An investigation into human perception highlights the automatic preference and prominence given to hands

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Abstract

Hand perception, akin to face perception, enables the discernment and communication of human intentions or emotions. Whilst face perception has been extensively investigated in terms of cognitive and neural processes, much less is known about the cognitive processes and neural activations associated with hand perception, which this PhD project aims to study. The project posits two primary questions: (1) Are viewed hands, particularly hands with distorted finger postures, such as those that may occur after an accident, exceptionally salient? Are hands with distorted finger postures quantitatively more salient than hands with natural finger postures? (2) Is there a particular cognitive process underlying this attention, such as the activation of the viewer's sensorimotor cortex as seen in automatic mental simulation, and are there distinct cognitive processes or brain activation patterns involved in processing distorted finger postures compared to natural finger postures? Despite the potential significance of hands in revealing intentions or emotions, as opposed to the potential of faces, this issue has received considerably less research attention, particularly regarding the perception of distorted finger postures, which remains a largely unexplored issue apart from a limited number of studies focusing on brain activation.

The aim of this thesis is to employ visual search and eye movement paradigms to investigate the processing of hands and, in particular, distorted finger postures. By examining how people visually search for and attend to these stimuli, we seek to gain insights into the underlying mechanisms involved in perceiving and processing distorted finger postures. A further aim is to address how salient information is processed by means of automatic mental simulation in the Simon task and motor cognition tasks. In addition to behavioural measures, previously acquired EEG data were also analysed in this thesis to detect motor cortex activation as a correlate of automatic mental simulation in the perception of hands with distorted finger postures.

From the results of the visual search and eye movement tasks (Experiments 1, 3 and 5), the main findings of this research are that the hand images were more salient than the whole body images, both in active and passive vision. In addition, in the visual search and eye movement tasks (Experiments 2, 4 and 6), the distorted finger postures were found to be more salient than the natural finger postures, both in active and passive vision. From the control experiments (Control Experiments 1, 2 and 3), the findings are that the salience of hands was not caused by affective reaction and arousal, nor by limbs with similar anatomic structures. Results from the Simon task and the hand laterality judgement tasks (Experiments 7 to 10) both provide consistent evidence supporting the occurrence of automatic mental simulation. It is evident that automatic mental simulation for hands occurs in the Simon task. Additionally, evidence was found in the hand laterality judgement tasks supporting automatic mental simulation for both hands (together) and for a single hand. However, it was not evident that automatic mental simulation occurred for individual finger images when participants were instructed to respond with their corresponding fingers. The analysis of the EEG data revealed no interaction in mu oscillations between the factors of stimulus type (hand and chair, with the chair serving as the control stimulus) and configuration (distorted and natural/standard) and no difference in mu oscillations between the viewing of distorted and natural finger postures; however, a trend in differences in mu oscillations was found between the viewing of distorted and natural shapes (for the factor of configuration).

In conclusion, this PhD research demonstrates that viewed hands, particularly those with distorted finger postures, exhibit heightened salience in visual perception tasks, suggesting the involvement of automatic mental simulation processes. Thus, the PhD project explores the cognitive and neural mechanisms underlying hand perception, focusing specifically on distorted fingers. This study aims to elucidate why these distorted finger perceptions occur and what insights or conclusions can be drawn about neural processing and cognitive functions related to these distortions.

Publications

Conference proceedings

1. Chen, H.-Y., Schürmann, M., Keeble, D. (2021, May). Inhibiting saccades to hands: High-level Visual Processes Modulate Oculomotor Control [Poster presentation]. Vision Sciences Society, Virtual Meeting.
2. Chen, H.-Y., Schürmann, M., Estudillo A., Keeble, D. (2020, October). Visual Search Differences for Images of Distorted Finger Postures Versus Chairs as Control Images [Conference presentation]. 59th Annual Conference of Taiwanese Psychological Association, Virtual Meeting.
3. Chen, H.-Y., Schürmann, M., Keeble, D. (2020, September). Spatial Stimulus-Response Compatibility and Mental Simulation Modulate Manual Responses to Images of Hands [Conference presentation]. The 84th Annual Convention of the Japanese Psychological Association, Virtual Meeting.
4. Chen, H.-Y., Estudillo A., Mennie, N. (2018, October). An Eye-Tracking and Pupillometry Study on Perception of Distorted Finger Postures [Conference presentation]. 57th Annual Conference of Taiwanese Psychological Association, Tainan, Taiwan.
5. Chen, H.-Y., Estudillo A., Mennie, N. (2018, July). Is Visual Search Different for Faces, Whole Bodies or Hands? [Poster presentation]. The 14th Asia-Pacific Conference on Vision, Hangzhou, China.

