -2.96, $p = .01$), along with Real-Big and Toy-Big comparison ($t$(14) = -5.15, $p < .001$). As can be seen from the figure 2.11, overall adult participants made more mistakes when categorising the Real-Big objects, compared to the other categories.

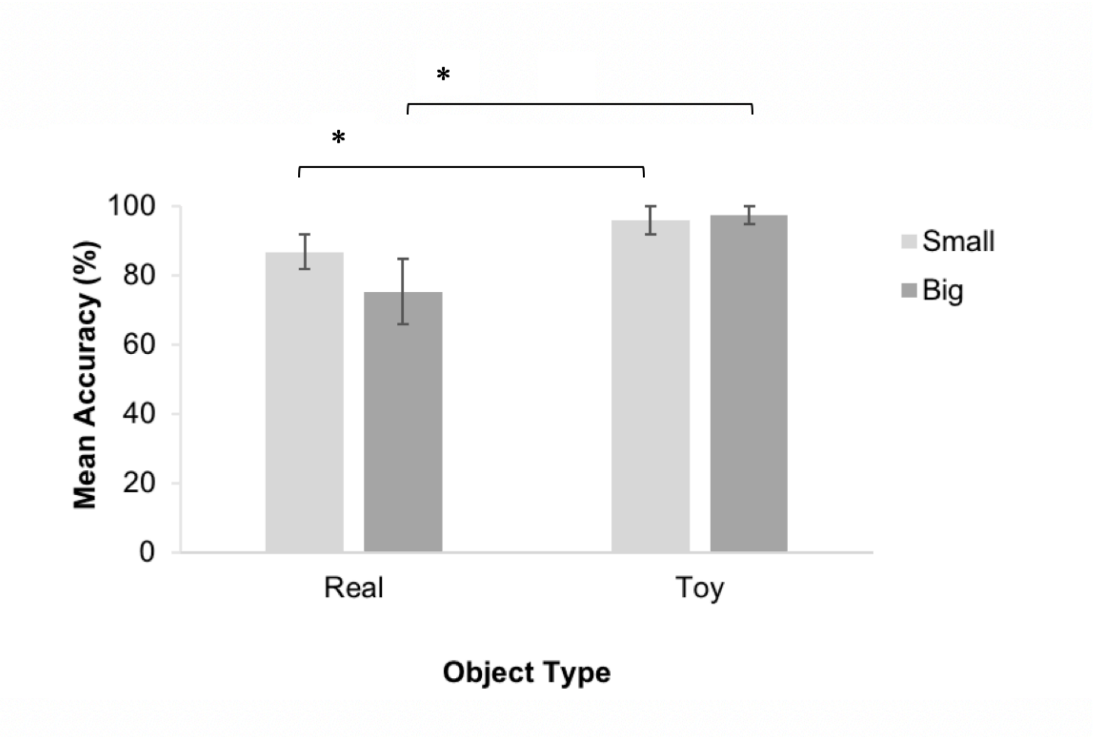


*Figure 2.11.* Mean accuracy on the categorisation task (ms) for 18-21-year-old participants, as a function of Size (small vs big), Object type (real vs toy). Error bars represent +/- 95% CI’s. Asterisks denotes a significant difference ($p < .05$).

**Choice reaction time.** All RT results are for correct responses made on the categorization task, no cut-off was applied to the categorisation RT data for all groups. Grubbs test was used to check for outliers, none of the participants mean RT's were deemed to be significant outliers. The researcher made the response on behalf of the child for this task. The reason for this decision was three-fold; the primary aim of this task was to establish the participants accuracy when categorising the object, to determine if they experienced scaling errors, as described in (DeLoache et al., 2004). As it is well known that choice RTs cause a general time cost, when compared to simple RTs (Klapp, 1995). Using this method of response minimises any additional costs from the child's ability to perform the task. Furthermore, this time cost has been demonstrated to affect not only cognitive processes but also muscle activity (Simmons et al., 2002). Finally, there is a lack of literature support to suggest that 3-4-year-olds are capable of making speeded responses, the youngest age of participants in studies using manual response times are children aged 4, where extensive task practise is usually employed (Kiselev et al., 2009; Thomas & Nelson, 2001). In addition to responding on behalf of 3-4-year-olds, researchers also respond on behalf of the 5-6-year-olds (despite the knowledge that they are able to perform such a task).

The two youngest age groups were merged again for this analysis, as they did not significantly differ from each other ($t(36) = 1.11, p = .273$). A 2 x 2 within-groups ANOVA was conducted on choice RT with Size (big vs small) and Object type (toys vs real objects) as factors.

There was a significant main effect of Object type on RTs ($F(1, 37) = 8.73, p = .01$, $\eta p^2 = .191$), participants were faster to categorise images of Toys ($M = 2{,}278$, $SD = 766$), compared to images of Real objects ($M = 2{,}619$, $SD = 766$). There was no main effect of Size ($F(1, 37) = 1.36, p = .251, \eta p^2 = .036$). There was a significant interaction between Size and Object type ($F(1, 37) = 7.55, p = .009, \eta p^2 = .169$). The planned comparisons revealed that there was a significant difference between Real-Big compared to Toy-Big objects (*t*(37) = 3.66, $p < .001$), however there was no significant difference between Real-Small compared to Toy-Small objects (*t*(37) = 1.59, $p = .120$). As can be seen from figure 2.12, Big-Toys were responded to the fastest, whilst Real-Big objects were responded to the slowest.

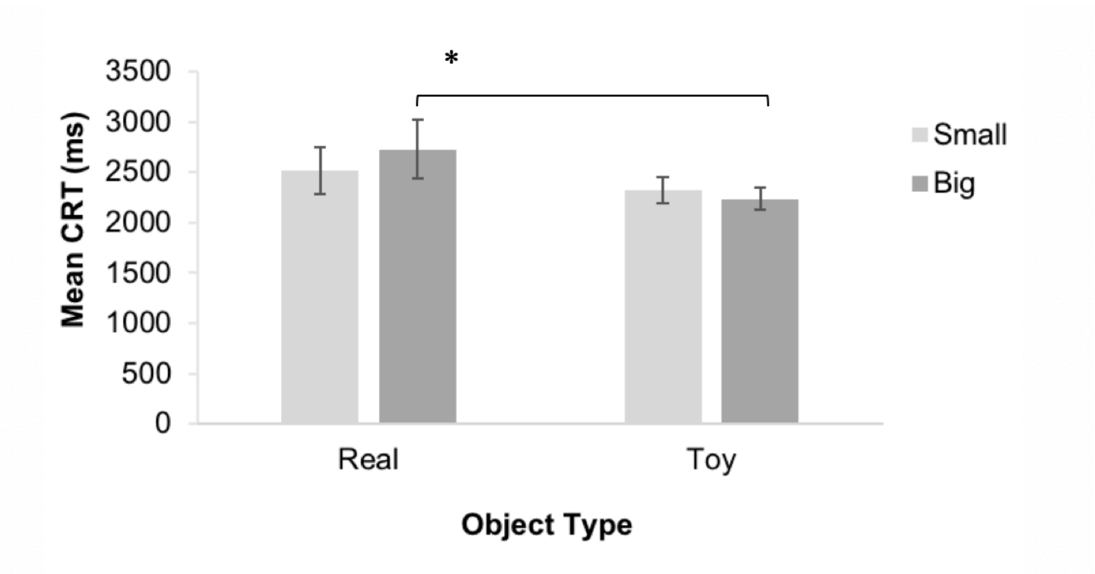


*Figure 2.12.* Mean RT for the categorisation task (ms) for participants age 3-6-year-olds, for each condition; Real (small vs big) and Toy (small vs big) objects. Error bars represent +/- 95% CI's. Asterisks denotes significant difference ($p < .05$).

The same 2 x 2 within-groups ANOVA was conducted with the adult data. There was a significant main effect of Object type on RTs ($F(1, 14) = 38.69, p < .001, \eta p^2 = .734$), participants were faster to categorise images of Toys (*M* = 931, *SD* = 153), compared to images of Real objects (*M* = 1,151, *SD* = 147). There was no main effect of Size ($F(1, 14) = 0.24, p = .638, \eta p^2 = .016$). Also, there was not a significant interaction between Size and Object type ($F(1, 14) = 0.07, p = .796, \eta p^2 = .005$). As can be seen from figure 2.13, Toys were responded to the faster than Real objects.

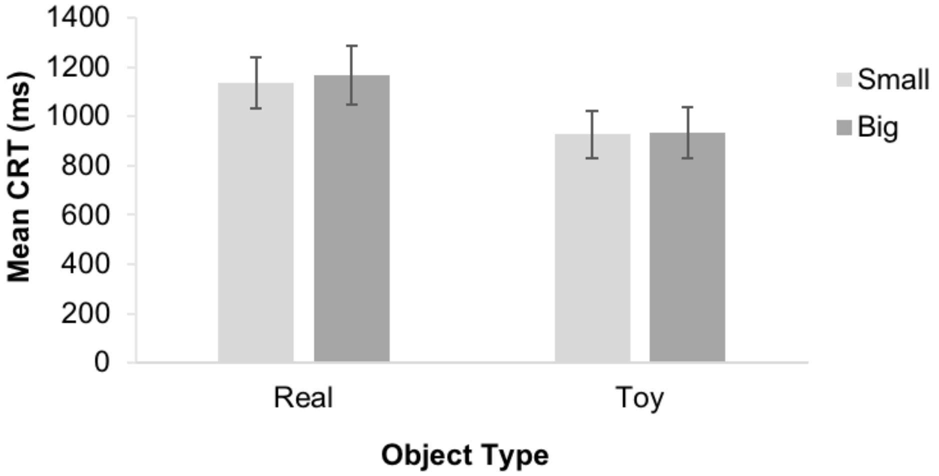


*Figure 2.13.* Mean RT for the categorisation task (ms) for participants age 18-21 years-old, for each condition; Real (small vs big) and Toy (small vs big) Objects. Error bars represent +/- 95% CI's.

**Simple Reaction Time Task**

**Accuracy.** The group of 3-4-year-olds' accuracy was generally too low (*M* = 47%, *SD* = 22.56) to be considered viable for the analysis of detection scores, as such this age groups will not be included in the following analysis.

As only a few of the 5-6-year-old children (N = 7) successfully completed both blocks, only the data from the first block was analysed for the developmental group. Two participants did not complete the first block and so were removed from the dataset. Additionally, a cut-off of 2 SD of all participant RTs (1,150ms) was used to identify late responses. After the removal of these late responses, 4 participants had to be removed due to high errors (task accuracy was below chance). After these participants were removed, there were no extreme outlying mean accuracy scores in the remaining 23 participants, according to Grubbs' test. The resulting accuracy varied substantially in the age ground, ranging from 54 - 96%, (*M* = 81%, *SD* = 13.4). A total of 13 5-6-year-old participants did not wear the pinhole glasses in this study. A preliminary analysis revealed no significant difference between the participants wearing the glasses compared to those who did not wear the glasses ($t(34) = 0.73$, $p = .473$), so these results were merged. In terms of the adult participants, two participants were removed from the sample, due to high inaccuracies (+ 25%) and a technical error. The accuracy of the remaining 12 participants was high, ranging from 84 to 100 % (*M* = 95%, *SD* = 4.38).

A 2 x 2 x 2 mixed ANOVA was conducted on simple RT accuracy. The within groups variable consisted of Size (big vs small) and Object type (toy vs real objects). The between variable was the Age of the participants (5-6-year-olds vs 18-21-year-olds). There was a significant main effect of Age on accuracy ($F(1, 34) = 6.93$, $p = .013$, $\eta p^2 = .169$), as might be expected, adults (*M* = 94%, *SD* = 5.14) were more accurate than children (*M* = 83%, *SD* = 14.15).

All the other main effects as well as interactions did not reach significance, including; Object type ($F(1,34) = 0.02$, $p = .888$, $\eta p^2 = .001$), Size ($F(1,34) = 0.05$ $p = .821$, $\eta p^2 = .002$), Size by type ($F(1,34) = 0.18$, $p = .678$, $\eta p^2 = .005$), Size by Age ($F(1,34) = 1$, $p = .324$, $\eta p^2 = .029$), Object type by Age ($F(1,34) = 0.02$, $p = .757$, $\eta p^2 = .003$) or Size by Age by Object type ($F(1,34) = 0.09$, $p = .764$, $\eta p^2 = .003$) (see figure 2.14) .

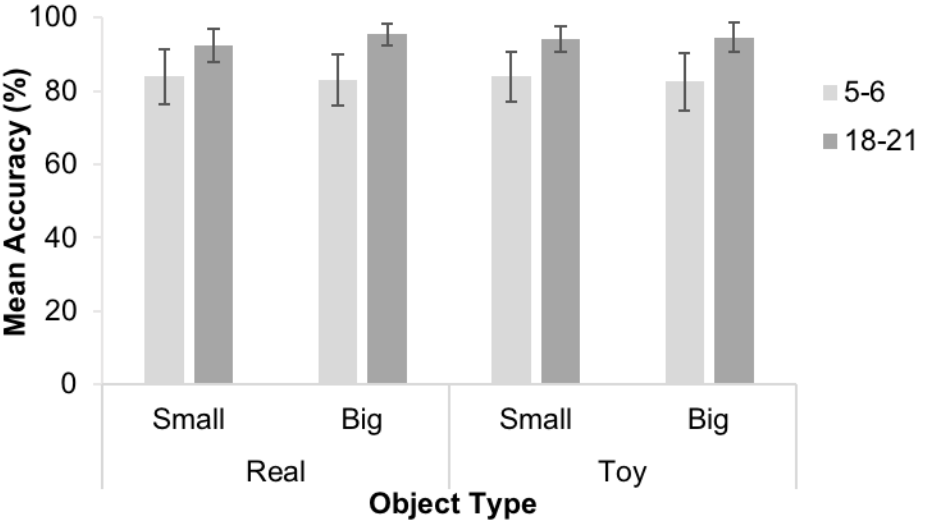


*Figure 2.14.* Mean accuracy (%) for the simple RT task, for each condition; Real (small vs big) and Toy (small vs big) Objects and for each age group (5-6 & 18-21-year-olds). Error bars represent +/- 95% CI's.

**Simple reaction times.** All responses were included from correct experimental response trials. A cut-off of 140 ms was used for anticipations for all age groups, the upper cut-off for adults was 650 ms (Sperandio et al., 2009). For the child groups a +2 SD cut-off was applied to all responses within that age group (once anticipations and misses were removed) (Kiselev et al., 2009).

There was no significant difference between the participants wearing glasses compared to not wearing glasses ($t(34) = -0.44$, $p = .662$), so these results were merged. A 2 x 2 x 2 mixed ANOVA was conducted on simple RT'. The within group variables consisted of Size (big vs small) and Object type (toy vs real objects). The between group variable was the Age of the participant (5-6-year-olds vs 18-21-year-olds).

There was a significant main effect of Age on simple RT ($F(1,34) = 18.42$, $p < .001$, $\eta p^2 = .351$), adults were faster ($M = 343$, $SD = 82.56$) than 5-6-year-olds ($M = 528$, $SD = 142$). There was no significant main effect of Size ($F(1,34) = 1.66$, $p = .207$, $\eta p^2 = .048$) or Object type ($F(1,34) = 1.93$, $p = .174$, $\eta p^2 = .054$). Similarly, none of the interactions were significant, including; Size by Object type ($F(1,34) = 0.00$, $p = .967$, $\eta p^2 = .000$), type by Age ($F(1, 34) = 0.99$, $p = .326$, $\eta p^2 = .028$), Size by Age ($F(1,34) = 1.6$, $p = .214$, $\eta p^2 = .045$) and Object type, Size and Age ($F(1,34) = 0.13$, $p = .724$, $\eta p^2 = .004$) (see figure 2.15).

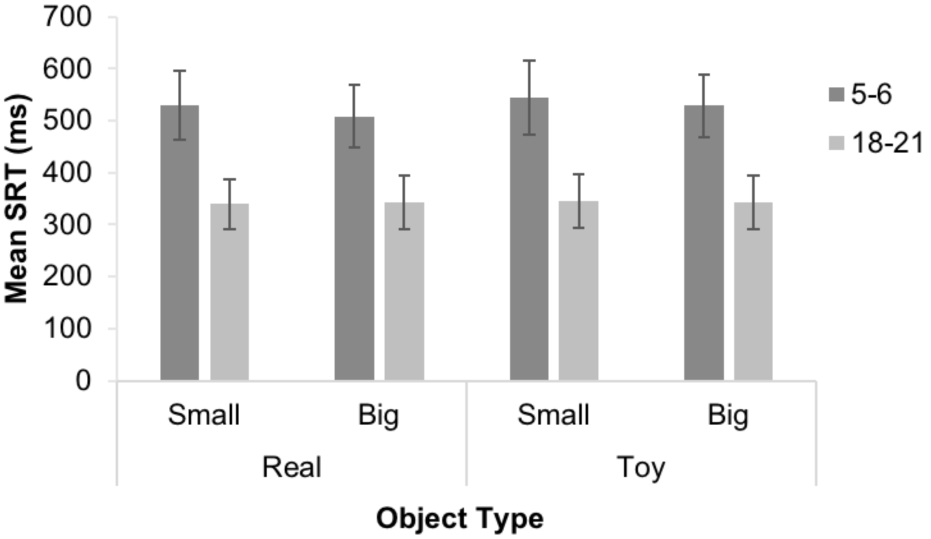


*Figure 2.15.* Mean simple RT's (ms), for each condition; Real (small vs big) and Toy (small vs big) objects and for each age group (5-6 and 18-21-year-olds). Error bars represent +/- 95% CI's.

## Discussion

The aim of this study was to assess if the symbolic size of an object is an automatic property of a familiar object image, when viewed under reduced viewing conditions. In addition, we aimed to establish if there was a difference, in the influence of symbolic size and familiar size, between those individuals with a current learning experience of symbolic objects (i.e. children), compared to those individuals who have passed this intensive developmental stage (i.e. adults). In the first task of this study, images of familiar objects were presented in a choice RT task, to establish if participants could correctly categorise each image as either a toy object or a real object. Following this task, the same images appeared in a simple RT task, this time the images were viewed under reduced viewing conditions. In both experiments all images were presented at the same physical size and with the same average luminance. Three age groups were tested, including; 18 to 21, 5 to 6 and 3 to 4-year-olds.

Overall, there was no significant difference in the categorisation task accuracy or RT, between the children aged 3 to 4 and 5 to 6-years-old. As such the data from the two groups was merged. Both the children and adults were better at categorising toys compared to real objects and produced more errors when categorising real-big objects. For the children, the ability to make the correct decision was mirrored in the speed to respond, with conditions that generated longer response times also having more errors. However, no such pattern was observed in adults.

For the simple RT task, the data from the youngest group had to be excluded, due to a low number of valid trials, along with a large proportion of participants who chose not to comply with the task instructions. In addition, the majority of 5 to 6-year-olds chose not to wear the reduction glasses during the task, although responses did not significantly differ between the non-wearers and wearers. Despite the expected developmental differences in RT and accuracy, between the 5 to 6-year-old and adult participants, there were no other significant effects. Specifically, there was no significant interaction between the Age group, the Type of object and the Familiar object size. In the following discussion, the results of the analyses for accuracy and RT for both the choice and simple RT task are discussed in more detail. Consideration is given for possible limitations of the findings and methods used, along with suggestions for future research directions.

## Categorisation Task

As was expected, accuracy and response times for the categorisation task did not significantly differ for 3-4 and 5-6-year-olds. Although the hypothesis for the time taken to perform the choice RT was correct, it was only an estimation based on previous developmental trends for RT tasks (Kiselev et al., 2009). Overall, there is a lack of research covering speeded responses for 3-year-olds. However, the accuracy finding is in direct agreement with previous research which found that from the age of 3 children are able to categorise objects as being real or toys (Bunce & Harris, 2013).

The finding that toys would be categorised more easily is unexpected. Several reasons are considered. Firstly, it is possible that the category of ‘toy’ is more specific than ‘real’ as seen in Bunce & Harris (2013). The term ‘real’ can be interpreted as being the authenticity of the object or the ontology of the object. Authenticity is the understanding intended in the present study. The meaning of authenticity is whether or not the object is the original version (e.g. you can have an authentic or a replica football t-shirt). Ontology is the idea that something is not fictional, for example a cartoon character is not real. In the aforementioned study, 3-4-year-old always referred to the authenticity of an object, whereas 5-6-year-olds often referred to the ontological status. As such, it is possible that this delay, certainly for the adults and 5-6-year-olds could be caused by the meaning of “real”. Perhaps another more specific term could be used next time for example ‘the original’. Alternatively, a definition of ‘real’ could be given before participants complete the task.

Another possibility is that differences were found based on the visual similarities within the toy group. Most toys are made from plastic, whereas the real objects are made from multiple materials. As such, future studies should only pick real objects that are matched in material to reduce variation. Interestingly, a study has been conducted investigating the difference in time spent examining toys made of different materials with 15-month-old infants.

In addition, this study also examined differences across cultures by having American and Malawian (African) participants. The Malawian children did not have experience with either plastic or wooden toys, providing a nice way to control for material experience. In contrast, the American infants had lots of experience but only with plastic toys. There were no cultural differences in this study, all of the children could generalise across the plastic animals to the wooden animals, but not the other way around. Additionally, children could not generalise across other categories or exemplars. Although some noteworthy variables were included in this study, it would be important to investigate some of these factors in isolation, in order to determine the cause of these effects.

An example of a limitation in this study is the materials used to create the stimuli. Specifically, the sensory experience of a wooden sculpted toy compared to a plastic toy differs greatly, for example; in the weight and texture of the object. Visually, the wooden models only had shading to depict the details of the animal, whereas the plastic toys had a higher level of detail, including the use of colours. The low-level features of an object are particularly important in children, as their ability to differentiate between items of low-contrast and spatial frequency is not as well-developed as in adults (Benedek, Benedek, Kéri, & Janáky, 2003; Leat et al., 2009). The aforementioned study is certainly inspirational. It would be interesting to establish if children who do not frequently experience plastic toys, could still differentiate between toys and real objects. Such findings, would add support to the theory that an objects physical property and not the degree of experience with the object, cause such categorisation effects.

Another explanation for the categorisation effect in the present study, could be that a technique was used to perform the task, such that the participant simply decided if the object was a toy. Theoretically, yes / no judgments are easier to perform, compared to multiple-choice judgments, as demonstrated by participants ability to perform faster and more accurately in such tasks (Miller & Low, 2000).

Slowing in response times for the children could have been reflective of their uncertainty when making the judgment. In which case it is interesting that adults do not demonstrate such uncertainty. Returning to the accuracy of the categorisation task, it is possible that many of the real-big objects were incorrectly perceived as being toy objects. During the development of the stimuli for this paradigm, consideration was given to the possibility that various toys can be mistaken for real objects. For instance, a toy car can sometimes look very similar to a real car, particularly when presented briefly and at a small physical size. Whilst every effort was made to select good quality real object images, future studies should conduct a preliminary study, to establish that the real-big object images clearly depict a real object.

### Simple Reaction Time Task Performance

Due to low participation and high errors, analysis was not conducted on the data from the 3-4-year-olds. The 5-6-year-olds data were only taken from one block, due to low numbers of participants who successfully completed the second block. In addition, many of the 5-6-year-old participants did not wear the pin-hole glasses for the whole session. However, statistical analysis revealed that there was no significant difference in task performance based on whether or not the participants wore the pin-hole glasses, as such the data were merged. The adult participants wore the glasses throughout the task and the data from both blocks was included in the analysis. The statistical analysis for the accuracy of simple RT's revealed that there was only a significant difference in age. As might be expected children were less accurate at performing the simple RT task, compared to adults. Similarly, children were generally slower to respond than adult participants. However, no other significant difference was found.

As there is no literature on the ability of 3-4-year-olds to perform simple RT tasks, it is a novel finding that 3-4-year-olds could not participate or in some cases persist in the simple RT task. Future studies that plan to use a simple RT paradigm with children aged 3-4-years-old, might achieve more viable data with the inclusion of multiple training sessions (e.g. as in Brewer & Smith, 1989).

Unexpectedly, the majority of the children aged between 5-6-year-olds could not complete the simple RT task under reduced viewing conditions. This finding was unexpected given that children aged 5-6 are capable of producing speeded responses (Cantor & Cantor, 1965; Simmons et al., 2002; Thomas & Nelson, 2001) and since reduced viewing conditions have been used in perceptual tasks, with children of this age (Leibowitz et al., 1967). It is proposed that the combination of these two methods was too taxing for children of this age. Future studies should implement a short training phase with children, to allow them to get used to the viewing conditions and the task.

Alternatively, the absence of a viewing condition effect for children of this age, may be because object familiar size is not prioritised in the visual system at this age. Visual reduction have been used to enhance the effects of familiar object size with adults (See Chapter 3; Gogel, 1969). In comparison, such techniques have only been used to assess the influence of distance cues in children (Leibowitz et al., 1967). As such, this experiment provides the first support for a lack of familiar size effect under reduced viewing conditions in children. Previous research has suggested that the functionality of an object and not its size, is the priority of the developing visual system (Casler, Eshleman, Greene, & Terziyan, 2011).

The mean speed and accuracy on the simple RT task was in line with the hypothesis, such that children responded more slowly and less accurately compared to adults. These findings are in line with previous research (Hale, 1990; Kiselev et al., 2009; Philip, 1934) and are suggested to be due to an improvement of inhibition control (Lida et al., 2010) and accuracy monitoring with age (Brewer & Smith, 1989). However, the absence of a simple RT effect based on familiar object size and symbolic size, was unexpected. Several reasons for these findings are now given.

Consideration should be given to the order of task presentation, with the categorisation task being performed before the simple RT task. Theoretically, the process of categorising an object may force a particular direction of processing. For instance, by categorising the images by their object type (real vs toy), it is possible that any semantic effects might be extinguished in the following task. The order of viewing conditions may have also contributed to the absence of the familiar size effect, since participants viewed the same stimuli under regular viewing conditions at a constant retinal size and distance, before taking part in the reduced viewing conditions.

Coincidentally, one of the experiments performed in experiment 5 of Chapter 3, aimed to manipulate the experience of stimuli size, in order to measure the impact on simple RTs. In the experiment, participants viewed and handled unfamiliar objects under regular viewing conditions *before* taking part in a reduced viewing condition simple RT task. Interestingly, there was no effect of retinal or experienced size on simple RT's. However, in direct contrast to the present study, the aforementioned experiment used novel objects. As such, the lack of simple RT effect in the present experiment could still be attributed to the task order effects, such that the recently experienced retinal size of the object, viewed under regular viewing conditions, may have extinguished any possible monocular effects. As such, next time the order of the two tasks should be counterbalanced.

It is possible, that too many small objects were included in this experiment, reducing the effect of the larger objects. As many of the adults incorrectly identified real large objects as toys, it is possible that many of the large objects were identified as being small, leading to a reduction in the effect. This suggestion is pertinent, since only 10 exemplars were included in each category. In comparison, previous adult experiments demonstrating familiar size effects, used 30 or 60 exemplars for each experiment (Chapter 3; experiment 4 & 5). The mean accuracy for adults in the real-big category was 75%, meaning that at least 2-3 stimuli were not identified to be big objects. As previously suggested, it would be advantageous to create a database of pre-confirmed large familiar objects, to be sure that stimuli reflect the intended familiar size.

## Future Directions

It would be interesting to explore the effect of accuracy in categorising miniature familiar big objects by inviting experts in model miniature objects (i.e. model car collectors) to perform a similar experiment to those shown here. Since experts should be more visually familiar with their expert item, they should be able to easily distinguish between the full size and miniature version of the object. Indeed, previous research has suggested that the effect of visual expertise is detectable early on in visual processing (Tanaka & Curran, 2001). As such, this sample of experts should not face the same difficulties as the adults in the present study, when categorising and responding to such images. It would be interesting to investigate if object size is an early element of this categorisation. Using a car as a test item would be particularly favourable, as there is a relatively big difference between the miniature object and the original object.

In order to examine DeLoache et al's (2004) size-scaling effect more thoroughly, future studies could use child-sized objects instead of toys, to see if the functionality of the object affects responses. For example, a child-sized seat is smaller than a regular seat but affords the same physical action. In this way, the functionality of the object can be controlled, allowing only the familiar size of the object to vary.

Interestingly, the ease of functionality is one of the key motives for including scaled objects in a preschool environment. A famous pioneer of infant education Dr Maria Montessori, introduced the use of scaled furniture within the learning environment (Montessori, 2012). The motive for using the scaled furniture was because Dr Montessori considered the accessibility of the regular adult environment to be a physical barrier to children's developmental progress. For instance, a child is more likely to sit nicely at a table if they can frequently and easily gain access to a chair and table (Montessori, 2012). As such, if children are used to interacting with objects that have a similar shape and function but vary on their ease of access, investigations into the influence of functional familiarity on perceptual responses can be explored.

## Conclusion

In this study, both 3-6-year-olds and adults were faster and more accurate at categorising toys compared to real objects. A number of explanations for this finding are given, including; the object materials used, the ability of the observe to comprehend the concept of ‘real’ and the use of a strategy during the categorisation task. Interestingly, both adults and children were more prone to making errors with object images from the real-big size category. These finding could be caused by the average size context, which was bias to a familiar small size. As such, future research should incorporate more familiar large exemplars.

For the first time, it has been found that 3-4-year-olds are unable to perform simple RT tasks. Future experiments would benefit from a series of training sessions to develop this ability (e.g. as in Brewer & Smith, 1989), this would also benefit the 5-6-year-old group who did not complete all of the blocks under the restricted viewing conditions.

Unexpectedly, there was no significant difference in simple RT’s between objects of different familiar-size in any age group. Several reasons for this finding are suggested, including; the influence of the categorisation task on the simple RT task and the lack of variation between the familiar size of the objects. Solutions to such problems would include; counterbalancing the order of the tasks and including more ‘big’ familiar object exemplars.

Future research suggestions include the use of child-size objects as stimuli instead of toys, to better explore DeLoache et al’s (2004) size-scaling finding. Another proposed study involves measuring the ability of miniature experts, such as car model enthusiasts, to categorise and respond to miniature compared to real objects. Since theoretically, objects experts should excel at such a task.

# Chapter 3: Familiar Size Effects on Reaction Time: When Congruent is Better

Previous research has demonstrated that the familiarity of an object is an important cue in visual perception (Andrés, Chambeaud, & Barraza, 2015; Bunn, Tyler, & Moss, 1998; Gogel, 1969). The ability to recognise an object as familiar is arguably a primitive skill, observable in both monkeys and human infants (Peissig, Singer, Kawasaki, & Sheinberg, 2007; Yonas, Pettersen, & Granrud, 1982). This capability is particularly fascinating as the sensory input received at the eye is ever-changing: an object's colour, size and shape can vary depending on changes in factors, such as the luminance of the environment, the distance from the observer or the orientation of the object. Consider, for instance, a cow viewed at a close distance, on a sunny day, facing towards the observer, compared to a cow located far away from the observer, on a cloudy day, facing away from the observer. The retinal image produced would vary considerably and, yet, perceptually an observer is still able to identify both images as being a cow. Many researchers support the idea that familiar objects have a stored internal representation, that can be accessed during the process of object recognition (Konkle & Oliva, 2011; Schiffman, 1967; Slack, 1956).

One critical feature of an objects identity is its familiar size. Indeed, people are generally good at inferring familiar size from images of familiar objects (Konkle & Oliva, 2011). By using different perceptual tasks, including size ranking, size adjustment and drawing, Konkle and Oliva (2011) demonstrated that participants are able to use their knowledge about the familiar size of objects to demonstrate relational size differences. The relationship between online estimates of familiar size compared to size estimates from memory have also been investigated, revealing that both estimates are relatively accurate (Bolles & Bailey, 1956). Taken together these studies demonstrate that the size of familiar objects is well-known and easily accessed.

Object features, such as shape and colour, are also powerful contributors to the identification of familiar objects (Humphreys, Price, & Riddoch, 1999). It should be clarified that the process of identifying an object to the degree of naming is more complex than simply recognising the object (Humphreys et al., 1997). Humphrey et al (1997) proposed that the process of naming an object involves top-down modulation. In terms of neurological activity, they suggest this top-down modulation is reflected in the progression of activity through the brain. Initially sensory visual input enters the early visual processing areas of the occipital lobe, spreads forward through the temporal lobe but returns once more to early visual regions, before spreading back along the temporal lobe (Humphreys et al., 1997). This return of activation reflects the contribution of relevant semantic information to the incoming activity (Humphreys et al., 1997). Interestingly, familiar size is not stated as being an important feature in either categorisation or identification processes. As such, the role of familiar size in object recognition is unaddressed.

However, top-down effects of size perception on the activity of early visual area V1 have been recently reported in fMRI studies with basic visual stimuli (Murray et al., 2006; Song, Schwarzkopf, & Rees, 2011; Sperandio, Chouinard, et al., 2012). Such research challenges the traditional understanding of the activity in V1 being solely reflective of the veridical retinal experience, as demonstrated by the existence of a retinotopic map (Engel et al., 1997). Interestingly, such research raises the possibility that familiar object size could have a similar top-down influence during object recognition, expanding Humphrey et al's (1998) theory.

Supporting Humphrey et al's (1997) theory of top-down processing for object identification, Grill-Spector and Kanwisher (2005) found that by the time participants could detect the presence of an object within the scene, they were also able to categorise that object. However, a longer stimulus duration was required by the participants to be able to name the object. For example; when presented with an image of a seagull, participants would be quicker to categorise the image as a ‘bird’ or a ‘vehicle’, than to identify if the image was a ‘seagull’ or a ‘dove’. Hence, categorisation must precede the process of direct identification during object recognition. These findings suggest that categorisation is an automatic property of object identification, as stated in the article title “As soon as you know it is there, you know what it is” (Grill-Spector & Kanwisher, 2005).

Biederman and Cooper (1992) carried out a study that investigated familiar size more directly, using a visual search task. In this study participants were asked to find certain objects within a scene. The researchers found that many factors influenced the time needed to find the target object, such as its physical position or the likelihood of its occurrence in the environment. Interestingly, they also showed that participants were slower to detect objects that were incorrectly scaled in the context of other correctly scaled objects. For instance, in a scene depicting a street, an off-sized shrunken car would be harder to detect than a regular-sized bicycle. These results are indicative of an implicit influence of familiar size expectation on attention and perception.

In another study using a speeded response task, participants were asked to make a decision about the difference in physical size between a pair of images of familiar objects (Konkle & Oliva, 2012a). The researchers found a Stroop-like effect, such that when the physical size difference between two images was incongruent to the real-life difference in familiar size (i.e. big image of a mouse compared with a small image of a bus), the participants responded more slowly, compared to when the physical size difference was congruent (i.e. a small image of an apple compared to a big image of an elephant). These findings support the idea that an objects size may be an automatic property of object recognition, since participants’ behaviour was implicitly influenced by familiar size.

The effect of conceptual size on the speed of response has previously been shown by several studies. In one such study, Sereno et al (2009) used a Stroop-like task, where participants indicated if the word presented was a word or non-word. The words were presented at one of two physical sizes, by being presented with either capital letters (BIG) or lowercase letters (small). In addition, the words semantically represented either a small or big animal. The researchers found that when the difference in semantic size was congruent with the difference in physical size of the words (i.e. “mouse” compared to “ELEPHANT”), responses were faster than when the inverse was true (i.e. “MOUSE” compared to “elephant”). The authors concluded that when a word is presented, its meaning is processed automatically, alongside the semantic features of the stimuli.

In a more recent study (Gabay et al., 2013), a priming paradigm using animals of various familiar sizes as primes and text numbers as targets, showed that the familiar size of the prime had an influence on the speed to categorise the target number as big or small. More specifically, congruency in size between the prime and target (e.g. ‘elephant’ and the number 9) was beneficial to response times, compared to incongruency (e.g. ‘elephant’ and the number 3). Such findings are supportive of the idea that the semantic size of an object is automatically abstracted from visual input and that a common conceptual size representation exists across different formats (e.g. numerical values and the physical size of an object).

In a more implicit task using simple RTs, Sperandio et al (2009) demonstrated an effect of perceived size of familiar stimuli on the speed of processing. In this task, participants were simply asked to press a button as soon as an image appeared on the screen. Viewing distance was manipulated by placing the screen at three different distances, whilst the retinal size of the stimulus was kept constant, along with the overall luminance. The experimenters found that when the stimuli consisted of a plain circle, simple RT was directly related to the retinal size of the image i.e. faster RTs to retinally bigger size. However, when the plain stimuli were replaced with an image of a tennis ball, they found that RT reflected the perceived size of the image. Such that RTs to the tennis ball that was physically big and placed at the furthest distance, was responded to more quickly compared to the tennis ball that was physically small and placed closer to the participant. These changes in RT were present, despite the fact that both stimuli subtended the same visual angle on the retina.

Previous psychophysics findings have demonstrated that simple RTs are affected by retinal size and luminance, such that stimuli that have a bigger visual angle or brighter luminance produce faster RTs, compared to the inverse conditions (Osaka, 1976). The novelty of Sperandio et al's (2009) results was the demonstration that simple RTs are also affected by *perceived* size. In fact, participants perceived the tennis balls shown at the furthest distance to be bigger and reacted to them quicker than the tennis balls shown closer to them, despite the retinal size and luminance of the image being held constant across distance. These findings support the idea that perceived size and familiar object size are automatic properties of object perception, such that they modulate basic behavioural responses, i.e. detection. In line with Sperandio et al (2009), more recent studies using visual illusions and virtual reality have reported that simple RTs reflect perceived size (Plewan et al., 2012; Savazzi et al., 2012; Sperandio et al., 2010).

Taking into consideration the literature reviewed above, here it is proposed that familiar object size may be an automatic property of object recognition, as reflected by the general ease in identifying the size of familiar objects (Bolles & Bailey, 1956; Konkle & Oliva, 2011). Supporting these direct measures, familiar size effects have also been observed through changes in response speeds in implicit tasks, as demonstrated by visual search, Stroop-like and simple RT findings (Biederman et al., 1982; Konkle & Oliva, 2012a; Sperandio et al., 2009).

To test this hypothesis, simple RTs will be measured in response to images of familiar objects. It is proposed that participants will be faster to respond to objects that have a familiar size that is big, if this size effect is caused by the perceived size of the stimuli (Sperandio et al, 2009). In contrast, based on the evidence that familiar size is automatically processed, it is hypothesised that when the familiar object size of an image is congruent to the size shown on screen (e.g. a crayon) responses will be faster, compared to when the familiar size of the object deviates from the size shown on screen (e.g. a house) (Konkle & Oliva, 2011).

Using an implicit measure (i.e. simple RT) is beneficial not only to reduce possible demand characteristics related to instructions that concern the concept of size (see Chapter 2 for more discussion), but also to have a better understanding of the influence of familiar size on the speed of processing. Currently, the effect of familiar size has been examined in more complex cognitive tasks, including Stroop and visual search tasks (Biederman & Cooper, 1992; Gabay et al., 2013; Konkle & Oliva, 2012a; Sereno et al., 2009). Simple RTs are a basic and stereotyped behavioural response, that does not require an explicit processing of the visual stimuli, unlike the previously mentioned methods that do require explicit comprehension of the objects identity or category. As such, the benefit of using a simple RT task is that the influence of familiar size on basic visual processing can be examined, without the possibility of the task influencing responses.

In the following series of experiments, the influence of familiar object size on simple RT will be investigated. Alongside this experimental question, the influence of animacy on simple RT will also be explored. Animacy is one of the cognitive dimensions most frequently explored in conjunction with familiar size (Gabay et al., 2013; Konkle & Oliva, 2012a; Rubinsten & Henik, 2002). The investigation of animacy is of particular interest, given that recent neuroimaging research has suggested that the representation of animals and non-animals is distinct in the brain in terms of anatomical pathways and general levels of activity

(Konkle & Caramazza, 2013, 2016; Zhu, Drewes, Peatfield, & Melcher, 2016). Moreover, behavioural and ERP findings have demonstrated a distinct temporal advantage for animals compared to non-animals (McMullen & Purdy, 2006; New, Cosmides, & Tooby, 2007; Proverbio, Del Zotto, & Zani, 2007), which suggests that simple RT might be faster to animate than inanimate objects.

In the present study, a visual reduction technique will be used, involving a reduction tunnel, monocular viewing and pinhole glasses, to remove the amount of depth cues to distance, such as vergence and accommodation (Epstein, 1963; Holway & Boring, 1941; Ittelson, 1951). Previous research has demonstrated that under such conditions the perceptual influence of familiar size is enhanced (Gogel & Newton, 1969). Finally, the effect of experience on simple RTs will also be considered through the introduction of novel objects (i.e. unfamiliar Lego shapes). Previous research has demonstrated that a relatively short period of visual experience with a novel object is insufficient to generate an implicit size congruency effect (Konkle & Oliva, 2012a). Therefore, in the present study, participants will be asked to visually and haptically explore the novel objects, before taking part in the RT task.

It is hoped that with this line of study a deeper understanding can be gained of the influence of familiar object size and animacy on simple RT, expanding the current understanding of object recognition and, more generally of the visual perceptual system.

Please note that experiments 3-7 have recently been published in the *Journal of Experimental Psychology: Human Perception and Performance* (Fisher & Sperandio, 2018; See appendix A).

## Experiment 3: The Influence of Familiar Size and Animacy on Simple RTs

In the first experiment, images of familiar objects were presented using a simple RT paradigm. Participants were asked to press a designated button as soon as they detected an image appearing on the screen. Stimuli were randomly presented from a selection of images chosen for their familiar size (small or big) and animacy (animate or inanimate).

Previous research has demonstrated that familiar size can speed up participants' performance in judging the physical size of an object compared to its pair but only when the object's familiar size pairing was congruent with the physical size presented on a screen (Konkle & Oliva, 2012a). To put it simply, participants were faster to respond to a small apple (11° of visual angle) presented with a big piano (18°) (congruent pairing), compared to a big rubber duck (18°) presented with a small couch (11°) (incongruent pairing).

The aim of Experiment 3 was to verify if the same effect can be generalized to simple RTs. Simple RTs can be considered as one of the most basic measures of speed of processing, whereby participants are reporting their conscious perception of the onset of a target by means of stereotyped (basic) speeded responses (Johnson et al., 1985).

Therefore, if familiar size is an automatic property of object representation (Konkle & Oliva, 2012a), then one would expect simple RTs to be faster in response to those stimuli that are physically closer to their familiar size. For example, participants should be faster to detect a picture of a mouse than a picture of an elephant, when both image sizes subtend the same visual angle.

Another cognitive dimension investigated in the present experiment was animacy. Although a large body of evidence has supported the idea of different neural mechanisms dedicated to animate and inanimate object categories (e.g. Caramazza & Shelton, 1998; Cichy, Pantazis, & Oliva, 2014; Konkle & Caramazza, 2013; Mahon, Anzellotti, Schwarzbach, Zampini, & Caramazza, 2009; McMullen & Purdy, 2006, for reviews see Gerlach, 2007; Martin, 2007), much less consensus exists as to whether or not there is an advantage for animate/living objects over inanimate/non-living objects. On the one hand, there is evidence that images of animals are detected more quickly by the observers (e.g. Li, VanRullen, Koch, & Perona, 2002; New, Cosmides, & Tooby, 2007). On the other hand, no difference across the two categories has also been reported (Praß, Grimsen, König, & Fahle, 2013; VanRullen & Thorpe, 2001). Here, the effect of animacy on simple RTs is examined. One should note that although simple RTs do not require object categorization or identification, it has been reported that detection and categorization occur simultaneously, namely as soon as the observers detect an object, they already know its category (K Grill-Spector & Kanwisher, 2005; Mack, Gauthier, Sadr, & Palmeri, 2008). Therefore, one might expect to find an effect of animacy on simple RTs.

Animacy is frequently examined in association with familiar size  (e.g. Konkle & Oliva, 2007, 2011, 2012; Gabay, Leibovich, Henik, & Gronau, 2013). Interestingly, there is fMRI evidence to indicate a tripartite organisation of neural activity for object representation such that objects are functionally organized into three cortical zones that preferentially respond to: i) large objects; ii) small objects; iii) animals (Konkle & Caramazza, 2013). This finding suggests that the representation of animate stimuli should be independent of familiar size. Therefore, it is conceivable that an effect of animacy and familiar size on RTs may be found, but not an interaction between these two factors.

The images presented in this experiment were controlled to have the same overall luminance and aspect ratio. Controlling for these factors was deemed necessary as it is well known that luminance and physical size affect RT, such that bigger and brighter stimuli on the retina typically produce faster responses (e.g. Osaka, 1976; Pins & Bonnet, 1996).

## Method

### Participants

Twenty-four participants (2 males), ranging in age from 18 to 44 years (*M*=21 *SD* = 5.52) took part in the experiment. The sample size for this and all following experiments was deemed to be appropriate to attain a moderate effect size with α = .05 and power = .80, according to calculations performed in G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) Participants were all right-handed. In this and all following experiments, participants had normal or corrected-to-normal vision, gave informed consent prior to testing and received course credits or payment for their time. All methods were compliant with the rules and regulations of the Psychology Ethics committee of the University of East Anglia.

### Apparatus

Participants sat in a dimly lit room with their head on a chin rest placed 57 cm away from a PC monitor. Visual stimuli were presented on a DELL screen (17 inches) with a screen resolution of 1280 x 1024. The stimuli and the psychophysical experiments were programmed in E-Prime version 2.0 software (Psychology Software Tools, Pittsburgh, USA). A Konica Minolta LS-100 luminance photometer was used to measure luminance of the screen and stimuli. Stimuli were displayed on a grey background with a luminance of 128 cd/m$^2$. A black fixation cross (font Arial, size 16 pt.) was presented at the centre of the screen. Size and luminance of the stimuli were adjusted using GNU image manipulation program, version 2.8.6 (available at: www.GIMP.com).

### Stimuli

Stimuli consisted of colour images of real objects matched in luminance and approximate aspect ratio. To this end, the average luminance of each image was adjusted to correspond to 40 cd/m$^2$ and the size of each image was scaled to fit inside a 6x6 cm frame, producing a visual angle of 6° when viewed at the 57 cm distance. Images were selected according to their familiar size, using a range of sizes similar to that employed by Konkle and Caramazza (2013). Those images classified as 'small' had a familiar size that ranged between 0.8 cm and 50 cm (*M*= 10.52 cm, *SD*=10.47), while those classified as 'big' had a familiar size that ranged between 76 cm and 30,000 cm (*M*=1405 cm, *SD*= 4643). Depending on the image, the maximum size could have been in height, width or length. For example, an elephant which is biggest by its length, measuring from its head to its bottom around 500 cm on average, would be placed in the ‘big’ category (note that information about actual size was collected from various internet sources). Half of the images were animate objects and the other half were inanimate (Figure 1a). The 'animate' condition included pictures of animals, while the 'inanimate' included non-living objects (Konkle & Caramazza, 2013). Images were compiled from different sources, including the Normative BOSS collections V1&V2 (Brodeur, Dionne-Dostie, Montreuil, & Lepage, 2010), Animacy x Size database (Konkle & Caramazza, 2013), Big and Small database (Konkle & Oliva, 2012b), POPORO database (Kovalenko, Chaumon, & Busch, 2012), Unique objects database (Brady, Konkle, Gill, Oliva, & Alvarez, 2013) as well as a variety of self-sourced images. For full details of image sources for this and following experiments, see Table 1 in Supplementary Materials. Headphones were given to participants to deliver a warning signal. A button response box was used to record responses.

**Design and Procedure**

The layout of each trial consisted of a black cross presented on the screen for 1000 ms, followed by a 1000 Hz ‘beep’ sound (1000 ms). After this, a random interval ranging between 400 and 600 ms was introduced before an image of a familiar object or a blank screen ('catch trial') was presented for 80 ms. A period of 2000 ms was given to allow for a response (Figure 3.1. b). Participants were instructed to respond as fast as possible to the onset of any stimulus image by pressing a designated button on a response box and to refrain from responding on catch trials. A practice block was included to ensure participants familiarized themselves with the task. There were 30 trials for each of the four conditions of stimulus presentation (small/big x animate/inanimate) plus 18 catch trials, presented in two blocks, yielding 276 trials in total. Participants were offered breaks at regular intervals to prevent fatigue. Stimuli were presented in a random fashion.

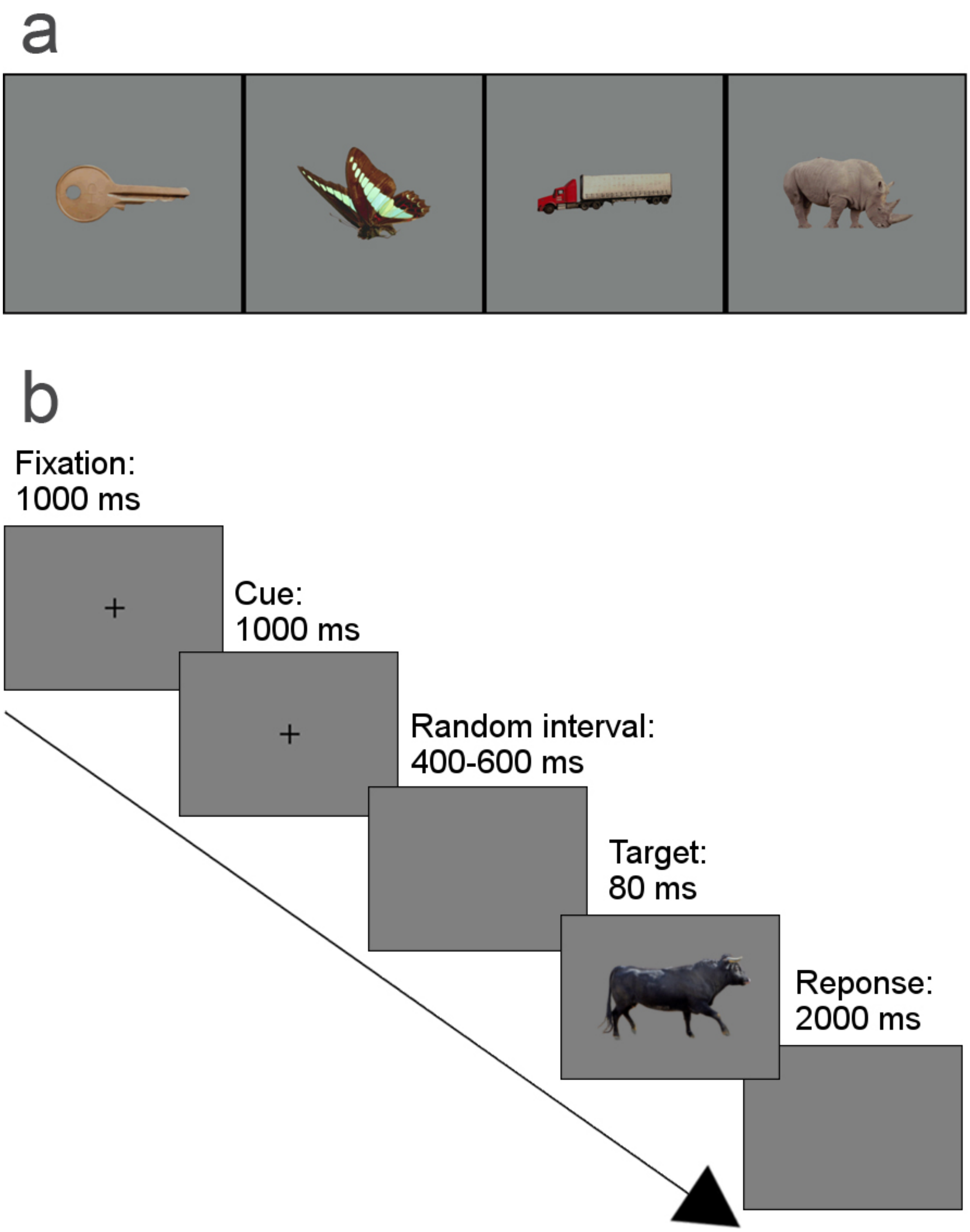


*Figure 3.1.* Stimuli and trial sequence: (A) Example of stimulus display for each experimental condition in Experiments 3 and 4. Thirty stimuli were chosen depending on their familiar size (small vs. big) and were either animate or inanimate objects. All images were adjusted to match in average luminance (30 cd/$m^2$) and fit inside a frame of fixed size (6° x 6°). The aspect ratio of each image was maintained to prevent distortion. From Left to Right: small inanimate (key), small animate (butterfly), big inanimate (lorry) and big animate

(rhinoceros). (B) Example of experimental trial sequence and timing. At the beginning of each trial a fixation cross was presented for 1000 ms followed by a warning signal. Next, a random interval (400 - 600 ms) was introduced, followed by a stimulus of 80 ms. Then, a blank screen was presented until the response button was pressed or the time limit of 2000 ms was reached. During catch trials, the stimulus was replaced by a blank screen and participants were asked to refrain from responding.

## Results

In this and in the following simple RT experiments, anticipations (RTs < 140 ms) and delayed responses (RTs > 650 ms) in relation to stimulus onset, were excluded from the analyses (Sperandio et al., 2009).

### Task Accuracy

In this experiment, all participants had high accuracy rates, ranging from 89.44 to 99.64% (*M*= 95%, *SD*= 0.03). There was no significant effect of Familiar size *(F*(1,23)= 0.08, $p$ = .777, n$p^{2}$= .004), Animacy (*F*(1,23)= 0.03, $p$ = .855, n$p^2$ = .001) or an interaction between the two factors on task accuracy (*F*(1,23)= 1.11, $p$ = .304, n$p^2$ = .046).

### Reaction Times

A 2x2 repeated measures ANOVA was conducted on the RT data with Familiar size (small vs. big) and Animacy (animate vs. inanimate) as main factors. A significant main effect of Animacy was found (*F*(1, 23)=16.78 , $p$ < .001, $\eta p^2$ = .422); participants were significantly slower to respond to inanimate (*M*= 211, *SD*= 26.73) compared to animate objects (*M*= 207, *SD*= 25.80). However, neither the main effect of Familiar size (*F*(1, 23)= 0.73, $p$ = .403, $\eta p^2$ = .031; big objects: *M*= 208, *SD*= 24.84; small objects: *M*= 209, *SD*= 27.76) nor its interaction with Animacy (*F*(1, 23)= 1.39, $p$ = .25, $\eta p^2$ = .057) were significant (figure 3.2). Therefore, contrary to our expectations, there was no effect of Familiar size on

RTs. However, in line with previous findings supporting early categorisation of objects (Clarke, Taylor, Devereux, Randall, & Tyler, 2013), an advantage was observed for animate compared to inanimate objects on the speed of response. As there was no significant effects of factor type on task accuracy, these results are not due to speed-accuracy trade-off, where increases in speed are at the cost of the ability to perform the task accurately (Heitz, 2014).

To rule out the possibility that the effect of animacy on RTs was simply related to differences in spatial frequency between animate and inanimate objects (Harel & Bentin, 2009; Viggiano, Costantini, Vannucci, & Righi, 2004), an analysis of the low-level statistical features to compare the spatial frequency spectrum between the two semantic categories was conducted, using the Natural Image Statistical Toolbox for MATLAB (Bainbridge & Oliva, 2015). As it turned out, there was no difference in terms of spatial frequency between animate and inanimate images (*p* = .86).

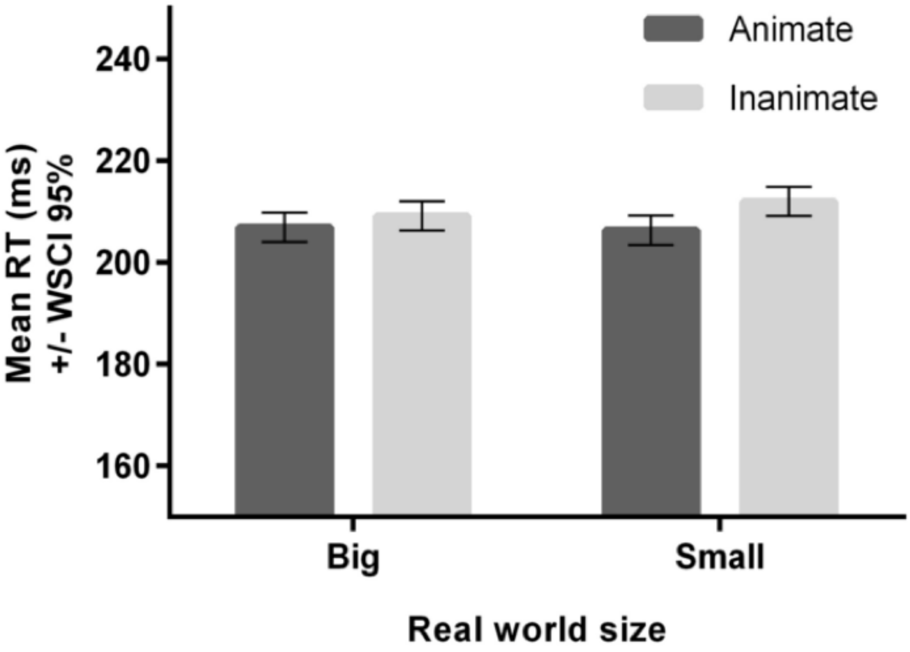


*Figure 3.2.* Results of Experiments 3: Mean RTs (ms) as a function of Familiar size and Animacy, under regular viewing conditions. Error bars represent within-subjects +/- 95% confidence intervals (WSCI) (Masson & Loftus, 2003).

## Experiment 4: The Influence of Familiar Size and Animacy on Simple RTs, Under Reduced Viewing Conditions

In experiment 4, the stimuli and design remained the same as in the previous experiment. However, restricted viewing conditions were created by means of a dark room, a reduction tunnel and a monocular pinhole (Holway & Boring, 1941; Sperandio et al., 2009). As established by Holway and Boring (1941), under these viewing conditions the availability of visual cues about distance information is greatly reduced. Specifically, the monocular viewing condition removes binocular cues (e.g. vergence and retinal disparity), pinhole vision impairs the observers' ability to accommodate, and the use of a dark room combined with a reduction tunnel eliminates contextual cues and addition light sources. Reducing these depth cues results in a decrease of depth perception, forcing the visual perceptual system to rely more on retinal size information (Holway & Boring, 1941; Sperandio et al., 2009). Therefore, under such circumstances, perceptual judgments tend to reflect retinal size rather than perceived size (i.e. the product of distance information and retinal size).

Interestingly, Sperandio et al (2009) showed that RTs to stimuli of constant retinal size were governed by perceived size only when participants were presented with images of familiar objects (i.e. tennis balls) rather than unfamiliar plain shapes (i.e. circles). However, these effects were extinguished when reduced viewing conditions were implemented: RTs to the familiar object simply reflected the retinal size of the image. It should be noted, however, that in Sperandio et al.'s (2009) study only one familiar object was used, alongside the retinal size manipulation, making it impossible to establish any effects of familiar size on RTs. Given that several previous studies have shown that under reduced viewing conditions, perception relies more heavily on familiar size information (e.g. Gogel, 1969; Epstein, 1963; Ittelson, 1951; Schiffman, 1967; Slack, 1956), experiment 3 was repeated under such restricted viewing conditions to verify whether or not familiar size can influence RTs.

## Method

### Participants

Twenty-six participants took part in the experiment. However, the data of two participants were removed due to low accuracy ( > 20% of errors) and technical difficulties. Those included in the final sample (24) ranged in age from 18 to 38 years (*M*= 22, *SD*= 4.93). Four of the participants were left-handed, 9 were left-eye dominant and 6 of them were males.

### Apparatus

To generate reduced viewing conditions, participants performed the task in an otherwise dark room and viewed the stimuli through a reduction tunnel and a 1 mm pinhole with their dominant eye. The screen's background was changed to black (0.01 cd/m2 of luminance) and the colour of the fixation cross was changed to white. Participants' eye dominance was assessed using the Dolman's method (also known as “hole-in-the-card” test; e.g. Cheng, Yen, Lin, Hsia, & Hsu, 2004). Participants wore pinhole glasses in which all the holes but the most centrally located one were covered with black tape. They then looked into a tube of 8 cm in diameter and 60 cm in length (i.e. 'reduction tunnel'). The tube led to the computer screen where the images were displayed. Headphones were given to participants to deliver a warning signal. A button response box was used to record responses.

### Stimuli

The stimuli used in this experiment were the same as in the previous experiment, however, due to changes in viewing conditions stimuli now subtended a visual angle of 5.7° instead of 6°.

### Design and Procedure

The experimental design was the same as in the previous experiment.

Participants were seated 60 cm away from the screen of the computer, in front of the end of the reduction tunnel. They were asked to wear a pair of pinhole glasses that had one central 1x1 mm aperture aligned with the dominant eye. The participant was also asked to wear headphones and to place their hand on the response button.

## Results

### Task Accuracy

The participants' accuracy ranged from 88.37 to 99.64% (M= 97%, SD= 0.03). There was no significant effect of Familiar size ($F(1,23)= 0.32$, $p = .576$, n$p^2$= .014), Animacy ($F(1,23)= 0.02$, $p = .885$, n$p^2$ = .001) or an interaction between the two on task accuracy ($F(1,23)= 2.87$, $p = .104$, n$p^2$ = .111).

### Reaction Times

A 2x2 repeated measures ANOVA was conducted on the RT data with Familiar size (small vs. big) and Animacy (animate vs inanimate) as main factors. A significant main effect of Familiar size was found ($F(1, 23)= 13.71$, $p = .001$, $\eta p^2$ = .373); participants were significantly faster at responding to Small (*M*= 275, *SD*= 51.50) compared to Big (*M*= 280, *SD*= 53.14) familiar objects. A significant main effect of Animacy was also found ($F(1, 23) =20.7$, $p < .001$, $\eta p^2$ = .474); as observed in Experiment 3, participants were significantly slower at responding to inanimate (*M*= 282, *SD*= 51.66) compared to animate objects (*M*= 274, *SD*= 52.84). However, the two-way interaction did not reach significance ($F(1, 23) = 0.81$, $p = .379$, $\eta p^2$ = .034) (figure 3.3).

Under reduced viewing conditions, we replicated the effect of animacy observed in experiment 3; RTs in response to pictures of animals were faster than non-animals. This suggests that that advantage in processing animate stimuli is independent to the changes in viewing conditions, as the animacy effect on RT was observed both under natural (experiment 3) and reduced (experiment 4) viewing conditions. Again, such effects are independent of task-accuracy.

We also found an effect of size, such that there was an advantage in RTs for small objects compared to big objects, indicating that RTs are modulated by familiar size but only under restricted conditions of observation, when depth cues are removed.

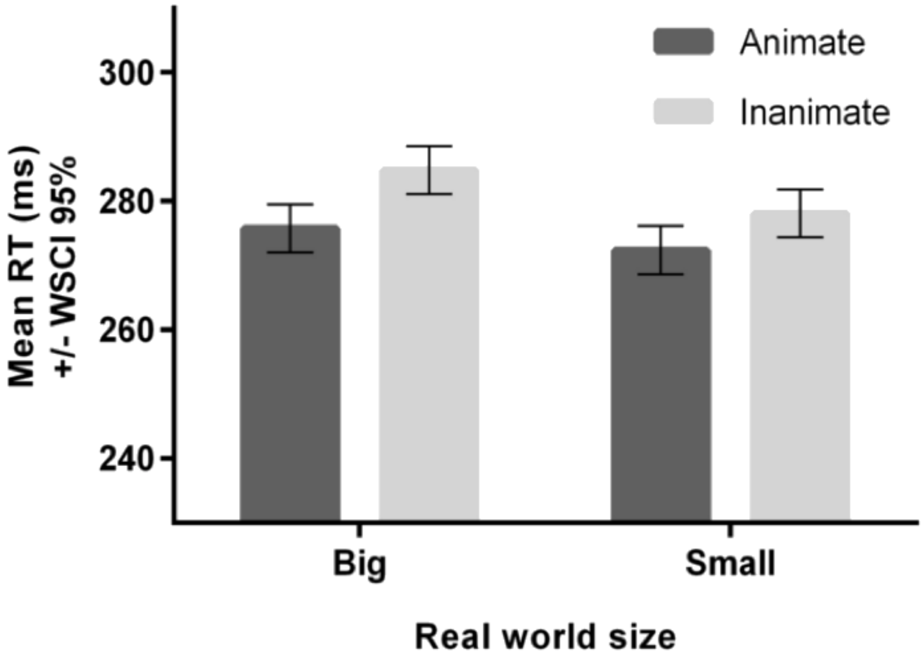


*Figure 3.3.* Results of Experiments 4: Mean RT (ms) as a function of Familiar size and Animacy, under reduced viewing conditions. Error bars represent within-subjects +/- 95% confidence intervals (WSCI) (Masson & Loftus, 2003).

### Experiments 5 and 6: Is the Effect of Familiar Size on Simple RTs Proportionate?

The main aim of the following two experiments was to verify whether or not simple RTs are systematically affected by familiar size when off-sized versions of familiar objects (i.e. bigger or smaller on the screen compared to their size in the real-world) are viewed under restricted conditions of observation. In experiment 5, familiar objects of normal-size to progressively under-size, were shown on the screen with constant aspect ratio. In experiment

6, familiar objects of normal-size to progressively over-size were shown on the screen with constant aspect ratio. Objects were considered to be normal-sized if their physical size on the screen corresponded to a visual angle that was consistent with the typical size of the object viewed at a typical distance. For example, a candy would need to be placed at 60 cm of viewing distance to subtend 5.7° of visual angle, while a double-decker bus would need to be placed 122 m away from the participant's eyes to generate the same retinal image size (Figure 3.4.). As such, it was hypothesized that detection time would be systematically modulated by the increased incongruence between familiar and physical size of the stimuli presented on the screen.

As familiar size was the primary concern of the present investigation, the effect of animacy will not be explored further in the subsequent experiments.

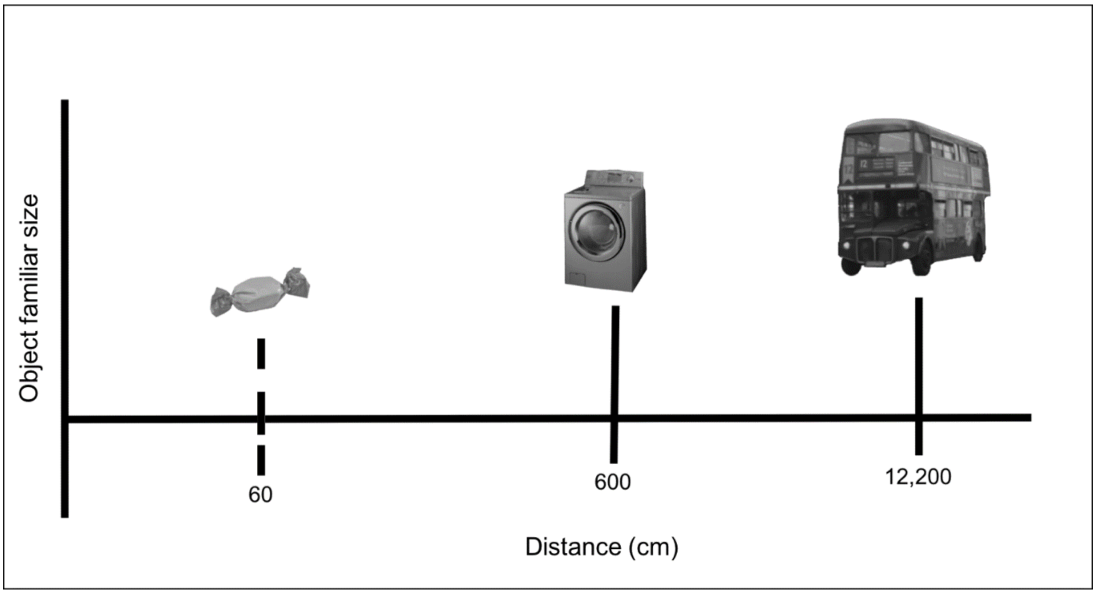


*Figure 3.4.* Relationship between familiar size and distance for a specified visual angle. The dashed line represents the viewing distance used in experiments 5-8 (i.e. 60 cm). The distance (indicated by the vertical lines) and the size of the images are proportional to the typical size-distance relationship in order to subtend the visual angle tested in experiment 5 (i.e. 5.7°). Exemplars from each category of familiar size are depicted (i.e. x1, 1/10, and 1/100).

## Experiment 5: From Normal to Under-Sized Stimuli

### Method

#### Participants

Twenty-nine participants took part in the experiment. However, only the data of 28 participants were included in the analysis. One participant was removed due to technical difficulties. Those included in the final sample, ranged in age from 18 to 23 years (*M*= 19, *SD*= 1). Five of the participants were left-handed, five were left eye-dominant and seven of them were males.

#### Apparatus

The same apparatus as in experiment 4 was used here.

#### Stimuli

Stimuli were selected according to the level of incongruence between their familiar size and physical size presented on the screen. Based on this criterion, three intervals were determined: 1 (normal-sized stimuli), 1/10 (under-sized stimuli) and 1/100 (under-sized stimuli). Objects were chosen such that they would fit within a hand (x1), be half the size of a person (1/10) and be bigger than a person (1/100); a similar criterion for stimulus selection was used by Konkle and Caramazza (2013). Those images classified as '1' had a familiar size that ranged between 5 cm and 7 cm (*M*= 6.61 cm, *SD*= 0.92), those classified as '1/10' had a familiar size that ranged between 50 cm and 70 cm (*M*= 68.09 cm, *SD*= 10.94) and those classified as '1/100' had a familiar size that was greater than or equal to 500 cm (*M*= 5912 cm, *SD*= 8165). As in the previous experiments, all images were of constant physical size (5.7°) and luminance (30 cd/m$^2$). Therefore, only '1' stimuli were the same size as in the real world (normal-sized), whereas '1/10' and '1/100' stimuli were smaller than in the real world (under-sized). Some of the images used in this experiment were previously used in experiments 3 and 4 (see table 1 in Appendix A: supplementary materials).

### Design and Procedure

Participants performed the experiment under restricted viewing conditions, as described in experiment 4. The experimental design was similar to experiment 3 except for the number of trials: there were 30 trials for each of the three size intervals (1 vs. 1/10 vs. 1/100), plus 14 catch trials, presented in two blocks, yielding 208 trials in total.

## Results

### Task Accuracy

The participants' accuracy ranged from 85 to 100% (*M*= 96%, *SD*= 0.04). There was no significant effect of Familiar size on task accuracy ($F(2,54)= 0.42, p = .661, \eta p^2 = .015$).

### Reaction Times

As Mauchly's test of sphericity was significant ($\chi^2(2) = 9.39, p = .009$), the Greenhouse-Geisser value was reported. One-way repeated measures ANOVA was conducted on the RT data with Familiar size (1 vs. 1/10 vs. 1/100) as the main factor. The ANOVA showed a main effect of Familiar size on RTs ($F(1.54, 41.44) = 4.55, p = .024, \eta p^2 = .144$). Post-hoc tests with Bonferroni correction revealed that this effect was mainly driven by a difference in RTs between the two extreme conditions. Participants were significantly faster to respond to objects presented at their true size (*M*= 286, *SD*= 62.97) compared to objects that were presented at 1/100th of their familiar size (*M*= 295, *SD*= 62.92) ($p_{corr}$ = .018). However, the differences between 1/10th objects (M= 289, SD= 59.66) and those shown at their true size ($p_{corr}$ = .421), along with 1/10th compared to 1/100th objects ($p_{corr}$ = .399) were not significant. Although some of the comparisons did not reach significance, visual inspection of figure 3.5. clearly shows a linear trend, which was supported by a linear contrast analysis ($F(1, 27) = 8.93$, $p = .006$, $\eta p^2 = .248$). Additionally, a Pearson's correlation coefficient (r) was calculated between RT for each image averaged across participants and log-transformed real-world size (See table 4 in Appendix A for supplementary materials). The correlation revealed a positive relationship between RTs and real-world size ($r(88)$= .33, $p = .001$) (figure 3.6).

These results demonstrate that simple RTs are affected by familiar size in a systematic manner when the discrepancy between physical size and familiar size increases proportionally. Such effects are independent of task accuracy.

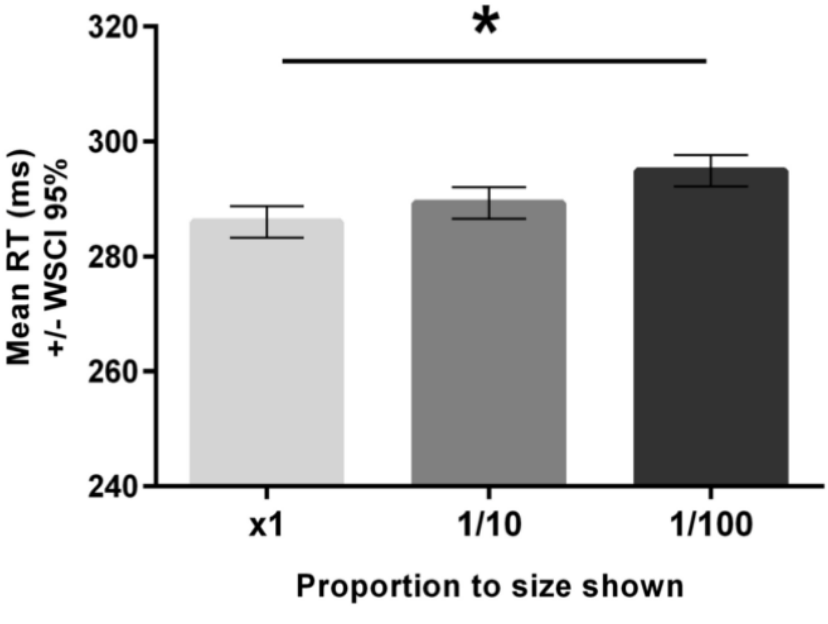


*Figure 3.5.* Results of Experiment 5: Mean RTs (ms) as a function of familiar size, under reduced viewing conditions (left to right: increasing familiar size). The asterisk denotes a significant difference (pcorr < .05) between means based on Bonferroni corrected t-tests.

Error bars represent within-subjects +/- 95% confidence intervals (WSCI) (Masson & Loftus, 2003).

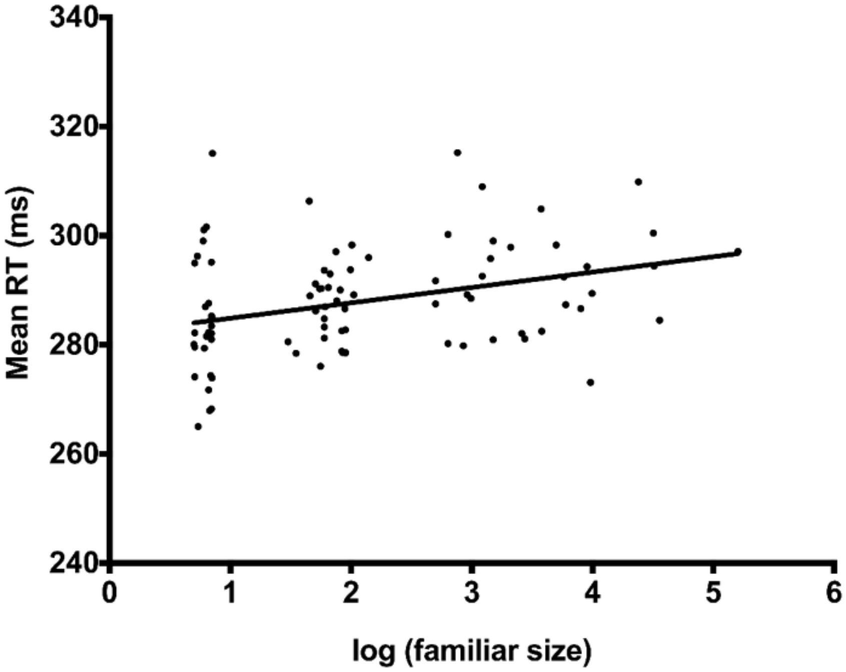


*Figure 3.6.* Correlation between the mean RT and familiar size of the stimuli used in Experiment 5. The x-axis corresponds to the log-transformed size of the object (originally in centimetres) and the y-axis corresponds to the mean RT (ms) for each image.

## Experiment 6: From Normal to Over-Sized Stimuli

### Method

### Participants

Twenty-eight participants took part in this experiment (3 male, 7 left eye-dominant and 3 left handed). They ranged in age from 18 to 55 years (*M*= 23, S*D*= 9.42).

## Apparatus

As in experiment 5, images of real objects were selected based on the proportion of their familiar size to their physical size presented on the screen and were categorised as: x1 (normal-sized stimuli), x2 (over-sized stimuli) and x10 (over-sized stimuli). As it was not possible to directly mirror the different intervals in familiar size as in experiment 5, due to the fact that very small objects (e.g. tip of a pen) seen as enlarged can become unfamiliar and difficult to recognise, we simply chose 3 different size intervals that would not include objects smaller than 0.4 cm in the real world.

Those images classified as '1' had a familiar size that ranged between 5 cm and 7 cm (*M*= 6.58 cm, *SD*= 0.89), those classified as 'x 2' had a familiar size that ranged between 2.5 cm and 3.5 cm (*M*= 2.96 cm, *SD*= 0.52) and those classified as 'x10' had a familiar size that ranged between 0.6 cm and 1.6 cm (*M*= 0.96 cm, *SD*= 0.33).

Again, all images were balanced for luminance (30 cd/m2) and were scaled to subtend 5.7° of visual angle. Therefore, only '1' stimuli were the same size as in the real world (normal-sized), whereas 'x2' and 'x10' stimuli were bigger than in the real world (over-sized), some images were the same as those used in the previous experiment (see table 3 in the supplementary materials of Appendix A).

## Design and Procedure

See Experiment 5.

## Results

## Task Accuracy

Accuracy was high, ranging from 88.94 to 99.52% (*M*= 97%, *SD*= 0.03). There was no significant main effect of Familiar size on task accuracy ($F(2,54)= 2.43$, $p = .098$, $\eta p^2 = .082$).

**Reaction Times**

A one-way repeated measures ANOVA was conducted with Familiar size (1 vs. x2 vs. x10) as the main factor. The ANOVA revealed no main effect of Familiar size on RTs (*F*(2, 54) =1.33, $p = .273$, $\eta p^2 = .047$; x1: *M*= 291, *SD*= 41.96; x2: *M*= 295, *SD*= 44.07; x10: *M*= 293, *SD*= 42.09). Similarly, the linear contrast analysis did not reach significance (*F*(1,27) =1.24, $p = .275$, $\eta p^2 = .044$) (figure 3.7). A Pearson's correlation coefficient (r) was calculated between RTs for each image averaged across participants and the log-transformation of each object's size. RT did not correlate with familiar size (*r*(88)= -0.001, $p = .496$) (figure 3.8).

This lack of effect on RTs for small objects shown at a magnified size could be attributed to a reduced discrepancy (i.e. less variability) between physical and familiar size, which was not the case for experiment 5 where the size range was much wider. Specifically, while the range difference between the two extreme categories in experiment 5 was 4.51 in log-units, this difference in experiment 6 was only 1.25 in log-units. An alternative explanation for the results could be due to the participants' inability to correctly identify some of the magnified objects, especially those from the smallest category (x10). In fact, while we are used to see large objects as small on the retina (as in experiment 5), we rarely experience tiny objects as big on the retina, unless they are held very close to the eyes (in experiment 6, x10 objects would need to be placed at 6 cm of viewing distance from the eyes to generate 5.7° of visual angle). Therefore, magnified small objects could have been treated by the visual system as unfamiliar images.

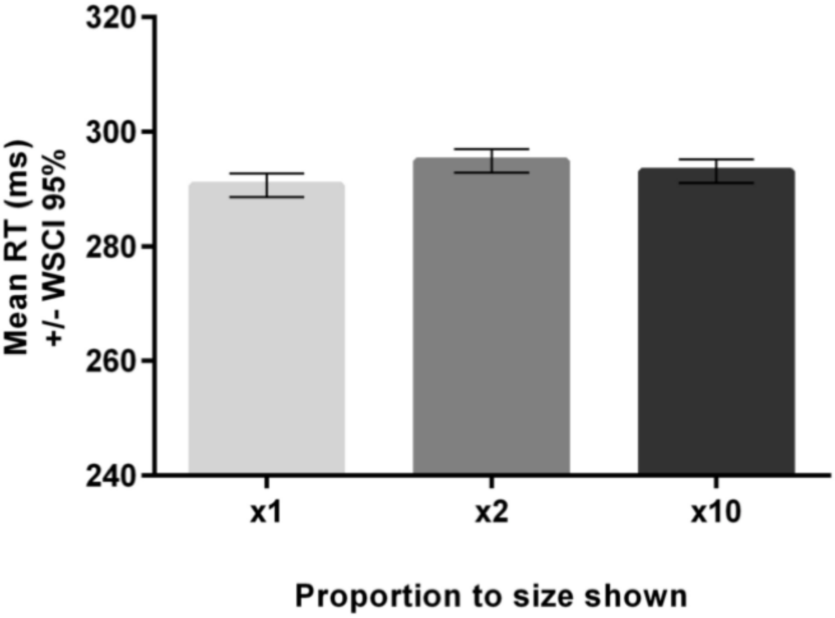


*Figure 3.7.* Results of Experiment 6: Mean RTs (ms) as a function of familiar size, under reduced viewing conditions (left to right: decreasing familiar size). Error bars represent within-subjects +/- 95% confidence intervals (WSCI) (Masson & Loftus, 2003).

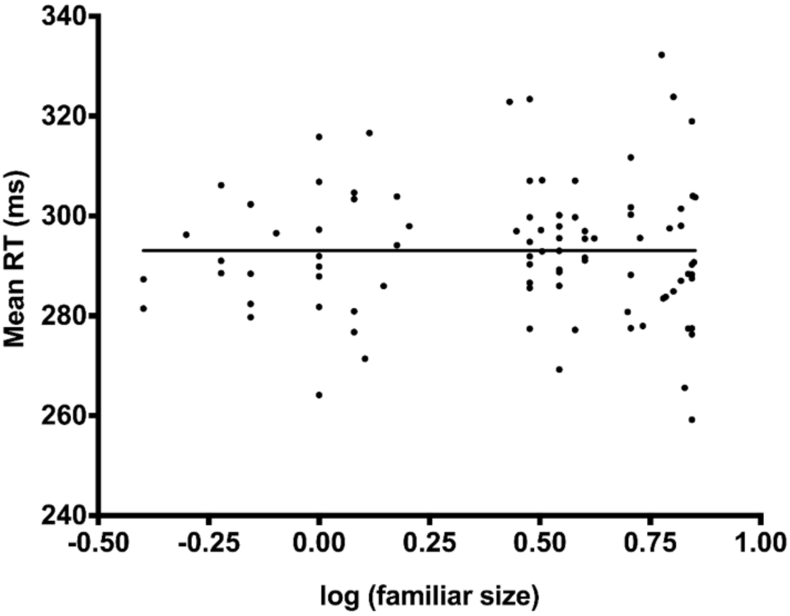


*Figure 3.8.* Correlation between the mean RT and familiar size of the stimuli used in Experiment 6. The x-axis corresponds to the log-transformed size of the object (originally in centimetres) and the y-axis corresponds to the mean RT (ms) for each image.

## Experiment 7: The Effect of Familiar Size on Manual Estimates.

The aim of this experiment was to establish if the effect of familiar size on RTs, observed under reduced viewing conditions (experiments 4 and 5) could be attributed to perceived size, as previous studies have demonstrated that simple RTs are faster in response to objects that are perceived as bigger even when their retinal image is constant (Sperandio et al., 2009; Sperandio, Savazzi, & Marzi, 2010; Plewan, Weidner, & Fink, 2012; Savazzi, Emanuele, Scalf, & Beck, 2012).

In the current experiment, participants judged the perceived size of stimuli under restricted conditions of observation. Therefore, if the effects of familiar size on RTs reported in experiments 4 and 5 are due to perceived size, then one might expect to find that objects shown at their familiar size will be perceived as bigger compared to those objects presented at a size that is incongruent with their known size. In other words, those objects that generated faster RTs (i.e. stimuli congruent with prior knowledge about real-world size) should also be estimated as larger than those objects that generated slower RTs (i.e. incongruent stimuli) in agreement with the findings discussed above where perceived larger objects are responded to more quickly than perceived smaller objects

### Method

#### Participants

Thirty participants took part in this experiment, however, two were removed due to failure to comply with the task instructions and technical issues. The remaining participants (7 left handed, 7 left eye-dominant and 7 males) ranged in age from 18 to 44 years (*M*= 20, *SD*= 4.79).

#### Apparatus

The same images and apparatus as described in experiment 5 were used here. Measurements of manual estimations were taken in millimeters by the experimenter using a pair of digital callipers. Two little points were drawn on the forefinger and thumb of the participant’s right hand and served as markers for the measurements.

## Design and Procedure

Participants were asked to estimate the size of the object presented on the screen using their thumb and forefinger. Perceived size was measured by means of manual size estimation. Manual size estimation has been widely used in the literature to record perceived size (e.g. Haffenden & Goodale, 1998; Sperandio, Lak, & Goodale, 2012; Westwood & Goodale, 2003) , even under reduced viewing conditions (Marotta & Goodale, 2001). Its effectiveness and sensitivity in measuring changes in size perception have been previously demonstrated (e.g. Franz, 2003; Franz & Gegenfurtner, 2008). The advantages of using MSE are that the fingers return to the starting position (i.e. pinch returns to an estimate of zero) and the estimate can be made without looking at the hand, making this measure more ‘implicit’ and less prone to memory effects and anchoring biases than other forms of perceptual reports (e.g. Bolles & Bailey, 1956). Images of familiar objects were divided into two blocks, depending on their dimension properties (width vs. height), which determined the orientation of the hand during the manual estimation task. For example, an elongated object such as a glue stick presented vertically, would meet the criterion for maximum height but not width. There were 41 images that met the criterion for maximum width and 46 images that met the criterion for maximum height. The remaining images that met both criteria (N = 3) were placed into the width category to even out the number of trials with respect to the height category. Prior to testing, participants were instructed on how to perform the manual estimation task according to the 'width' or 'height' block and were asked to complete a practice session involving both hand orientations. Participants used their dominant hand and eye to perform the task. The two experimental blocks (width vs. height) were presented in counterbalanced order. Stimuli within each block were randomly presented.

At the beginning of each block, participants received instructions about the relevant dimension to be judged (width vs. height). A typical trial consisted of a cross appearing on the screen, followed by an image of an object. The participant then manually estimated the object. Once the participant was happy with his/her judgment, the experimenter recorded the manual estimation using the digital callipers. In between trials, participants were required to rest their hand on the table with their right forefinger and thumb pinched together. A break was given between the two blocks. The experiment consisted of 30 trials for each of the three size intervals (1 vs. 1/10 vs. 1/100), yielding 90 trials in total.

## Results

A one-way ANOVA with Familiar size (1 vs. 1/10 vs. 1/100) as main factor was carried out on manual estimates. As Mauchly's test of sphericity was significant ($\chi^2(2) = 22.25$, $p < .001$), the Greenhouse-Geisser value was reported.