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Declaration

I declare that all experimental studies throughout this thesis were carried out by myself. This excludes

1) EEG Experimental work on Experiment 12 which conducted alone when I was studying master in University of Nottingham.
2) Face images are from face database of the University of Nottingham.
3) Hand images were generated by Miguel who was a PhD student in the University of Nottingham in Blender files. However, the modifications were made by Hsin-Yuan Chen.

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Chapter 1 Introduction

This thesis explores the significance of hands with distorted finger postures and their visual mechanisms as they pertain to automatic mental simulation. The research findings contribute to the ongoing development of knowledge about human body perception and automatic mental simulation. The introductory chapter is organised into six sections. The first section focuses on the salience of hands, examining their importance in human communication and interaction. The role hands play in conveying nonverbal cues and their involvement in the perception of touch and manipulation of objects is discussed. The second section explores the salience of distorted finger postures. Here, the focus is on the significance of recognising and interpreting implausible hand and finger configurations. This section includes the impact of such postures on human perception. The third section explores the automatic mental simulation of hands and elaborates on how the brain automatically processes and generates mental representations of hands and their movements. This section explores the neural mechanisms underlying automatic mental simulation and the role this simulation plays in understanding hand actions and interactions. The fourth section outlines the thesis, presenting the overall structure and organisation of the research. It details the specific chapters and sections that follow the introduction, offering a clear roadmap for the reader. The fifth section presents the research aim of this thesis and highlights the purposes to be fulfilled through the investigation. This section identifies key questions, the methods employed, and the expected contributions made to the field of human body perception in automatic mental simulation. The final section describes the impact of the COVID-19 pandemic restrictions and the adaptations and changes that were made to ensure that the integrity and validity of the study were upheld.

1.1 Are Hands Salient in Visual Perception? Why Might There be Specific Responses to Hands?

Hands are salient in the visual perception of the human body. The literature on this topic is extensive. This section compares the differences between the responses to hands and the responses to whole bodies (without heads) using physiological evidence, visual search and eye movements. An overview of the literature that relates to the work is presented in the following sections.

1.1.1 Are hands salient like faces?

Faces are very important in social interaction and communication and are processed in preference to inanimate objects (Figure 1-1) (Horstmann, 2007, 2009). To date, face perception is believed to differ from the perception of hands, whole bodies and inanimate objects (Kanwisher & Yovel, 2006; Tsao & Livingstone, 2008b). Because faces can reveal considerable information, they serve as a tool for interacting with others. The importance of faces in human body perception (in this thesis, human body perception includes hand, face, and whole body perception) is thought to be unique (Jack & Schyns, 2015, 2017). However, it is now being found that other parts of the human body might play a more important role in visual processing than previously thought and that they might also play an important role in communication and social interaction (Edey, Yon, Cook, Dumontheil, & Press, 2017; Sowden, Schuster, Keating, Fraser, & Cook, 2021).

Figure 1-1 Examples of human facial expressions
The human face can express more emotions than any other part of the human body (Cowen & Keltner, 2020; Kurdi, Lozano, & Banaji, 2017).

Evidence indicates that both the face and the body are equally effective for detecting the presence of persons in natural scenes. This suggests that the body, as much as the face, is crucial in identifying other, which is foundational for social interaction (Bindemann, Scheepers, Ferguson, & Burton, 2010; Niimi, 2020). Consequently, it is important to assess the factors related to human body perception, hand perception in particular. There are several reasons for isolating hand perception from human body perception. Firstly, research results can improve the understanding of hand expressions in social perception and the understanding of human communication through gestures. These results contribute to the understanding of how nonverbal behaviours relate to communication. For example, hands are used to emphasise the verbal message and to direct the interlocutor's attention. As stated in this work and previous literature, hands have a higher status in social perception than other parts of the human body (excluding faces): in other words, hands have a special status (Cartmill, Beilock, & Goldin-Meadow, 2012; Cochet & Guidetti, 2018; Wilmut, Wann, & Brown, 2006). Secondly, humans have exceptional manual dexterity (as do other primates), allowing them to manipulate objects (Bracci, Cavina-Pratesi, Ietswaart, Caramazza, & Peelen, 2012; Bracci, Ietswaart, Peelen, & Cavina-Pratesi, 2010). When humans learn to use new tools, they pay special attention to how their hands handle the object (Bracci et al., 2012; Bracci et al., 2010). Notably, visual control is used whilst performing an action to monitor and adjust the orientation of the hand, even whilst performing seemingly simple grasping movements. Given the particular importance of the hand in our ability to interact with the environment, the question arises whether the hand may be preferentially represented in human visual behaviour (Bracci et al., 2012; Bracci et al., 2010). Humans are experts in interpreting hand postures (Mataric & Pomplun, 1998; Morrisey & Rutherford, 2013). Indeed, human proficiency in hand recognition is typically acquired at an early developmental stage, as infants engage in the practice of visual-motor coordination through observation of the hand movements of others (Adolph & Franchak, 2017; Franchak, Kretch, & Adolph, 2017). As early as a few months old, infants instinctively use various hand gestures and pay more attention to the hand movements of others than relying on the other's gaze alone to orient attention.

Hands play such an important role in social and cognitive development that they may benefit from special processing, similar to that of faces (Senju et al., 2015; Tessari, Ottoboni, Mazzatenta, Merla, & Nicoletti, 2012). Additionally, it is observed that adults tend to pay considerable attention to the hand movements of others during social interactions (Festman, Adam, Pratt, & Fischer, 2013; Wiemers & Fischer, 2016). Hands are essential social signals that contribute to the clarification of intentions and feelings (Bracci et al., 2010; Espírito Santo, Maxim, & Schürmann, 2017).

Since 1969, the phenomenon of visual perception of hands has been an area of concentrated academic inquiry and empirical investigation (Gross, Bender, & Rocha-

Miranda, 1969). A study in nonhuman primates has demonstrated that certain neural populations within the superior temporal sulcus (STS) exhibit pronounced responses to visual stimuli resembling primate hand silhouettes. This suggests that these neural ensembles might preferentially respond to stimuli with hand-like characteristics, indicating a specialisation in identifying hand shapes (Gross et al., 1969; Gross, Rocha-Miranda, & Bender, 1972). Further investigations into the visual processing systems of primates have reinforced the significance of the STS in recognising complex biological shapes. The pronounced neural responses to hand-like silhouettes suggest that the STS contains specialised neurons dedicated to processing socially and biologically relevant visual stimuli without reliance on motion cues (Sáry, Vogels, & Orban, 1993; Tanaka, 1996). This specialisation may be a result of evolutionary pressures, as the ability to recognise hand shapes is crucial for interpreting gestures and nonverbal communication in social interactions among primates. Moreover, the selectivity for hand shapes in the STS is part of a broader pattern of neural specialisation for body parts and faces, indicating that this brain region plays a central role in high-level visual perception. The recognition of hand shapes contributes to an individual's ability to understand others' actions and intentions, which is essential for cooperative behaviours and social cohesion within primate groups.