The effect of Familiar size on manual estimates was significant ($F(1.27, 34.29) = 11.91$, $p = .001$, $\eta p^2 = .306$). Post-hoc tests with Bonferroni correction revealed that the difference between x1 ($M = 57.29$, $SD = 15.77$) and 1/100 ($M = 62.99$, $SD = 17.59$) was significant ($p_{corr} = .003$), along with the difference between 1/10 ($M = 58.88$, $SD = 16.15$) and 1/100 ($p_{corr} = .009$). Although the comparison between x1 and 1/10 was only approaching significance ($p_{corr} = .074$), a proportionate relationship between the means of each size condition can be observed in figure 3.9 and is supported by the linear contrast analysis, which was significant ($F(1, 27) = 13.87$, $p = .001$, $\eta p^2 = .339$).

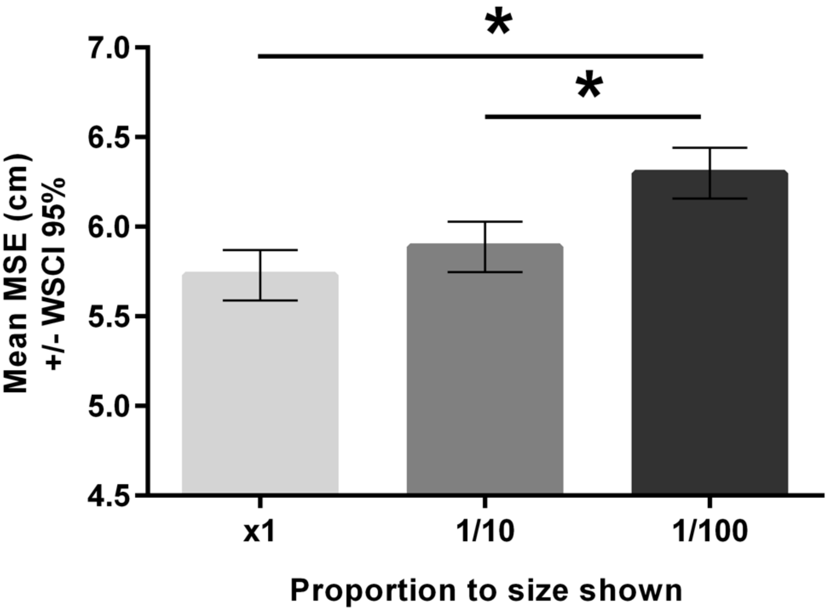


*Figure 3.9.* Results of Experiment 7. Mean manual size estimation (cm) for the three categories of familiar size (increasing familiar size from left to right) with estimations collapsed across hand orientation. Error bars represent within-subjects +/- 95% confidence intervals (WSCI) (Masson & Loftus, 2003). The asterisk denotes a significant difference *(pcorr* < 0.01) between means based on Bonferroni corrected t-tests.

These results show that the perceived size of real-world objects can be influenced by their familiar size, such that when objects were presented at the same retinal size, participants perceived those objects that are known to be big as larger than those that are known to be small. These findings are consistent with previous studies on the effects of familiar size on perceived size and distance under restricted conditions of observation. For example, it has been demonstrated that when photographs of a golf ball and a baseball were presented at the same retinal size and distance, under reduced viewing conditions, observers perceived the baseball to be bigger and further away than the golf ball (Ono, 1969). Similarly, observers judged coins of small familiar size as closer and smaller than their familiar bigger counterparts, despite being presented at the same retinal size and distance (Epstein & Baratz, 1964). These previous reports, along with our results, support the hypothesis that familiar size influences our perception of objects' size, when depth cues are removed. However, contrary to our expectations, the direction of the effect of familiar size suggests that perceived size cannot account for the RT advantage reported in the above experiments. It rather reflects the level of congruence between stored representation of size and the actual object's size, whereby consistency across these two sources of information determines faster RTs.

## Experiments 8: The Influence of Short Term Experience with Novel Objects on Simple Reaction Times.

In order to establish if short-term experience can be used to generate a similar effect of familiar size as observed in the experimets above, models were constructed out of Lego and Duplo blocks. These models were proportionatly sized, with each Lego block (e.g. 1.13 cm in height) being ½ the size of each Duplo block (e.g. 2.26 cm in height).

Previous research, has used similar proportionately-sized models to examine the influence of short-term experience on performance, in a Stroop-like task (Konkle & Oliva, 2012a). In the aforementioned study, participants observed models of objects and were given tasks to enhance their familiarity with their size. For example; participants were asked to detect if an object had been visually changed between images, they were also asked to decide if one object was conceptually bigger or smaller than the other. They were then shown pairs of these novel objects on the screen at different sizes and asked to categorise the physical size of the images.

In other experiments included in this study (Konkle & Oliva, 2012a), if both the familiar-size difference and physical-size difference were congruent for a pair of familiar object images (e.g. a big image of a piano with a little image of an apple), then choice RTs were faster, compared to if this size difference was incongruent (e.g. an image of a big apple with an image of a small piano). In the experiment involving novel objects, such size effects were no longer present. Hence, short-term experience of size, does not affect speed of categorization in a Stroop-like task.

In the present experiment, the influence of short-term experience of size was measured using simple RTs. In the exploration phase, participants were allowed to explore the objects both visually and haptically. Although previous research has demonstrated visual experience to be more important than haptic experience in object recognition and size perception (Rock & Victor, 1964), haptic information alone still significantly contributes to object idenitification (Klatzky, Lederman, & Metzger, 1985). Additionally, an fMRI study (Amedi, 2002) has demonstrated an overlap in the response of visual areas in the lateral occipital cortex (LOC) during object recognition, when novel objects are learnt by haptic and visual experience. These findings suggest that there is a commonality in the way that objects are processed, independent of the mode of experience. Finally, there is behavioural evidence that touch and vision can both facilitate the recognition of objects (Helbig & Ernst, 2007; Kassuba, Klinge, Hölig, Röder, & Siebner, 2013; Wijntjes, Volcic, Pont, Koenderink, & Kappers, 2009). As such, in the current experiment participants were asked to observe and handle the new models, in order to gain experience with the objects and their size.

## Method

### Participants

Twenty-seven participants initially took part in this experiment. However, four participants were removed; two participants had low accuracy (> 20% of errors), another participant had a mean RT that was deemed to be significantly slow, according to Grubbs test (Grubbs, 1969), and there was a technical difficulty for another participant. The remaining 23 participants ranged in age from 18 to 22 years-old ($M_{age}$= 19, SD= 0.94), took part in this experiment. Five of them were left-handed and five were left-eye dominant. There were 11 participants in condition A and 12 in condition B.

## Apparatus

The experiment consisted of an experience phase, where participants became familiar with the novel objects, and a testing phase, where participants performed the task. For the experience phase, a timer was used to ensure the participant did not spend longer than 10 minutes experiencing the objects. For the testing phase, the same apparatus for reduced viewing conditions, as described in experiment 4, was used here. Additionally, a button response box was used to record responses and headphones were used to deliver a warning signal during the testing phase.

## Stimuli

The stimuli used in this experiment included two model types, as can be seen in figure 3.10: one model was constructed from green and red bricks in a pyramid shape (images A & B), the second model was constructed from orange and blue bricks and was more vertical (images C & D). For the experience phase, participants viewed both object types, but one was created out of Lego bricks, whilst the other was created out of Duplo bricks, meaning that the Lego models were half the size of those constructed out of Duplo. The model size in the experience phase was counterbalanced between participants, such that participants in group A experienced the combination of Object A and Object C (see figure 3.10), whereas, group B experienced the combination Object B and Object D (see figure 3.10). Therefore, whilst all participants experienced both object types, one of the two objects presented was always constructed out of Lego(i.e. small), whilst the other was constructed out of Duplo(i.e. big).

Photos of the models were taken from the same distance and under the same lighting conditions. The photos were re-sized so as to match the models' physical size (e.g. Model A was 4.52 cm in height, as was the height of the image of the object, when presented on the screen). The luminance of the photos was adjusted to produce the same average luminance for all stimuli (30 cd/m$^2$). The visual angle of the images was ~3° for the Lego sized images and ~6° for the Duplo sized images.

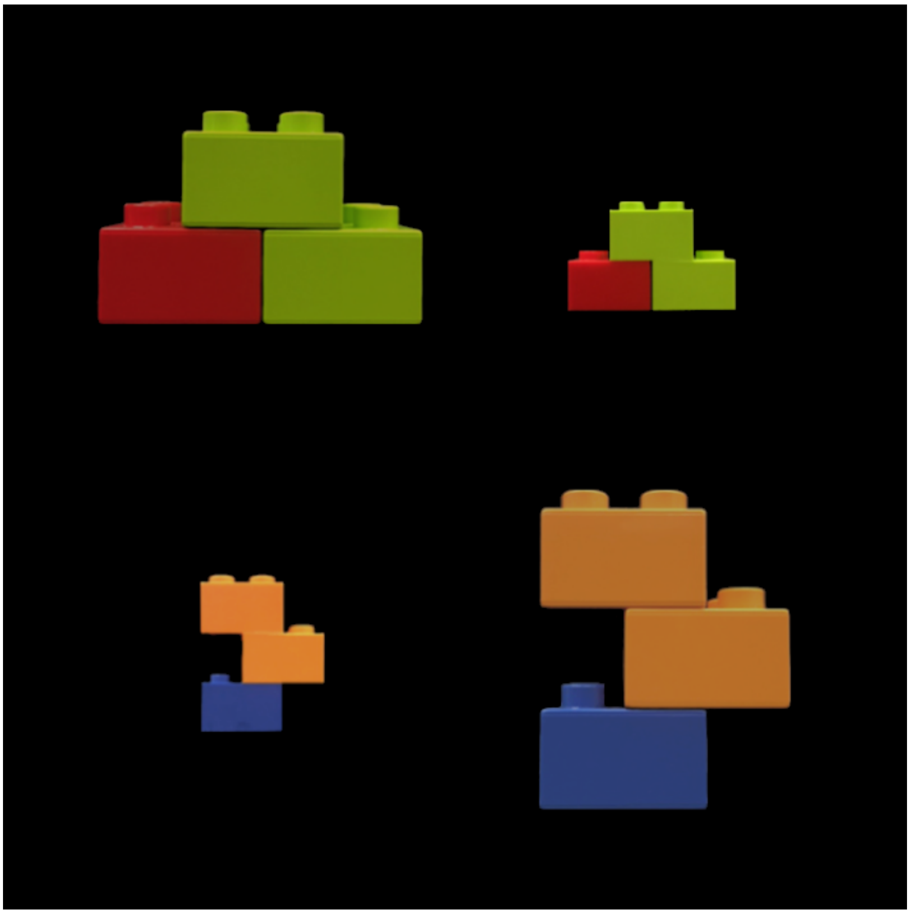


*Figure 3.10.* The four possible models presented to the participants in the testing phase. In the experience phase, participants in group A, interacted with the top and the bottom left objects (A and C), whilst group B participants, interacted with the top and bottom right objects (B and D). Object type 1 corresponded to the green and red model with a pyramid shaped (the top row), whilst Object type 2 was the more vertical model made out of orange and blue bricks (bottom row).

## Design and Procedure

A 2 x 2 within groups design was used. The first independent variable was the size knowledge and had two levels: experienced vs unexperienced. The second independent variable was the physical size, i.e. the size of the object presented on the screen, with two levels; small vs big. The dependent variable was the mean simple RT response. As the object type that participants interacted with in the experience phase was counterbalanced across the two groups, the data from group A and B was collapsed together.

Prior to testing, the standard forms were presented to the participants, including a demographics and handedness form (see experiments 3 for details). An eye dominance assessment was conducted to determine the eye that would be used during the simple RT task (see experiment 4 for more details on reduced viewing conditions). During the experience phase, the participant was asked to sit to the left of the computer and reduction setup. Participants were encouraged to pick up and compare the models presented to them, in particular paying attention to the physical appearance of the models, such as their size and colour (see appendix C for standardised instructions).

The participant was asked to turn away from the experimenter, whilst she setup the models. The objects were presented at the same viewing distance (57 cm) from the participant in a random order but in the same orientation as the images presented later during the testing phase. Participants were required to interact with the models for 10 minutes. The two possible combinations of block size (Lego/small vs Duplo/big) and shape (pyramid vs vertical, see figure 3.10) were predetermined and participants were randomly allocated to one of the two conditions.

After the experience phase, the participants sat in front of the computer and reduction tunnel, they were also given the pinhole glasses to wear. Participants were informed that they would be shown photos of the objects they had just experienced and that independent of if they recognised the object or not, they should press the indicated button as soon as they saw any object image appear on the screen. They were told to watch out for trials when no image appeared and to not press the button on these occasions (i.e. catch trial). A practise block was given and then if the participant was happy with the task, they were asked to continue to the experimental session.

For the testing phase, images of the four novel objects were used as visual stimuli. Each stimulus was repeated 30 times, producing a total of 120 images. The same proportion of catch trials was used as before, producing a total of 18 catch trials and an overall trial number of 138 presented in two blocks with a break in between. Stimuli were randomly presented. Upon completion of the study, participants were debriefed, and all questions were answered.

## Results

### Task Accuracy

Overall, task accuracy was high ranging from 88.41 to 100% (*M*= 96%, *SD*= 3.18). A 2 x 2 repeated measures ANOVA was conducted with Physical size (Lego/small or Duplo/big) and Size knowledge (experienced or unexperienced) as main factors. The results of the ANOVA revealed that there were no significant main effects of Size knowledge ($F(1,22)= 1.34$, $p = .405$, $np^2 = .032$), or Physical size ($F(1,22)= 1.335$, $p = .262$, $np^2 = .057$) on task accuracy. The interaction was also non-significant ($F(1,22)= 0.39$, $p = .541$, $np^2 = .017$).

### Reaction Times

A 2 x 2 repeated measures ANOVA was conducted on simple RTs with for Physical size (Lego/small or Duplo/big) and Size knowledge (experienced or unexperienced) as main factors. The results of the ANOVA revealed that there were no significant main effects of Size knowledge ($F(1,22)= 1.45$, $p = .242$, $np^2 = .062$), Physical size ($F(1,22)= 1.19$, $p = .287$, $np^2 = .051$), nor an interaction ($F(1,22)= 0.46$, $p = .505$, $np^2= .02$) on simple RTs.

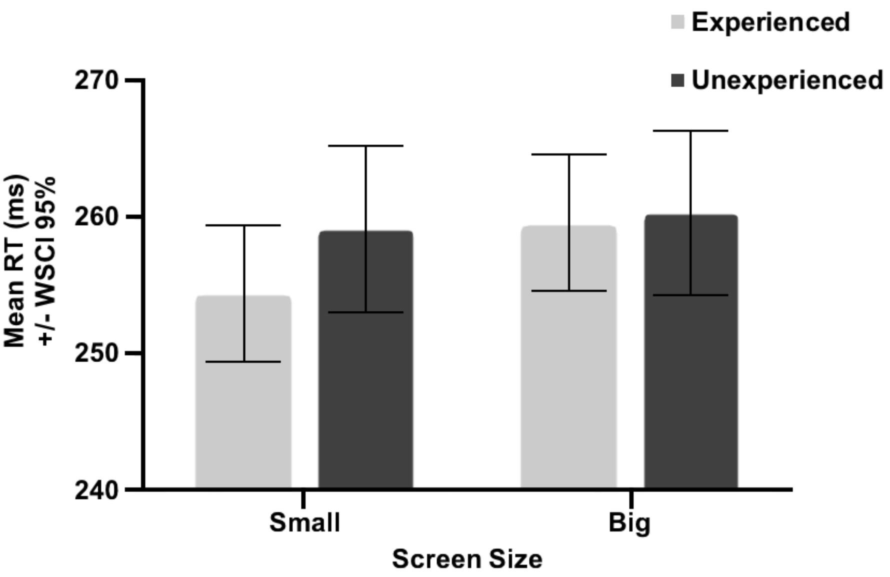


*Figure 3.11.* The mean RT as a function of Physical size (small vs big) and Size knowledge (Lego/small vs Duplo/big). Error bars represent within-subjects +/- 95% confidence intervals (WSCI) (Masson & Loftus, 2003).

In support of previous research investigating the influence of short-term experience on object familiarity effects (Konkle & Oliva, 2012a), in the present experiment no effect of short-term experience was found on simple RTs. Surprisingly, the classic advantage on simple RTs for physically (retinally) bigger images (Osaka, 1976) was absent in this study. This unexpected result could perhaps be due to the small difference in visual angle between the Lego and Duplo stimuli and the application of reduced veiwing conditions.

## Discussion

Findings from experiment 3 showed that under regular viewing conditions there was no effect of familiar size on simple RT's. However, there was an effect of animacy on speed to respond, such that animals were responded to more quickly than inanimate objects.

In experiment 4, the effects of familiar size on simple RT's were observed when reduced viewing conditions were implemented. Furthering this finding, experiment 5 revealed that there was a significant linear relationship between familiar objects size and RT, such that reaction times were faster to stimuli whose familiar size was congruent with the size shown on the screen. Experiment 6, showed that the relationship between familiar size and simple RTs disappeared when images of magnified objects (e.g. blueberry) were displayed, suggesting the influence of familiar size on detection is specific to shrunken object images.

In experiment 7, when participants were asked to judge the size of the stimuli, it was observed that perceptual estimates reflected the familiar size of the object, such that familiar small objects were estimated to be smaller than familiar big objects, when viewed under reduced viewing conditions. These effects were present despite the retinal size remaining constant for all images. In experiment 8, it was revealed that short-term experience with novel objects is not sufficient to generate the same effect of familiar size on simple RTs as observed in experiment 4 and 5. Surprisingly, the classic simple RT advantage to physically bigger images (Osaka, 1976) was absent in this experiment.

In all of the experiments, task accuracy was unaffected by the factors investigated in this study. As such, the simple RT results reported here were not a product of speed accuracy trade-off (Heitz, 2014), whereby the speed of response is affected by the participants ability to be accurate. For example, consistently responding too quickly can skew results to appear as if responses are valid and fast (since anticipations are removed). As such the inverse efficiency index corrects this skew, by incorporating the error in to the speed of response.

## Animacy

Animals are frequently used as stimuli in research on familiar and conceptual size. As a variety of behavioural and brain imaging studies have demonstrated that animal stimuli are processed differently (Konkle & Caramazza, 2013, 2016; Zhu, Drewes, Peatfield, & Melcher, 2016), the present study investigated for the first time the effect of animacy on simple RTs. In support of several behavioural findings (McMullen & Purdy, 2006; New, Cosmides, &

Tooby, 2007; Proverbio, Del Zotto, & Zani, 2007), the current study found that participants were faster to respond to images of animals compared to non-animals. Crucially, these effects were independent of low-level image properties, which have been suggested to be responsible for the behavioural advantage often reported in the literature for animate objects (Harel & Bentin, 2009; Viggiano, Costantini, Vannucci, & Righi, 2004). The animacy effect is supportive to the idea that object category effects, specifically animacy, are present at early stages of visual processing (Caramazza & Shelton, 1998; Grill-Spector & Kanwisher, 2005). A large contribution of the literature on this topic was built from case studies of patients, particularly with damage occuring in the temporal lobe, who demonstrated impairments in the recognition of animals (Caramazza & Shelton, 1998; Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996; Stewart, Parkin, & Hunkin, 1992; Warrington & Shallice, 1984).

Three theories are proposed to explain the animacy effect; the familiarity theory (Funnell & Sheridan, 1992), the image properties theory (Gaffan & Heywood, 1993; Viggiano et al., 2004) and the evolutionary theory (Martin, 2007). The first explantion for these findings, is the proposal that animals are not as familiar to observers as inanimate objects, as demonstrated in an animacy categorisation task (Funnell & Sheridan, 1992). Opposing research found that the effect of animacy persisted in the categorisation task, when familiarity was balanced across all stimuli (Bunn et al., 1998). As the level of familiarity to the stimuli was not assessed in the current study, our findings cannot support or disconfirm this theory. However, if animal stimuli are not familiar, response times to these stimuli should be slower, given that nonfamiliar objects are processed more slowly than familiar objects (McMullen & Purdy, 2006). In the present study animals are responded to more quickly than inanimate object, reducing the probability of this account.

The image properties theory suggests that underlying image properties cause the behavioural advantages observed in some studies and that the semantic/categorical information of stimuli is not relevant. Images of animals are typically characterised by low-spatial frequency and similar physical properties, for example; four legs and a head (Gaffan & Heywood, 1993; Viggiano et al., 2004). However, applying the natural image statistical toolbox for MATLAB (Bainbridge & Oliva, 2015) to the images of experiment 3, we found that the animal images did not significantly differ from inanimate images, as such, spatial frequency differences were not driving the effect, as was previously proposed (Harel & Bentin, 2009; Viggiano, Costantini, Vannucci, & Righi, 2004).

The final theory, known as the evolutionary theory, proposes that objects that are important for survival, are processed by a specialised accelerated network, separate from that of regular object image processing (Martin, 2007). Furthermore, a variety of objects such as; animals, food and tools are proposed to benefit from this network (Martin, 2007). However, other researchers propose that Animals are the only object that is specialised in this manner (Caramazza & Shelton, 1998). These same researchers proposed that the visual system is changed and adapted based on evolutionary pressures. Resulting in an advantage for specific image properties that are related to the stimuli of evolutionary importance, in a top-down manner (Caramazza & Shelton, 1998). Taken together, the evolutionary pathways theory is currently the most appropriate explanation for our findings. Future research should investigate other objects considered to be preferentially processed by the evolutionary pathway, including tools and food (Martin, 2007). It is interesting to note that in terms of familiar size, tools and food commonly reside in the ‘small’ category of the visual stimuli used in this study.

The degree to which animacy effects can be said to be hard-wired and innate are debatable. Resting-state research found that there are distinct neural pathways for animate and inanimate in adult humans (Konkle & Caramazza, 2016), supporting the idea that animacy effects are hard-wired. In addition, non-human primates are capable of distinguishing between animate and non-animate line drawing (Gaffan & Heywood, 1993). Indicating that the ability to separate animate from inanimate objects is primitive and does not require high-levels of cognition. Counter to these discoveries, in an fMRI study, the BOLD signal response of 6-10-year-old children did not significantly differ in response to animate compared to inanimate object images (Dekker, Mareschal, Sereno, & Johnson, 2011). Suggesting that perhaps the formation of independent pathways for animate and inanimate objects occurs with increasing age.

An explanation for this diverging evidence is that the temporal effects observed in the current study may be linked to changes in the processing speed and not the level of activity in the brain. Future research with children could implement the simple RT task in the present study to investigate the temporal effects of animacy, since children are capable of producing speeded responses from the age of 5-years-old (Cantor & Cantor, 1965; Thomas & Nelson, 2001).

The independence of animacy to familiar size is supportive of previous findings that found familiar object size effects using animal stimuli (Gabay et al., 2013; Long & Konkle, 2017). Interestingly, the lack of interaction is in agreement with relevant fMRI findings that have shown the existence of three distinct neural pathways for animals, small inanimate and big inanimate objects (Konkle & Caramazza, 2013).

These findings are also supportive of the conceptual theory of size (Gabay, Kalanthroff, Henik, & Gronau, 2016; Gabay et al., 2013; Henik & Tzelgov, 1982), The conceptual theory of size proposes that there is a commonality in the processing of size information (e.g. for instance an elephant and the number 100 are both conceptually big). In a fMRI study (Gabay et al, 2016), participants were trained to recognise the conceptual size of a novel object, relative to animals of varying familiar sizes. Following the training session, participants entered an fMRI scanner and completed a size judgment task with the newly learnt objects as stimuli. In the task participants indicated if a newly learnt object was bigger or smaller than the proceeding newly learnt object. The task was completed again but with numerical digits instead of the newly learnt objects, in order to define regions of interest in the brain for conceptually small (e.g. 3) or big stimuli (e.g. 9). Analysis of the blood oxygenation level dependent (BOLD) signal revealed that the conceptual size of the newly trained objects was related to changes in activity within the ventral temporal regions of the brain. Specifically, activity levels in the lateral temporal regions was stronger for conceptually small objects and small digits (e.g. 3), compared to conceptually big objects and big digits (e.g. 9). Whereas, the inverse relationship was observed  in the medial temporal regions.

The authors suggest that these areas are related to the position in which the object is typically experienced at the retina. Supporting Malach, Levy, & Hasson (2002) theory, that smaller objects are typically located centrally in the field of vision, relative to big object, which are typically represented in the centre and the periphery's of the visual field. As such visual experience with stimuli at the retinal level is proposed to influence top-down processing of familiar object size, a concept that will be discussed in more detail in the following section. Taken together, future research should incorporate animacy as an independent variable in studies of familiar size. Particularly as neurological research has demonstrated an absence of independent size pathways for animate objects (Konkle & Caramazza, 2013), further research is needed to determine the dynamics of familiar size within the animacy pathway.

## Familiar Size and Reduced Viewing Conditions

The first experiment in this chapter (experiment 3) failed to show any familiar size effects on simple RTs under regular viewing conditions, leading to the possibility that a different visual-perceptual process takes place when object images are viewed under restricted conditions. In Sperandio et al's (2009) study, when visual stimuli consisted of familiar objects of known size (i.e. tennis balls), it was hypothesised that an expectation of size had occurred, such that when the objects did not conform to the predicted changes in retinal size with distance, the object images were perceived to be off-sized (i.e. magnified at greater viewing distances). In the present study, the retinal size and viewing distance were maintained throughout the testing session, as such no cues to distance were varied. Therefore, it is not surprising that familiar size did not affect RTs under natural viewing conditions, since the perceptual system can rely on several distance cues, both of retinal and extraocular origin (Gogel, 1969). However, under reduced viewing conditions, we did find an effect of familiar object size on simple RTs. This finding was in agreement with Gogel's (1969) observations, who demonstrated that under reduced viewing conditions the visual system relies more heavily on extraocular information, such as the objects' familiar size.

The original hypothesis was built on the idea that familiar objects possess an internal representation, and that a match in retinal size of the image to the familiar size of the object demonstrates a processing advantage. These findings are supported by the findings of a Stroop-like task (Konkle & Oliva, 2012a), in this study participants made judgments about the physical size of a pair of object images. Participants judgments were faster when the difference in *familiar* size between a pair of object images was congruent with the *physical* size difference (Konkle & Oliva, 2012a).

As observed in experiment 6, the congruency size effect observed in the present study is proposed to be relatively insensitive. Such that the discrepancy between the retinal size and internal representation of the familiar objects is big enough to be able to detect an influence of familiar size on simple RT. In experiment 5 we showed an effect of familiar size on RTs for progressively shrunken objects, in experiment 6 we were unable to obtain similar effects for enlarged objects. This could be due to a reduced variability between retinal size of the stimuli presented on the screen and the familiar size. In fact, in experiment 6 the maximal physical size of the stimuli presented on the screen was 10 times their familiar size (e.g. a blueberry would normally produce a visual angle of ~1.2°), a difference that was much reduced compared to experiment 5 where visual stimuli included objects whose maximal physical size was 100 times their familiar size (e.g. an aeroplane would  normally produce a visual angle of ~178°). In order to establish if enlarged objects can also produce an effect on RTs similar to those observed in experiment 5 with shrunken objects, images would need to be presented at a bigger size. For example, a washing machine could be projected on to a large screen at its familiar size. However, as the restricted viewing conditions only allow a small visual angle to be viewed, we would also need to increase viewing distance to be able to show objects at their true size. Although we attempted to pilot this kind of experiment, we were unable to implement such testing conditions, due to a number of issues including difficulties in matching stimuli according to the image resolution and luminance. Another issue associated with enlarged objects is that the objects are never (or at least very infrequently) experienced at this retinal size. As a consequence, the observer's ability to identify the magnified objects would be compromised. For example, an image of a grain of rice enlarged to 6 cm would be unrecognisable.

An alternative cause for the lack of size effect in experiment 6 could be due to a necessity for a strong 'preferred' size of an object, in order for the effect to occur. Although the majority of familiar objects have a familiar size (Bolles & Bailey, 1956; Konkle & Oliva, 2011), several objects may suffer from this confound. From a subjective perspective, many of the objects presented in the smallest size categories, could assigned to several of the size categories. For example, a strawberry can vary greatly in familiar size, it could be ~2 cm or even ~6 cm in height. If there is greater variability in 'preferred' familiar size for small objects, it is possible that this could have reduced the chance of a familiar size effect occurring in experiment 6. Future research should conduct a familiar size preference task, in a similar style to those used in Konkle & Oliva's (2012) study. Specifically, participants could be asked to resize an image of an object until they felt it was sized appropriately. This should produce an average 'preferred' size for each item. However, given the findings in Chapter 2 (experiment 2), where big familiar objects were misperceived as small familiar objects when placed in the context of many familiar small objects, both small and big familiar sized objects should be used, to avoid biases.

Interestingly, the effect of familiar size on RTs occurred only under reduced viewing conditions. It is proposed that these reduced viewing conditions reduce the amount of depth information, specifically extraocular cues, such as accommodation, vergence and visual disparity, which usually contribute towards the identification and estimation of object size (e.g. Gibson, 2015). A result of these changes could be the reliance on alternative strategies of identification, such as internal representations and the basic physical features of familiar objects, such as size. Indeed, many researchers have proposed that we access an internal representation that includes the familiar size of an object during recognition (Konkle & Oliva, 2011; Schiffman, 1967; Slack, 1956).

Taken together, our findings demonstrate that simple RT's can be examined under reduced viewing conditions, to determine the degree of congruence in size between the internal representation and retinal input of a familiar object. Although our conclusion that simple RT is affected by familiar size is limited to shrunken objects and cannot be extended to enlarged objects, the current study is useful in understanding the speed of processing of familiar objects when regular cues to distance are unavailable. .

### How Does Familiar Size Influence Simple RT?

Our findings showed that simple RTs were influence by familiar size in a manner that was unrelated to perceived size. This contradicts previous reports of a relationship between perceived size and RTs, such that objects perceived as bigger are responded to more quickly than smaller objects (Plewan et al., 2012; Savazzi et al., 2012; Sperandio et al., 2009, 2010). Three hypotheses are considered to explain these findings. The first hypothesis is that under reduced viewing conditions simple RTs do not reflect perceived size but instead the degree of congruency between internal representation of the objects size and the retinal size. The second hypothesis is based on a relatively new idea, that larger objects are perceived to occur later on the screen, resulting in slower RT's (Kanai, Dalmaijer, Sherman, Kawakita, & Paffen, 2017; Ono & Kawahara, 2007; Rammsayer & Verner, 2015; Thomas & Cantor, 1975; Xuan, Zhang, He, & Chen, 2007). This intriguing idea should be investigated in the future, by measuring the temporal perception of the stimulus onset, using a task such as the temporal order judgment task (e.g. Gibbon & Rutschmann, 1969). In this task, two familiar objects would be shown at the same time to participants. After the images are removed from the screen, participants will then be asked to indicate which of the images they perceived to have appeared on the screen first of all (e.g. Gibbon & Rutschmann, 1969). If the perceived size is related to the perception of stimulus onset, we would expect participants to report that the familiar small objects occurred before the familiar big objects.

Another hypothesis concerns the eccentricity of the stimuli. The effect of eccentricity on RTs is well-known; as an images moves across the visual field, from the centre of the retina out towards the periphery, the speed of response to that object decreases with increasing eccentricity (Chelazzi et al., 1988; Marzi, Mancini, Metitieri, & Savazzi, 2006; Marzi & Di Stefano, 1981). Several brain imaging studies involving the localisation of object processing, have shown that objects that are most commonly experienced in the centre of the retina and that these objects tend to be small (e.g. faces), whereas those objects typically viewed in the periphery are bigger objects (e.g. buildings) (Levy, Hasson, Avidan, Hendler, & Malach, 2001; Malach et al., 2002). It has also been suggested that way we experience the image of an object can affect the way we learn its conceptual size (Gabay et al., 2016, 2013). As such, we speculate that our findings could be explained by an ‘eccentricity effect’ of stored representations of familiar objects. In other words, the conceptual knowledge of an object may influence the processing speed of the familiar object, such that those objects experienced more peripherally (big objects) at were processed more slowly than those typically experienced in our central vision (small objects).

Results of experiment 7 showed that perceptual judgements of size, as measured by means of a manual estimation task, were unrelated to the effects of familiar size on RTs. In line with previous research (Gogel, 1969), experiment 7 demonstrated that under reduced viewing conditions, perceived size is affected by familiar size, such that familiar small objects are perceived to be physically smaller than familiar big objects. During the manual size estimation task (see experiment 7), the object image was presented until participants were happy with their judgment, allowing both the perceptual and action pathways to be updated by the sensory information. In comparison, for the simple RT task, participants responded as soon as they detected the presence of a briefly shown image. Hence, the size information of the visual stimuli was available for a prolonged period of time during the manual estimation task, in comparison to the RT task. Naming studies have demonstrated that whilst categorical object effects are observed after a short duration, more specific identification of an object, such as its name, is available after a longer period of processing (Humphreys et al., 1997). Considering such a theory, it is possible that different perceptual processes were involved during the detection task and the estimation task, leading to the different results. To assess this possibility, one could attempt to systematically alter the presentation duration of the objects stimuli to see if RT’s might reflect more closely the perceived size.

## The Role of Experience

In the final experiment of this chapter (experiment 8), the role of short-term size experience on speed of processing, was investigated. Results showed that interacting with novel objects for about 10 minutes is not enough to generate an effect of familiar size on RTs, as reported above. Surprisingly, experiment 8 failed to replicate the classic size effect on RTs, whereby increased visual angles produce decreased RTs (Osaka, 1976; Pins & Bonnet, 1996). It is possible that the size difference between the Lego model and the Duplo model was not big enough to generate even this well-established size effect on RTs under reduced viewing conditions. However, the discovery that short-term familiarity with a novel object does not produce familiar size effects on simple RTs, is in line with previous research (Konkle & Oliva, 2012). The conditions necessary to develop familiar size are still unclear.

## Conclusion

A novel finding of the present study was the simple RT advantage to animate compared to inanimate objects, these findings agree with previous research demonstrating an advantage in processing speed for animal stimuli (McMullen & Purdy, 2006; New, Cosmides, & Tooby, 2007; Proverbio, Del Zotto, & Zani, 2007). Such effects are not explained by low-level image properties (Harel & Bentin, 2009; Viggiano, Costantini, Vannucci, & Righi, 2004) and are independent of viewing conditions. The theory that best accounts for these findings is the evolutionary theory, which proposes that there is a specialised speeded network for processing animate images (Martin, 2007). However, further electrophysiological imaging studies are needed, in order to confirm this theory.

The current research also provides an understanding of how and the extent to which familiar object size affects the speed of response. Our findings demonstrate a clear relationship between familiar objects size and the speed of processing, only under reduced viewing conditions. However, such effects were not observed for enlarged objects and were unrelated to perceptual estimates of size The influence of familiar size on simple RT was the result of a congruency effect. Familiar objects that matched the size shown on screen were faster to be processed compared to familiar objects whose size deviated substantially from the size on screen. This congruency effect was specific to progressively shrunken objects and was not observed for magnified objects. Familiar size also affected perceived size with small familiar object judged as smaller than big familiar objects of matched retinal size. Finally, we demonstrated that the influence of familiar size on detection is the result of long-term experience of size, as short periods of interaction with unfamiliar objects did not elicit the same effects on reaction times.

Why does familiar size affect simple RT? This question remains open, although it could be argued that this effect is the product of common spatial properties shared by objects of similar familiar size (Long & Konkle, 2017; Long et al., 2016), suggesting that low-level features might mediate our findings. Alternatively, the effect could be explained by a top-down influence of stored knowledge about familiar size (Gabay et al., 2016, 2013). To establish if conceptual or low-level properties of the familiar object are responsible for familiar size effects, an event-related potential (ERP) study could be carried out. ERP is a technique that allows to measure the time course of activity over the scalp evoked by visual stimuli with high temporal resolution, In the ERP study, images of familiar objects along with their scrambled versions could be presented. If the familiar size effects observed in the current study are present early on in visual processing and disappear with the scrambled versions of the objects, it could be concluded that conceptual size, rather than underlying visual features, is responsible for such effects. The next chapter will describe the results of such a study.

The current research also provides support for the theory that familiar object size effects are linked to internal size-representations. These findings are harmonious to previous research that suggested a speed of processing advantage for familiar size congruency (Gabay et al., 2013; Konkle & Oliva, 2012a; Sereno et al., 2009).

Why does familiar size affect simple RT? This question remains open, although it could be argued that these effects are a product of common spatial properties shared by objects of a similar size (Long & Konkle, 2017; Long et al., 2016). Alternatively, the effect could be driven by a top-down influence of conceptual familiar object size (Gabay et al., 2016, 2013).

Independent of the cause, these findings demonstrate a clear positive linear relationship between familiar objects size and the speed of processing, under reduced viewing conditions. Such effects were not observable for enlarged objects and were counter to expected perceptual estimates of size, where faster responses were related to smaller physical size. Leading to the conclusion that the reduced viewing conditions produced a congruency effect. Objects that matched the size shown on screen were faster to be processed compared to familiar objects whose size deviated substantially from the size on screen. The perceptual size estimates revealed that the perceived size of the image was influenced by the internal representation of the familiar object. While, short-term combined haptic and perceptual experience with novel objects did not influence simple RT's, nor did the size of the object presented on the screen. The cause of such findings is unclear and as such future studies should investigate the degree of visual angle necessary to produce changes in simple RT under reduced viewing conditions.

Alternative methods should be used to measure the speed of processing in order to establish if conceptual or physical properties are responsible for familiar size effects. One such method would be to use a brain imaging technique such as electroencephalograms (EEG) to measure the time course of activity over early visual areas, with the inclusion of scrambled versions of the object images. If the temporal size effects observed in the present studies are also reflected in peak latency responses to intact but not scrambled versions of the object images, it would be reasonable to concluded that the effects observed in the present study are due to the familiar size information and not underlying visual features.

Additionally, future research should look to explore the role of magnification of familiar objects on speed to respond, since size effects were not observed in this size group. However, stimuli selected for magnification must be checked for good agreements of familiar size, since it has been proposed that small objects may have variety of acceptable familiar sizes. Finally, the debate about the development of familiar size and processing advantage for animal stimuli is still open. As such future research should aim to establish a time frame of such development.

# Chapter 4: Effects of Familiar Object Size on Visual Evoked Potentials

As mentioned in the previous chapters, familiar object size is an important aspect of object size perception, helping us to determine the size and distance of objects in the world around us. In Chapter 3, we observed for the first time a benefit in the speed of response for familiar objects that were physically congruent with their known size. For example, participants were faster to respond to a crayon when it matched its familiar size on the screen, compared to a bus of constant retinal size. This effect was unrelated to the perceived size of the object images, but it rather reflected the level of congruency between familiar size and retinal size, such that real-world large objects (e.g. bus) were responded to more slowly than small objects (e.g. crayon) that subtended the same visual angle. The literature summarised in this introduction will demonstrate that the anatomical and functional substrates for object image processing and familiar size are well-known, whereas the temporal dynamics of these phenomena are still unclear. As such, the current study used ERPs to investigate for the first time the time-course of familiar size and to establish at what stages visual processing of familiar object size occurs.

In the overview of the literature presented below, the key theories of object processing will be presented alongside its behavioural and neurological underpinnings. In the second half of this introduction, the relatively underdeveloped area of research concerning familiar object size will be presented in the context of the existing behavioural and neurological findings. Finally, aims and hypotheses of the current study will be reported.

## Object Image Processing

One key theory of object image processing is what will be grossly termed here as the 'internal representations theory'(Ullman, 1989), which proposes that once incoming visual information passes through the early visual cortex, the content of the visual signal is matched to existing representations of familiar objects. For example, an image that depicts whiskers would be matched to all of the internal representations that possess whiskers e.g. cats and mice (Ullman, 1989).

Various properties have been suggested to be important in this process, such as the individual elements of the image (e.g. an eye in a face or a wheel on a bike), the invariant property of the overall shape (e.g. animal vs a car) and where the object is placed in space (Ullman, 1989). The traditional views of the internal representation of familiar objects asserts that processing occurs in a top-down fashion, with the incoming visual information being considered with respect to existing internal knowledge (Ullman, 1989). .

This idea is supported by the work of Lloyd-Jones and Humphreys (1997), who found that participants were slower to make a judgment about whether the object was living or not, when the object belonged to a group were the exemplars were more similar (e.g. fruit compared to vegetables) compared to when the exemplar members were more visually dissimilar (e.g. clothing compared to furniture). The authors also reported that when participants were asked to name the same objects, they were faster when the object belonged to a category of visually similar exemplars. For example, it was easier for participants to name an orange and a tomato than a jumper and a wardrobe. The researchers proposed that the processing of object images occurs with reference to stored knowledge of various visually and categorically similar objects. Therefore, object processing is not the same for all objects but is dependent on the task. These findings, alongside case studies with brain damaged patients and involving brain imaging studies (Humphreys, Riddoch, & Price, 1997), led researchers to developed a theory known as the ‘hierarchical interactive theory’ (HIT) (Humphreys & Forde, 2001).

The HIT theory suggests that the matching between the incoming visual input and the internal representation only occurs when the task demands either categorisation or identification of the object. For instance, during a naming task, all possible matches are brought together and semantic information about related objects is compared to the test stimulus. Comparisons are made until a match in the object's specific identity can be made (Humphreys, Price, & Riddoch, 1999; Humphreys, Riddoch, & Price, 1997). An important feature of the categorisation process is that a semantic match to a specific internal representation is not required. Instead, a series of matches are made to various group members, based on shared image properties. As a consequence, processing is faster for visually similar objects (e.g. orange, tomato or apple), compared to visually different objects (e.g. orange and a bus) that tend to belong to separate categories. For example, the vast majority of mammals have four legs and a head, leading to a commonality in the visual input received for such stimuli.

The HIT theory (Humphreys et al., 1999; Humphreys et al., 1997) is further supported by behavioural research, that demonstrated an advantage in response times for participants to *categorise* but not *identify* an object image, in a choice RT task (Grill-Spector & Kanwisher, 2005). In this study participants were asked to categorise a selection of familiar objects (e.g. dog or car). The researchers found that participants could correctly categorise the object within the same time frame as simply detecting the image onset. In contrast a significant increase in time was required to specify the exact identity of the object (e.g. pigeon or dove) (Grill-Spector & Kanwisher, 2005).

In terms of neuroanatomy and timing, both identification and categorisation are proposed to take place in the visual ventral stream (Goodale & Milner, 1992; Milner & Goodale, 2008; Proverbio, Del Zotto, & Zani, 2007). However, categorisation is considered to occur earlier, with many ERP studies suggesting that categorisation occurs during the first few hundred milliseconds (i.e. P1 and N1 components), as demonstrated by various ERP studies (Proverbio et al., 2007; Simanova, van Gerven, Oostenveld, & Hagoort, 2010; Zhu et al., 2016). Conversely, the process of semantic identification or naming has been suggested to take place after 150ms from the stimulus onset (Levelt, Praamstra, Meyer, Helenius, & Salmelin, 1998), with some researchers suggesting that identification occurs around the N300 component (Eddy, Schmid, & Holcomb, 2006; McPherson & Holcomb, 1999; Schendan & Ganis, 2015; Schendan & Lucia, 2010).

FMRI studies have shown that changes in activity in response to specific object categories is apparent in the lateral occipital cortex (LOC) (Grill-Spector, Kourtzi, & Kanwisher, 2001; Konkle & Oliva, 2012b). The localization of activity related to identification has been suggested to originate in the medial temporal lobe (Humphreys & Forde, 2001; Humphreys et al., 1999, 1997), specifically the perirhinal cortex (Lee, Bandelow, Schwarzbauer, Henson, & Graham, 2006; Tyler et al., 2004).

An alternative explanation for the advantage in processing time for categorisation over identification, is that categorisation simply relies upon commonalities in mid and low-level properties of the images, including spatial frequency (Andrews, Watson, Rice, & Hartley, 2018; Bex & Makous, 2002; Collin, 2006; Konkle & Oliva, 2012b). Hence, according to this theory, categorisation does not require the top-down influence of semantic stored representations. In agreement with this idea, Konkle and Olive (2012b) found that objects from within the same category activated the same brain areas in the visual stream. The authors proposed that this was due to underlying image properties shared by objects within the same category. A proposal that was supported by Andrews et al (2018), who found, using fMRI, that the level of activity observed in the ventral stream was directly related to shared underlying image statistics, such that if two objects were visually similar, they would be more likely to produce activity around the same brain area within the ventral stream.

Another study showed that spatial frequency exerts an influence on object categorisation, depending on the task (Collin, 2006). Specifically, images were pre-filtered to obscure the visibility of the objects identity. The participants were told they could alter the spatial frequency of the image, in order to establish the objects category. When given only the option to decrease spatial frequency, the participants decreased the spatial frequency less, in order to categorise an object image at the subordinate (e.g. yacht), compared to the basic level (e.g. boat). There was no difference in categorisation type, when participants were given the option to increase the spatial frequency. These findings not only support the role of spatial frequency in object recognition, but they also draw together the underlying image properties with the ability to determine the basic category of an object. Such findings support the HIT theory of object recognition (Humphreys & Forde, 2001).

From the aforementioned research, it is apparent that much has been established as to the neural correlates of object recognition in the ventral visual pathways. However, little is known about the representation of familiar object size in the visual ventral stream, as will now be discussed.

## Size Processing

In terms of how the brain processes image size, the physical size of a basic visual image can be differentiated in early visual regions of the brain. Activation measured using fMRI techniques demonstrates that there is a direct link between the amount of stimulation at the eye and the degree of activity measured in early visual regions. Specifically, stimuli which have a large retinal eccentricity (visual angle) produce a greater area of activity in V1, a property which is known as retinotopic mapping (Engel, Glover, & Wandell, 1997).

Changes in perceived as a result of  size illusions also affect brain activity measured in early visual areas, such as V1. Specifically, an increase in perceived size corresponds to an increase in neural activity in V1 (Murray et al., 2006; Sperandio, Chouinard, et al., 2012). By the same token, an magnetoencephalogram (MEG) study (Weidner & Fink, 2007) showed that perceived size differences produced by visual illusions originated from early visual areas.

However, in this study they were able to determine that such effects were observable within the first 100 ms from stimulus onset (corresponding to component C1), supporting the idea that the processing of perceived size effects may occur very early, even at the level of the primary visual cortex, although the spatial resolution of the MEG did not allow the researchers to find the precise source of such activity (Weidner & Fink, 2007). This research suggests that both bottom-up processing of retinal size and top-down processing of perceptual size can occur within the first few 100 ms of activity.

As mentioned earlier, Sperandio et al (2009) using a simple reaction time task have demonstrated that retinal image size and distance information can be quickly combined together to influence speeded motor responses. Specifically, a perceptually big stimulus results in faster simple RTs compared to a perceptually small stimulus. The relationship between simple RT and perceived size has also been replicated using visual illusions (Plewan et al., 2012; Savazzi et al., 2012; Sperandio et al., 2010). It is conceivable that such behavioural results could be related to the activity of the primary visual cortex, as indicated by the fMRI studies mentioned above (Weidner & Fink, 2007; (Murray et al., 2006; Sperandio, Chouinard, et al., 2012; Engel et al, 1997) .

Interestingly, familiar object size also affects the speed of processing. In Experiment 5 of Chapter 3 we found that simple RT's to briefly presented familiar object images, viewed under reduced viewing conditions, reflected the degree of size congruency. Such that objects images, whose familiar size matched their physical size on the screen (e.g. a crayon) were processed faster than objects, whose physical size was incongruent with the stored representation of size (e.g. a bus). Similarly, congruency effects have been observed in a Stroop-like task (Konkle & Oliva, 2012). Participants were presented with pairs of familiar objects of different physical size. In the task, participants had to indicate which of the two images was physically bigger than the other. The findings showed that participants were faster to make the size judgment when the difference in physical size of the images on the screen matched the real size difference between the objects. For instance, judgments would be faster for a small image of an apple and a big image of a piano, compared to an incongruent size pairing, such as a big image of an apple and a small image of a piano. This supports the theory that the familiar size of an object automatically influences the speed of response.

In a study involving digits and familiar objects (Gabay et al., 2013), familiar objects of different conceptual size were presented as primes followed by digits as targets. Participants were asked to indicate if the digit was an odd or even number. The researchers found that when the familiar size of the prime proceeding the digit was congruent with the magnitude of the digit (e.g. elephant - 9), judgments were made faster than when the digit and prime were incongruent. (e.g. mouse - 9), suggesting that familiar size and numerical size are linked. The authors termed this form of size as conceptual size.

Similarly, Sereno et al. (2009) demonstrated the effects of familiar size on response times using word stimuli rather than pictures. In this study, a singular word was displayed, and participants were asked to make a judgment about whether the word presented was a word or a non-word. The words were displayed in either capitals (e.g. EGG) or lowercase (e.g. egg) letters, making the word appear big or small respectively. The authors found that when the physical size of the word was congruent with the familiar size of the object (e.g. egg or BUS), decisions were made more quickly than when physical and familiar size were incongruent (e.g. EGG or bus). These findings suggest that the semantic knowledge of familiar size conveyed by a word, can influence unrelated semantic judgments.

Taken together, the findings of the aforementioned behavioural research supports the idea that familiar object size affects the regular processing speed of objects, as demonstrated by tasks that do not explicitly require knowledge about familiar size (Fisher & Sperandio, 2018; Konkle & Oliva, 2012a). Intriguingly, such findings are not limited to the format of the visual image, extending across digits and words (Gabay et al., 2013; Sereno et al., 2009). The influence across formats could be indicative of the influence of familiar object size influence in object recognition, as cross-format effects, such as those mentioned above, are also reported in studies on object recognition (Humphreys & Forde, 2001; Humphreys et al., 1997), supporting the idea of semantic influences in object processing.

In terms of the neural underpinning of such familiar size effects, Konkle and Caramazza (2013) as well as Konkle and Oliva (2012) established that activity within the occipitotemporal area (OT) reflects familiar object size. This finding is further supported by research that demonstrated that the OT cortex in humans corresponds to the inferior temporal (IT) lobe in monkeys (Kourtzi & Kanwisher, 2001). This is of particular interest to the present study as the IT region in monkeys is responsible for both object size invariance and variance of objects (Humphrey & Weiskrantz, 1969; Ungerleider et al., 1977), although these studies did not directly test familiar size.

Although a few neuroimaging studies have examined the neural substrates of familiar size (Gabay et al., 2016; Konkle & Caramazza, 2013; Konkle & Oliva, 2012b), the temporal features of such representations remain unknown.

## Current Experiment

For the first time, the electrophysiological correlates of familiar size will be measured. In order to establish the temporal dynamics of familiar size, a technique with high temporal resolution is required, such as such ERPs. The stimuli developed for Experiment 5 of Chapter 3 will be used in the current ERP study. Specifically, three different size categories will be used, i.e. small, medium and big. The images will be presented under regular and reduced viewing conditions. The use of restricted viewing conditions was deemed necessary, in the light of the findings reported in the previous chapter, where familiar size effects on simple

RT were observed (Chapter 3).  Moreover, previous research has shown that the influence of familiar size is enhanced by reduced viewing conditions (Gogel, 1969), for reasons that are still unknown. Earlier studies on the influence of reduced viewing conditions on performance suggest that one of the ‘side effects’ of this manipulation, namely RT slowing, can be largely attributed to a reduction in the amount of luminance, since the pupil is artificially restricted (Minucci & Connors, 1964). Although the reduction of the flux alone is reported to only explain some of the slowing (Minucci & Connors, 1964), as such there are other factors, such as the absence of convergence that could contribute to this effect.

Therefore, reduced viewing conditions produce an overall deficit in visual stimulation, in addition to the absence of incoming pictorial agreement. The combination of these two factors has been suggested to cause a general slowing in performance, which is evident in the mean RTs of experiment 5, Chapter 3. As such, the current study aims to establish if reduced viewing leads to an influence of size on processing at the neurological level.

Two possible mechanisms are proposed to predict the neurological response to this size effect. The first mechanism is the idea that the size effects is present during regular viewing conditions and is observable through brain imaging. However, the size effect is only observable in simple RTs during reduced viewing conditions, since the general slowing experienced with reduced viewing conditions exaggerates the temporal effects. Alternatively, it is possible that the simple RT effect is not present during regular viewing conditions and is only observable both cerebrally and behaviourally when reduced viewing conditions are applied. Such effects may be a consequence of the visual system being taxed, leading to an increased reliance on pictorial cues (Gogel, 1969). It is hoped that the following experiment will unveil which of these two mechanisms holds true.

In order to test the hypothesis that the underlying image properties are responsible for effects of familiar size (Long & Konkle, 2017; Long et al., 2016), scrambled versions of the visual stimuli will be included in the paradigm. The scrambled images will be presented in a separate block and participants will be asked to perform a simple RT task. If the same behavioural and electrophysiological effects are measured for both scrambled and intact images, then it could be concluded that these underlying image properties are responsible for the effects of familiar size.

In this experiment, we decided to include two additional behavioural measure, namely a categorisation task and a size ranking task (respectively; Bolles & Bailey, 1956; Konkle & Oliva, 2011), to determine the extent to which participants can categorise or rank the object images based on their known size.

### Hypothesis

For the ERP analyses, it was hypothesised that familiar size will emerge at the point of typical object categorisation, since effects of perceived size in other contexts such as visual illusions, have been observed around this time period (Weidner & Fink, 2007; Xuan, Chen, He, & Zhang, 2009). In particular, we might expect to observe the effect of familiar size in correspondence with the P1 or N1 components.

**Amplitude hypothesis.** In terms of amplitude, a three-way interaction is between Image type, Viewing condition and Familiar size was expected, such that intact big familiar objects under reduced viewing conditions only will produce larger amplitudes than the other conditions, in line with amplitude changes with size reported in previous ERP studies (Eason & Dudley, 1971; Schaffer, Schubö, & Meinecke, 2011), as well as the findings on perceptual judgments reported in experiment 7 of Chapter 3.

These results would indicate that size is an automatic semantic property that affects early visual components in a top-down fashion, similar to those observed with faces and animals (Harel & Bentin, 2009; Rossion & Jacques, 2008; Viggiano et al., 2004).

**Latency hypothesis.** Under reduced viewing conditions, it was expected that mean peak latencies will be quicker for familiar small compared to familiar big intact objects, based on the RT advantage for congruent familiar objects reported in experiment 5 of Chapter 3. A main effect of viewing condition on latency was also predicted, with faster latencies for regular compared to reduced viewing conditions (Adachi-Usami & Lehmann, 1983).

For the behavioural results, we predicted to replicate the effect of familiar size on simple RTs, as shown in Chapter 3: experiment 5, whereby reaction times will be slower for those objects that are furthest from the internal representation of size, compared to those objects whose familiar size matches the size shown on screen.

For the categorisation task and a size ranking task which tested participants' knowledge of size, we predicted that all participants will exhibit at a high level of understanding of familiar size. Previous research has demonstrated that participants are generally good at knowing the size of an object (Bolles & Bailey, 1956; Konkle & Oliva, 2011).

To summarize, the present study aims to establish if familiar object size effects are present in early visual processing, as measured by visual evoked potentials to familiar object stimuli. In addition, the role of Image type (intact vs scrambled) and Viewing condition (regular vs reduced) will also be investigated.

## Experiment 9: What are the Effects of Familiar Object Size on Visual Evoked Potentials?

## Method

### Participants

A total of 19 right-handed participants ranging in age from 18-29-years-old (*M*= 22, *SD*= 3.55) completed all parts of the study. Seven of the participants were male and two of them were left eye-dominant. All participants had intact or corrected to intact vision. In addition to the 19 participants described here, three additional participants took part, but their data was not included in the analysis, as they did not return for the second half of the study. The study was conducted in line with the Ethics procedure approved by UEA's Psychology ethics committee. Participants were given money or course credits in exchange for their time.

### Design

The study used a 3 x 2 x 2 within-subject design. There were three independent variables: Familiar object size, Image type, and Viewing condition. Familiar object size had three levels: small (x1 the size shown on screen), medium (1/10th the size shown on screen) and big (1/100th the size shown on screen). Please note that for the ERP analysis, only the small and big familiar object images were used as this size difference has been found significant in our previous study (see Chapter 3: experiment 6). The independent variable Image type had two levels: the original object image ('intact') or a scrambled version of the image (see figure 4.1 for examples). Finally, Viewing condition had two levels: regular viewing conditions or reduced viewing conditions. There were three dependent variables recorded during the EEG study: amplitude and latency of the ERP (which was time-locked to stimulus onset via markers) and simple RTs (which were also time -locked to the stimulus onset).

## Stimuli

The same stimuli and conditions as described in experiment 5 (Chapter 3) were applied here. The main change with respect to the original paradigm was the inclusion of phase-scrambled version of the images to control for the effect of low-level properties of the stimuli. These new images were created using a MATLAB code from SHINE toolbox (Willenbockel et al., 2010). An example of stimuli can be seen in figure 4.1. The scrambled and intact images were presented in separate blocks and counterbalancing of blocks was applied between participants. Additionally, the number of catch trials was doubled with respect to the original paradigm, given the increased number of trials required by the EEG experiment to allow for meaningful analysis of the signal. There were two testing sessions which were completed by each participant on separate days; one session was performed under reduced viewing conditions, while the other session under regular viewing conditions. Each testing session consisted of 14 blocks: 7 blocks of intact images and 7 blocks of scrambled images. The order of the blocks was counterbalanced across participants and across the viewing conditions. In an experimental block there were 30 different object images for each of the 3 size categories and 28 catch trials, resulting in a total of 108 trials. The blocks presenting the scrambled images contained the same number of stimuli and catch trials. Stimuli within each block were presented in a random order. Each participant completed two testing sessions. The program for the stimulus presentation was created using MATLAB.

Another important alteration to the original paradigm was the inclusion of an inter-trial timing to allow for recordings of post-stimulus EEG signals (figure 4.1). Specifically, in the original paradigm a press of the button during the response time would instantly start the next trial. However, in the EEG version of the program there was a variable inter-trial interval ranging randomly between 650 ms and 1200 ms.

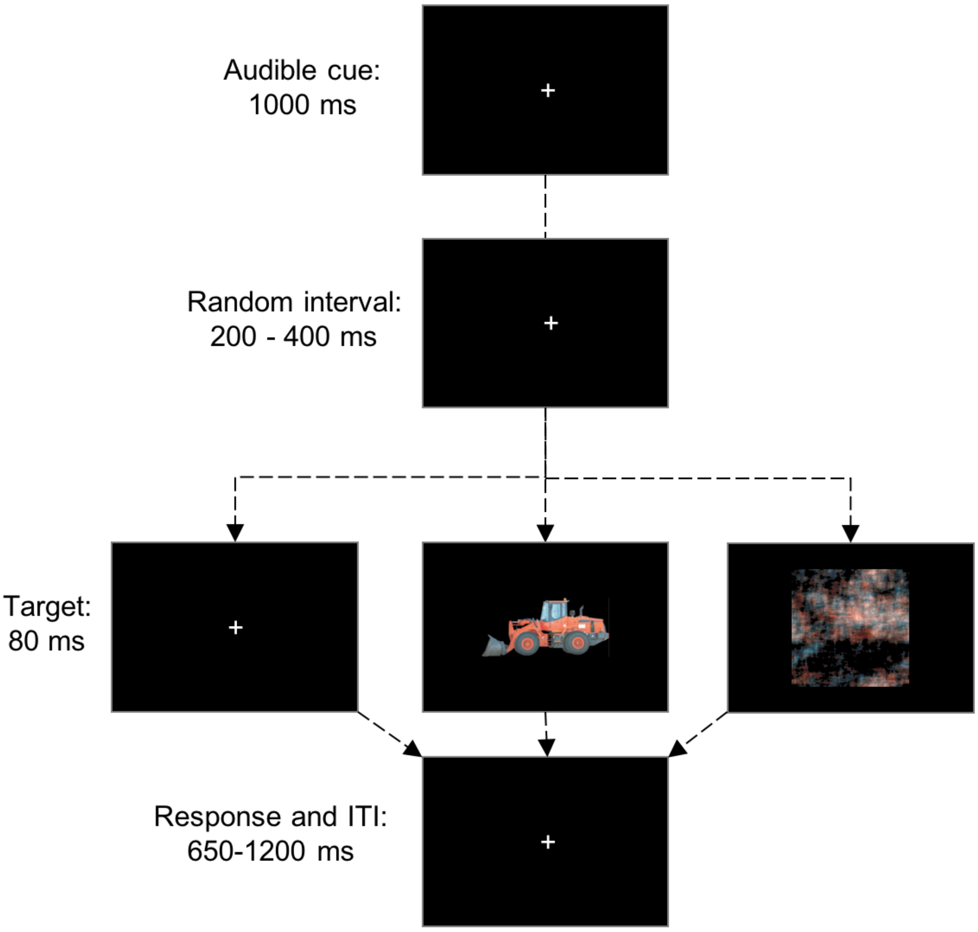


*Figure 4.1.* The experimental paradigm. The section labelled ‘Target’ shows the three possible types of stimuli (from left to right): catch trial, intact object and scrambled object. The image shown here (i.e. tractor) is displayed at 1/100th of its Familiar object size, however it should be noted that images at x10 and x1 their Familiar object size were also used (see Chapter 3: Experiment 5 for additional examples). The label ‘Cue’ refers to the 1000 Hz acoustic warning signal that was played to indicate the start of a new trial to the participant.

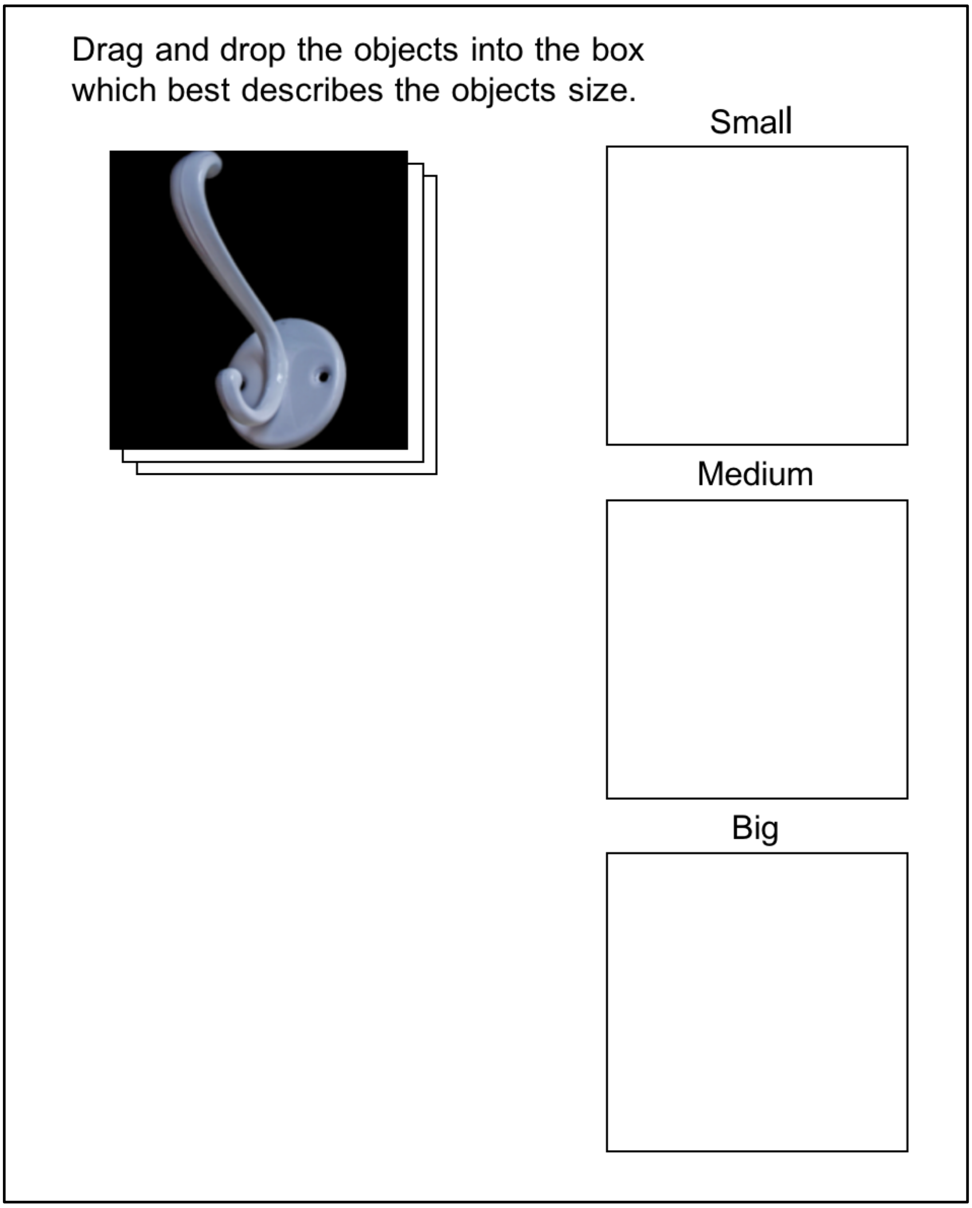
**Procedure**

Prior to testing, participants were given a tour of the lab and the procedures of the experiment were explained. An information sheet, along with a consent and demographics form, were also given. After the forms were completed and signed, an eye dominance assessment was conducted using the Dolman's hole in the card method (Cheng et al., 2004). As described in Chapter 3, participants were asked to wear and adjust the 'reduction goggles' to ensure that only a central pin-sized hole was available for the dominant eye to see through (only for reduced viewing conditions). Participants were asked to sit in front of a monitor placed at 60 cm of viewing distance and the experimenter placed the EEG cap on the participants' head. Once the cap was comfortably secured to the participants' head, the experimenter attached the electrodes using conductive gel. The quality of the EEG signal was ensured by checking the LED impedance light system and by observing the EEG waveforms produced via the BrainVision analyzer 2 software (Brain Products GmbH). Next, the participant was asked to place the goggles on (only for reduced viewing conditions), the quality of the signal was checked again, the reference electrode was secured on the nose, and the Electrooculography (EOG) electrode was placed on the right cheek, just below the goggles.

To guarantee data of high quality, participants were invited to view the active EEG signal, to discourage any excessive body movements, including teeth grinding and head movements. They were then instructed to perform the RT task. Specifically, they were asked to give fast but accurate responses and to react as soon as, and only when, an image appeared on the screen, whilst being prepared to refrain from responding when no image was presented. Ten practice trials were offered to allow participants to familiarize themselves with the task and procedures. The experimenter manually started the practise and monitored the quality of the EEG signal via the BrainVision analyser 2 program, so noisy electrode signals could be identified and subsequently fixed.

As mentioned above, viewing condition was manipulated in two separate testing sessions. In the first session, participants performed the task under reduced viewing conditions (i.e. lights off, an 8 cm diameter tunnel leading to the screen, pinhole glasses, and monocular vision). In the second session, participants completed the task under regular viewing conditions (lights on, binocular vision). Participants were encouraged to take breaks between the blocks, in order to stay alert. When necessary, the experimenter adjusted the electrodes to improve signal quality at the end of the breaks.

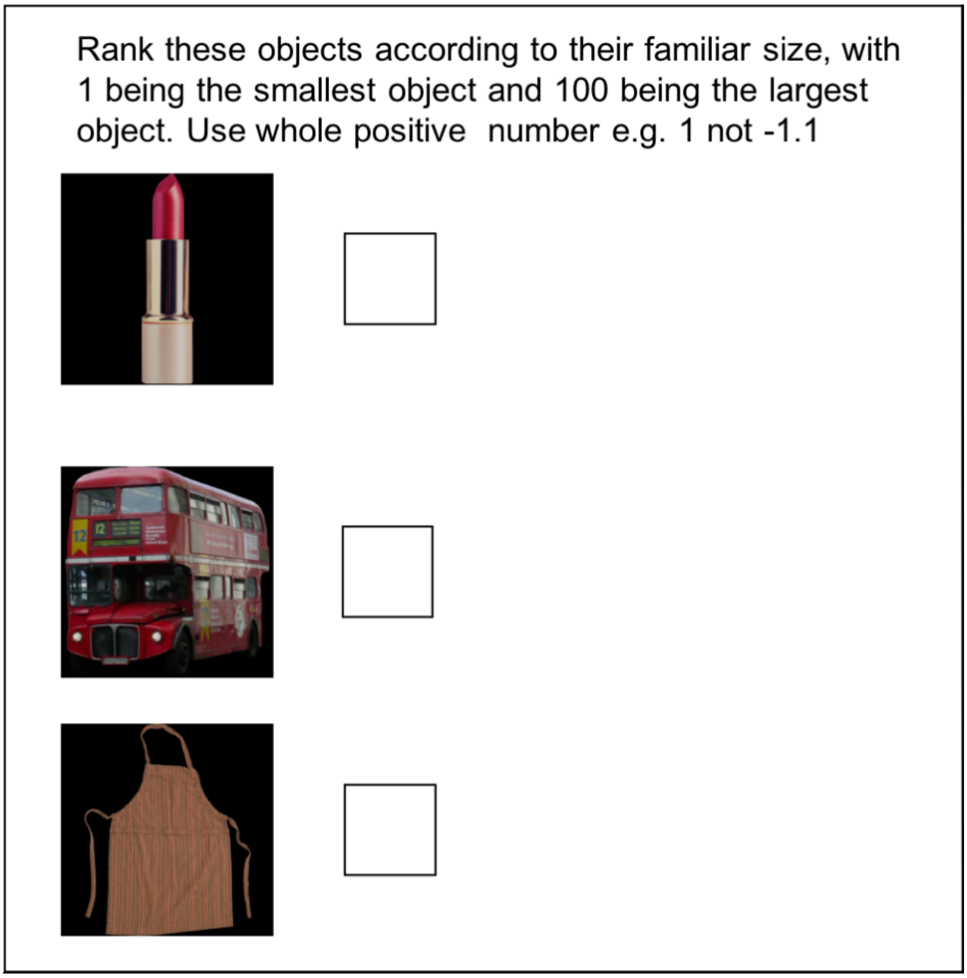
In the second session, two additional behavioural measures were taken, namely categorisation and rating. The categorisation task was completed online through a survey on Qualtrics (Qualtrics, Provo, UT). As can be seen in figure 4.2, participants were asked to place the object image in the most appropriate size category box, i.e. small, medium, big, using the computer mouse to drag and drop the image in to the most appropriate location. The participants were advised that once they placed the image into a box they should not attempt to change their response due to restrictions with the program. The same 90 images of the main EEG experiment were used in this task.



Drag and drop the objects into the box which best describes the objects size.

*Figure 4.2.* The categorization task. The example of image shown at the top left (i.e. peg) belongs to the small category. Images were stacked beneath this image, so once the participant categorised the image by dragging and dropping it into one of the three boxes (small, medium or big), another object image appeared, until all 90 images were categorised.

In the ranking task, the same 90 images were shown again but for this task participants were asked to rank the objects using a scale ranging from 1 to 100 (see figure 4.3). Participants were given a keyboard to enter the corresponding rank number into the box located to the right of the image. They were allowed to use the same ranking number more than once and were advised to compare the size of the object to one another in making their judgments.



Rank these objects according to their familiar size, with 1 being the smallest object and 100 being the largest object. Use whole positive number e.g. 1 not -1.1

*Figure 4.3.* An example of the ranking task with 3 of the possible 90 images shown. Participants were asked to key in the rank that best represented the size of the familiar objects, with respect to the other 89 images, into the box located to the right of the image.

After completing the session, the experimenter thanked the participant for their time, verbally debriefed the participant by means of a debrief form and answered any questions.

### EEG Acquisition

A nylon cap with 64 Ag/AgCl active electrodes (Brain Products GmbH) was secured to the participants' head. Brain Analyser Software (Brain products GmbH) was used to record the electroencephalographic response from the scalp. The international 10-20 system was used, recording from 61 electrodes, including; Fp1, Fp2, AF7, AF3, AF4, AF8, F7, F5, F3, F1, Fz, F2, F4, F6, F8, FT7, FC5,FC3,FC1, FC2, FC4, FC6, FT8, FT10, T7, C5, C3, C1, Cz, C2, C4, C6, T8, TP9, CP5, CP3, CP1, CPz, CP2, CP4, CP6, TP6, TP10, P7, P5, P3, P1, Pz, P2, P4, P6, P8, PO7, PO3, POz, PO4, PO8, PO9, O1, Oz, O2, and PO10 (see figure 4.4). The electrode corresponding to TP7 was removed from the cap and reassigned to the right cheek, just below the right eye in order to record eye movements. The ground was installed in the FCz position of the cap and the reference was placed on the tip of the nose. Impedance was kept below 20 kΩ and the EEG signal was amplified by 500K and sampled at a rate of 500 HZ.

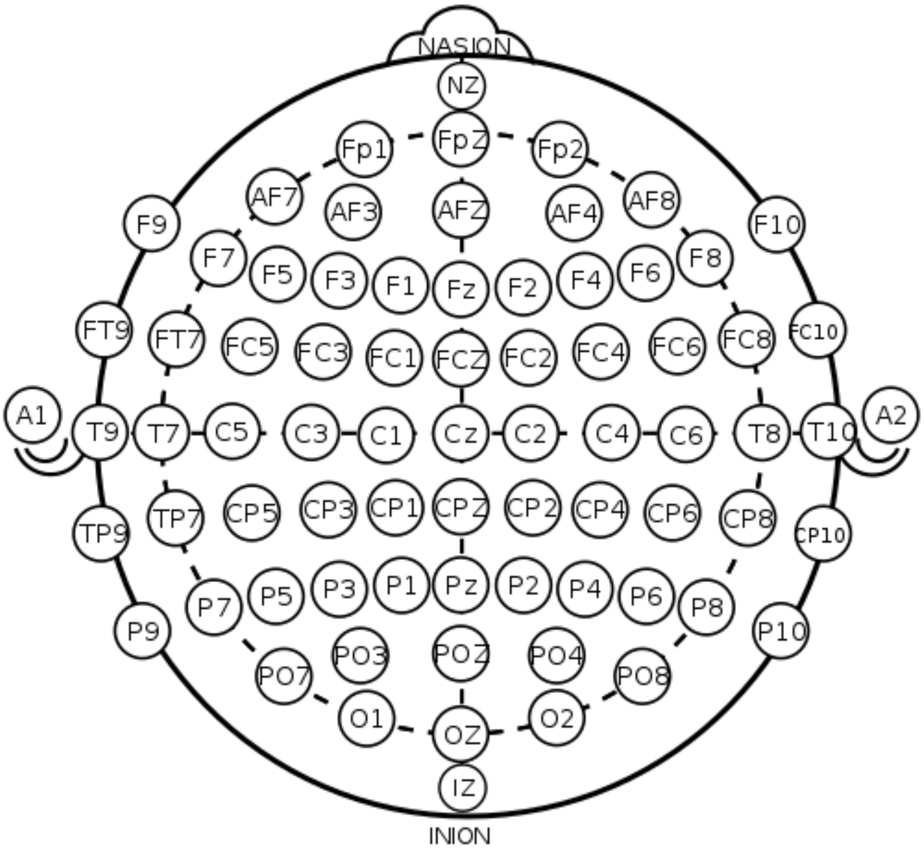


*Figure 4.4.* The standard placement of 64 electrodes following the 10-20 system. Note that from this standard setup Cz, FCz and TP7, were reassigned to reference applied to the nose, the ground and the EOG, respectively.

### Data Pre-Processing

For the off-line analysis, EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) were used to process the data. A low-pass 30 Hz filter was applied to the data. The data was then epoched with a baseline correction of 100 ms pre-stimulus onset, ending 500 ms post-stimulus onset. An artefact detection moving window, with a peak-to-peak threshold of 100 μvolts, was used to detect artefacts. Those channels that were highlighted as contributing significantly to increased noise were interpolated using spherical interpolation. After processing, all participants' EEG data had an average error rate of below 10%. Data was then averaged across trials for each experimental condition to create ERPs.

## Results

## Behavioural Results

### Simple Reaction Time Task

**Accuracy.** Using Grubbs test (Grubbs, 1969), one participant was deemed to be a significant outlier, so his data was removed from analysis, leaving a final sample of 18 participants (6 males, *Mage*= 22, *SD*= 3.59). Generally, accuracy was high ranging from 80 to 100% (*M*= 95%, *SD*= 5.71). A three-way repeated measures ANOVA with Viewing conditions (reduced vs regular), Image type (intact vs scrambled) and Familiar object size (small, medium or big) as main factors, was conducted on the task accuracy. There was no main effect of Viewing condition ($F(1,17) = 0.70, p = .415$, $np^2 = .039$). Nor Image type ($F(1,17) = 0.00, p = .951$, $np^2 = .001$) or Familiar object size ($F(2,34) = 0.27, p = .764$, $np^2 =$

.016) reached significance. All the interactions were also not significant (all $p > .05$) (see figure 4.5).

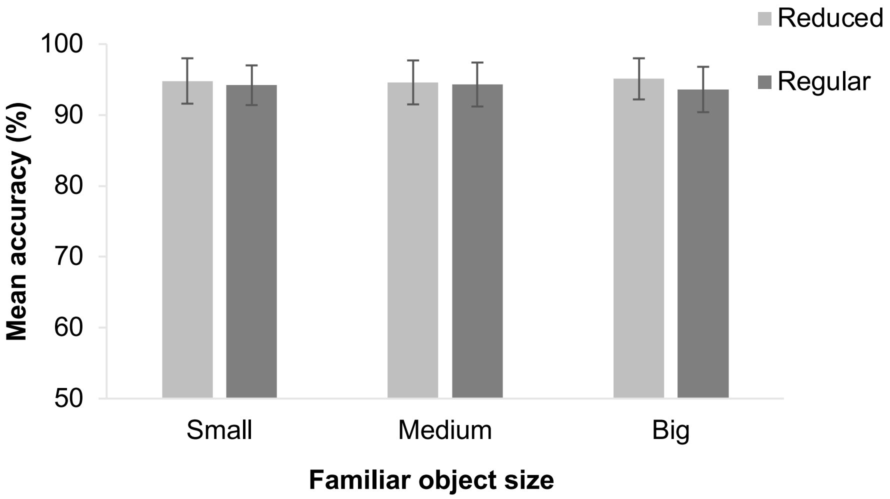


*Figure 4.5.* Mean task accuracy by Viewing condition (regular and reduced), Familiar object size (x1, 1/10 and 1/100 the real size), and Image type (intact and scrambled. Error bars represent +/- 95% CIs.

**Reaction times.** No significant outliers were found using the Grubbs test (Grubbs, 1969). Anticipations and delays were removed from the data using a cut-off of 140-650 ms (Sperandio et al., 2009). A repeated measures 2 x 2 x 3 ANOVA was conducted on simple RTs, with Viewing conditions (reduced vs regular), Image type (intact vs scrambled) and Familiar object size (small, medium or big) as main factors. There was a main effect of Viewing condition *(F(*1,18) = 73.53, $p < .001$, np$^2$ = .803). As has been observed in previous experiments (Chapter 3: experiment 3 & 4), participants were significantly faster to respond to stimuli under full (*M*= 227, *SD*= 22.53) compared to reduced viewing conditions (*M*= 271, *SD*= 32.66).

There was no significant main effect of Image type on RTs *(F(*1,18) = 2.76, $p = .114$, $\eta p^2 = .133$). Surprisingly, there was no significant effect of Familiar object size on RTs

*(F(*2,36) =2.167, *p* = .129, $\eta p^2$ = .107). None of the interactions reached significance (all *p* > .05) (see figure 4.6 & 4.7).

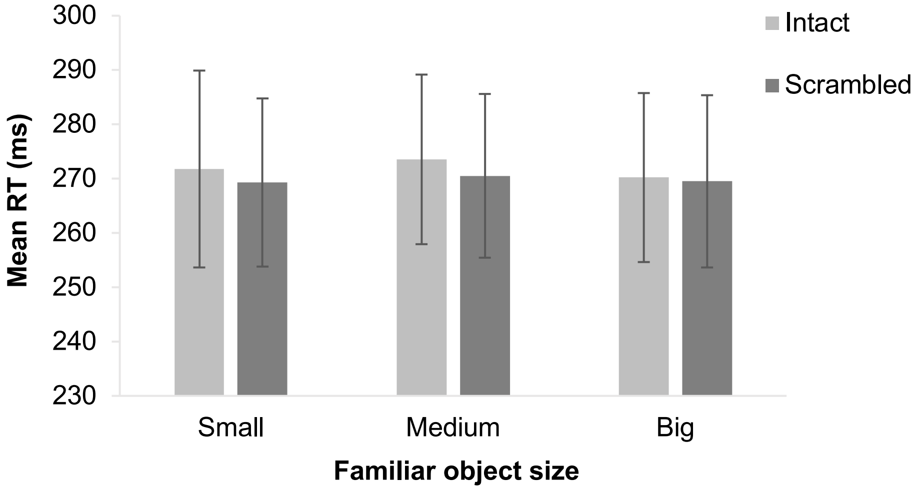


*Figure 4.6.* Mean simple RTs under reduced viewing conditions as a function of Image type (intact vs scrambled) and Familiar size (small vs. big). Error bars represent +/- 95% CIs.

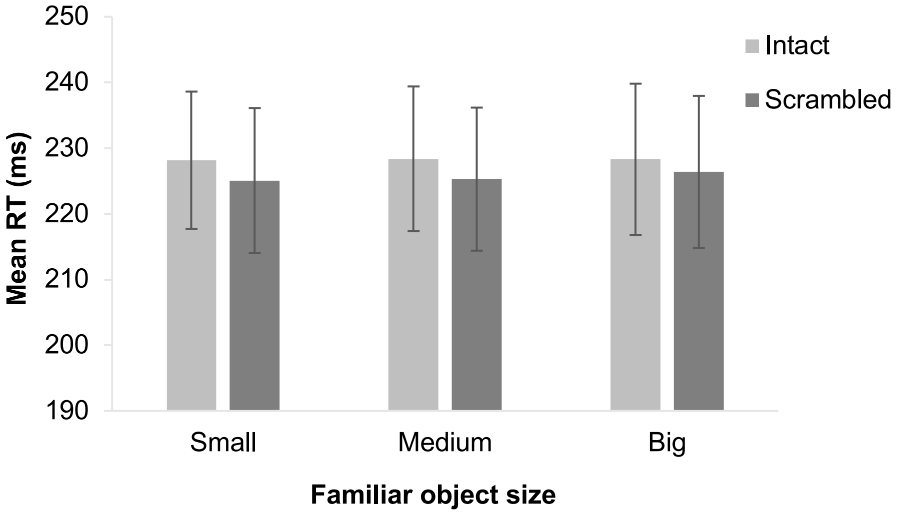


*Figure 4.7.* Mean simple RTs under regular viewing conditions as a function of Image type (intact vs scrambled) and Familiar size (small vs. big). Error bars represent +/- 95% CIs.

**Additional analysis.** As we were unable to replicate the effects of familiar size on simple RTs, we considered several changes to the paradigm as responsible for the different findings. In order to assess this possibility, an analysis was conducted comparing the mean RT and accuracy from Experiment 5: Chapter 3, to the mean RT and accuracy from the present study, but only from the trials that included intact images. In the present study participants were slightly quicker with less variability (*M*= 287, *SD*= 37.11) than in the previous study (*M*= 290, *SD*= 61.20).

An independent samples two-tailed t-test was conducted to examine the difference between the mean RT's for the original compared to the current study. In this statistical analysis equal variance could not be assumed, most probably due to the different samples size ($p = .037$), so a correction was applied. The results show that the average RTs for participants in the original study do not significantly differ from those in the current study ($t(44.56)= 0.22$, $p = .829$).

Another independent sample two-tailed t-test was conducted to examine the difference between the mean task accuracy for the original compared to the current study. Again, the equality of variance could also not be assumed ($p = .037$), so a correction was applied. Overall there was no significant difference between the old and new study ($t(31.014)= 0.38$, $p = .705$). The mean accuracy for the new study (*M*= 96.32, *SD*= 4.23), was very similar to the mean accuracy in the original study (*M*= 96.75, *SD*= 3.08).

## Categorisation Task

Two participants were identified as outliers with Grubbs test (Grubbs, 1969) and so were removed from further analysis. After removal of these two participants, categorisation accuracy for the remaining 17 participants (7 male, $M_{age}$= 22, *SD*= 3.62) was generally high, ranging from 83 to 98% (*M*= 94% *SD*= 4.23).

A one-way within-groups ANOVA with Familiar object size (small, vs medium, vs big), as the main factor revealed a significant effect on size categorisation accuracy ($F(2,32) = 5.19$, $p = .011$, $\eta p^2 = .245$). Post-hoc comparisons with Bonferroni correction revealed that there was a significant difference between the categorisation accuracy for small familiar objects and medium familiar objects (*p* = .02), but there was no significant difference between small and big (*p* = .455) and medium and big (*p* = .306) objects.

As can be seen from the figure 4.8 below, participants were more accurate when categorising familiar small and familiar big objects than the medium familiar objects. Further investigation into the behavioural data shows that one object in particular contributed greatly to the error in categorisation, namely the wreath was more frequently categorised as small (*M*= 63%) rather than medium. It is possible that this item was not properly recognised by the participants and therefore miscategorised.  However, even with the exclusion of such item, the mean accuracy (*M*= 84%) for the medium category was still lower than the other two categories. The decision to exclude the medium Familiar object size group from the ERP analysis was further justified by these findings, since this size category was not as familiar to participants as the smallest and biggest size categories.

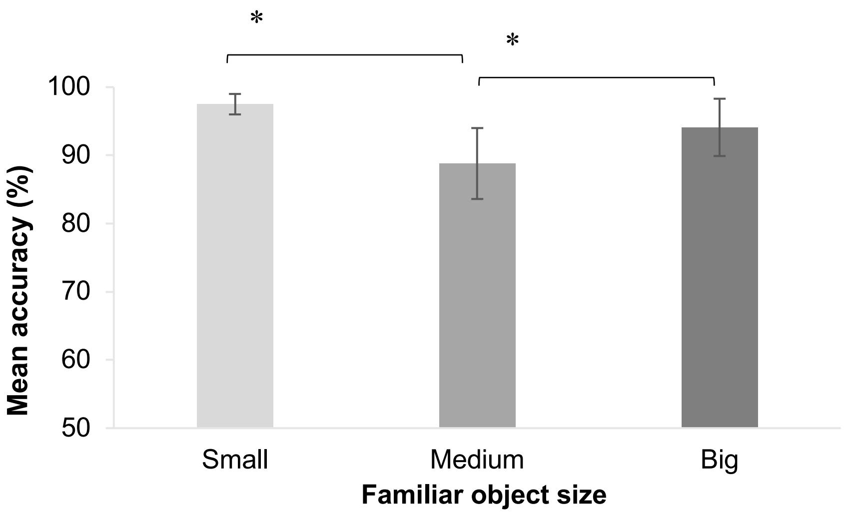


*Figure 4.8.* Mean accuracy of the categorisation task for each Familiar object size. Error bars represent +/- 95% CIs. Asterisk denotes a significant difference (*p* < .05).

## Ranking Task

The ranks were distributed across a range of 2 to 88 (*M*= 32, *SD*= 25.65). The ranks were correlated with the real-world size of the objects in log-units (see figure 4.9). Pearson's correlation revealed a strong positive relationship between the mean ranked size and the real-world size in log-units (*r* (90)= 0.96, *p* < .001). This result suggests that the participants could accurately rank the object images based on their knowledge about object size in the real world.