Hand and body postures complement one another in emphasising words and expressing feelings. Hand pointing gestures are an essential element in human communication, drawing attention to an intended spot or object (Herbort & Kunde, 2016, 2018). The ability to point is an important skill for humans, as it is one of the primary ways humans communicate with others. Hands are the next feature that humans notice after faces when they look at someone (Fausey, Jayaraman, & Smith, 2016). Effective processing of visual information from hands is crucial from an evolutionary and social standpoint (Axelsson, Robbins, Copeland, & Covell, 2019; Azarian, Esser, & Peterson, 2016). Numerous studies have been done on how the brain reacts to faces and whole bodies, whilst for hands, brain activity during the processing of visual information from hands, which is extremely noticeable in social perception, is comparatively poorly understood. Moreover, there has been virtually no research on hand postures with visual search and eye movements to measure human behaviour. Although it is known that hands are a salient part of the human body, it is not known how strong the salience of hands is as compared to the salience of other parts of the human body, nor is the underlying mechanism of hand perception known. To address these gaps in understanding, this thesis proposes a series of experiments using visual search tasks and eye tracking methods to quantify the salience of hands compared to other body parts and elucidate the underlying mechanisms of hand perception.

Research on hand perception has been ongoing since 1969, with significant developments in the past few decades. Studies have revealed that the brain mechanisms for hand perception are distinct from those for whole body perception (Downing, Jiang, Shuman, & Kanwisher, 2001; Downing & Peelen, 2016; Morrisey & Rutherford, 2013; Peelen & Downing, 2007). Although much research has focused on the study of hand perception to better understand the role of the hand in the visual perception of human bodies, most studies in the field of hand perception have focused only on physiological research and not on visual search research or eye movement research. However, the results of physiological research cannot be used to fully explain explicit human behaviour in response to hand stimuli. This problem requires an alternative approach using visual search tasks and eye tracking methods.

Figure 1-2 Examples of hand gestures
They attract considerable attention. Images source from Hertzberg ; People ; Toastmasters .

Figure 1-3 Examples of hand postures.
Like hand gestures, they attract considerable attention. Images source from Toastmasters ; Wikipedia .

Hand expressions are categorised as hand gestures and hand postures in this thesis (Vicario & Newman, 2013; Wood, Martin, Alibali, & Niedenthal, 2019). At this point, it is necessary to clarify what is meant exactly by hand gestures and hand postures. Hand gestures are hand expressions which communicate considerable social information, whereas hand postures are hand expressions which show little social information, as can be seen in the figures above (Figure 1-2, Figure 1-3). Despite this, both-hand gestures and hand positions attract considerable attention from observers (Driver & Spence, 1998; Kendon, 1994). In this thesis, only hand postures were investigated because of the possible interference from additional social information carried by hand gestures.

1.1.2 Predictions for the response differences in visual perception between hands and whole bodies

This thesis set out to test the prediction that response differences between hands and whole bodies are significant in visual search and eye movement tasks. The prediction regarding visual search tasks was that the average reaction time and efficiency of the visual search of hands would be different to that of whole bodies. This difference was thought to be caused by the difference between the attention given to hands and that given to whole bodies in both active and passive vision. The prediction regarding eye movement tasks was that the saccade latencies and error rates for hands and whole bodies would vary. To clarify whether there were differences of attention in active vision between hands and whole bodies, the effect of passive vision had to be excluded as active vision cannot be isolated from visual search. The term ‘active vision’ focuses on the sequential nature of visual information intake (Findlay & Gilchrist, 2001), concentrating explicitly on the effect of eye movements. ‘Passive vision’ focuses on receiving visual information passively, explicitly concentrating on situations without the intervention of eye movements (Luna, Velanova, & Geier, 2008; Rucci & Victor, 2015).

1.1.3 Is there evidence for the distinctions between the effects of hand and whole body images in physiological studies?

A considerable number of studies have investigated how the brain processes visual stimuli, faces and whole bodies in particular. Comparatively little is known about brain activation during the visual processing of hands, although a few studies have been conducted on this topic (Bracci et al., 2010; Downing et al., 2001; Espírito Santo, Maxim, et al., 2017; Peelen & Downing, 2005). Some physiological studies provide evidence that hand-sensitive areas are distinct from the extrastriate body area, which is a specific brain region responding to whole bodies, and that they are also distinct from the fusiform body area, a specific brain region responding to individual parts of the human body (e.g., limbs) (Bracci et al., 2010; Downing & Peelen, 2011). In this study, the brain demonstrated hemispheric lateralisation to the 'visual stimuli of hands and whole bodies' (henceforth 'hands' and 'whole bodies') and revealed separate neural responses to hands and whole bodies in the lateral occipital sulcus in the left extrastriate visual cortex, which partially overlapped with the left extrastriate body area (Bracci et al., 2010). This latter region responded most strongly to hands, followed by robotic hands, fingers, then feet; however, its response to assorted body parts (including arms, legs and torsos) was not significantly different for each type of body part. In comparison, the right extrastriate body area responded more strongly to all nonhand parts than to hands. This shows that a hand-sensitive area can be identified in the fMRI, consistent with the priority processing of visually perceived hands.

Some studies have shown electrophysiological evidence for hand-sensitive brain activation, arising at an early latency: N1 response, which is one of the event-related potential (ERP) components, in which the latency of the hands (174 ms) is significantly different from the latency of the faces (173 ms) (Espírito Santo, Maxim, et al., 2017; Thierry et al., 2006). ERPs are small changes in electrical brain activity related to an event and are revealed by averaging many periods that are time-locked to the event by electroencephalography (EEG) (Rossion, 2014; Rossion, Retter, & Liu-Shuang, 2020). However, there is no significant difference in N1 response between the latency of hands (174 ms) and that of whole bodies (174 ms). In addition, the findings showed that the ERP amplitude of hands differs from the ERP amplitude of whole bodies, based on the results of hand-sensitive brain activation. Furthermore, the ERP evidence showed different amplitudes between faces and whole bodies. Comparisons of ERPs elicited from faces and whole bodies have revealed distinct neural responses in the lateral occipital or occipitotemporal areas. Faces typically elicit a negative component called N170, which peaks at approximately 170 ms post-stimulus onset and is most prominent over the visual cortex. This component, occurring between 120-200 ms, reflects a transient increase in EEG amplitude in the 5-15 Hz range and is associated with the conscious interpretation of an input as a face (Rossion, 2014; Thierry et al., 2006). In contrast, whole bodies elicit a similar but slightly later negative component called N190. The N190 appears to generalise to some degree to schematic depictions of the human form, suggesting that whilst the neural representations of human faces and bodies are intertwined, they remain functionally distinct. (Thierry et al., 2006). These findings highlight the specificity of face processing in the brain whilst also indicating a broader network for processing human forms.

1.1.4 Is there evidence for the distinctions between the effects of hand and whole body images in visual search?

In order to determine the effects of hands and whole bodies on visual perception, it would be beneficial to analyse how stimuli affect visual attention. This is because visual attention, as demonstrated by visual search, a versatile paradigm for studying the intuitive and cognitive processes of visual attention, can indicate the salience of hands and whole bodies. The visual search paradigm has been used to study many phenomena. Changing the search task can alter attention reactions. Attention selects and limits the information available at various levels of processing (Jiang, 2018; Kruse, Bogler, Haynes, & Schütz-Bosbach, 2016). Two behavioural measures are of concern in classic visual search tasks: reaction time (RT) and accuracy (Wolfe, 2018). RT here is defined as the time participants take to respond to the stimuli; accuracy here is defined as the proportion of correct responses in a visual search (Porter, Troscianko, & Gilchrist, 2007).

In typical visual search tasks with RT measurements, stimuli are presented until participants respond. There is little literature in visual search studies on comparisons between different parts of the human body (excluding faces), particularly comparisons between hands and whole bodies, neither traditional discrimination of visual patterns nor rapid discrimination of visual patterns (henceforth ‘visual search tasks with RT measurements’ and ‘visual search tasks with accuracy measurements’ respectively). Although to date, little evidence has been found in visual search studies dissociating hands from whole bodies, there is considerable literature on comparisons between faces and nonface objects (Goold & Meng, 2016; Hershler & Hochstein, 2005, 2006; VanRullen, 2006), which can inform research into hands and whole bodies. Previous studies suggest that it is possible to transfer RT and accuracy visual search paradigms to investigate the difference between hands and whole bodies.