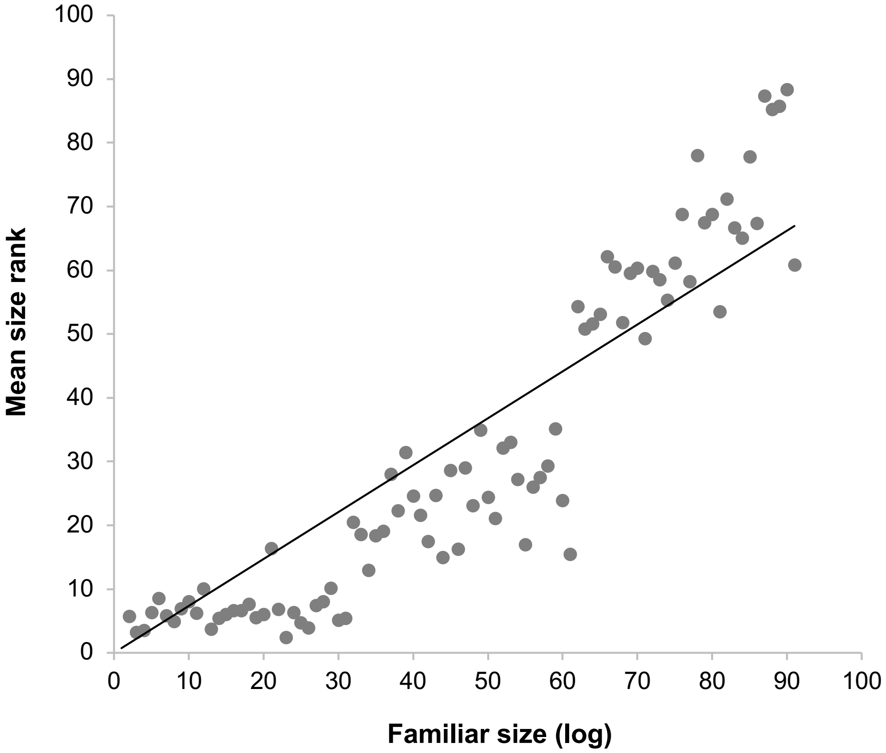


*Figure 4.9.* Correlation between the mean estimated size of familiar objects (ranks between 1 and 100) and their real-world size (in log-units).

## ERP Results

### Defining the Electrodes of Interest

To identify electrodes of interest, topographic maps of the ERP response on the scalp were created. To build the scalp maps, the mean peak latency for the early visual components of P1, N1 and P2, were considered. A temporal window of +/- 20 ms around the mean peak latency was then defined.

Scalp maps of mean amplitudes within these temporal windows were then created for each condition using ERPLAB (Lopez-Calderon & Luck, 2014). From these scalp maps, 8 electrodes of interest were identified as being of maximal activity in every condition. These electrodes corresponded to: PO8, PO4, O2, O1, PO3, PO7, Oz and POz (see figures 4.10, 4.11, 4.12 and 4.13). As the activity did not substantially vary across these 8 electrodes, the following ERP analyses on peak amplitude and latency were performed on the average activity of these sites.

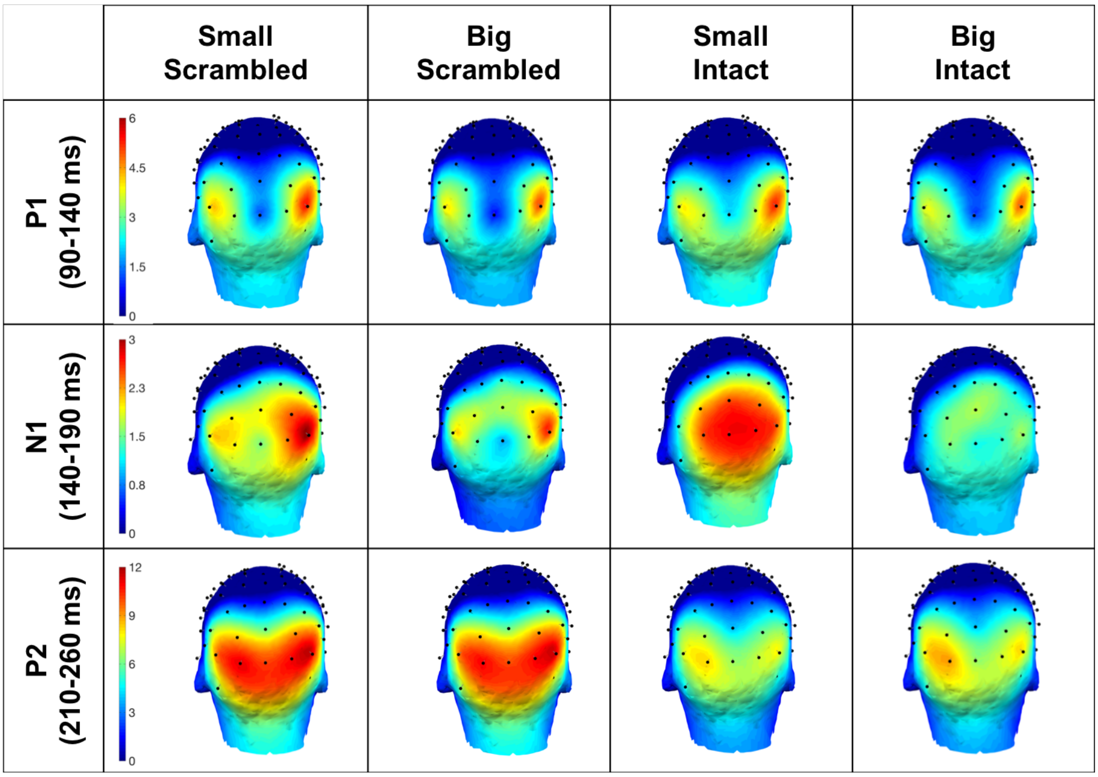


*Figure 4.10.* Scalp maps for regular viewing conditions. The vertical axis shows the three components P1, N1 and P2, within each specified temporal window. The horizontal axis shows the ERP response as a function of Familiar object size (small vs big) and Image type (scrambled vs intact). The activity is shown in microvolts, with dark red areas representing the highest response and dark blue areas representing the least response.

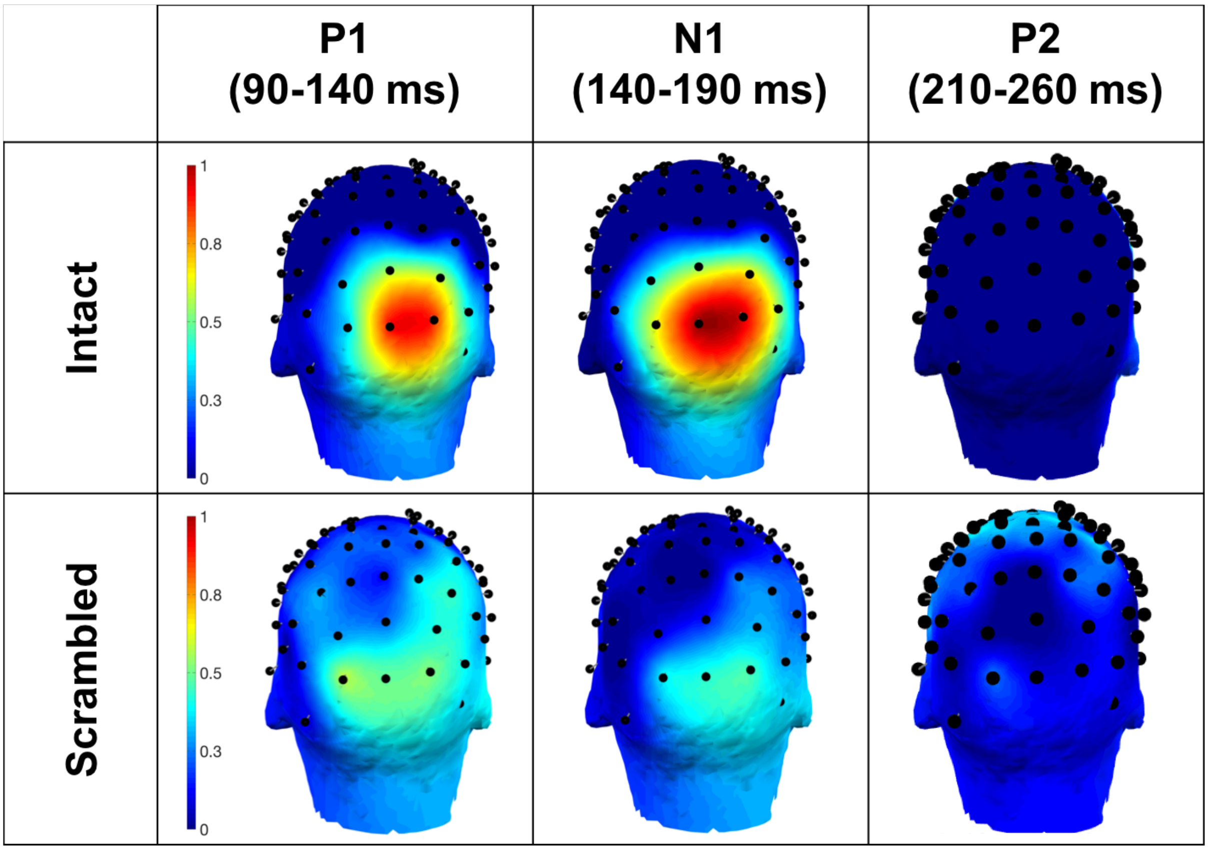


*Figure 4.11.* Scalp difference map for the mean amplitude of Small – Big familiar object size under regular viewing conditions. The horizontal axis shows the three components P1, N1 and P2, within each specified temporal window. The vertical axis shows the Image type (intact vs scrambled). The activity is shown in microvolts, with dark red areas representing the highest response and dark blue areas representing the least response.

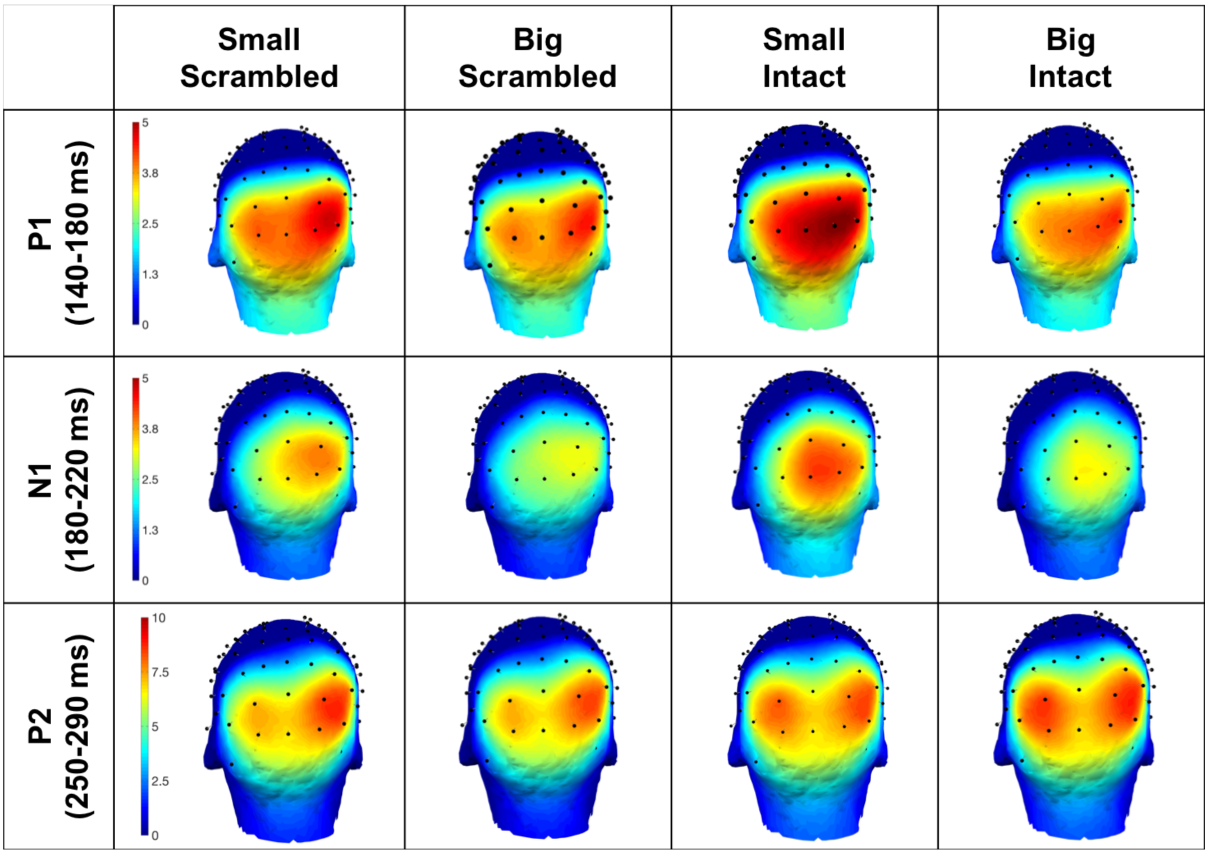


*Figure 4.12.* Scalp maps for reduced viewing conditions. The vertical axis shows the three components P1, N1 and P2, within each specified temporal window. The horizontal axis shows the ERP response as a function of Familiar object size (small vs big) and Image type (scrambled vs intact). The activity is shown in microvolts, with dark red areas representing the highest response and dark blue areas representing the least response.

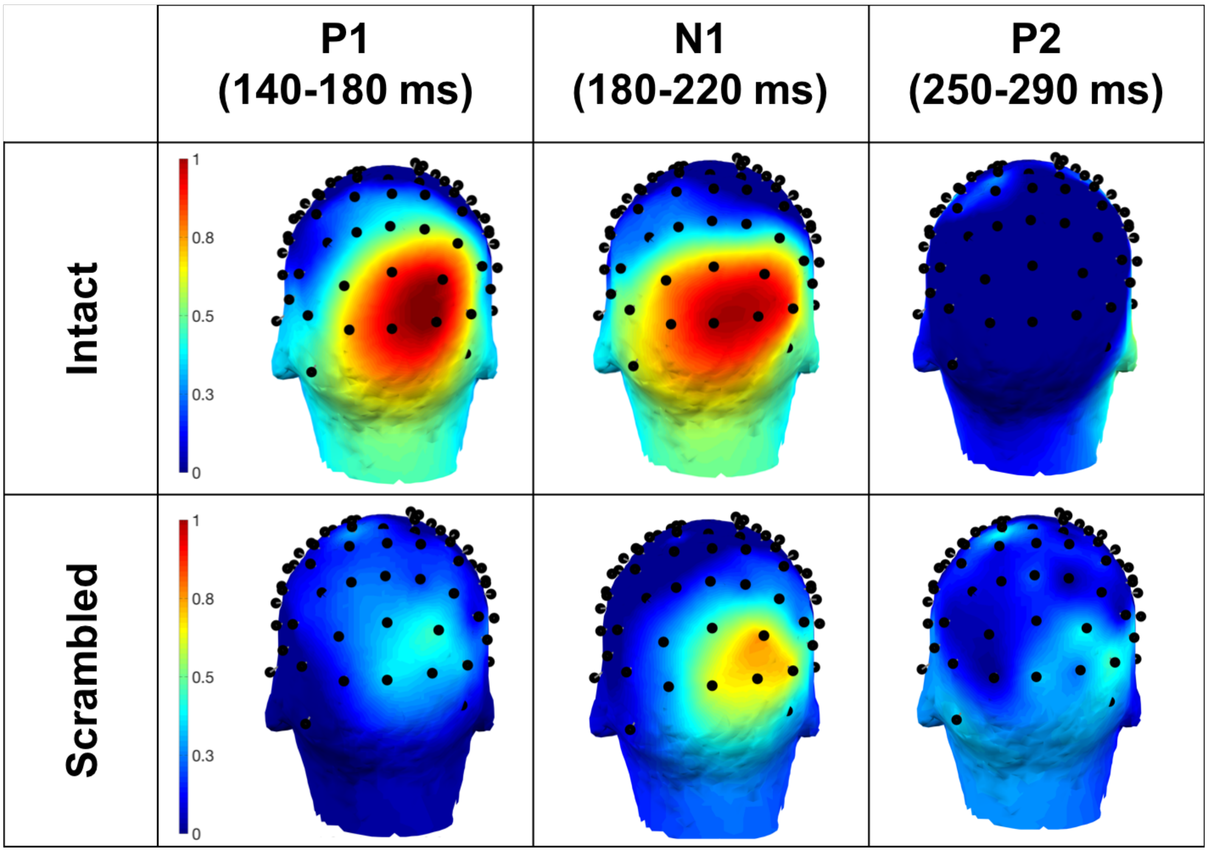


*Figure 4.13.* Scalp difference map for the mean amplitude of Small – Big familiar object size under reduced viewing conditions. The horizontal axis shows the three components P1, N1 and P2, within each specified temporal window. The vertical axis shows the Image type (intact vs scrambled). The activity is shown in microvolts, with dark red areas representing the highest response and dark blue areas representing the least response.

### Data Exploration

As can be seen from the grand average of the ERPs for viewing conditions in figure 4.14, the ERP components P1, N1 and P2 are clear and evident. For the regular viewing condition, P1 peaked at ~110 ms, N1 at ~170 ms and P2 at ~235 ms.  However, component C1 is not present (this can also be seen in the waveforms of the following results). Hence, C1 will not be analysed in the following sections.

As can be seen in figure 4.14, Viewing condition clearly affected the ERP response. There was a distinct slowing in the ERP response when reduced viewing conditions are implemented. Specifically, a difference of ~40ms between Viewing conditions were evident across the response period. Nonetheless, the classic visual evoked components are still observable. For reduced viewing conditions, P1 occurred at ~160 ms, N1 at ~200 ms and P2 at ~270 ms. Notably, the amplitude generally appeared to be reduced for the reduced viewing conditions compared to the regular viewing conditions by (~40% for N1 and ~30% for P2).

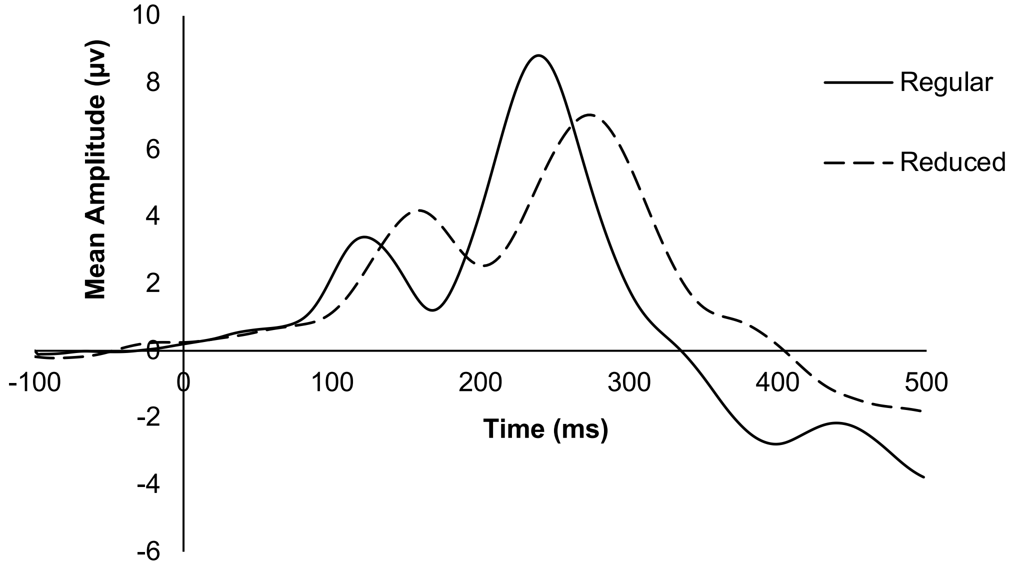


*Figure 4.14.* Grand average for Viewing conditions, averaged across participants. Note that response was averaged across the electrodes of interest; Oz, O1, O2, POz, PO3, PO4, PO7 and PO8.

Paired sample t-tests revealed that the comparison between latencies reduced and regular viewing conditions was significant for all three components (all $p < .001$). However, the same analysis for mean peak amplitude did not show any significant results for P1 ($p = .16$), N1 ($p = .168$) or P2 ($p = .087$).

### Regular Viewing Conditions

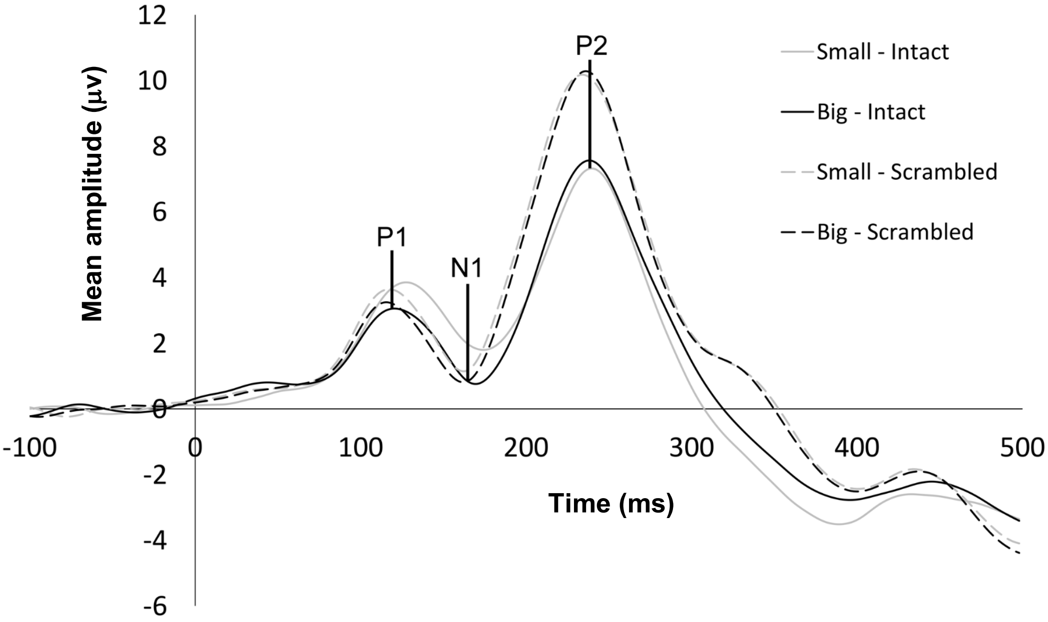


*Figure 4.15.* Grand average for regular viewing conditions as a function of Image type (intact or scrambled) and Familiar object size (big or small).

**Amplitude**

A repeated-measures 2 x 2 ANOVA was conducted on P1, N1 and P2 amplitude with Familiar object size (small vs big) and Image type (intact vs scrambled) as main factors under regular viewing conditions (see figure 4.15).

**P1 component.** There was a main effect of Familiar object size *(F(*1,18) = 16.32, *p* = .001, ηp$^2$ = .476), with a bigger amplitude in response to familiar small objects (*M*= 3.38, *SD*= 2.26) compared to familiar big objects (*M*= 2.77, *SD*= 2.42). There was no main effect of Image type on mean peak amplitude *(F(*1,18) = 1.33, *p* = .265, ηp$^2$ = .069). However, there was an interaction between Image type and Familiar object size on mean peak amplitude *(F(*1,18) = 7.88, *p* = .012, ηp$^2$ = .304). Planned comparisons revealed that there was a significant difference between small (*M*= 3.67, *SD*= 2.18) and big (*M*= 2.80, *SD*= 2.52) intact images (*p* < .001), but not between the scrambled small images (*M*= 3.09, *SD*= 2.34) and the scrambled big images (*M*= 2.74, *SD*= 2.31; *p* = .082) (see figure 4.16).

*Figure 4.16.* Mean peak amplitude for component P1 under regular Viewing conditions. Error bars represent +/- 95% CIs. Asterisk denotes a significant difference (*p* < .05).

**N1 component.** The ANOVA revealed a main effect of Familiar object size on peak amplitude *(F(*1,18) = 12.83, *p* = .002, $\eta p^2$ = .416), with greater amplitude for familiar small objects (*M*= 1.88, *SD*= 3.04) than familiar big objects (*M*= 1.28, *SD*= 3.16). There was no main effect of Image type *(F(*1,18) = 0.16, *p* = .69, $\eta p^2$ = .009) nor an interaction between Image type and Familiar object size *(F(*1,18) = 2.63, *p* = .122, $\eta p^2$ = .128).

**P2 component.** There was no main effect of Familiar object size on mean peak amplitude *(F(*1,18) = 0.01, *p* = .916, $\eta p^2$ = .001). However, there was a main effect of Image type *(F(*1,18) = 13.71, *p* = .002, $\eta p^2$ = .432), such that scrambled images had an increased amplitude (*M*= 9.42, *SD*= 3.11) in comparison to intact images (*M*= 7.56, *SD*= 3.13). There was no interaction between Image type and Familiar object size *(F(*1,18) = 0.88, *p* = .361, $\eta p^2$ = .047) .

**Latency**

A repeated-measures 2 x 2 ANOVA was conducted on P1, N1 and P2 latency with Familiar object size (small vs big) and Image type (intact vs scrambled) as main factors, under regular viewing conditions.

**P1 component.** The main effect of Familiar object size on mean peak latency did not reach significance ($F(1,18) = 3.60$, $p = .074$, $\eta p^2 = .167$), whereas there was a significant effect of Image type ($F(1,18) = 23.32$, $p < .001$, $\eta p^2 = .564$), with faster latencies to scrambled ($M$= 116, $SD$= 10.04) compared to intact images ($M$= 125, $SD$= 12.16). There was no significant interaction between Image type and Familiar object size on mean peak latency ($F(1,18) = 0.08$, $p = .784$, $\eta p^2 = .004$).

**N1 component.** The main effect of Familiar object size on mean peak latency did not reach significance ($F(1,18) = 1.30$, $p = .27$, $\eta p^2 = .067$). There was a significant effect of Image type ($F(1,18) = 28.09$, $p < .001$, $\eta p^2 = .609$), with faster latencies to scrambled ($M$= 162, $SD$= 8.62) than intact images ($M$= 171, $SD$= 10.60). There was no significant interaction between Image type and Familiar object size ($F(1,18) = 0.53$, $p = .477$, $\eta p^2 = .029$).

**P2 component**. There was no main effect of Familiar object size on mean peak latency ($F(1,18) = 2.41$, $p = .138$, $\eta p^2 = .118$). However, there was a significant main effect of Image type ($F(1,18) = 16.39$, $p < .001$, $\eta p^2 = .477$), such that scrambled images ($M$= 235, $SD$= 8.03) were processed faster than intact images ($M$= 238, $SD$= 8.65). There was also a significant interaction between Familiar object size and Image type on mean peak latency ($F(1,18) = 16.39$, $p < .001$, $\eta p^2 = .477$). Planned comparisons revealed that the comparison between familiar small intact objects ($M$= 240, $SD$= 9.32) and familiar big intact objects ($M$= 235, $SD$= 7.98) was significant ($p = .007$). However, the comparison between scrambled small ($M$= 234, $SD$= 8.08) and scrambled big objects ($M$= 235, $SD$= 7.98) was not ($p = .103$) observable in figure 4.17.

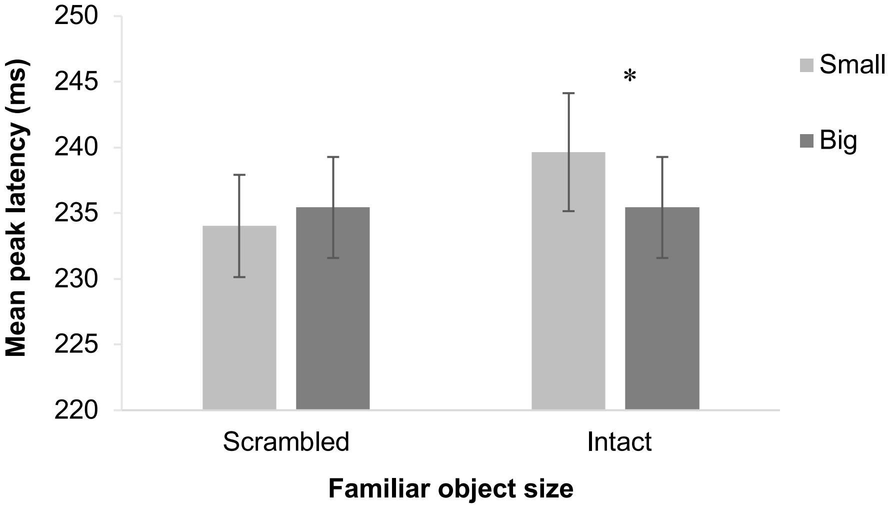


*Figure 4.17.* The peak latency (ms) is shown for the component P2 under regular Viewing conditions. Error bars represent +/- 95% CIs. Asterisk denotes a significant difference ($p < .05$).

**Summary**

The findings indicate that under regular viewing condition there was a bigger P1 amplitude in response to familiar small objects compared to big objects. Importantly, this difference in amplitude was significantly greater in response to the intact than scrambled images, as can be seen in figure 4.16. The effect of Familiar object size on amplitude was also observed for N1 but not P2 components (see figures 4.11 and 4.15). During the temporal window of P2, scrambled object images produced greater amplitudes compared to intact object images. With respect to latency, responses to scrambled images were significantly faster compared to intact images across component P1 and N1. In the P2 latency, a slowing in response to the small intact object images was observed, when compared with mean latency for big intact objects (see figure 4.17 and 4.18).

## Reduced Viewing Conditions

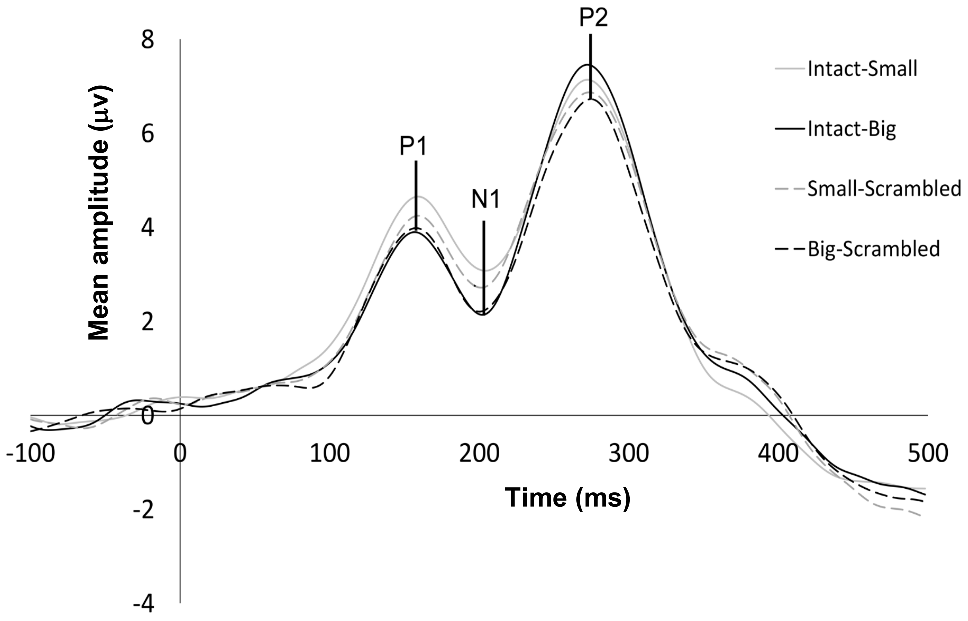


*Figure 4.18.* Grand average for reduced viewing conditions for the average of all participants, as a function of Image type (intact or scrambled) and Familiar object size (big or small) as main factors.

### Amplitude

A repeated-measures 2 x 2 ANOVA was conducted on P1, N1, and P2 amplitude with Familiar object size (small vs big) and Images type (intact vs scrambled) under reduced viewing conditions.

**P1 component.** There was a main effect of Familiar object size *(F(*1,18) = 17.22, *p* = .001, ηp$^2$ = .489), with a bigger amplitude in response to familiar small objects (*M*= 4.16, *SD*= 1.78) compared to familiar big objects (*M*= 3.72, *SD*= 1.70). There was no main effect of Image type on mean peak amplitude *(F(*1,18) = 1.34, *p* = .263, ηp$^2$ = .069) nor an interaction between Image type and Familiar object size on mean peak amplitude *(F(*1,18) = 2.11, *p* = .164, ηp$^2$ = .105).

**N1 component**. There was a main effect of Familiar object size *(F(*1,18) = 15.91, *p* = .001, $\eta p^2 = .469$), with a bigger amplitude in response to familiar small objects (*M*= 3.17, *SD*= 2.48) compared to familiar big objects (*M*= 2.60, *SD*= 2.45). There was no main effect of Image type on mean peak amplitude *(F(*1,18) = 0.35, *p* = .56, $\eta p^2 = .019$), nor an interaction between Image type and Familiar object size on mean peak amplitude *(F(*1,18) = 0.96, *p* = .34, $\eta p^2 = .051$).

**P2 component.** There was no main effect of size *(F(*1,18) = 0.28, *p* = .602, $\eta p^2 = .015$), Image type (*F(*1,18) = 0.07, *p* = .789, $\eta p^2 = .004$), nor an interaction between Image type and Familiar object size on mean peak amplitude *(F(*1,18) = 1.06, *p* = .316, $\eta p^2 = .056$).

### Latency

**P1 component**. There was a main effect of Familiar object size *(F(*1,18) = 5.07, *p* = .037, $\eta p^2 = .22$), with a faster latency in response to familiar big objects (*M*= 159, *SD*= 13.49) compared to familiar small objects (*M*= 161, *SD*= 14.20). There was no main effect of Image type on mean peak latency *(F(*1,18) = 0.61, *p* = .446, $\eta p^2 = .033$), nor an interaction between Image type and Familiar object size on mean peak latency *(F(*1,18) = 1.00, *p* = .331, $\eta p^2 = .052$).

**N1 component.** There were no main effects of Familiar object size *(F(*1,18) = 0.13, *p* = .725, $\eta p^2 = .007$) , Image type (*F(*1,18) = 0.12, *p* = .733, $\eta p^2 = .007$) nor an interaction between Image type and Familiar object size on mean peak latency *(F(*1,18) = 0.04, *p* = .848, $\eta p^2 = .002$).

**P2 component.** There were no main effects of Familiar object size *(F(*1,18) = 0.23, *p* = .635, $\eta p^2 = .013$) and Image type (*F(*1,18) = 0.22, *p* = .643, $\eta p^2 = .012$), nor an interaction between Image type and Familiar object size on mean peak latency *(F(*1,18) = 0.28, *p* = .606, $\eta p^2 = .015$).

### Summary

In terms of amplitude, at P1 and N1, there was a bigger amplitude to familiar small images compared to familiar big images, as was the case in regular viewing conditions. There were no significant effects in terms of amplitude at P2. For mean peak latency, at P1 there was a significant effect of Familiar object size, such that the mean peak latency was faster to big compared to small objects. There were no effects on latency at N1 or P2.

## Interactions with Viewing Conditions

The analysis of the three-way interaction between Familiar object size, Image type and Viewing condition is presented as follows, so as to highlight any potential influence of viewing conditions.

### Amplitudes

A repeated measures 2 x 2 x 2 ANOVA with Viewing condition (Full vs Reduced), Image Type (Intact vs Scrambled), and Familiar object size (small vs big) as main factors, was carried out on the mean amplitude for each component.

**P1 component**. None of the interactions with Viewing condition were significant, including Viewing condition by Familiar object size ($F(1,18)= 0.84$, $p = .371$, $\eta p^2 = .045$), Viewing condition by Image type ($F(1,18)= 0.06$, $p = .817$, $\eta p^2 = .003$) nor Viewing condition by Familiar object size by Image type ($F(1,18)= 0.21$, $p = .654$, $\eta p^2 = .011$).

**N1 component.** Viewing condition by Familiar object size was significant ($F(1,18)= 4.58$, $p = .046$, $\eta p^2 = .203$). Planned comparisons, revealed a significant difference in mean amplitude between small (*M*= 3.17 *,* *SD*= 2.48) and big familiar sized objects (*M*= 2.60*, SD*= 2.44) ($p = .001$) under reduced viewing conditions, whereas the difference in mean amplitude between small (*M*= 1.89*, SD*= 3.04) and big familiar sized objects (*M*= 2.07*, SD*= 2.97) under regular viewing conditions was not significant ($p = 0.585$). Viewing condition by Image type ($F(1,18)= 1.55$, $p = .23$, $\eta p^2 = .079$) and Viewing condition by Familiar object size by Image type ($F(1,18)= 3.84$, $p = .066$, $\eta p^2 = .176$) were not significant.

**P2 component.** There was a significant interaction between Viewing condition and Image type (*F*(1,18)= 9.90, *p* = .006, ηp$^2$ = .355). Planned comparisons revealed, that under regular viewing conditions, scrambled objects (*M*= 9.42*, SD*= 1.49) produced a significantly bigger amplitude (*p* = .002) compared to intact objects (*M*= 7.56*, SD*= 1.50). In contrast, the difference in amplitude between intact (*M*= 6.61*, SD*= 1.71) and scrambled (*M*= 6.47*, SD*= 1.64) images for reduced conditions was not significant (*p* = .789). The other interactions did not reach significance, including Viewing condition by Familiar object size (*F*(1,18)= 0.30, *p* = .593, ηp$^2$ = .016) and Image type by Familiar size by Viewing condition (*F*(1,18)= 0.04, *p* = .85, ηp$^2$ = .002) (see figure 4.19).

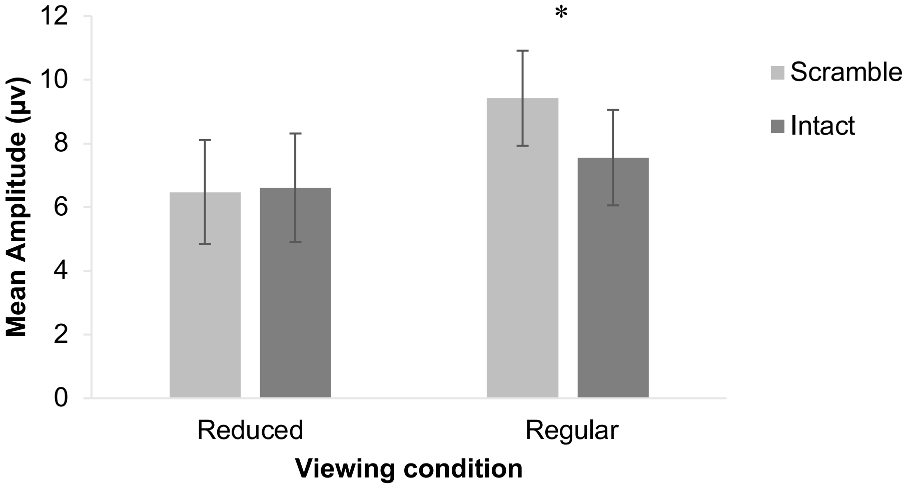


*Figure 4.19.* The mean amplitude (µv) as a function of Viewing condition (reduced vs regular) and Image type (intact vs scrambled) is shown for the component P2. Error bars represent +/- 95% CIs. Asterisk denotes a significant difference (*p* < .05).

## Latency

A repeated measures 2 x 2 x 2 ANOVA with Viewing condition (Full vs Reduced), Image Type (Intact vs Scrambled), and Familiar object size (small vs big) as main factors, was carried out on the peak latency for each component.

**P1 component.** Viewing condition by Image type was the only significant interaction (*F*(1,18)= 13.95, *p* = .002, ηp$^2$ = .437). Planned comparisons revealed that the difference in latency between intact (*M*= 161*, SD*= 6.87) and scrambled (*M*= 159*, SD*= 6.16) images under reduced viewing condition was not significant (*p* = .446). However, the difference in mean latency between intact (*M*= 125*, SD*= 5.80) and scrambled (*M*= 116*, SD*= 4.73) images under regular viewing condition did reach significance (*p* < .001). The other interactions did not reach significance, namely Viewing condition by Familiar object size (*F*(1,18)= 0.50, *p* = .49, ηp$^2$ = .027), Viewing condition by Familiar object size by Image type (*F*(1,18)= 0.52, *p* = .48, ηp$^2$ = .028) (see figure 4.20).

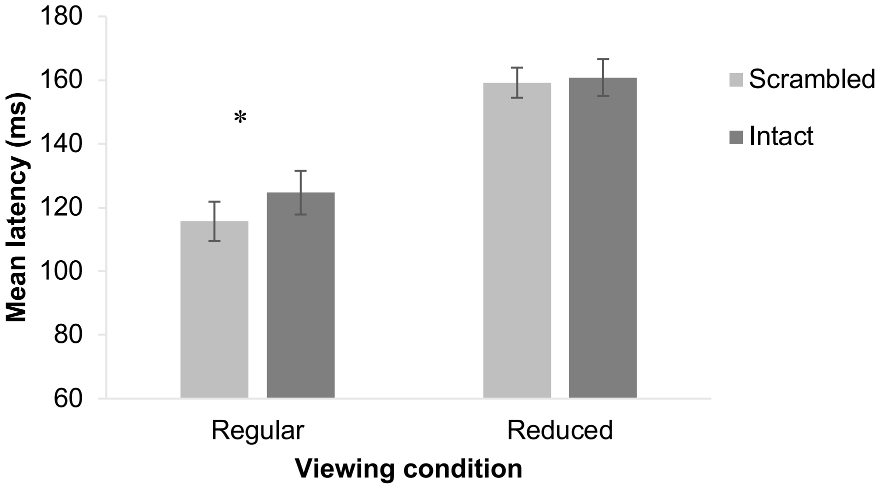


*Figure 4.20.* The peak latency (ms) as a function of Viewing condition (regular vs reduced) and Image type (intact vs scrambled) is shown for the component P1. Error bars represent +/- 95% CIs. Asterisk denotes a significant difference (*p* < .05).

**N1 component.** Viewing condition by Image type was the only significant interaction (*F*(1,18)= 20.95, *p* < .001, ηp$^2$ = .538). Planned comparisons revealed that the difference in latency between intact (*M*= 203*, SD*= 5.49) and scrambled (*M*= 203*, SD*= 5.49) images under reduced viewing condition was not significant (*p* = .733). In contrast, the mean latency between intact (*M*= 171*, SD*= 4.91) and scrambled (*M*= 162*, SD*= 3.95) images under regular viewing condition did reach significance ($p < .001$). The other interactions were not significant, including Viewing condition by Familiar object size ($F(1,18)= 0.88$, $p = .36$, $\eta p^2 = .047$) and Viewing condition by Familiar object size by Image type ($F(1,18)= 0.49$, $p = .495$, $\eta p^2 = .026$) (see figure 4.21).

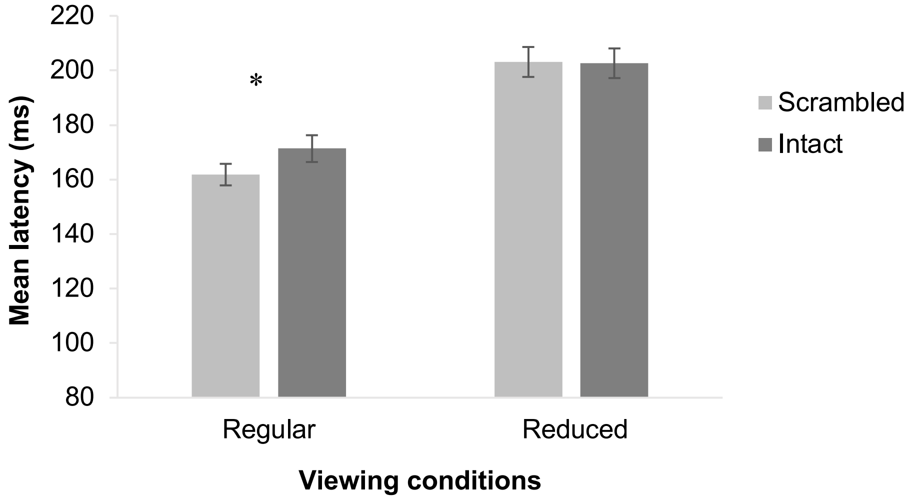


*Figure 4.21.* The peak latency (ms) as a function of Viewing condition (regular vs reduced) and Image type (intact vs scrambled) is shown for the component N1. Error bars represent +/- 95% CIs. Asterisk denotes a significant difference ($p < .05$).

**P2 component.** None of the interactions were significant at this component, specifically Viewing condition by Familiar object size ($F(1,18)= 3.52$, $p = .077$, $\eta p^2 = .164$), Viewing condition by Image type ($F(1,18)= 3.77$, $p = .068$, $\eta p^2 = .173$), and Viewing condition by Familiar object size by Image type ($F(1,18)= 2.4$, $p = .139$, $\eta p^2 = .118$).

## Summary

Overall none of the three-way interactions between Familiar size by Image type by Viewing condition were significant, whereas some of the two-way interactions with Viewing condition did reach significance. Particularly, there were significant differences in ERP activity generated during regular viewing conditions. For example, scrambled images had bigger amplitudes than intact images at P2 and there were faster latencies for scrambled compared to intact images during P1 and N1 under regular viewing conditions only. The only significant effect specific to reduced viewing condition was an effect of familiar size recorded at N1, such that small familiar objects produced greater amplitudes than big familiar objects.

## Spatial Frequency Results

In order to establish if underlying image properties might be responsible for the familiar size effects on the ERPs, a spatial frequency analysis was conducted, using the natural image statistical toolbox for MATLAB (Bainbridge & Oliva, 2015). The toolbox produced a QhF value, which corresponds to the average percentage of high spatial frequency across each image. A one-way ANOVA with Familiar object size (small, medium, big) as main factor was carried out on the mean QhF values .

The data failed the Levene's test for homogeneity of variance ($p < .001$). As such, Welch's ANOVA, an alternative to a one-way independent measures ANOVA, was conducted. Welch's ANOVA revealed a significant effect of Familiar size ($F(2, 45.05) = 7.88$, $p < .001$). Games-Howell post-hoc tests (Bonferroni equivalent) revealed that small objects ($M$= 7.07, $SD$= 4.33) had significantly lower levels of high spatial frequency compared to medium objects ($M$= 16.67, $SD$= 20.83) ($p = .049$). Small object also had significantly lower levels of high spatial frequency compared to big objects ($M$= 14.28, $SD$= 11.08) ($p = .006$). However, there was no significant difference in QhF values between medium and big objects ($p = .843$). It is interesting to note that the medium sized object had on average higher spatial frequency and more variance than the other two size categories (see figure 4.22).

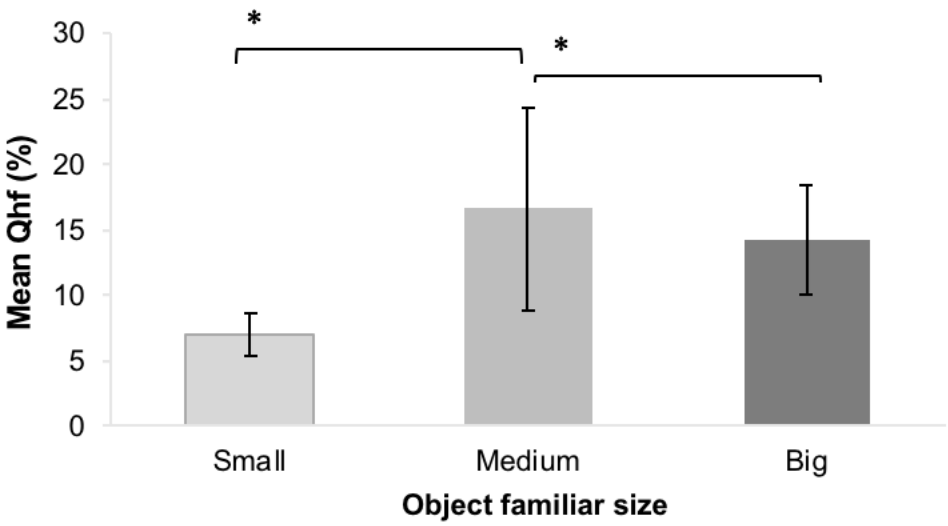


*Figure 4.22.* Mean QhF values, representing the mean percentage of high spatial frequency within the images of the three familiar size categories. Error bars represent +/- 95% CI's.

**Summary**

The mean percentage of high spatial frequency present in the images of each size category was significantly different, such that small object images had significantly lower levels of high spatial frequency, compared to medium and big objects. However, the mean percentage of high spatial frequency for medium and big objects did not significantly differ. These findings are in agreement with claims that images of big objects tend to have more details and, therefore, higher spatial frequency compared to small objects (Bainbridge & Oliva, 2015).

## Discussion

In this ERP experiment, participants completed a simple RT task while EEG activity was recorded on their scalp to measure behavioural and electrophysiological changes associated with familiar size from stimuli of three distinct size categories (i.e. small, medium, big). Images consisted of both intact objects and their scrambled versions and were viewed both under regular and reduced viewing conditions across two testing sessions. The aim of the study was to understand the temporal dynamics underlying the processing of familiar object size. In particular, the study aimed to identify if differences in brain activity between small and large object images would be similar to the time course observed for object categorisation, occurring as early as 100 ms from stimuli onset (Proverbio et al., 2007; Simanova et al., 2010; Zhu et al., 2016).

After completing the simple RT task, participants also completed two additional behavioural tasks, where they were asked to judge the same intact images used in the simple RT task. The first task required the participants to categorise the familiar object images as small, medium or big. The second task required participants to rank the size of the familiar objects on a scale from 1 to 100. These measures were included to assess the degree of familiarity to the size of the objects used in the main experiment. In addition to these measures, the spatial frequency of all the object images was analysed to test if the effect of familiar size relies on underlying image properties.

## Behavioural Results

### RT Results

Our findings demonstrated an effect of viewing condition on simple RTs: participants were faster under regular compared to reduced viewing conditions. This result was in agreement with previous research which also demonstrated slower latencies for reduced compared to regular viewing conditions (Adachi-Usami & Lehmann, 1983). Surprisingly, we were unable to replicate our previous findings: simple RTs were unaffected by familiar size. This unexpected finding could be attributed to changes in the paradigm required to adapt the experiment to the ERP recordings, such as the inclusion of an inter-trial interval or the increment of catch trials.

Previous research has suggested that changes in the duration between the warning signal and stimuli can affect the speed to respond (Bertelson, 1966; Drazin, 1961). Additionally, the inclusion of more catch trials in a block, appears to generally improve task accuracy, whilst slightly decreasing RT's (Seibold, Bausenhart, Rolke, & Ulrich, 2011). Although it must be noted that in the study by Seibold et al (2011), the percentage of catch trials was increased in increments of 25%, whereas we doubled our 15% of catch trials to 30%.

However, an additional analysis that compared RTs and accuracy between the original (Chapter 3: Experiment 5) and the adapted paradigm revealed no significant differences, which suggests that there might be other explanations for the lack of familiar size effects in the ERP study.

However, an additional analysis that compared RTs and accuracy between the original (Chapter 3: Experiment 5) and the adapted paradigm revealed no significant differences which suggests that there might be other explanations for the lack of familiar size effects in the ERP study. It is possible that the inclusion of scrambled images might have affected the categorisation process.

It could be speculated that the RTs in the ERP study were driven by a more gross categorisation, whereby images that were largely pictorially different (e.g. possessing a border or not possessing a border), caused the visual system to categorise such images in a more gross manner, e.g. scrambled or intact, compared to at the more specific level observed when object images were physically similar. As this is just a speculation, additional simple RT research would be needed to confirm this hypothesis.

### Categorization and Ranking Results

Overall participants demonstrated a clear understanding of the familiar size of the objects used in this experiment. The categorisation task revealed that accuracy was significantly better for small and big objects, compared to medium sized objects.

However, the ranking task revealed that despite these variations in categorisation accuracy across the size groups, there was a strong positive correlation between the ranked size and familiar size (in log-units). These findings are in line with previous research, which demonstrated that generally people have a strong ability of participants to recognise an object's familiar size, demonstrated using both categorical and ranking tasks (Bolles & Bailey, 1956; Konkle & Oliva, 2011). It is interesting to note that here participants perform more accurately in the ranking task, compared to the categorisation task. As the order of the tasks was held constant across participants, it is not clear if this difference is due to practise effects or the task itself. Future studies should counterbalance task order to assess the role of task on accuracy. It is also interesting to note the increased variability in the accuracy of categorisation for medium objects, where objects were mis-categorised more frequently towards the small category

## EEG Results

### Amplitude

Our results showed that familiar size is processed at the level of P1 and N1 components, as revealed by differences in mean peak amplitude across size categories, such that familiar small objects produced larger amplitudes compared to familiar big objects. However, the effect of familiar size on the early visual components was recorded for both intact and scrambled images. This finding is in support of Long and Konkle's (2017) proposal that the processing of familiar size is mediated by underlying image properties of the object.

Interestingly, the analysis of spatial frequency of the images used in this study revealed that the small category had significantly lower spatial frequency values compared to the medium and big objects. Therefore, the finding of an increased amplitude registered at P1 to small objects with low spatial frequency, falls in line with previous research which suggests that low-spatial frequency images produce greater amplitudes at P1 (Rokszin, Győri-Dani, Bácsi, Nyúl, & Csifcsák, 2018).

Interestingly, a significant interaction between familiar size and image type was observed *only* under regular viewing conditions at P1. The interaction was driven by a significant difference between small and big familiar objects for intact images, but not for scrambled images. Surprisingly, there was no interaction between familiar size and image type under reduced viewing condition, which suggests that intact and scrambled images were treated in a similar manner by the visual system under such viewing conditions. This result was unexpected as it contradicts our behavioural findings reported in Chapter 3 (Fisher & Sperandio, 2018) as well as previous findings (Gogel, 1969) that the effect of familiar size is enhanced under reduced viewing conditions.

The P1 component is traditionally associated with the processing of visual features and is typically resistant to most forms of top-down manipulation, aside from attention and arousal (Luck et al., 1994). The finding that familiar size affected P1 amplitude to the same extent for both intact and scrambled images , argues against the idea that P1 is resistant to bottom-up manipulation, as the underlying image properties of the scrambled and the intact objects within each size category were theoretically the same.

Consideration to the method of scrambling should be considered with respect to these findings. Criticisms have been made toward the use of phase-scrambled images, specifically that the absence of an outline in the image significantly alters neurological and behavioural responses (Stojanoski, 2014). Additionally, the curvature of an image is also suggested to play an important role in size categorisation (Long & Konkle's, 2017). Long and Konkle (2017) demonstrated that small objects are more curved than big objects, causing implicit size congruency effects. Such that participants are more likely to be faster to categorise an object image as big, when it is square rather than circular.

In the current study, all scrambled images were square and otherwise lacked form. Given that size effects were observed in response to both image types (intact and scrambled), it appears that lower-level features such as spatial frequency, may account for these size effects. But it is also possible that under regular viewing conditions pictorial details, such as borders (Stojanoski, 2014) and inferred curvature (Long & Konkle, 2017), were more influential in size processing.

The effect of familiar size on N1 amplitude was unexpected, since semantic categorisation of objects is suggested to occur at this point (Proverbio et al., 2007; Simanova et al., 2010; Zhu et al., 2016). Therefore, an interaction between familiar size and image type should be expected, as the images presented to the participants were semantically distinct. However, such findings support the theory that underlying image properties are responsible for categorisation effects, observed within the first few 100 ms of processing in the ventral visual stream, encompassing the N1 component (Andrews et al., 2018; Bex & Makous, 2002; Collin, 2006; Konkle & Oliva, 2012b).

The only effect at P2 was observed under regular viewing conditions, where scrambled objects produced bigger amplitudes compared to intact objects. Although this effect of enhanced P2 component to scrambled images has not been reported before, an fMRI study showed enhanced levels of activity in early visual regions to scrambled compared to intact images (Lerner, Hendler, Ben-Bashat, Harel, & Malach, 2001). This supports research that suggests scrambled images produce different levels of brain activity, when compared to intact images in the visual ventral stream (Schendan & Lucia, 2010; Stojanoski, 2014).

## Latency

Under regular viewing conditions there was a distinct advantage in processing speed for scrambled compared to intact object images at all three components; P1, N1 and P2. This finding is novel and might be related to the increased fMRI response in early visual areas to scrambled images, mentioned earlier (Lerner et al., 2001). The current findings perhaps indicate a form of implicit categorisation by image type. Despite the fact that the underlying image properties of the two image types were the same (e.g. luminance, spatial frequency), the overall shape of the scrambled images was more consistent (square) compared to the intact objects, which varied considerably in shape. Such a difference may be responsible for the increased speed of processing for the scrambled images. Although this decrease in latency in the ERP response was not related to a significant difference between intact and scrambled images in terms of reaction times or accuracy. As such, future research could investigate different kinds of scrambled images (e.g. phase scrambled, text forms and diffeomorphic filters) in order to establish the influence of basic object image properties on neurological processing.

During regular viewing conditions at the P2 component, intact small objects appear to be processed more slowly than big objects. Although not directly related to the current study, a similar pattern of activity has also been reported in an ERP study when images of lions were presented (Itier, 2004). Specifically, there was an increased amplitude at P1 and slowing of the waveform from around 150 ms (N1). Although the slowing of the waveform is *significant* at a later time point in the present study (P2), the waveform for this condition is observably delayed over N1. The authors suggested that this type of waveform is typically produced by stimuli that are evolutionarily important to the visual system, such as faces (Itier, 2004).

Under reduced viewing conditions only one significant effect was found, namely during the P1 component familiar big objects were processed faster than familiar small object images (~ 4 ms). This finding was completely unexpected, given the reaction time results previously observed (Chapter 3: Experiment 3 & 4). It is interesting to note that these timing effects were observed under reduced viewing conditions, supporting the idea that basic visual properties are processed differently under reduced viewing conditions.

An investigation in to the literature on restricted viewing conditions did not provide any explanation for such effects. Previous studies utilising restricted viewing conditions typically use simplistic stimuli (Adachi-Usami & Lehmann, 1983; Lunghi, Berchicci, Morrone, & Di Russo, 2015; Skrandies, 1993). Given this difference, it is difficult to relate the findings in the present study to existing EEG literature. Considering research using basic visual stimuli (e.g. Gabor gratings), no interaction between spatial frequency and viewing condition were presented (Adachi-Usami & Lehmann, 1983; Lunghi et al., 2015; Skrandies, 1993). Until further research is conducted, it is concluded that under reduced viewing conditions there appears to be a benefit for familiar big objects in terms of speed of processing during the first 100 ms after stimulus onset. Future research should investigate the role of low-level image properties, such as high spatial frequency, in the speed of processing under reduced viewing condition.

### Viewing Condition

In terms of latency, there was a significant effect of viewing condition, such that regular viewing conditions yielded faster latencies compared to reduced viewing conditions by around 24 ms. This finding was expected since previous research has found that amplitude is reduced and latency is slowed during reduced viewing conditions (Adachi-Usami & Lehmann, 1983). Interestingly, the findings reported in this thesis consistently showed a slowing of simple RTs under reduced viewing conditions compared to regular viewing conditions; similar results were reported in the literature (Campbell & Robson, 1968; Minucci & Connors, 1964; Sperandio et al., 2009).

The consensus on the cause of this slowing of RTs has not been reached. One explanation for the increase in RTs, known as 'the summation theory', asserts that the artificial pupil (i.e. pinhole) used in these conditions reduces the amount of light able to reach the eye and this reduction in stimulation results in a decreased amplitude of activity in the brain (Minucci & Connors, 1964). Other researchers suggest that restricted viewing enhances agreement of the image between the two eyes, removing an important visual cue under regular viewing conditions (Jones & Lee, 1981). Another explanation relies on the fact that monocular view reduces the level of contrast sensitivity, compared to binocular view (Campbell & Robson, 1968). Future research should test these factors, in order to better understand the effects of reduced viewing conditions.

## Conclusion

In the current study, contrary to our initial hypothesis we did not observe an influence of familiar object size on latency for intact stimuli under reduced viewing condition, at any of the three components examined (P1, N1 or P2).

Unexpectedly, there was a substantial benefit to peak latency for scrambled images viewed under regular conditions. These effects were observable at all three components, along with an increased peak amplitude at P2. As such, it is proposed that either there is an implicit top-down categorisation of scrambled vs intact images. This implicit categorisation would allow the observer to quickly identify whether or not semantic information is available in the visual stimulus. The likelihood of this hypothesis is enhanced in the current experiment since each experimental block contained only one image type. The presence of both image types within the same block would reduce the predictability of the image type.

Alternatively, it is possible that image properties that were present in the intact images required greater visual processing than scrambled images. For example, an intact image has an outline and is experienced more centrally, compared to a scrambled image. To determine which of these theories best explains familiar object size effects, future research would need to rule out visual differences between control stimuli and experimental stimuli. For instance, different methods of scrambling could be used, to reduce the likelihood of alternative image properties causing the effect. For example, in Long et al (2016), textform methods of scrambling were employed, where the scrambled image is more centrally confined.

No such effects of image type on latency or amplitude were observed under reduced viewing conditions. This raises the question as to if impairing the view of an object by using reduced viewing conditions produces an increased reliance of top-down information (Konkle & Oliva, 2012a). Perhaps at the determent to any bottom-up influences experienced during visual processing. Inversely, it is possible that pictorial differences are less important during image processing under reduced viewing conditions. For example, research investigating the influence of reduced viewing condition has found that contrast sensitivity is reduced during reduced viewing conditions (Campbell & Robson, 1968). Although contrast was controlled when we generated the scrambled images, the research by Campbell and Robson (1968) demonstrated how the processing of visual images during reduced vision can be impaired. As mentioned earlier, future research should investigate the effects of reduced viewing conditions on the visual processing to better understand the mechanisms behind these manipulations.

To conclude, since unidentifiable scrambled images produced similar effects of familiar size at early visual components P1, N1 and P2 under regular viewing conditions, these findings oppose the theory that behavioural effects of familiar size observed in previous studies (Fisher & Sperandio, 2018; Konkle & Oliva, 2012a) are a results of matching to a specific internal representation based on semantic properties (Ullman, 1989). Although our findings showed an effect of familiar size on amplitude at the timeframe of categorisation, around P1-N1 (Proverbio et al., 2007; Scott, Tanaka, Sheinberg, & Curran, 2006; Simanova et al., 2010), they also showed that amplitude did not differentiate between semantic and non-semantic content, as demonstrated for other specialised categories, such as faces and animals (Harel & Bentin, 2009; Rossion & Jacques, 2008; Viggiano et al., 2004). Based on the current findings, we can conclude that familiar size occurs early in visual processing, around 100 ms after stimulus onset, but as a result of low-level image properties. Specifically, greater activity was registered in response to small objects, which were characterised by lower spatial frequency stimuli, compared to objects with high spatial frequency, such as familiar big objects (Rokszin et al., 2018).

However, we should consider the limits of the stimuli used to control for underlying image properties and utilise different varieties of scrambled images. Under regular viewing conditions, activity during P1 and P2 revealed familiar object size differences for intact images only. A such, it would be reasonable to conclude that the present findings demonstrate a semantic influence of size on visual processing, however, physical differences between the scrambled images and intact images (i.e. the lack of image border) should be removed in future studies for this theory to be supported.

## Future research

Future studies should be carried out to determine the influence of phase-scrambled images on simple RT paradigms, in comparison to alternative scrambling methods of regular object images.

It may also be interesting to test if the spatial-frequency sensitivity related to familiar object size is present in young children, in order to see if this specialisation is an innate ability or develops with age. Research involving children aged 7-15 demonstrated that specialisation to specific spatial frequencies is present in 7-8-year olds but shows the inverse relationship compared to the other age groups (Rokszin et al., 2018). Specifically, 7-8-year olds were worse at detecting low-spatial frequencies and had lower amplitudes in P1 responses for such stimuli, compared to high-spatial frequency responses. This is in direct contrast to all other age groups which demonstrated lower amplitudes at P1 for high-spatial frequency compared to low-spatial frequency. This research supports the idea that experience determined such specialised neurological responses to specific underlying image properties. However, this research only uses black and white images with scenic context, which could involve different processing pathways to that of a coloured figure without scenery. As such future research is required with the presentation of different kinds of visual stimuli.

The main model discussed in this chapter, coined as the "HIT" model Humphreys et al., 1997) was developed using both image and word stimuli. To be able to apply this model to the current research more fully, future studies should compare if familiar objects of various sizes in word format could be used to study size categorisation. If we were to find the same effects observed here with word stimuli, we could infer that the HIT model, rather than an explanation merely based on low-level image properties, is accountable for such findings (Humphreys et al., 1997).

Another reason for using word stimuli comes from a study that found a difference in choice RTs based on the familiar size of the objects stimuli (Sereno et al., 2009). In this study participants judged if a target was a word or nonword. Researchers found that participants were faster to make their judgments, when the physical size of the object word was congruent to the familiar size (i.e. ELEPHANT), compared to the inverse (i.e. elephant) (Sereno et al., 2009). A similar congruency effect was also observed within a Stroop-like task, which found faster responses to pairs of images, when the difference in screen size was congruent with the difference between the familiar object size (i.e. big piano and a little apple), compared to the inverse (i.e. a little piano and a big apple) (Konkle & Oliva, 2012a).

These congruency effects between physical size and familiar size, support the findings of Chapter 3. As such, a word priming task could be implemented in future studies, where the familiar object word could be presented as a prime followed by a plain shape target (e.g. a plain grey circle). The advantage of such a method is that it removes any possibility of influencing low-level image properties, since the RT would be made to a stable visual image. It is predicted that with such a paradigm, RTs would be faster to targets following familiar small object primes (e.g. apple), as opposed to familiar big object primes (e.g. tractor), following the results of Chapter 3.

## Closing Remarks

Previous research suggests that the early component P1 is only responsive to low-level image properties, attention and arousal (Luck, 1994). However, here for the first time we demonstrated an effect of previous knowledge about object size on P1 amplitude, such that familiar small objects generated greater amplitudes than familiar big objects. However, as the effect of familiar size on P1 amplitude was registered for both familiar and scrambled images under reduced viewing conditions and at P2 under regular conditions, it could be argued that low-level image properties, such as spatial frequency, contributed to ERP results. Other image properties that are absent in the scrambled version of the object image, such as curvature or squareness (Long et al., 2016), could also be responsible for this finding.

Surprisingly, we were unable to replicate the effect of familiar size on simple RTs, as reported earlier in this thesis. One should consider the several changes that were applied to the original paradigm to fit the parameters required for the EEG recording, e.g. the inclusion of scrambled images and an inter-trial interval, which could have confounded the current findings.

In conclusion, the influence of familiar size takes place at the early stages of visual processing, specifically at the level of P1. The effect of familiar size observed in this study could be explained by differences in low-level image properties between small and big familiar objects, since similar effects of familiar size on amplitude were obtained with scrambled images. However, an explanation based on compatibility theory, as described in Chapter 3 should not be excluded completely. In fact, we did observe familiar size effects that were exclusive to intact object images under regular viewing conditions, as such it is possible that the match between physical and semantic size was responsible for the modulation of the ERP response under such conditions.

# Chapter 5: General Discussion

In this thesis, the temporal dynamics of size constancy and familiar object size were explored in adults and children. Simple RTs were used as an implicit measure of the perceptual experience of familiar object size. An overview will now be provided for each chapter, including the main findings, conclusions, possible limitations and future proposals. Finally, a summary of the main findings will be provided in the closing section of this general discussion.

## Developmental Trajectories of Perceived Size

In chapter 2, two developmental studies were performed to explore if size constancy and familiar size change with age. In the first experiment, we examined whether or not size constancy develops with age through a simple RT task. School age children (5 to 13-year-olds) and adults took part in this experiment. A familiar object image, i.e. a tennis ball, was presented at two distances, whilst the retinal size and luminance of the familiar object image was kept constant. Results revealed that to some extent, size constancy in response to familiar objects was present in children from the age of 5 years-old. Simple RT followed the rules of size constancy for all age groups, with faster responses to physically big tennis balls placed further away compared to small tennis balls placed closer to the participant, despite both stimuli generated the same image on the retina. These findings support the theory that size constancy is already present in children (Granrud, 2006; Slater et al., 1990). Although an increase in task accuracy is expected with age (Kiselev et al., 2009; Lida et al., 2010), unexpectedly there was a significant interaction between object size and age group on task accuracy. As such, task accuracy was dependent on the size of the stimuli experienced, particularly for the youngest age group. Therefore, the data was analysed using the inverse efficiency index (IEI) to take into account accuracy (Bruyer & Brysbaert, 2011). Once accuracy was incorporated with the mean simple RT, size constancy was only reported in the

7 to 8-year-olds and adult participants. These findings undermine the size constancy effects observed in the simple RT analysis and brings into question the validity of the conclusion that size constancy is present in children as young as 5 years old.  Two possibilities were considered for the findings of experiment 1. Firstly, the possibility that size constancy is not present in young children, but a speed accuracy trade-off led to the appearance of this effect in simple RTs. Secondly, the possibility that size constancy is present in young children, but children exhibit difficulties in making responses in a timely fashion. Hence, simple RT is not a valid measure of size constancy in young children.

A review of the literature highlighted that children younger than the age of 8-years-old are not fully developed in terms of their ability to detect differences in contrast (Leat et al., 2009). As the stimuli used (white and yellow) had a low contrast, when compared to the background (white), it is plausible that the detection of the onset of the target could have been more difficult for younger participants compared to older participants. As such, the paradigm could be improved by using a black background, in order to increase the level of contrast between the background and target. Future investigations should also include training in simple RT, as more practise sessions may improve task performance (e.g. as in Brewer & Smith, 1989).

To conclude the findings of experiment 1, to some extent these results indicate that size constancy is present in children as young as 5 years old. However, speed-accuracy trade-offs and underdeveloped contrast sensitivity undermine the strength of this conclusion. As such, future research is needed to explore the influence of these factors on size constancy abilities.

In the second developmental experiment, the influence of symbolic size of familiar objects was explored. In this study, images of toy objects and real objects were matched for semantic content (e.g. a toy hammer and a real hammer) but categorised by the familiar object size held by the real version of the object (e.g. a toy car would be categorised as big, since a real car is big). Four stimulus categories were defined; familiar real *small* objects in either real format (e.g. hammer) or toy format (e.g. toy hammer), familiar real *big* objects in either real format (e.g. car) or toy format (e.g. toy car). The first task involved categorising each object image as a toy or real object. The second task consisted of a simple RT task under reduced viewing conditions. The age range explored were children aged 3 to 4, 5 to 6-years-old and adults.

In the categorisation task, both adults and children were significantly less accurate at categorising the real-big objects compared to the other categories. Interestingly, children were also slower to make responses to this category. Overall, both children and adults were better at categorising toys compared to real objects. The reduction in accuracy to real-big objects was attributed to the dominance of familiar small objects in this paradigm. Specifically, three of the four categories had a familiar size that was small, including both of the toy categories and the small real object category. For example, a real hammer (i.e. real-small), a toy hammer (i.e. toy-small) and a toy car (i.e. toy-big) all have a familiar size which is small, where as a real car (i.e. real-big) is the only object out of these four examples that has a familiar big size. As such, future research should balance the familiar size of the objects used within the paradigm, in order to avoid the confound of an infrequent familiar size category, as demonstrated by the mis-categorisation of several of the items in the familiar real-big category (experiment 2: Chapter 2).

The familiar size effect demonstrated in the categorisation task, could also reflect the degree of size congruency between the familiar size of the object and the size of the image presented on the screen, as later proposed in chapter 3. Specifically, the familiar size of the real-big objects deviated the most from the physical size shown on the screen, resulting in an increase in categorization errors. Interestingly, in chapter 4 the errors made in the size categorisation task were observed in the medium size objects, which were categorised toward the direction of the object *image size*, such that medium objects were often mis-categorised as small objects. This supports the theory proposed in chapter 3, namely that the degree of congruency between an internal representation and the objects physical size, can aid the visual processing of familiar objects.

Such size congruency effects have also been observed in a Stroop-like task, where participants judged the *physical* size difference between pairs of images (Konkle & Oliva, 2012a). Results showed that RT differences reflected the familiar size difference between pairs of familiar object stimuli, such that the judgment was made more quickly when the *physical* size difference between the two images was congruent to the *familiar* size difference (e.g. a small mouse with a big house would produce faster RTs, compared to a big mouse and a small house).

The findings revealed no significant effect of familiar size on mean accuracy or simple RTs. Several points should be considered when interpreting this finding. Firstly, there were more familiar small compared to familiar big exemplars, as such there may not have been enough variation in size to cause a familiar size effect. Particularly, participants frequently miscategorised familiar big objects as small, in the proceeding task. Secondly, objects may vary in their degree of familiarity with the size. In order to establish the validity of these conclusions, future research should aim to attain a good agreement of the familiar object size for all exemplars, before conducting a simple RT task.

Future investigations, using the simple RT paradigm, should consider presenting children's furniture as stimuli, in conjunction with adult versions. By using these visual stimuli, it would be easier to speak to the debate of object size scaling (DeLoache et al., 2013, 2004), as the objects are physically used in the same way. It would also allow for the exploration of familiarity in children and adults.

Although no familiar or symbolic size effects were found under reduced viewing conditions in adults or children, participants in both groups were better at categorising objects as a 'toy' compared to 'real' object. Two hypotheses are suggested for this effect. The first is the possibility of a 'sizing bias', caused by a majority of objects having a familiar small size. Specifically, big objects were misperceived as toy-like in the context of the other small objects. The suggestion that the big objects were perceived as toys, may also explain the absence of a familiar size effect in the simple RT task. Future research is needed in order to determine if the range of sizes considered is wide enough to affect RTs, as supported by the lack of familiar size effect in experiment 2 (Chapter 2) and in experiment 6 (Chapter 3).

To conclude, results of Chapter 2 demonstrate that to some extent size constancy mechanisms are present from the age of 5 and familiar size effects are observable in children from as young as 3 years-old.

### Familiar Size Effects on Reaction Time: When Congruent is Better

In Chapter 3, the systematic influence of familiar object size on simple RT' in adults was investigated. In the first experiment, under regular viewing conditions, the influence of animacy and familiar object size on simple RTs was explored. The decision to include both of these cognitive dimensions as independent variables, was due to the frequent use of animate and inanimate objects in research examining familiar object size (Gabay et al., 2013; Konkle & Oliva, 2012a). Moreover, there is recent neuroimaging and behavioural evidence that supports the idea of different neural pathways and speed of processing for animate compared to inanimate objects (Konkle & Caramazza, 2013; McMullen & Purdy, 2006; New et al., 2007; Zhu et al., 2016).

In the second experiment, reduced viewing conditions were applied to the original paradigm, as such conditions have been shown to enhance familiar size effects during size perception tasks (Gogel, 1969). The following experiments (5 and 6) explored if the effect of familiar size is proportionate, by presenting inanimate objects only under reduced viewing conditions. In experiment 5, familiar object images that were shrunken in size, compared to their familiar size, were shown. In experiment 6, participants were presented with familiar object images that had been enlarged in size, relative to their familiar size .

In order to measure participants' perceptual experience, in experiment 7, participants were asked to manually estimate the size of the object images that had previously been shown in experiment 5. In the final experiment (8), the influence of familiar size of novel objects, as established through short-term haptic and visual experience of unfamiliar Lego and Duplo models, was measured using simple RTs.

For the first time, under regular viewing conditions, an animacy effect on simple RTs was found. Specifically, participants were faster to respond to images of animals compared to non-animals. This effect was unrelated to low-level features of the stimuli, such as spatial frequency. These findings support the evolutionary proposal that the processing of animate objects is distinct to that of inanimate objects, contributing to the proposal that an ultra-efficient neural pathway exists for evolutionarily important visual stimuli (Martin, 2007; New et al., 2007).

It is currently not possible to determine if this animacy effect is innate, since relatively little developmental research has been conducted on animacy. As such, future research should investigate the temporal dynamics of animacy in children, by means of simple RTs (e.g. Chapter 2) or brain imaging techniques, such as electroencephalography (EEG) (e.g. Carver et al., 2006; Taylor & Baldeweg, 2002).

In experiment 4, when reduced viewing conditions were implemented, we observed in addition to this animacy effect, an independent effect of familiar object size, with faster RTs to familiar small compared to familiar big objects. Experiment 5 revealed that a *proportionate* relationship existed between the familiar size and simple RTs, under these conditions. Specifically, objects that were closer in familiar size to the size shown on screen (e.g. a crayon), were responded to faster compared to those objects that were shrunken in size (e.g. a house). However, the only significant comparison was between the biggest difference in size (i.e. x1 vs 1/100).

In experiment 6, when presenting objects that had been enlarged from their familiar size to the screen size, there was no familiar size effect. This lack of effect was attributed to the limited range of size of small familiar objects. In fact, the size of the familiar object selected could only be enlarged by 10 on the screen, since objects with a smaller real-world size would not be visible to the human eye, and thus would be unfamiliar.

In experiment 7, the shrunken familiar objects that were previously presented in experiment 5, were manually estimated by participants. The results revealed an effect of familiar size on perceived size, such that familiar small objects were perceived to be smaller than familiar big objects.

In the final experiment (8), an investigation into the influence of short-term familiarity on simple RT was explored. Simple RTs to the newly learnt objects were measured, under restricted viewing conditions. The results revealed that there was no influence of short-term experience of size on simple RTs.

The familiar size effects observed in Chapter 3 were attributed to congruency, (Konkle & Oliva, 2012a; Sereno et al., 2009) and not perceptual size (Gogel, 1969). Specifically, objects that were closer in terms of familiar size to the size of the image shown on screen (congruent) were processed more quickly, compared to objects that were further in terms of familiar size to the size of the image shown on screen (incongruent). Unfortunately, this effect was not observed for magnified objects. It is possible that the absence of a familiar size effect for magnified objects, could be due to a level of uncertainty about their real-world size. In fact, since many of the small objects in the real-world vary in size (e.g. buttons or strawberries). As such, future research should measure the optimal range of size for all familiar objects, before assessing the influence of familiar size on simple RTs.

An alternative explanation for the familiar size effect in Chapter 3, is that the perception of the onset timing of the image was directly related to the perceived size of the object image. Specifically, those object images that were perceived as bigger, were also perceived to be presented on the screen later, compared to those images that were perceived as smaller (Kanai, Dalmaijer, Sherman, Kawakita, & Paffen, 2017; Ono & Kawahara, 2007; Rammsayer & Verner, 2015; Thomas & Cantor, 1975; Xuan, Zhang, He, & Chen, 2007). The perceived delay in the onset of perceptually bigger objects is proposed to be due to processes that occur at the early stages of visual processing (Gibbon & Rutschmann, 1969). However, the relationship between the perceived onset time and simple RT is still unclear, with researchers suggesting that more advanced cognitive mechanisms are involved in judgments of stimulus onset (Gibbon & Rutschmann, 1969).

The theory of perceived stimulus onset supports the findings presented in Chapter 3. In fact, the onset of familiar big objects (e.g. a bus or train), that were also perceived to be physically bigger (as demonstrated by the manual estimates in Experiment 7), would be perceived to be delayed, compared to familiar small objects. To confirm this possibility, two additional studies would need to be conducted. Specifically, an additional manual size estimation task could be performed in order to measure the perceived onset of familiar objects. The findings of such a study would establish if there is a direct relationship between perceived stimulus onset, familiar size and simple RT, under reduced viewing conditions (e.g. Kanai, Dalmaijer, Sherman, Kawakita, & Paffen, 2017)

To conclude, findings of chapter 3 demonstrate for the first time, under reduced viewing conditions only, that there was an effect of familiar object size on simple RTs for shrunken familiar objects, which was modulated by the degree of congruency. Namely, objects that had a familiar size that was closer to the physical size on screen were responded to more quickly, compared to familiar objects that were substantially shrunken in size.

### Effects of Familiar Object Size on Visual Evoked Potentials

Electroencephalography (EEG) was used to measure for the first time, changes in brain activity in relation to familiar object size. In this study, the viewing conditions were manipulated across two testing sessions, starting with reduced viewing conditions (i.e. monocular, pin-hole glasses and reduction tunnel), followed by regular viewing conditions in the second session. The participants performed a simple RT task, similar to the paradigm used in chapter 3, with the inclusion of intact and phase-scrambled versions of the object images used in the original study (experiment 5: Chapter 3). Scrambled images were included in this paradigm to control for the influence of underlying image properties, such as spatial frequency.

In addition to the RT task and EEG recording, participants also performed two tasks that tested their knowledge of familiar object size. The first task was a categorisation task, which involved categorising the intact version of the object images as either small, medium or big. The second task was a size ranking task, where participants had to assign a value ranging from 1-100 to the same images displayed in a randomised list format.

In terms of electrophysiological responses, there were unexpected main effects of image type (intact vs scrambled) on the ERP response. Specifically, peak amplitude for scrambled images was greater, under regular viewing conditions across all three early components (P1, N1 and P2). In addition, there was also a faster latency at component P2 for scrambled images under regular viewing conditions. These findings along with the absence of expected effects of familiar size for the simple RT task, lead to the conclusion that the scrambled images had an unexpected large-scale effect on responses. As such, it is possible that the inclusion of such stimuli has confounded the original investigation. Indeed, phase-scrambled stimuli have been suggested to produce an overall increase in variability in behavioural paradigms (Stojanoski, 2014).

More importantly, a familiar objects size effect was present at components P1 and N1. such that familiar small objects produced greater amplitudes compared to familiar big objects. However, this effect was only significantly different for intact and scrambled images at P1, under regular viewing conditions. Though this effect could be attributed to the top-down influence of familiar size knowledge, It is also possible that this difference was due to image boundary effects, caused by the absence of an outline in the scrambled images (Stojanoski, 2014). Future research should include a different type of scrambled stimuli, in order to measure the effect of boundaries on the P1 component.

As changes in activity at component P1 are usually associated with underlying image properties, such as spatial frequency (Andrews et al., 2018; Bex & Makous, 2002; Luck, 1994), a spatial frequency analysis was conducted on the intact images, comparing the 3 familiar object sizes. A significant difference in spatial frequency (SF) was observed between the small and big, and the small and medium size of familiar object images. Specifically, small familiar objects had a lower spatial frequency (SF) relative to big and medium objects, which had higher SF. These findings are counter to the suggestions of other researchers, that large objects possess low SF (Sereno et al., 2009). Interestingly, the same authors also suggested that low SF images are processed faster via the magnocellular pathway (Sereno, 1993). In contrast, we did not observe any effects on the EEG latencies at each component, except for the faster N1 for familiar big objects under regular viewing conditions. In our original behavioural study (experiment 4 and 5: Chapter 3), participants were faster to make simple RT responses to the familiar small objects that had low SF, compared to big and medium sized familiar objects, that had high SF. Although the linear relationship observed in the original RT experiment is not completely explained in terms of SF.

The lack of effects of familiar size on speed of processing in the EEG and behavioural results of Chapter 4, opposes the theory of perceived onset, which asserts that perceptually big images are perceived to appear later than perceptually small objects (Gibbon & Rutschmann, 1969; Kanai, Dalmaijer, Sherman, Kawakita, & Paffen, 2017), as proposed in Chapter 3. It is suggested that perhaps the influence of scrambled images produced a gross categorisation of images within the brain between semantic and non-semantic information, resulting in the extinction of the size congruency mechanism. Future research would need to remove the phase-scrambled images to test this possibility.

In terms of the size judgment tasks, reassuringly all stimuli were easily ranked, although categorisation of medium sized objects was prone to error. The decrease in accuracy for the categorisation task, adds support to the hypothesis that familiar size processing may have been affected during the simple RT task of the ERP study, since the familiar size of the objects should be well defined by the time the participant reaches the categorisation task, as participants had frequent exposure to the familiar object images in the simple RT task.

In conclusion to the findings of Chapter 4, there was no significant electrophysiological changes related to the effects of familiar size as observed in Chapter 3. It is proposed that the lack of this effect is due to the addition of phase-scrambled images in the paradigm. Despite the lack of the expected effects on latency to intact objects under reduced viewing conditions, two findings were of particular interest. Specifically, during the first 100 ms (P1) the mean peak amplitude was significantly increased for small-intact objects relative to big-intact objects. In terms of latency, within the first 200ms (P2), there was also a significant slowing in latency for small intact objects relative to big intact objects. This pattern of the waveform has been observed previously in an ERP study using evolutionarily relevant stimuli, such as lions and faces (Itier, 2004). These finding support the idea that familiar small objects are processed in a different manner to familiar big objects and that such findings may be caused by a top-down contribution in object image processing.

The query originally raised in the general introduction, namely: ‘are familiar object size effects present during regular viewing conditions but enhanced by reduced viewing conditions?’, can now be answered. It appears that familiar object size effects are present during early visual processing and are observed during regular viewing conditions. In contrast, the effect of familiar size on RT was enhanced by using reduced viewing conditions (chapter 3). Caution must be taken with this conclusion, since the behavioural conditions under which these enhanced effects were found, did not produce the same behavioural size effects observed in a previous study (experiment 5: chapter 3). As such, future research should reassess ERP responses using the original paradigm and stimuli, to confirm if this familiar size effect is also observable under reduced viewing conditions.

Ultimately, under reduced viewing conditions, differences in ERPs were observed for familiar object size but such effects were present in scrambled and intact object images. The analysis of the spatial frequency of the two familiar size categories, revealed a significant difference between familiar big and small object images. As such the familiar size effects observed within the first 100 ms of stimulus onset can be attributed to low-level object image properties.

## Future Directions

Overall, there is a lack of research into the perceptual experience of familiar objects in children. In particular, little is known about the neural underpinnings of basic visual object recognition in infants, an observation that has also been made by Smith (2013). Interestingly, Smith (2013) has suggested that the development of object recognition follows a similar pattern to the acquisition rate of object names, in that object recognition becomes easier with a larger vocabulary of nouns. This theory is harmonious with an adult model of object recognition, where categorisation is a process of continuous comparison with internal representations of other familiar objects (Humphreys & Forde, 2001). Although at present, this theory is unsubstantiated due to the absence of investigation into the development of object recognition (Smith, 2013). Future studies should aim to investigate the temporal features of general object recognition in school-aged children, using brain imaging techniques, such as EEG, that have a high level of temporal resolution (for examples of research involving EEG methods with infants and children see: Carver et al., 2006; Taylor & Baldeweg, 2002).

In order to establish if familiar object size processing occurs in the same way in children as adults, researchers could use EEG techniques to measure changes in brain activity in response to familiar object size. Specifically, to see if the patterns of activity observed in adult participants in Chapter 4, of increased amplitude at P1, followed by a slowing of peak latency at P2, in response to familiar small objects, are also observable in children. Evidence of a development of familiar size would add support to the idea that these object size effects are indeed 'familiar' in nature, requiring long-term experience with an object in order to develop a familiar size. This was confirmed by the findings reported in experiment 8 of Chapter 3, when newly experienced objects failed to produce familiar size effects, under reduced viewing conditions.

To extend on the theory that object naming is tightly intertwined with general object recognition (Smith, 2013), future research could explore the use of words as stimuli, instead of object images. The inclusion of words would allow for testing of the semantic size of an object. If semantic size is responsible for familiar size effects, similar effects on simple RT, as demonstrated in Chapter 3 would be obtained. In order to be able to separate the influence of visual input from the semantic content, a priming paradigm could be used. In this paradigm, the object word or image would be displayed as the prime, whilst a plain shape would serve as a target, to which participants would respond (e.g. Carr, McCauley, Sperber, & Parmelee, 1982). The advantage of such a paradigm would be the separation of online-visual format effects (e.g. words or images) to responses. Format differences have been demonstrated to affect processing. For example, in order to correctly identify the content of a stimulus, generally, participants require a longer exposure duration for text stimuli compared to image stimuli (Carr et al., 1982).

The proposal that familiar size effects may be observed in such a paradigm, is supported by Sereno et al (2009). In this study participants were faster at judging targets as words or non-words, when the familiar size of the word and the physical format of the word were congruent (e.g. PIANO), compared to when the word format was incongruent with the familiar size (e.g. piano). In the proposed study, faster RTs to targets proceeded by a familiar small object prime would be expected (e.g. a crayon, egg, apple etc), since the familiar size would be congruent with the target size.

Another advantage of using familiar object words, would be that such findings could be more directly related to Humphreys' model of object recognition, which focused largely on object naming and words (Humphreys & Forde, 2001; Humphreys et al., 1997). For instance, if we find an effect of familiar object size to speeded RT task when using words as stimuli, it would be reasonable to conclude that familiar object size occurs under the same timescale as that of object categorisation.

An alternative way to understand the influence of familiar object size, is to recruit participants who are experts in the identification of certain objects, as suggested in experiment 2 (chapter 2). Miniature model experts are the ideal candidates to better understand the role of object experience on early visual processing since a high level of visual familiarity to the specialised object is guaranteed. Specialisation of visual processing for experts to the specific object is evident in electrophysiological responses, such that they exhibit an enhanced negativity at the component N170 to their expert object, compared to objects from outside the area of expertise (Tanaka & Curran, 2001). Future research should include both the miniature and regular sized version of the expert object, to see whether familiar-size related differences are apparent at the neural level. It is proposed that along with the typical N170 effect described by Tanaka & Curran (2001), changes in the amplitude of P1 may also be observed, as familiar object size effects to intact images have been demonstrated at this component (Chapter 4).

## General Conclusion

In this thesis, we demonstrated that simple RTs can be used to examine size perception in adults and children. The findings show that size constancy abilities are already present in children from as young as 5-years-old. However, the possibility of a speed accuracy trade-off leads to cautious interpretation of such findings.

A congruency effect was also observed through participants abilities to categorise objects based on their familiar-size. For instance, in experiment 2 (Chapter 2) and experiment 9 (Chapter 4), the errors that participants made in these categorisation tasks were biased to the size of the object image presented on the screen, resulting in participants generally underestimating the familiar size of the object. These findings support the theory proposed in Chapter 3 that the speed of processing of images of familiar objects benefits from being congruent to the stored representation of size (e.g. a crayon presented on the screen at its familiar size) compared to objects that are incongruent in size (e.g. an image of a house which is relatively shrunken). However, the congruency effect in the simple RT task of Chapter 3 was only observed under reduced viewing conditions and was limited to shrunken objects. Moreover, the effect was unrelated to perceived size.

In Chapter 4, continuous electrophysiological recordings to familiar intact and scrambled images, revealed that a familiar size effect for intact stimuli was present across components P1 and P2. Surprisingly, no familiar size effect for intact stimuli were observed under reduced viewing conditions or in the simple RT task. The familiar size effects observed under regular viewing conditions are proposed to reflect a specialisation of the object recognition process between physical and familiar size congruency, as a result of top-down modulation. In contrast, behavioural effects were enhanced by restricted viewing but only under certain conditions, such as those demonstrated in experiments 4 & 5 (Chapter 3).

The main familiar size effects observed in the ERP analysis under both reduced and regular viewing conditions, were related to differences in underlying object image properties (i.e. spatial frequency), which differed for each familiar object size category. Specifically, familiar small object images were characterised by low-spatial frequency, whereas familiar big object images were characterised by high-spatial frequency. As such, it is possible that differences in spatial frequency were responsible for the familiar object size effects observed in early stages of visual processing. However, future studies should give care when selecting control stimuli, due to the unexpected changes observed in the behavioural results of chapter 4 which included phase-scrambled images, compared to the original study (chapter 3: experiment 5), which did not include any control stimuli.

In terms of the development of size constancy mechanisms, to a certain extent children from at least the age of 5 demonstrated a behaviour that reflected size constancy, in agreement with previous research which suggested that size constancy abilities are innate (Granrud, 2006; Slater et al., 1990). In terms of the development of familiar size, children aged between 3 and 6 years-old, along with adults, made a significant number of errors when categorising objects that had a familiar size that was incongruent with the screen size presented. Such size congruency effects were also observed in adult simple RT to familiar object images under reduced viewing conditions.

Although spatial frequency can explain the simple RT findings to a certain extent, since processing speeds were expected to be faster for low spatial frequency stimuli compared to high spatial frequency stimuli (Bainbridge & Oliva, 2015), limitations to this explanation should be considered. Specifically, there was a lack of linearity in the level of spatial frequency between the three familiar object size categories, as was observed in the simple RT results. Additionally, results from electrophysiological recordings revealed a familiar size effect that was exclusive to intact objects and not scrambled objects, at component P1 and P2 under regular viewing conditions. Given that the scrambled images have the same spatial frequency as the intact images, these differences cannot be explained by spatial frequency alone.

Nonetheless, our ERP findings demonstrate for the first time that intact images of familiar small objects are processed differently in the brain compared to familiar big objects (chapter 4), as seen in the P1 amplitude. It is proposed that under certain conditions, perhaps in the absence of scrambled images, such differences in visual processing can be registered in the form of simple RT differences, where familiar small objects that are congruent to the size presented on screen, can afford a faster speed of processing than larger objects that are not congruent to the size presented on screen (chapter 3). These congruency effects were also present in children from as young as 3-years-old, as demonstrated through errors made in an object categorisation task (experiment 2: chapter 2). Whilst the presence of size constancy mechanisms appears to be present from 5-years-old, issues with simple RT accuracy brings caution to such claims.

To conclude, the computation of perceived size is a fundamental ability of the visual system. Taken as a whole, our findings strongly suggest that familiar size is an automatic property of object recognition that occurs at early stages of visual processing, it develops early on in life, and can affect basic motor responses.

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# Appendix A

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## Familiar Size Effects on Reaction Time: When Congruent is Better

AQ: au

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Familiar size is known to influence our perception of object's size and distance. In this study, we examined whether or not simple RTs (RTs) are also affected by prior knowledge of objects' size. In a series of experiments, participants were asked to respond as quickly as possible to briefly presented images of familiar objects, equated for luminance and retinal size. The effects of familiar size and object animacy on RTs were investigated under natural (Experiment 1) and reduced (Experiment 2) viewing conditions. Restricted viewing conditions were introduced to manipulate the availability of depth cues. A systematic effect of familiar size on RTs was considered for progressively "shrunken" (Experiment 3) and "enlarged" (Experiment 4) objects on the screen with respect to their familiar size. Measures of perceived size were also taken by means of a manual estimation task (Experiment 5). Results showed an effect of animacy on simple RTs: Participants were faster to respond to images of animals than nonanimals. An effect of familiar size on simple RTs was also observed under reduced viewing conditions only: Objects shown closer to their real-world size were detected significantly more quickly than those further from their familiar size. However, this familiar-size advantage did not reflect perceived size. Hence, simple RTs under reduced viewing conditions are modulated by the degree of compatibility between physical size and long-term representations of size.

***Public Significance Statement***

In this study, we demonstrate that knowledge about object's size can influence RTs such that we are faster to detect briefly presented images of objects that match their familiar size. For example, a key shown at its familiar size is responded to more quickly than a bus shown at the same size. We also observe that animacy has an effect on our RTs, such that we are faster to detect images of animals than nonanimals. We argue that both familiar size and animacy are automatically processed by the brain in early stages of visual processing and might involve specialized neural networks.

AQ: 2 *Keywords:* real-world size, perceived size, animacy, simple RTs, restricted view

AQ: 1 *Supplemental materials:* http://dx.doi.org/10.1037/xhp0000543.supp

Familiar objects are often experienced at different distances and visual angles, producing different representations of the same object on the retina. These variations in distance and angle could be seen as problematic in the process of establishing object recognition. However, it is commonly understood that despite changes in viewing conditions, the observer is still able to identify certain properties of the object, such as its familiar size. Familiar size can be defined as the previously stored knowledge about the size of an object that constructs an understanding of the object's distance. This past experience provides important information about object's size which can help the observer in making size judgments (e.g., Schiffman, 1967; Slack, 1956). For example, previous research has demonstrated that participants were just as accurate at judging the size of a familiar object from direct view, as recalling its size from memory (Bolles & Bailey, 1956).

More recently, Konkle and Oliva (2007, 2011) have used a range of methods, including drawing, ranking, and size adjustment tasks, to assess the effects of previous knowledge of an object's size on size perception. These studies led to the same conclusion: Our perception and memory for objects reflect a normative size that is strongly related to the real-world size, also referred to as the "canonical visual size" (Konkle & Oliva, 2007, 2011). In other words, the authors demonstrated that through experience we retain information about the typical size of objects and this influences how we prefer and expect to perceive their size. Therefore, even though the sensory information about an object changes due to variations in viewing conditions, our perception of object's size is influenced by internal representations of its familiar size.

Interestingly, the same researchers implemented a Stroop-like task in another study to show that familiar size can also affect the speed of processing of real-world objects (Konkle & Oliva, 2012a). Their task involved the presentation of image pairs that consisted of various familiar objects displayed next to each other

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on a screen. One image was always presented at a larger physical (actual) size compared with the other image. The images corresponded to either big or small objects in the real world. Participants were asked to indicate which image had the biggest or smallest physical size from the pairing, a task that was unrelated to the knowledge of familiar size. It was observed that congruency in real-world size of the two images had an influence on the speed of response, such that there was an advantage in reaction time (RT) for those images whose physical size was congruent with the real-world size. For example, when presenting a big elephant and a small snail (congruent trial) responses were faster than when presenting a big snail and a small elephant (incongruent trial). This finding shows that familiar size is an automatic property of object representation that can affect the speed of processing of real-world objects. In keeping with these findings, other studies have demonstrated that some properties of objects are processed in an automatic fashion by the observer and as such can influence the early visual processing of objects. For example, Grill-Spector and Kanwisher (2005) reported that participants were able to identify (i.e., sail boat vs. ship) and categorize (i.e., boat vs. house) objects with the same level of speed and accuracy as for detection alone. Hence, object identity and categorization seem to take place early on in the processing of visual information.

The influence of perceived size on speed of processing has been explored by means of a simple RT approach by Sperandio, Savazzi, Gregory, and Marzi (2009). In this study, participants were asked to react as fast as possible to briefly presented visual stimuli of different physical size but subtending the same retinal angle as a result of their different viewing distance. Stimuli consisted of plain dots or pictures of tennis balls matched in luminance. It was found that simple RTs were significantly affected by perceived size only when familiar object stimuli (i.e., tennis ball) were presented. Therefore, simple RTs reflect perceived size even when the retinal angle subtended by the stimuli is constant: Participants responded faster to stimuli perceived as larger (i.e., big tennis ball at far distance) then stimuli perceived as smaller (i.e., small tennis ball at near distance). While the effect of *retinal* size on simple RT, whereby bigger stimuli on the retina produce faster responses, is well-established in the literature (e.g., Osaka, 1976), Sperandio et al.'s (2009) work suggested for the first time the existence of a relationship between *perceived* size and simple RTs. Importantly, the effect of perceived size on RTs was enhanced by the observer's familiarity with the objects. The finding that RTs are a measure of perceived size was further supported by other studies using visual illusions, in which illusory larger stimuli produced faster RTs than illusory smaller stimuli, although their retinal image was always the same (Plewan, Weidner, & Fink, 2012; Savazzi, Emanuele, Scalf, & Beck, 2012; Sperandio, Savazzi, & Marzi, 2010). Taken together, these previous studies demonstrate that speed of processing can be affected by perceived size and prior knowledge about the size of objects in the world. However, it is still unclear how as well as the extent to which familiar size affects simple RTs.

Here, we measured simple RTs in response to images of real-world objects with different familiar size (e.g., small or big). The images were briefly presented on the screen and subtended the same visual angle and luminance. Participants were asked to react to the images as soon as they saw them appear on the screen (Experiments 1–4). In the first two experiments, two cognitive dimensions of the stimuli were manipulated: familiar size (big vs. small) and animacy (animate vs. inanimate). Except for Experiment 1, where natural conditions of viewing were used, all the other experiments were carried out under reduced viewing conditions to manipulate the number of depth cues available (Holway & Boring, 1941) and enhance the effect of familiar size on perception (Epstein, 1963; Gogel, 1969; Ittelson, 1951). To examine if simple RTs are systematically affected by familiar size, off-sized versions of familiar objects (i.e., physically shrunken or enlarged on the screen with respect to their known size) with an increasing level of incongruence between their familiar and physical size were presented in Experiments 3 and 4. Finally, a manual size estimation task was used in Experiment 5 to measure the perceived size of familiar objects to establish if any effects of familiar size on RTs are due to perceived size, as previously reported (e.g., Sperandio et al., 2009). Given the evidence for an influence of both familiar and perceived size on speed of processing, we expected to find an effect of familiar size on simple RTs (Experiments 1–4) and that this effect would reflect how big an object appeared to the observer (Experiment 5).

## Experiment 1: The Influence of Familiar Size and Animacy on Simple RTs

In the first experiment, images of familiar objects were presented using a simple RT paradigm. Participants were asked to press a designated button as soon as they detected an image appearing on the screen. Stimuli were randomly presented from a selection of images chosen for their familiar size (small or big) and animacy (animate or inanimate).

Previous research has demonstrated that familiar size can speed up participants' performance in judging the physical size of an object compared with its pair but only when the object's familiar size pairing was congruent with the physical size presented on a screen (Konkle & Oliva, 2012a). To put it simply, participants were faster to respond to a small apple (11° of visual angle) presented with a big piano (18°; congruent pairing), compared with a big rubber duck (18°) presented with a small couch (11°; incongruent pairing).

The aim of Experiment 1 was to verify if the same effect can be generalized to simple RTs. Simple RTs can be considered as one of the most basic measures of speed of processing, whereby participants are reporting their conscious perception of the onset of a target by means of stereotyped (basic) speeded responses (Johnson et al., 1985).

Therefore, if familiar size is an automatic property of object representation (Konkle & Oliva, 2012a), then one would expect simple RTs to be faster in response to those stimuli that are physically closer to their familiar size. For example, participants should be faster to detect a picture of a mouse than a picture of an elephant, when both image sizes subtend the same visual angle.

Another cognitive dimension investigated in the present experiment was animacy. Although a large body of evidence has supported the idea of different neural mechanisms dedicated to animate and inanimate object categories (e.g., Caramazza & Shelton, 1998; Cichy, Pantazis, & Oliva, 2014; Konkle & Caramazza, 2013; Mahon, Anzellotti, Schwarzbach, Zampini, & Caramazza, 2009; McMullen & Purdy, 2006, for reviews see Gerlach, 2007; Martin, 2007), much less consensus exists as to whether or not there is an advantage for animate/living objects over inanimate/nonliving objects. On the one hand, there is evidence that images of animals are detected more quickly by the observers (e.g., Li, VanRullen, Koch, & Perona, 2002; New, Cosmides, & Tooby, 2007). On the other hand, no difference across the two categories has also been reported (Praß, Grimsen, König, & Fahle, 2013; VanRullen & Thorpe, 2001). Here, we examined the effect of animacy on simple RTs. One should note that although simple RTs do not require object categorization or identification, it has been reported that detection and categorization occur simultaneously, namely as soon as the observers detect an object, they already know its category (Grill-Spector & Kanwisher, 2005; Mack, Gauthier, Sadr, & Palmeri, 2008). Therefore, one might expect to find an effect of animacy on simple RTs.

Animacy is frequently examined in association with familiar size (e.g., Gabay, Leibovich, Henik, & Gronau, 2013; Konkle & Oliva, 2007, 2011, 2012b). Interestingly, there is fMRI evidence to indicate a tripartite organization of neural activity for object representation such that objects are functionally organized into three cortical zones that preferentially respond to: (1) large objects; (2) small objects; and (3) animals (Konkle & Caramazza, 2013). This finding suggests that the representation of animate stimuli should be independent of familiar size. Therefore, it is conceivable that we may find an effect of animacy and familiar size on RTs but not an interaction between these two factors.

The images presented in this experiment were controlled to have the same overall luminance and aspect ratio. Controlling for these factors was deemed necessary as it is well known that luminance and physical size affect RT, such that bigger and brighter stimuli on the retina typically produce faster responses (e.g., Osaka, 1976; Pins & Bonnet, 1996).

## Method

**Participants.** Twenty-four participants (two males), ranging in age from 18 to 44 years ($M = 21$ $SD = 5.52$) took part in the experiment. The sample size for this and all following experiments was deemed to be appropriate to attain a moderate effect size with $\alpha = .05$ and power $= .80$, according to calculations performed in G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) Participants were all right-handed. In this and all following experiments, participants had normal or corrected-to-normal vision, gave informed consent prior to testing and received course credits or payment for their time. All methods were compliant with the rules and regulations of the Psychology Ethics Committee of the University of East Anglia.

**Apparatus.** Participants sat in a dimly lit room with their head on a chin rest placed 57 cm away from a PC monitor. Visual stimuli were presented on a DELL screen (17 in.) with a screen resolution of 1,280 × 1,024. The stimuli and the psychophysical experiments were programmed in E-Prime Version 2.0 software (Psychology Software Tools, Pittsburgh, PA). A Konica Minolta LS-100 luminance photometer was used to measure luminance of the screen and stimuli. Stimuli were displayed on a gray background with a luminance of 128 cd/m$^2$. A black fixation cross (font Arial, size 16 point) was presented at the center of the screen. Size and luminance of the stimuli were adjusted using GNU image manipulation program, Version 2.8.6 (available at www.GIMP.com).

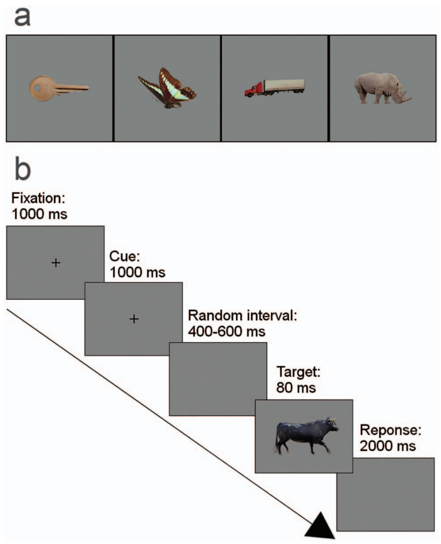
**Stimuli.** Stimuli consisted of color images of real objects matched in luminance and approximate aspect ratio. To this end, the average luminance of each image was adjusted to correspond to 40 cd/m$^2$ and the size of each image was scaled to fit inside a 6 cm × 6 cm frame, producing a visual angle of 6° when viewed at the 57-cm distance. Images were selected according to their familiar size, using a range of sizes similar to that employed by Konkle and Caramazza (2013). Those images classified as "small" had a familiar size that ranged between 0.8 cm and 50 cm ($M = 10.52$ cm, $SD = 10.47$), while those classified as "big" had a familiar size that ranged between 76 cm and 30,000 cm ($M = 1405.43$ cm, $SD = 4642.84$). Depending on the image, the maximum size could have been in height, width, or length. For example, an elephant which is biggest by its length, measuring from its head to its bottom around 500 cm on average, would be placed in the "big" category (note that information about actual size was collected from various Internet sources). Half of the images were animate objects and the other half were inanimate (Figure 1a). The F1 "animate" condition included pictures of animals, while the "inanimate" included nonliving objects (Konkle & Caramazza, 2013). Images were compiled from different sources, including the Normative BOSS collections V1&V2 (Brodeur, Dionne-Dostie, Montreuil, & Lepage, 2010), Animacy × Size database (Konkle & Caramazza, 2013), Big and Small database (Konkle & Oliva, 2012b), POPORO database (Kovalenko, Chaumon, & Busch, 2012), Unique Objects database (Brady, Konkle, Gill, Oliva, & Alvarez, 2013) as well as a variety of self-sourced images. For full details of image sources for this and following experiments, see Table 1 in the online supplementary materials. Headphones were given to participants to deliver a warning signal. A button response box was used to record responses.

**Design and procedure.** The layout of each trial consisted of a black cross presented on the screen for 1,000 ms, followed by a 1,000 Hz "beep" sound (1,000 ms). After this, a random interval ranging between 400 ms and 600 ms was introduced before an image of a familiar object or a blank screen ("catch trial") was presented for 80 ms. A period of 2,000 ms was given to allow for a response (Figure 1b). Participants were instructed to respond as fast as possible to the onset of any stimulus image by pressing a designated button on a response box and to refrain from responding on catch trials. A practice block was included to ensure participants familiarized themselves with the task. There were 30 trials for each of the four conditions of stimulus presentation (Small/Big × Animate/Inanimate) plus 18 catch trials, presented in two blocks, yielding 276 trials in total. Participants were offered breaks at regular intervals to prevent fatigue. Stimuli were presented in a random fashion.

## Results

In this and in the following experiments, anticipations (RTs $<$ 140 ms) and delayed responses (RTs $>$ 650 ms) in relation to stimulus onset, were excluded from the analyses (Sperandio et al., 2009). In this experiment, all participants had high accuracy rates, ranging from 89.44% to 99.64% ($M = 94.81$, $SD = 0.03$).

A 2 × 2 repeated measures ANOVA was conducted on the RT data with familiar size (small vs. big) and animacy (animate vs. inanimate) as main factors. A significant main effect of animacy was found, $F(1, 23) = 16.778$, $p < .001$, $\eta_p^2 = .422$; participants



ONLINE COLOR

*Figure 1.* Stimuli and trial sequence: (a) Example of stimulus display for each experimental condition in Experiments 1 and 2. Thirty stimuli were chosen depending on their familiar size (small vs. big) and were either animate or inanimate objects. All images were adjusted to match in average luminance (30 cd/m$^2$) and fit inside a frame of fixed size (6° × 6°). The aspect ratio of each image was maintained to prevent distortion. From left to right: small inanimate (key), small animate (butterfly), big inanimate (lorry), and big animate (rhinoceros). (b) Example of experimental trial sequence and timing. At the beginning of each trial a fixation cross was presented for 1,000 ms followed by a warning signal. Next, a random interval (400 ms–600 ms) was introduced, followed by a stimulus of 80 ms. Then, a blank screen was presented until the response button was pressed or the time limit of 2,000 ms was reached. During catch trials, the stimulus was replaced by a blank screen and participants were asked to refrain from responding. See the online article for the color version of this figure.

were significantly slower to respond to inanimate ($M$ = 210.56, $SD$ = 26.73) compared with animate objects ($M$ = 206.64, $SD$ = 25.80). However, neither the main effect of familiar size, $F(1, 23) = 0.726$, $p = .403$, $\eta_p^2 = .031$; big objects: $M$ = 208.04, $SD$ = 24.84; small objects: $M$ = 209.16, $SD$ = 27.76) nor its interaction with animacy, $F(1, 23) = 1.39$, $p = .25$, $\eta_p^2 = .057$, were significant (Figure 2a). F2 Therefore, contrary to our expectations, we did not find an effect of familiar size on RTs. However, in line with previous findings supporting early categorization of objects (Clarke, Taylor, Devereux, Randall, & Tyler, 2013), we observed an advantage for animate compared to inanimate objects on the speed of response. To rule out the possibility that the effect of animacy on RTs was simply related to differences in spatial frequency between animate and inanimate objects (Harel & Bentin, 2009; Viggiano, Costantini, Vannucci, & Righi, 2004), an analysis of the low-level statistical features to compare the spatial frequency spectrum between the two semantic categories was conducted, using the Natural Image Statistical Toolbox for MATLAB (Bainbridge & Oliva, 2015). As it turned out, there was AQ: 4 no difference in terms of spatial frequency between animate and inanimate images ($p$ = .86; see online supplementary materials, Table 5).

## Experiment 2: The Influence of Familiar Size and Animacy on Simple RTs, Under Reduced Viewing Conditions

In Experiment 2, the stimuli and design remained the same as in the previous experiment. However, restricted viewing conditions were created by means of a dark room, a reduction tunnel and a monocular pinhole (Holway & Boring, 1941; Sperandio et al., 2009). As established by Holway and Boring (1941), under these viewing conditions the availability of visual cues about distance information is greatly reduced. Specifically, the monocular viewing condition removes binocular cues (e.g., vergence and retinal disparity), pinhole vision impairs the observers' ability to accommodate, and the use of a dark room combined with a reduction tunnel eliminates contextual cues and addition light sources. Re-

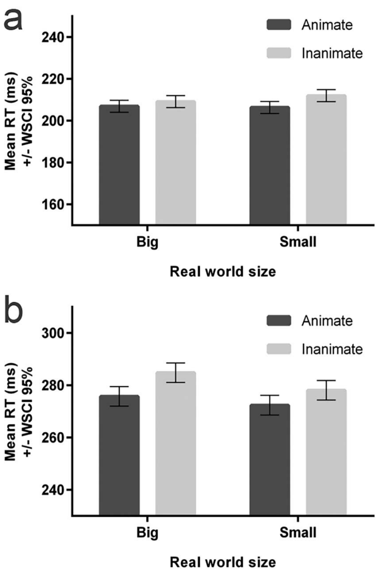


*Figure 2.* Results of Experiments 1 and 2: (a) Experiment 1. Mean RTs (ms) as a function of familiar size and animacy, under regular viewing conditions. (b) Experiment 2. Mean RT (ms) as a function of familiar size and animacy, under reduced viewing conditions. Error bars in both graphs represent within-subjects 95% confidence intervals (WSCI; Loftus & Masson, 1994). AQ: 11

ducing these depth cues results in a decrease of depth perception, forcing the visual perceptual system to rely more on retinal size information (Holway & Boring, 1941; Sperandio et al., 2009). Therefore, under such circumstances, perceptual judgments tend to reflect retinal size rather than perceived size (i.e., the product of distance information and retinal size).

Interestingly, Sperandio, et al. (2009) showed that RTs to stimuli of constant retinal size were governed by perceived size only when participants were presented with images of familiar objects (i.e., tennis balls) rather than unfamiliar plain shapes (i.e., circles). However, these effects were extinguished when reduced viewing conditions were implemented: RTs to the familiar object simply reflected the retinal size of the image. It should be noted, however, that in Sperandio et al.'s (2009) study only one familiar object was used and the retinal size was manipulated, making it impossible to establish any effects of familiar size on RTs. Given that several previous studies have shown that under reduced viewing conditions, perception relies more heavily on familiar size information (e.g., Epstein, 1963; Gogel, 1969; Ittelson, 1951; Schiffman, 1967; Slack, 1956), we repeated Experiment 1 under such restricted viewing conditions to verify whether or not familiar size can influence RTs.

## Method

**Participants.** Twenty-six participants took part in the experiment. However, the data of two participants were removed due to low accuracy (>20% of errors) and technical difficulties. Those included in the final sample (24) ranged in age from 18 to 38 years ($M = 22$, $SD = 4.93$). Four of the participants were left-handed, nine were left-eye dominant and six were males.

**Apparatus.** To generate reduced viewing conditions, participants performed the task in an otherwise dark room and viewed the stimuli through a reduction tunnel and a 1-mm pinhole with their dominant eye. The screen's background was changed to black (0.01 cd/m$^2$ of luminance) and the color of the fixation cross was changed to white. Participants' eye dominance was assessed using the Dolman's method (also known as "hole-in-the-card" test; e.g., Cheng, Yen, Lin, Hsia, & Hsu, 2004). Participants wore pinhole glasses in which all the holes but the most centrally located one were covered with black tape. They then looked into a tube of 8 cm in diameter and 60 cm in length (i.e., "reduction tunnel"). The tube led to the computer screen where the images were displayed. Headphones were given to participants to deliver a warning signal. A button response box was used to record responses.

**Stimuli.** The stimuli used in this experiment were the same as in the previous experiment, however, due to changes in viewing conditions stimuli now subtended a visual angle of 5.7° instead of 6°.

**Design and procedure.** The experimental design was the same as in the previous experiment.

Participants were seated 60 cm away from the screen of the computer, in front of the end of the reduction tunnel. They were asked to wear a pair of pinhole glasses that had one central 1 mm × 1 mm aperture aligned with the dominant eye. The participant was also asked to wear headphones and to place their hand on the response button.

## Results

The participants' accuracy ranged from 88.37% to 99.64% ($M = 96.62$, $SD = 0.03$). A 2 × 2 repeated measures ANOVA was conducted on the RT data with familiar size (small vs. big) and animacy (animate vs. inanimate) as main factors. A significant main effect of familiar size was found, $F(1, 23) = 13.711$, $p = .001$, $\eta_p^2 = .373$; participants were significantly faster at responding to small ($M = 275.25$, $SD = 51.50$) compared with big ($M = 280.31$, $SD = 53.14$) familiar objects. A significant main effect of animacy was also found, $F(1, 23) = 20.695$, $p < .001$, $\eta_p^2 = .474$; as observed in Experiment 1, participants were significantly slower at responding to inanimate ($M = 281.47$, $SD = 51.66$) compared with animate objects ($M = 274.08$, $SD = 52.84$). However, the two-way interaction did not reach significance, $F(1, 23) = 0.805$, $p = .379$, $\eta_p^2 = .034$ (Figure 2b).

Under reduced viewing conditions, we replicated the effect of animacy observed in Experiment 1; RTs in response to pictures of animals were faster than nonanimals. This suggests that that advantage in processing animate stimuli is independent to the changes in viewing conditions, as the animacy effect on RT was observed both under natural (Experiment 1) and reduced (Experiment 2) viewing conditions.

We also found an effect of size, such that there was an advantage in RTs for small objects compared with big objects, indicating that RTs are modulated by familiar size but only under restricted conditions of observation, when depth cues are removed.

## Is the Effect of Familiar Size on Simple RTs Proportionate?

The main aim of the following two experiments was to verify whether or not simple RTs are systematically affected by familiar size when off-sized versions of familiar objects (i.e., bigger or smaller on the screen compared to their size in the real-world) are viewed under restricted conditions of observation. In Experiment 3, familiar objects of normal size to progressively undersize, were shown on the screen with constant aspect ratio. In Experiment 4, familiar objects of normal size to progressively oversize were shown on the screen with constant aspect ratio. Objects were considered to be normal sized if their physical size on the screen corresponded to a visual angle that was consistent with the typical size of the object viewed at a typical distance. For example, a candy would need to be placed at 60 cm of viewing distance to subtend 5.7° of visual angle, while a double-decker bus would need to be placed 122 m away from the participant's eyes to generate the same retinal image size (see Figure 3). As such, it was hypothesized that detection time would be systematically modulated by the increased incongruence between familiar and physical size of the stimuli presented on the screen.

As familiar size was the primary concern of the present investigation, the effect of animacy will not be explored further in the subsequent experiments.

## Experiment 3: From Normal to Undersized Stimuli

## Method

**Participants.** Twenty-nine participants took part in the experiment. However, only the data of 28 participants were included in

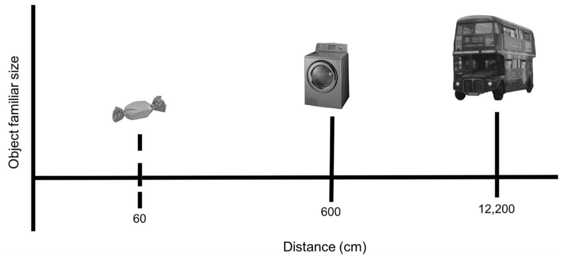


*Figure 3.* Relationship between familiar size and distance for a specified visual angle. The dashed line represents the viewing distance used in Experiments 3–5 (i.e., 60 cm). The distance (indicated by the vertical lines) and the size of the images are proportional to the typical size-distance relationship in order to subtend the visual angle tested in Experiment 3 (i.e., 5.7°). Exemplars from each category of familiar size are depicted (i.e., ×1, 1/10, and 1/100).

the analysis. One participant was removed due to technical difficulties. Those included in the final sample, ranged in age from 18 to 23 years ($M = 19$, $SD = 1$). Five of the participants were left-handed, five were left eye-dominant and seven were males.

**Apparatus.** The same apparatus as in Experiment 2 was used here.

**Stimuli.** Stimuli were selected according to the level of incongruence between their familiar size and physical size presented on the screen. Based on this criterion, three intervals were determined: 1 (normal-sized stimuli), 1/10 (undersized stimuli), and 1/100 (undersized stimuli). Objects were chosen such that they would fit within a hand (x1), be half the size of a person (1/10) and be bigger than a person (1/100); a similar criterion for stimulus selection was used by Konkle and Caramazza (2013). Those images classified as "1" had a familiar size that ranged between 5 cm and 7 cm ($M = 6.61$ cm, $SD = 0.92$), those classified as "1/10" had a familiar size that ranged between 50 cm and 70 cm ($M = 68.09$ cm, $SD = 10.94$) and those classified as "1/100" had a familiar size that was greater than or equal to 500 cm ($M = 5912$ cm, $SD = 8165$). As in the previous experiments, all images were of constant physical size (5.7°) and luminance (30 cd/m$^2$). Therefore, only "1" stimuli were the same size as in the real world (normal-sized), whereas "1/10" and "1/100" stimuli were smaller than in the real world (undersized). Some of the images used in this experiment were previously used in Experiments 1 and 2 (see Table 2 in the online supplementary material for details about image source).

**Design and procedure.** Participants performed the experiment under restricted viewing conditions, as described in Experiment 2. The experimental design was similar to Experiment 1 except for the number of trials: there were 30 trials for each of the three size intervals (1 vs. 1/10 vs. 1/100), plus 14 catch trials, presented in two blocks, yielding 208 trials in total.

## Results

The participants' accuracy ranged from 85% to 100% ($M = 96.08$, $SD = 0.04$). As Mauchly's test of sphericity was significant, $\chi^2(2) = 9.386$, $p = .009$, the Greenhouse-Geisser value was reported. One-way repeated measures ANOVA was conducted on the RT data with familiar size (1 vs. 1/10 vs. 1/100) as the main factor. The ANOVA showed a main effect of familiar size on RTs, $F(1.535, 41.443) = 4.553$, $p = .024$, $\eta_p^2 = .144$. Post hoc tests with Bonferroni correction revealed that this effect was mainly driven by a difference in RTs between the two extreme conditions. Participants were significantly faster to respond to objects presented at their true size ($M = 286.02$, $SD = 62.97$) compared with objects that were presented at 1/100th of their familiar size ($M = 294.89$, $SD = 62.92$; $p_{corr} = .018$). However, the differences between 1/10th objects ($M = 289.29$, $SD = 59.66$) and those shown at their true size ($p_{corr} = .421$), along with 1/10th compared with 1/100th objects ($p_{corr} = .399$) were not significant. Although some of the comparisons did not reach significance, visual inspection of Figure 4a clearly shows a linear trend, which was supported F4 by a linear contrast analysis ($F[1, 27] = 8.927$, $p = .006$, $\eta_p^2 = .248$). Additionally, a Pearson's correlation coefficient (r) was calculated between RT for each image averaged across participants and log-transformed real-world size (see Table 4 in the online supplementary materials for details). The correlation revealed a positive relationship between RTs and real-world size, $r(88) = .334$, $p = .001$ (Figure 5A). F5

These results demonstrate that simple RTs are affected by familiar size in a systematic manner when the discrepancy between physical size and familiar size increases proportionally.

## Experiment 4: From Normal to Oversized Stimuli

### Method

**Participants.** Twenty-eight participants took part in this experiment (three male, seven left eye-dominant, and three left-handed). They ranged in age from 18 to 55 years ($M = 23$, S$D = 9.42$).

**Apparatus.** As in Experiment 3, images of real objects were selected based on the proportion of their familiar size to their physical size presented on the screen and were categorized as: ×1 (normal-sized stimuli), ×2 (oversized stimuli), and ×10 (over-

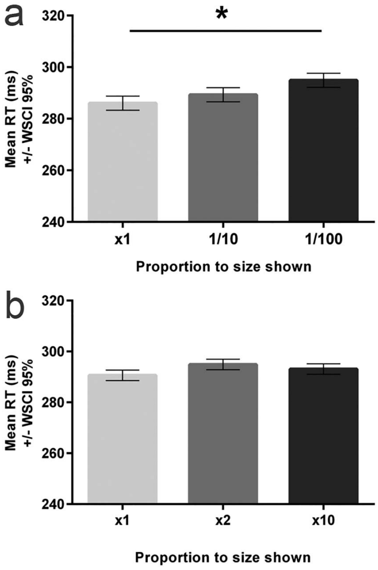


*Figure 4.* Results of Experiment 3 and 4: (a) Experiment 3 mean RTs (ms) as a function of familiar size, under reduced viewing conditions (left to right: increasing familiar size). The asterisk denotes a significant difference ($p_{corr} < 0.05$) between means based on Bonferroni corrected *t* tests. (b) Experiment 4 mean RTs (ms) as a function of familiar size, under reduced viewing conditions (left to right: decreasing familiar size). Error bars in both graphs represent within-subjects 95% confidence intervals (WSCI; Loftus & Masson, 1994).

sized stimuli). As it was not possible to directly mirror the different intervals in familiar size as in Experiment 3, due to the fact that very small objects (e.g., tip of a pen) seen as enlarged can become unfamiliar and difficult to recognize, we simply chose three different size intervals that would not include objects smaller than 0.4 cm in the real world.

Those images classified as "1" had a familiar size that ranged between 5 cm and 7 cm (*M* = 6.58 cm, *SD* = 0.89), those classified as "x2" had a familiar size that ranged between 2.5 cm and 3.5 cm (*M* = 2.96 cm, *SD* = 0.52), and those classified as "x10" had a familiar size that ranged between 0.4 cm and 1.6 cm (*M* = 0.96 cm, *SD* = 0.33).

Again, all images were balanced for luminance (30 cd/m$^2$) and were scaled to subtend 5.7° of visual angle. Therefore, only "1" stimuli were the same size as in the real world (normal-sized), whereas "x2" and "x10" stimuli were bigger than in the real world (oversized), some images were the same as those used in the previous experiment (see Table 3 in the online supplementary materials).

**Design and procedure.** See Experiment 3.

## Results

Accuracy was high, ranging from 88.94% to 99.52% (*M* = 97.28, *SD* = 0.03). A one-way repeated measures ANOVA was conducted with familiar size (1 vs. ×2 vs. ×10) as the main factor. The ANOVA revealed no main effect of familiar size on RTs (*F*(2, 54) = 1.332, *p* = .273, ηp2 = .047; ×1: *M* = 290.64, *SD* = 41.96; ×2: *M* = 294.92, *SD* = 44.07; ×10: *M* = 293.12, *SD* = 42.09). Similarly, the linear contrast analysis did not reach significance, *F*(1, 27) = 1.241, *p* = .275, $\eta_p^2$ = .044 (Figure 4b). As for Experiment 3, a Pearson's correlation coefficient (r) was calculated between RTs for each image averaged across participants and the log-transformation of each object's size. RT did not correlate with real-world size, *r*(88) = −0.001, *p* = .496 (Figure 5B).

This lack of effect on RTs for small objects shown at a magnified size could be attributed to a reduced discrepancy (i.e., less variability) between physical and familiar size, which was not the case for Experiment 3 where the size range was much wider. Specifically, while the range difference between the two extreme categories in Experiment 3 was 4.51 in log-units, this difference in Experiment 4 was only 1.25 in log-units. An alternative explanation for the results could be that participants were unable to correctly identify some of the magnified objects, especially those

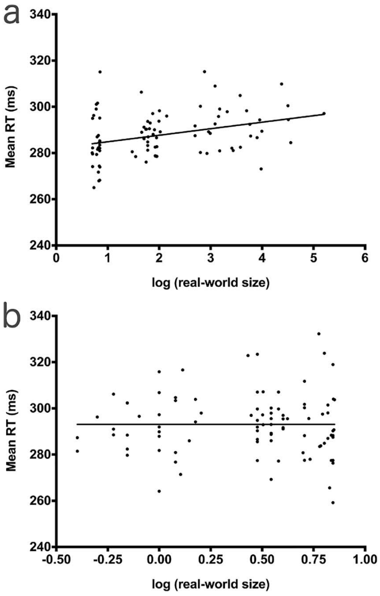


*Figure 5.* Correlation between the mean RT and actual real-world size of the stimuli used in (a) Experiment 3 and (b) Experiment 4. The *x*-axis corresponds to the log-transformed size of the object (originally in centimeters) and the *y*-axis corresponds to the mean RT (ms) for each image.

from the smallest category (x10). In fact, while we are used to see large objects as small on the retina (as in Experiment 3), we rarely experience tiny objects as big on the retina, unless they are held very close to the eyes (in Experiment 4, ×10 objects would need to be placed at 6 cm of viewing distance from the eyes to generate 5.7° of visual angle). Therefore, magnified small objects could have been treated by the visual system as unfamiliar images.

## Experiment 5: The Effect of Familiar Size on Manual Estimates

The aim of this experiment was to establish if the effect of familiar size on RTs, observed under reduced viewing conditions (Experiments 2 and 3) could be attributed to perceived size, as previous studies have demonstrated that simple RTs are faster in response to objects that are perceived as bigger even when their retinal image is constant (Plewan et al., 2012; Savazzi et al., 2012; Sperandio et al., 2009, 2010).

In Experiment 5, participants judged the perceived size of stimuli under restricted conditions of observation. Therefore, if the effects of familiar size on RTs reported in Experiments 2 and 3 are due to perceived size, then one might expect to find that objects shown at their familiar size will be perceived as bigger compared with those objects presented at a size that is incongruent with their known size. In other words, those objects that generated faster RTs (i.e., stimuli congruent with prior knowledge about real-world size) should also be estimated as larger than those objects that generated slower RTs (i.e., incongruent stimuli) in agreement with the findings discussed above where perceived larger objects are responded to more quickly than perceived smaller objects.

### Method

**Participants.** Thirty participants took part in this experiment, however, two were removed due to failure to comply with the task instructions and technical issues. The remaining participants (seven left-handed, seven left eye-dominant, and seven males) ranged in age from 18 to 44 years ($M = 20$, $SD = 4.79$).

**Apparatus.** The same images and apparatus as described in Experiment 3 were used here. Measurements of manual estimations were taken in millimeters by the experimenter using a pair of digital calipers. Two little points were drawn on the forefinger and thumb of the participant's right hand and served as markers for the measurements.

**Design and procedure.** Participants were asked to estimate the size of the object presented on the screen using their thumb and forefinger. Perceived size was measured by means of manual size estimation. Manual size estimation has been widely used in the literature to record perceived size (e.g., Haffenden & Goodale, 1998; Sperandio, Lak, & Goodale, 2012; Westwood & Goodale, 2003), even under reduced viewing conditions (Marotta & Goodale, 2001). Its effectiveness and sensitivity in measuring changes in size perception have been previously demonstrated (e.g., Franz, 2003; Franz & Gegenfurtner, 2008). The advantages of using *MSE* are that the fingers return to the starting position (i.e., pinch returns to an estimate of zero) and the estimate can be made without looking at the hand, making this measure more "implicit" and less prone to memory effects and anchoring biases than other forms of perceptual reports (e.g., Bolles & Bailey, 1956). Images of familiar objects were divided into two blocks, depending on their dimension properties (width vs. height), which determined the orientation of the hand during the manual estimation task. For example, an elongated object such as a glue stick presented vertically, would meet the criterion for maximum height but not width. There were 41 images that met the criterion for maximum width and 46 images that met the criterion for maximum height. The remaining images that met both criteria ($N = 3$) were placed into the width category to even out the number of trials with respect to the height category. Prior to testing, participants were instructed on how to perform the manual estimation task according to the "width" or "height" block and were asked to complete a practice session involving both hand orientations. Participants used their dominant hand and eye to perform the task. The two experimental blocks (width vs. height) were presented in counterbalanced order. Stimuli within each block were randomly presented.

At the beginning of each block, participants received instructions about the relevant dimension to be judged (width vs. height). A typical trial consisted of a cross appearing on the screen, followed by an image of an object. The participant then manually estimated the object. Once the participant was happy with his or her judgment, the experimenter recorded the manual estimation using the digital calipers. In between trials, participants were required to rest their hand on the table with their right forefinger and thumb pinched together. A break was given between the two blocks.

The experiment consisted of 30 trials for each of the three size intervals (1 vs. 1/10 vs. 1/100), yielding 90 trials in total.

### Results

A one-way ANOVA with familiar size (1 vs. 1/10 vs. 1/100) as main factor was carried out on manual estimates. As Mauchly's test of sphericity was significant, $\chi^2(2) = 22.249$, $p < .001$, the Greenhouse-Geisser value was reported.

The effect of familiar size on manual estimates was significant, $F(1.27, 34.285) = 11.905$, $p = .001$, $\eta_p^2 = .306$. Post hoc tests with Bonferroni correction revealed that the difference between ×1 ($M = 57.29$, $SD = 15.77$) and 1/100 ($M = 62.99$, $SD = 17.59$) was significant ($p_{corr} = .003$), along with the difference between 1/10 ($M = 58.88$, $SD = 16.15$) and 1/100 ($p_{corr} = .009$). Although the comparison between ×1 and 1/10 was only approaching significance ($p_{corr} = .074$), a proportionate relationship between the means of each size condition can be observed in Figure 6 and is supported by the linear contrast analysis, which was significant, $F(1, 27) = 13.867$, $p = .001$, $\eta_p^2 = .339$. F6

These results show that the perceived size of real-world objects can be influenced by their familiar size, such that when objects were presented at the same retinal size, participants perceived those objects that are known to be big as larger than those that are known to be small. These findings are consistent with previous studies on the effects of familiar size on perceived size and distance under restricted conditions of observation. For example, it has been demonstrated that when photographs of a golf ball and a baseball were presented at the same retinal size and distance, under reduced viewing conditions, observers perceived the baseball to be bigger and further away than the golf ball (Ono, 1969). Similarly, observers judged coins of small familiar size as closer and smaller than their familiar bigger counterparts, despite being presented at

Taken together, these findings provide converging evidence for the existence of separate mechanisms for animate and inanimate object categories, which might explain the animacy effects described above. In line with previous findings, our participants were faster to simply detect the onset of images of animals compared to nonanimals in the current investigation, providing further support to the idea that animate objects are attended to more quickly than inanimate objects. To the best of our knowledge, this is the first demonstration of an animacy effect on simple RTs. Notably, the animacy effect observed here was unrelated to low-level visual features of the stimuli, such as differences in spatial frequency between the two semantic categories, which argues against the hypothesis that the behavioral advantage for animate objects relies merely on underlying statistical properties of the images (Harel & Bentin, 2009; Viggiano et al., 2004). Instead, our findings might be indicative of an evolutionary advantage for animate objects, as originally suggested by Caramazza and Shelton (1998).

## Familiar Size Effect

Behavioral effects of familiar size have also been reported in the literature. For example, it has been established that the perceived size of an object is influenced by its familiar size, such that individuals are more accurate at estimating the size of familiar than nonfamiliar objects (e.g., Bolles & Bailey, 1956; Slack, 1956). This effect of object familiarity is evident particularly under reduced viewing conditions, where the usual cues to distance, such as vergence, accommodation, and retinal disparity, are restricted (e.g., Epstein, 1963; Gogel, 1969; Ittelson, 1951; Schiffman, 1967).

Moreover, it has been shown that familiar size can affect speed of processing. In a Stroop-like paradigm, pairs of familiar objects were shown and participants were asked to indicate which one of the two images was visually bigger. Responses were faster if the difference in size between the two images was congruent to the true size difference between the familiar objects; for example, a big elephant and a small mouse would be responded to more quickly than a small elephant and a big mouse (Konkle & Oliva, 2012a). By the same token, Gabay, Leibovich, Henik, and Gronau (2013) demonstrated in a priming study involving objects of equal retinal size but different familiar size as primes and integers as targets that participants' response time in making odd-even judgments of the target increased when the conceptual size of the object image was incongruent with the integer's value. For example, an elephant prime followed by the number one determined a slower response compared with a trial in which the number one was primed by the picture of a mouse. These findings show that a cost in response time is incurred when there is a lack of shared conceptual representations between pairs of familiar objects (Konkle & Oliva, 2012a) or prime and target stimuli (Gabay et al., 2013) and suggest that familiar size is an automatic object property. Here, we found that simple RT, a stereotyped motor response, is also influenced by familiar size with faster responses to stimuli that are physically closer to their real-world size. One might argue that the effect of familiar size on simple RTs depends on the degree of congruence between the physical size of the object displayed on the screen and its internal representation of size, whereby a cost is incurred for increased degrees of incongruence, which slow down RTs. In other words, it is conceivable that the difference in speed of processing (~7 ms on average for significant comparisons) between objects of different familiar-size intervals could reflect the time taken for the visual system to process the stimulus, access to the stored representation of size, and perform a computational adjustment with respect to such an internal representation, with a benefit for object images that physically match their internal representation. However, further electrophysiological research would need to be conducted to confirm this hypothesis.

Interestingly, there are instances in which response times tend to favor big objects, so that familiar big objects are responded to more quickly than small objects. One such study involved a lexical-decision task, where participants were simply asked to identify if the letters presented formed a word (e.g., apple) or a nonword (e.g., lerop; Sereno, O'Donnell, & Sereno, 2009). It was found that people were faster to classify word-stimuli when the word was a familiar big object (e.g., bus) compared with a familiar small object (e.g., pea). A similar effect was reported in Konkle and Oliva's (2012a) study described above, whereby along with the congruency finding, results revealed that familiar big objects were responded to faster than familiar small objects. This is also in agreement with the RT study carried out by Sperandio et al. (2009) in which participants were faster to react to perceived larger stimuli than perceived smaller stimuli of fixed retinal size, but only when images of familiar objects (i.e., tennis balls) instead of simple circles were presented, highlighting once again the importance of object familiarity on response speed. Our results indicate that the advantage of response speed did not correspond to the estimates of perceived size, which tended to increase with the real-world size. Therefore, our findings do not support the notion that "bigger is better" as sometimes reported in the literature (e.g., Konkle & Oliva, 2012a; Sereno et al., 2009; Sperandio et al., 2009; Witt & Proffitt, 2005), but rather "congruent is better," where smaller deviations from known size resulted in faster detection times.

From a neural perspective, it has been suggested that different brain areas represent objects of different familiar size in a manner that reflects an organization based upon their real-world size (Konkle & Oliva, 2012b). Using fMRI, Konkle and Oliva (2012b) showed that the occipito-temporal cortex is topographically organized according to familiar size. Particularly, the parahippocampal cortices (PHC) was preferentially activated by familiar big objects, whereas regions such as the lateral occipital (LO) complex and occipital temporal sulcus (OTS) were sensitive to familiar small objects. This activity was resistant to both low-level (e.g., changes in retinal size) and high-level (e.g., abstract concepts of size) effects (Konkle & Oliva, 2012b). More recently, Konkle and Caramazza (2013) has provided evidence for a tripartite distinction between response preferences for animals, big objects, and small objects in the occipital-temporal cortex. In particular, big objects were reported to preferentially activate medial regions (including PHC), whereas small objects activated more lateral regions of the occipital temporal cortex, such as the inferior temporal gyrus (ITG). Images of animals also preferentially activated more lateral regions in the occipital temporal cortex (Konkle & Caramazza, 2013). Interestingly, this tripartite organization of the ventral stream relies on separate subnetworks as demonstrated in a resting-state study (Konkle & Caramazza, 2016). Correspondingly, it has been shown that a patient with inferior occipitoparietal cortex damage was more accurate at judging the distance of familiar (e.g., plastic bottle) than unfamiliar objects (e.g., cube), suggesting that her depth perception, which was severely impaired by the lesion, could to some extent benefit from familiar size (Berryhill, Fendrich, & Olson, 2009).

To conclude, familiar size can influence the time it takes to process and respond to familiar stimuli with an advantage for those stimuli subtending retinal image sizes that are closer to their long-term representations of size. This behavioral advantage might reflect the spatial organization of neural response preferences as dictated by real-world size.

## Conclusion

In summary, here we demonstrate for the first time that a relationship exists between simple RTs, a stereotyped speeded response to stimulus onset, and familiar size, such that a simple RT advantage was recorded for objects shown closer to their "true" size. The familiar size effect on RTs did not reflect perceived size but rather the degree of congruency to a stored "normative" size. Furthermore, we have shown that simple RTs were modulated by animacy with faster detection times for images of animals than nonanimals. Taken as a whole, these findings suggest that both familiar size and animacy are automatic features of object representations that might take place at an early stage in the processing of visual information and might be subserved by distinct neural processes.

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Supplementary materials

Table 1

*Experiment 3 and 4: Small animate stimuli*

| Stimuli | Source |
|---|---|
| Ant.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Beatle.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Bee.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Bunny.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Butterfly.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Chick.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Chihuah.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Chipmonk.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Crab.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Cricket.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Frog.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Gerbil.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Goldfinch.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Goldfish.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Hamster.png | Photorack.net |
| Hedgehog.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Hummingbird.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Kitten.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Ladybird.png | PdPhoto.org |
| Lemur.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Lizard.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Moth.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Mouse.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Pigeon.png | Animacy x Size (Konkle & Caramazza, 2013) |
| PrarieDog.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Prawn.png | Photorack.net |
| Seagull.png | Publicdomainpictures.net |
| Seahorse.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Snail.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Squirrel.png | Animacy x Size (Konkle & Caramazza, 2013) |

Table 1

*Experiment 3 and 4: Small inanimate stimuli*

| Stimuli | Source |
|---|---|
| Bauble.png | Publicdomainpictures.net |
| Camera.png | Photorack.net |
| Candle.png | Own photo |
| Chesspeice.png | Imageafter.com |
| Clothespeg.png | Own photo |
| ComputerMouse.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Dice.png | Own photo |
| FivePence.png | Own photo |
| Key.png | Own photo |
| Kiwi.png | All-free-download.com |
| LightBulb.png | Photorack.net |
| Lipstick.png | All-free-download.com |
| Lock.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Mushroom.png | photorack.net |
| NailVarnish.png | Own photo |
| Onion.png | Own photo |
| Paperclip.png | photorack.net |
| PepperShaker.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Phone.png | Own photo |
| Pin.png | Own photo |
| PineCone.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Puzzle.png | All-free-download.com |
| Rubber.png | photorack.net |
| SafetyPin.png | Own photo |
| Sharpener.png | Own photo |
| Shuttlecock.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Tapemeasure.png | All-free-download.com |
| TennisBall.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Thimble.png | Animacy x Size (Konkle & Caramazza, 2013) |
| USB.png | Own photo |

Table 1

*Experiment 3 and 4: Big animate stimuli*

| Stimuli | Source |
|---|---|
| Buffalo.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Bull.png | BOSS V2 (Brodeur et al, 2010) |
| Camel.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Cow.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Croc.png | Animacy x Size (Konkle & Caramazza, 2013) |
| dog.png | Photorack.net |
| Dolphine.png | All-free-download.com |
| Elephant.png | Pics4Learning.com |
| Giraffe.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Gorilla.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Hippo.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Horse.png | Public-domain-photos |
| Ibex.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Kangaroo.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Lion.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Manatee.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Moose.png | Wikimedia.org |
| Orangutang.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Ostrich.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Panda.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Polarbear.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Puma.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Reindeer.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Rhino.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Sealion.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Shark.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Tiger.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Walrus.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Whale.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Zebra.png | Animacy x Size (Konkle & Caramazza, 2013) |

Table 1

*Experiment 3 and 4: Big inanimate stimuli*

| Big-Inanimate | Source |
|---|---|
| Aeroplane.png | public-domain-image.com |
| BBQ.png | Own photo |
| Bench.png | public-domain-image.com |
| BigBen.png | All-free-download.com |
| Bike.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Bunkbed.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Car.png | Wikimedia.org |
| Couch.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Cupboard.png | Imageafter.com |
| Door.png | Photorack.net |
| DrinksMachine.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Drumkit.png | Photorack.net |
| EiffelTower.png | Pics.tech4learning.com |
| Exercise_machine.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Ferry.png | Pics.tech4learning.com |
| Fridge.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Guitar.png | Wikimedia.org |
| Ladder.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Lawnmower.png | Own photo |
| Piano.png | Animacy x Size (Konkle & Caramazza, 2013) |
| TelephoneBox.png | All-free-download.com |
| Tent.png | Imageafter.com |
| Tractor.png | All-free-download.com |
| Traffic light.png | All-free-download.com |
| Treadmill.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Truck.png | All-free-download.com |
| WashingMachine.png | Animacy x Size (Konkle & Caramazza, 2013) |
| Wheelburrow.png | Animacy x Size (Konkle & Caramazza, 2013) |
| WheelieBin.png | Wikimedia.org |
| Windturbin.png | All-free-download.com |

Table 2
*Experiment 5: x1 group*

| Stimuli | Source |
|---|---|
| Bauble.png | exp1 |
| Bubbles.png | BOSS V1 (Brodeur et al, 2010) |
| Candy.png | BOSS V1 (Brodeur et al, 2010) |
| Carabiners.png | Big and Small (Konkle & Oliva, 2012) |
| Chess_knight.png# | exp1 |
| Clothespeg.png | exp1 |
| Coathook.png | BOSS V2 (Brodeur et al, 2010) |
| Crayon.png | BOSS V1 (Brodeur et al, 2010) |
| Egg.png | BOSS V1 (Brodeur et al, 2010) |
| Garlic.png | BOSS V1 (Brodeur et al, 2010) |
| Glue.png | BOSS V1 (Brodeur et al, 2010) |
| Hairclip.png | BOSS V1 (Brodeur et al, 2010) |
| Hourglass.png | BOSS V1 (Brodeur et al, 2010) |
| Keychain.png | BOSS V1 (Brodeur et al, 2010) |
| Kiwi.png | exp1 |
| Lighter.png | BOSS V1 (Brodeur et al, 2010) |
| Lipstick.png | exp1 |
| Lock.png | exp1 |
| Nailclippers.png | BOSS V1 (Brodeur et al, 2010) |
| NailVarnish.png | exp1 |
| Nametag.png | BOSS V2 (Brodeur et al, 2010) |
| PepperShaker.png | exp1 |
| Plaster.png | BOSS V1 (Brodeur et al, 2010) |
| Potato.png | BOSS V1 (Brodeur et al, 2010) |
| Rubberduck.png | Big and Small (Konkle & Oliva, 2012) |
| Shuttlecock.png | exp1 |
| Stapleremover.png | BOSS V1 (Brodeur et al, 2010) |
| Tapemeasure.png | exp1 |
| TennisBall.png | exp1 |
| Webcam.png | BOSS V2 (Brodeur et al, 2010) |

Table 2
*Experiment 5: 1/10 group*

| Stimuli | Source |
|---|---|
| BBQ.png | Own Photo |
| Bike.png | exp1 |
| Bin.png | BOSS V2 (Brodeur et al, 2010) |
| Boogieboard.png | BOSS V2 (Brodeur et al, 2010) |
| Corkboard.png | BOSS V2 (Brodeur et al, 2010) |
| Doormat.png | BOSS V2 (Brodeur et al, 2010) |
| Drying_rack.png | BOSS V2 (Brodeur et al, 2010) |
| Filling-cabinet.png | Own Photo |
| Fireplace.png | BOSS V2 (Brodeur et al, 2010) |
| Footrest.png | BOSS V2 (Brodeur et al, 2010) |
| Fridge.png | exp1 |
| Laundrybasket.png | BOSS V2 (Brodeur et al, 2010) |
| Nightstand.png | BOSS V2 (Brodeur et al, 2010) |
| Officechair.png | BOSS V1 (Brodeur et al, 2010) |
| Oven.png | BOSS V2 (Brodeur et al, 2010) |
| Petcarrier.png | BOSS V1 (Brodeur et al, 2010) |
| Pillow.png | BOSS V1 (Brodeur et al, 2010) |
| Punchingbag.png | BOSS V2 (Brodeur et al, 2010) |
| Radiator.png | BOSS V2 (Brodeur et al, 2010) |
| Satellitedish.png | BOSS V2 (Brodeur et al, 2010) |
| Shelf.png | BOSS V2 (Brodeur et al, 2010) |
| Apron.png | BOSS V2 (Brodeur et al, 2010) |
| Step-ladder.png | exp1 |
| Suitcase.png | BOSS V1 (Brodeur et al, 2010) |
| Television.png | BOSS V2 (Brodeur et al, 2010) |
| Towel.png | Own Photo |
| Traffic_light.png | exp1 |
| Washing_machine.png | Big and Small (Konkle & Oliva, 2012) |
| Wetfloor_sign.png | BOSS V2 (Brodeur et al, 2010) |
| Wreath.png | BOSS V2 (Brodeur et al, 2010) |

Table 2

*Experiment 5: 1/100 group*

| Stimuli | Source |
|---|---|
| Aeroplane.png | exp1 |
| Arch.png | exp1 |
| Coach.png | exp1 |
| Big_house.png | Imageafter.com |
| Cherrypicker.png | BOSS V2 (Brodeur et al, 2010) |
| Windturbin.png | exp1 |
| Caravan.png | Imageafter.com |
| Cran.png | Imageafter.com |
| Cruiseship.png | BOSS V2 (Brodeur et al, 2010) |
| Double_decker.png | Imageafter.com |
| Fountain.png | Big and Small (Konkle & Oliva, 2012) |
| Eiffeltower.png | exp1 |
| Ferris_wheel.png | Pixabay.com |
| Ferry.png | exp1 |
| Fire_engine.png | Big and Small (Konkle & Oliva, 2012) |
| Gazebo.png | BOSS V2 (Brodeur et al, 2010) |
| Hangar.png | BOSS V2 (Brodeur et al, 2010) |
| Helicopter.png | Big and Small (Konkle & Oliva, 2012) |
| Hot_AirBalloon.png | Big and Small (Konkle & Oliva, 2012) |
| Lighthouse.png | BOSS V2 (Brodeur et al, 2010) |
| Mobile_Home.png | Wikimedia.org |
| Sail_boat.png | BOSS V2 (Brodeur et al, 2010) |
| Skyscarper.png | Pixnio.com |
| Storage_container.png | Imageafter.com |
| Tank.png | figshare.com |
| Tractor.png | exp1 |
| Train.png | photorack.net |
| Truck.png | exp1 |
| Windmill.png | BOSS V2 (Brodeur et al, 2010) |
| BigBen.png | exp1 |

Table 3

*Experiment 6: x10 group*

| Stimuli | Source |
|---|---|
| blueberry.png | BOSS V1 (Brodeur et al, 2010) |
| button.png | BOSS V1 (Brodeur et al, 2010) |
| ceiling hook.png | Big and Small (Konkle & Oliva, 2012) |
| cheerio.png | Pixabay.com |
| chocolate chip.png | BOSS V2 (Brodeur et al, 2010) |
| Clove.png | Pixabay.com |
| coffee bean.png | Pixabay.com |
| Contact lens.png | BOSS V2 (Brodeur et al, 2010) |
| dice.png | exp1 |
| earbud.png | Wikimedia.org |
| earring back.png | Own Photo |
| kidney beans.png | POPORO (Kovalenko et al, 2012) |
| Lobster clasp.png | Wikimedia.org |
| marble.png | BOSS V2 (Brodeur et al, 2010) |
| Pearl.png | Pixabay.com |
| pill.png | 2400 Unique objects (Brady et al, 2013) |
| pomegranite.png | Wikimedia.org |
| popcorn.png | BOSS V2 (Brodeur et al, 2010) |
| puzzle piece.png | exp1 |
| raisin.png | BOSS V2 (Brodeur et al, 2010) |
| rhinestone.png | Big and Small (Konkle & Oliva, 2012) |
| rice.png | BOSS V2 (Brodeur et al, 2010) |
| screw.png | BOSS V1 (Brodeur et al, 2010) |
| skittle.png | Pixabay.com |
| Snap.png | Wikimedia.org |
| sunflower seeds.png | BOSS V2 (Brodeur et al, 2010) |
| Sweetcorn.png | Pixabay.com |
| thimble.png | BOSS V2 (Brodeur et al, 2010) |
| Thumb tack.png | Wikimedia.org |
| Tictac.png | Pixabay.com |

Table 3

*Experiment 6: x2 group*

| Stimuli | Source |
|---|---|
| acorn.png | BOSS V2 (Brodeur et al, 2010) |
| Alligator_clips.png | Wikimedia.org |
| Army_figure.png | Pixabay.com |
| Badge_Back.png | Own Photo |
| Bobbin.png | Wikimedia.org |
| bottlecap.png | Wikimedia.org |
| Candle.png | Own Photo |
| Clam.png | Big and Small (Konkle & Oliva, 2012) |
| Cork.png | BOSS V1 (Brodeur et al, 2010) |
| Earrings.png | BOSS V1 (Brodeur et al, 2010) |
| Ferrero.png | Wikimedia.org |
| fuse.png | Wikimedia.org |
| Fusilli .png | BOSS V1 (Brodeur et al, 2010) |
| golfball.png | BOSS V2 (Brodeur et al, 2010) |
| Guitar_pick.png | Wikimedia.org |
| Hairgrip.png | Wikimedia.org |
| jack .png | BOSS V1 (Brodeur et al, 2010) |
| key.png | Big and Small (Konkle & Oliva, 2012) |
| lego.png | Pixabay.com |
| Olive .png | BOSS V1 (Brodeur et al, 2010) |
| pokerchip.png | BOSS V2 (Brodeur et al, 2010) |
| Ring.png | Big and Small (Konkle & Oliva, 2012) |
| SafetyPin.png | Own Photo |
| SDcard.png | Wikimedia.org |
| Sharpener.png | Own Photo |
| Splitring .png | BOSS V1 (Brodeur et al, 2010) |
| Tape.png | Wikimedia.org |
| Toggle .png | flickr.com |
| walnut.png | BOSS V1 (Brodeur et al, 2010) |
| zip.png | Pixabay.com |

Table 3

*Experiment 6: x1 group*

| Stimuli | Source |
|---|---|
| Bauble.png | exp1 |
| Bubbles.png | BOSS V1 (Brodeur et al, 2010) |
| Candy.png | BOSS V1 (Brodeur et al, 2010) |
| Carabiners.png | Big and Small (Konkle & Oliva, 2012) |
| Chess_knight.png | exp1 |
| Clothespeg.png | exp1 |
| Coathook.png | BOSS V2 (Brodeur et al, 2010) |
| Crayon.png | BOSS V1 (Brodeur et al, 2010) |
| Egg.png | BOSS V1 (Brodeur et al, 2010) |
| Garlic.png | BOSS V1 (Brodeur et al, 2010) |
| Glue.png | BOSS V1 (Brodeur et al, 2010) |
| Hairclip.png | BOSS V1 (Brodeur et al, 2010) |
| Hourglass.png | BOSS V1 (Brodeur et al, 2010) |
| Keychain.png | BOSS V1 (Brodeur et al, 2010) |
| Kiwi.png | exp1 |
| Lighter.png | BOSS V1 (Brodeur et al, 2010) |
| Lipstick.png | exp1 |
| Lock.png | exp1 |
| Nailclippers.png | BOSS V1 (Brodeur et al, 2010) |
| NailVarnish.png | exp1 |
| Nametag.png | BOSS V2 (Brodeur et al, 2010) |
| PepperShaker.png | exp1 |
| Plaster.png | BOSS V1 (Brodeur et al, 2010) |
| Potato.png | BOSS V1 (Brodeur et al, 2010) |
| Rubberduck.png | Big and Small (Konkle & Oliva, 2012) |
| Shuttlecock.png | exp1 |
| Stapleremover.png | BOSS V1 (Brodeur et al, 2010) |
| Tapemeasure.png | exp1 |
| TennisBall.png | exp1 |
| Webcam.png | BOSS V2 (Brodeur et al, 2010) |

Table 4

*Logarithms for each object (part 1)*

| Name | LogSize | Exp |
|---|---|---|
| Carabiners.png | 0.70 | 3 |
| Candy.png | 0.71 | 3 |
| Chess_knight.png | 0.71 | 3 |
| Garlic.png | 0.71 | 3 |
| Hairclip.png | 0.71 | 3 |
| Keychain.png | 0.71 | 3 |
| Bubbles.png | 0.73 | 3 |
| Bauble.png | 0.73 | 3 |
| Coathook.png | 0.78 | 3 |
| Kiwi.png | 0.78 | 3 |
| Lock.png | 0.79 | 3 |
| Plaster.png | 0.79 | 3 |
| Egg.png | 0.80 | 3 |
| Potato.png | 0.80 | 3 |
| Rubberduck.png | 0.82 | 3 |
| Stapleremover.png | 0.82 | 3 |
| TennisBall.png | 0.82 | 3 |
| Nailclippers.png | 0.83 | 3 |
| Shuttlecock.png | 0.84 | 3 |
| Webcam.png | 0.84 | 3 |
| Clothespeg.png | 0.84 | 3 |
| Crayon.png | 0.84 | 3 |
| Hourglass.png | 0.84 | 3 |
| Lighter.png | 0.84 | 3 |
| Lipstick.png | 0.84 | 3 |
| PepperShaker.png | 0.84 | 3 |
| Tapemeasure.png | 0.84 | 3 |
| Nametag.png | 0.85 | 3 |
| Glue.png | 0.85 | 3 |
| NailVarnish.png | 0.85 | 3 |
| Footrest.png | 1.48 | 3 |
| Wreath.png | 1.54 | 3 |
| Pillow.png | 1.65 | 3 |
| Petcarrier.png | 1.66 | 3 |
| Laundrybasket.png | 1.71 | 3 |
| Nightstand.png | 1.71 | 3 |
| Suitcase.png | 1.74 | 3 |
| Oven.png | 1.75 | 3 |
| BBQ.png | 1.75 | 3 |
| Shelf.png | 1.78 | 3 |
| Doormat.png | 1.78 | 3 |
| Radiator.png | 1.78 | 3 |
| Wetfloor_sign.png | 1.78 | 3 |
| Satellitedish.png | 1.79 | 3 |
| Apron.png | 1.81 | 3 |
| Filling_cabinet.png | 1.83 | 3 |
| Step_ladder.png | 1.88 | 3 |
| Fireplace.png | 1.88 | 3 |
| Television.png | 1.91 | 3 |
| Boogieboard.png | 1.92 | 3 |
| Fridge.png | 1.92 | 3 |
| Washing_machine.png | 1.93 | 3 |
| Bin.png | 1.95 | 3 |
| Notice board | 1.95 | 3 |
| Officechair.png | 1.95 | 3 |
| Punchingbag.png | 1.95 | 3 |
| Traffic_light.png | 2.00 | 3 |
| Bike.png | 2.01 | 3 |
| Drying_rack.png | 2.02 | 3 |
| Towel.png | 2.15 | 3 |
| Fountain | 2.70 | 3 |
| Tractor | 2.70 | 3 |
| Gazebo | 2.80 | 3 |
| SailBoat | 2.80 | 3 |
| Windmill | 2.88 | 3 |
| FireEngine | 2.93 | 3 |
| StorageContainer | 2.96 | 3 |
| Tank | 2.99 | 3 |
| Truck | 3.09 | 3 |
| Caravan | 3.09 | 3 |
| Helicopter | 3.15 | 3 |
| Coach | 3.18 | 3 |
| DoubleDecker | 3.18 | 3 |
| Train | 3.32 | 3 |
| Lighthouse | 3.41 | 3 |
| MobileHome | 3.44 | 3 |
| Aeroplane | 3.57 | 3 |
| FerrisWheel | 3.58 | 3 |

Table 4

*Logarithms for each object (part 2)*

| Name | LogSize | Exp |
|---|---|---|
| Arch | 3.70 | 3 |
| Cherrypicker | 3.76 | 3 |
| Cran | 3.78 | 3 |
| SkyScraper | 3.90 | 3 |
| Hangar | 3.95 | 3 |
| BigBen | 3.98 | 3 |
| Windturbin | 4.00 | 3 |
| Ferry | 4.38 | 3 |
| BigHouse | 4.50 | 3 |
| EiffelTower | 4.51 | 3 |
| Cruiseship | 4.56 | 3 |
| HotAirBalloon | 5.20 | 3 |
| raisin.png | -0.40 | 4 |
| rhinestone.png | -0.40 | 4 |
| earringback.png | -0.30 | 4 |
| pill.png | -0.22 | 4 |
| sunflowerseed.png | -0.22 | 4 |
| Sweetcorn.png | -0.22 | 4 |
| Coffee.png | -0.15 | 4 |
| Pearl.png | -0.15 | 4 |
| Pomseed.png | -0.15 | 4 |
| popcorn.png | -0.15 | 4 |
| Snap.png | -0.15 | 4 |
| rice.png | -0.10 | 4 |
| Blueberry.png | 0.00 | 4 |
| chocolatechip.png | 0.00 | 4 |
| earbud.png | 0.00 | 4 |
| Hook.png | 0.00 | 4 |
| Lobsterclasp.png | 0.00 | 4 |
| screw.png | 0.00 | 4 |
| Thumbtack.png | 0.00 | 4 |
| Tictac.png | 0.00 | 4 |
| cheerio.png | 0.08 | 4 |
| Kidneybean.png | 0.08 | 4 |
| marble.png | 0.08 | 4 |
| skittle.png | 0.08 | 4 |
| Clove.png | 0.10 | 4 |
| button.png | 0.11 | 4 |
| Contactlens.png | 0.15 | 4 |

| Name | LogSize | Exp |
|---|---|---|
| Puzzle.png | 0.18 | 4 |
| thimble.png | 0.18 | 4 |
| dice.png | 0.20 | 4 |
| SafetyPin.png | 0.43 | 4 |
| Guitar_pick.png | 0.45 | 4 |
| acorn.png | 0.48 | 4 |
| Army_figure.png | 0.48 | 4 |
| Bobbin.png | 0.48 | 4 |
| earring.png | 0.48 | 4 |
| Fusilli.png | 0.48 | 4 |
| Ring.png | 0.48 | 4 |
| SDcard.png | 0.48 | 4 |
| Sharpener.png | 0.48 | 4 |
| Splitring.png | 0.48 | 4 |
| lego.png | 0.50 | 4 |
| bottlecap.png | 0.51 | 4 |
| Fuse.png | 0.51 | 4 |
| Strawberry.png | 0.54 | 4 |
| Alligator_clips.png | 0.54 | 4 |
| Clam.png | 0.54 | 4 |
| Hairgrip.png | 0.54 | 4 |
| jack.png | 0.54 | 4 |
| Olive.png | 0.54 | 4 |
| Toggle.png | 0.54 | 4 |
| zip.png | 0.54 | 4 |
| Badge_Back.png | 0.58 | 4 |
| Candle.png | 0.58 | 4 |
| Cork.png | 0.58 | 4 |
| key.png | 0.60 | 4 |
| pokerchip.png | 0.60 | 4 |
| Tape.png | 0.60 | 4 |
| walnut.png | 0.60 | 4 |
| golfball.png | 0.62 | 4 |
| Carabiners.png | 0.70 | 4 |
| Candy.png | 0.71 | 4 |
| Chess_knight.png | 0.71 | 4 |
| Garlic.png | 0.71 | 4 |
| Hairclip.png | 0.71 | 4 |
| Keychain.png | 0.71 | 4 |

Table 4

*Logarithms for each object (part 3)*

| Name | LogSize | Exp |
|---|---|---|
| Bubbles.png | 0.73 | 4 |
| Bauble.png | 0.73 | 4 |
| Coathook.png | 0.78 | 4 |
| Kiwi.png | 0.78 | 4 |
| Lock.png | 0.79 | 4 |
| Plaster.png | 0.79 | 4 |
| Egg.png | 0.80 | 4 |
| Potato.png | 0.80 | 4 |
| Rubberduck.png | 0.82 | 4 |
| Stapleremover.png | 0.82 | 4 |
| TennisBall.png | 0.82 | 4 |
| Nailclippers.png | 0.83 | 4 |
| Shuttlecock.png | 0.84 | 4 |
| Webcam.png | 0.84 | 4 |
| Clothespeg.png | 0.84 | 4 |
| Crayon.png | 0.84 | 4 |
| Hourglass.png | 0.84 | 4 |
| Lighter.png | 0.84 | 4 |
| Lipstick.png | 0.84 | 4 |
| PepperShaker.png | 0.84 | 4 |
| Tapemeasure.png | 0.84 | 4 |
| Nametag.png | 0.85 | 4 |
| Glue.png | 0.85 | 4 |
| NailVarnish.png | 0.85 | 4 |

Table 5

*Spatial frequency analysis for the Animacy effect: EhF values (an alternative to QhF) (part1)*

| Statistics | Measure 1 | Measure 2 | Measure 3 | Measure 4 | Measure 5 |
|---|---|---|---|---|---|
| *t*-values | -0.54 | -1.54 | -1.31 | -0.77 | 1.21 |
| *p*-values | 0.59 | 0.13 | 0.19 | 0.44 | 0.23 |

Table 5

*Spatial frequency analysis for the Animacy effect: QhF values (part 2)*

|  | Statistics |
|---|---|
| *t*-value | 0.18 |
| *p*-value | 0.86 |

Table 6

*Individual images (part 1)*

| Name | Web address |
|---|---|
| Aeroplane.png | http://www.public-domain-image.com/free-images/transportation-vehicles/aeroplanes-aircrafts/boeing-757-300-plane-aircraft/attachment/boeing-757-300-plane-aircraft |
| Alligator_clips | https://en.wikipedia.org/wiki/File:Three_alligator_clips.JPG |
| armyfigure.png | https://pixabay.com/en/symbol-army-soldiers-toy-figures-19896/ |
| Bauble.png | http://www.publicdomainpictures.net/view-image.php?image=1593&picture=christmas-baubles |
| Bench.png | http://www.public-domain-image.com/free-images/objects/bench-in-park-old/attachment/bench-in-park-old |
| Big_house.png | http://imageafter.com/image.php?image=b15architecture_exteriors024.jpg&download=no |
| BigBen.png | http://all-free-download.com/free-photos/download/london_big_ben_house_224564.html |
| Bobbin | https://commons.wikimedia.org/wiki/File:Bobbins_colored_thread.jpg |
| bottlecap | https://commons.wikimedia.org/wiki/File:Kronenkorken_01_KMJ.jpg |
| Camera.png | http://photorack.net/index.php?action=showpic&cat=34&pic=18425 |
| Car.png | https://commons.wikimedia.org/wiki/File:2011_Ford_Fiesta_SES_hatchback_--_02-18-2011.jpg |
| Caravan.png | http://ftp.imageafter.com/image.php?image=b21tabus815.jpg |
| Cheerio.png | https://pixabay.com/en/background-food-wallpaper-abstract-15177/ |
| Chesspeice.png | http://www.imageafter.com/image.php?image=b15objects016.jpg |
| Clove.png | https://pixabay.com/en/cloves-background-spices-aroma-20122/ |
| CoffeeBean.png | https://pixabay.com/en/coffee-bean-roasting-beans-90831/ |
| Cran.png | http://www.imageafter.com/image.php?image=b15vehicles_land000.jpg |
| Cupboard.png | http://2fwww.imageafter.com/image.php?image=b21tabus711.jpg&download=no |
| dog.png | http://photorack.net/index.php?action=showpic&cat=55&pic=615 |
| Dolphine.png | http://all-free-download.com/free-photos/dolphin_hd_pictures_168871_download.html |
| Door.png | http://photorack.net/index.php?action=showpic&cat=93&pic=3004 |
| Double_decker.png | http://www.imageafter.com/image.php?image=b17eva239.jpg |

Table 6

*Individual images (part 2)*

| Name | Web address |
|---|---|
| Drumkit.png | http://photorack.net/index.php?action=showpic&cat=108&pic=15890 |
| earbud | https://en.wikipedia.org/wiki/File:In-ears-earphones.png |
| EiffelTower.png | http://pics.tech4learning.com/details.php?img=eiffel1.jpg |
| Elephant.png | http://www.pics4learning.com/details.php?img=dscn0863.jpg |
| Ferrero | https://commons.wikimedia.org/wiki/File:Rocher-Layer-by-Layer.jpg |
| Ferriswheel.png | https://pixabay.com/en/big-wheel-carnival-ferris-wheel-249194/ |
| Ferry.png | http://pics.tech4learning.com/details.php?img=badgrcarferry.jpg |
| fuse | https://commons.wikimedia.org/wiki/File:13A_fuse.jpg |
| Guitar.png | https://commons.wikimedia.org/wiki/File:Acoustic_guitar.jpg |
| Guitar_pick | https://commons.wikimedia.org/wiki/File:Guitar_picks-KayEss-1.jpeg |
| Hairgrip | https://commons.wikimedia.org/wiki/File:Haarspangen.jpg |
| Hamster.png | http://photorack.net/index.php?action=showpic&cat=68&pic=21003 |
| Horse.png | http://www.public-domain-photos.com/search/horse |
| Kiwi.png | http://all-free-download.com/free-photos/kiwi.html |
| Ladybird.png | http://pdphoto.org/PictureDetail.php?mat=&pg=5351 |
| lego.png | https://pixabay.com/en/lego-children-toys-colorful-play-674880/ |
| LightBulb.png | http://photorack.net/index.php?action=showpic&cat=34&pic=18259 |
| Lipstick.png | http://all-free-download.com/free-photos/download/hd-beauty-image-01-hd-picture_168500.html |
| Lobster clasp | https://commons.wikimedia.org/wiki/File:Lobsterclasp.jpg |
| Mobile_Home.png | https://commons.wikimedia.org/wiki/File:Mobile_Home.JPG |
| Moose.png | https://commons.wikimedia.org/wiki/File:Moose_superior.jpg |

Table 6

*Individual images (part 3)*

| Name | Web address |
|---|---|
| Mushroon.png | http://photorack.net/index.php?action=showpic&cat=14&pic=8694 |
| Paperclip.png | http://photorack.net/index.php?action=showpic&cat=34&pic=18426 |
| pearl.png | https://pixabay.com/en/jewlry-pearl-necklace-chanel-rock-420018/ |

| | |
|---|---|
| pomegranite | https://commons.wikimedia.org/wiki/File:Pomseeds2.jpg |
| Prawn.png | http://photorack.net/index.php?action=showpic&cat=54&pic=26154 |
| Puzzle.png | http://all-free-download.com/free-photos/download/puzzle-puzzle-piece-play_221059.html |
| Rubber.png | http://photorack.net/index.php?action=showpic&cat=34&pic=18362 |
| Seagull.png | http://www.publicdomainpictures.net/hledej.php?x=0&y=0&hleda=seagull |
| skittle.png | https://pixabay.com/en/skittles-candy-colorful-snack-food-705242/ |
| Skyscarper.png | http://www.pixnio.com/free-images/architecture/city-downtown/downtown-big-city.jpg |
| Snap | https://commons.wikimedia.org/wiki/File:Druckknopf.jpg |
| Storage_container.png | http://ftp.imageafter.com/image.php?image=b17maartent311.jpg |
| sweetcorn.png | https://pixabay.com/en/corn-background-food-corn-kernels-290466/ |
| Tank.png | https://figshare.com/authors/_/1371030 |
| Tape | |
| Tapemeasure.png | http://all-free-download.com/free-photos/download/measure-tape_185908.html |
| TelephoneBox.png | http://all-free-download.com/free-photos/download/red_phone_box_190496.html |
| Tent.png | http://imageafter.com/image.php?image=b17maartent1285.jpg |
| Thumb tack | https://commons.wikimedia.org/wiki/File:Brass_thumbtack.jpg |
| tictac.png | https://pixabay.com/en/tablet-the-hand-hand-tictac-428328/ |
| Toggle | https://www.flickr.com/photos/jhritz/2035971729/in/photolist-o54g8R-46UTsR-5faoAA-r5iev-aRLQ4c-9wzDjY-EqTEx5-apNnXD-5faoDh-8fYz6i-deihjs-5wmNZE-9ksVGF-dCQYGj-9kvZcJ-6ADv4f-6ADv8A-6Azmw2-4cyza3-bBkhgg-9NCM2k-boqnwf-6Hx71E-6FTbpA-dLXGqw-9F3WBc-buLKoS-c4r1G-KBawyt-7pkQCe-8UKiRG-8UPtWu-2EZMpn-bK5oi-8UGg2K-6AhN5P-zdm22-cJVBk-RDN8-GbRTVR |
| Tractor.png | http://all-free-download.com/free-photos/download/caterpillar_tractor_185444.html |
| Traffic light.png | http://all-free-download.com/free-photos/download/light_picture_168532.html |
| Train.png | http://photorack.net/index.php?action=showpic&cat=114&pic=23282 |
| Truck.png | http://all-free-download.com/free-photos/download/truck_trailer_double_238542.html |
| WheelieBin.png | https://commons.wikimedia.org/wiki/File:Bin.JPG |
| Windturbin.png | http://all-free-download.com/free-photos/download/three_wind_turbines_188424.html |
| zip.png | https://pixabay.com/en/crayon-colors-art-zip-627895/ |

Table 7

*Image collections*

| Name | Website | Creator (year) | Journal |
|---|---|---|---|
| BOSS V1 | http://sites.google.com/site/mathieubrodeur/Home/boss | Brodeur, M. B., Dionne-Dostie, E., Montreuil, T., & Lepage, M. (2010) | PLoS ONE |
| BOSS V2 | http://sites.google.com/site/mathieubrodeur/Home/boss | Brodeur, M. B., Dionne-Dostie, E., Montreuil, T., & Lepage, M. (2010) | PLoS ONE |
| Size and Animacy | http://konklab.fas.harvard.edu/# | Konkle & Camazza (2013) | Journal of Neuroscience |
| Big and Small | http://konklab.fas.harvard.edu/# | Konkle & Oliva (2012) | Neuron |
| POPORO image set v4 | https://figshare.com/articles/Images/2067684 | Kovalenko, L.Y., Chaumon, M. & Busch, N.A (2012) | Brain Topography |
| 2400 Unique objects | https://bradylab.ucsd.edu/stimuli.html | Brady, T. F., Konkle, T.F., Gill, J., Oliva, A. and Alvarez, G.A. (2013). | Psychological Science |

## Appendix B

### Edinburgh Handedness Questionnaire

For each of the ten activities below, please tell us:

Which hand do you prefer for that activity? Do you ever use the other hand for the activity? Which hand do you prefer when…

| | Left or Right | Do you ever use the other hand? Yes or No |
|---|---|---|
| Signing | | |
| Writing | | |
| Drawing | | |
| Throwing | | |
| Using scissors | | |
| Using a Toothbrush | | |
| Using a Knife (without a fork) | | |
| Using a Spoon | | |
| Using a Broom (upper hand) | | |
| Striking a Match | | |
| Opening a Box (lid) | | |
| Foot to Kick With | | |
| Bat (swing) | | |

1. Do you consider yourself:

   Right-handed Left Handed Ambidextrous (both hands)

2. Is there anyone in your family who is Left-handed? Yes or No If yes, who

   ______________________________

3. Did you ever change handedness? Yes or No If yes, please explain

   ______________________________

   ______________________________

4. Is there any activity not on this list that you do consistently with your left hand? If so, please explain

   ______________________________

*This handedness questionnaire was adapted from: Oldfield, R.C. The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia. 9(1):97-113. 1971.*

Appendix C

# The Familiarisation Session

You will now be given 2 models to familiarise yourself with.
In order for the models to become familiar it is advised that you consider the shape, colour and detail of each model.

In order to do this you are encouraged to;

- Observe the model from different angles and distances (rotate the model or move yourself around the model)
- Pick the model up, handle and feel the model
- Compare each model to the other model both individually and together (look for similarities and differences)

You have **10 minutes** to familiarise yourself with these models.
After this session you will see the models appear in a short computer task.

Please ask the experimenter now if you have any questions before you begin.
(Although the models will withstand handling, please do not try to break the models)