In visual search tasks with RT measurements, evidence from the visual search shows that faces have a ‘pop-out effect’ when they are embedded among inanimate objects, and also when among animal faces (Hershler & Hochstein, 2005, 2006). ‘Pop-out effect’ refers to the phenomenon by which a unique visual target is rapidly detected among a set of distractors (Wolfe, 1994a, 1994b). The RTs in visual search are different when viewing different parts of the human body because the mechanisms for processing those different parts of visual information are different. The RT visual search task was used to investigate and compare the pop-out effect for hands, faces and whole bodies. Participants were requested to observe a target in an arrangement of distractors. The mean RTs and RT slopes of the different targets (hands, faces and whole bodies) were recorded. The mean RTs are the time that it takes to detect a target amongst its distractors (Wolfe, 2018; Wolfe, Palmer, & Horowitz, 2010). The RT slopes show the efficiency in detecting a target amongst its distractors (Wolfe, 2020, 2021).

The underlying mechanism for the pop-out effect is parallel search. In parallel search, all items (target and distractors) shown are processed in parallel (i.e., all items are processed simultaneously) and without capacity constraints when searching for targets among those distractors (Treisman, 1985; Wolfe, 2018). In this case, the pop-out effect occurs. Whereas, in serial search, all items shown are processed in serial fashion (i.e., all items are processed singly) and are shown with capacity constraints, and there is no pop-out effect. In recent years, researchers have not categorised their results into absolute parallel search or absolute serial search, as this distinction is considered too rigid. In addition, some visual searches can show an overlap between parallel search and serial search. This overlapped area is now being described as ‘efficient’ (Wolfe, 2018; Wolfe, Vo, Evans, & Greene, 2011). In this case, the pop-out effect describes the situation when the RT for the detection of the unusual component is dissociated from the number of distractors (Treisman, 1985; Treisman & Gormican, 1988). Here, the pop-out effect is a determining factor in high efficiency, and therefore parallel search has the highest efficiency in visual search.

Visual search studies indicate that faces trigger parallel search rather than serial search with distractors which are inanimate objects (Hershler & Hochstein, 2005, 2006). The RT slope for faces shows parallel search with the highest efficiency. Many studies have investigated faces using visual search tasks and have confirmed the presence of parallel search (Goold & Meng, 2016; Hershler & Hochstein, 2005, 2006; VanRullen, 2006). Like the human face, other parts of the human body are rich sources of socially relevant information about individuals (Goold & Meng, 2016; Hershler & Hochstein, 2005). Different cognitive models for visual search, based either on the dynamics of attention or on the similarity of object representations in visual processing, are evident for different parts of the human body and explain the different speed and accuracy recordings of visual search (Kotowicz, Rutishauser, & Koch, 2010; Zelinsky, 2008). Thus, this thesis used visual search tasks to investigate whether there was a difference between hands and whole bodies in visual search efficiencies. The purpose of the research in this PhD project is to determine whether the hand is more salient than the whole body in visual search tasks. To this end, visual search experiments are conducted in which participants must identify a target image among several distractors.

In visual search tasks with accuracy measurements, the stimuli are presented quickly, with an exposure of less than 200 ms, to avoid any participant eye movements (Wolfe, 2000, 2018). Accuracy measurements can usefully supplement and extend RT measurements, given that accuracy measurements are not affected by the issue of eye movements because the saccadic latency (onset time for eye movement) is more than 200 ms. Eye movements do not occur if the duration of the presentation is less than 200 ms (Findlay & Gilchrist, 2003). The visual search tasks with accuracy measurements overcome these limitations of visual search tasks with RT measurements, with the latter processing stimuli from both active vision and passive vision (Degno & Liversedge, 2020; Kornrumpf, Niefind, Sommer, & Dimigen, 2016). In contrast, the visual search tasks with accuracy measurements only collect data from passive vision.

Compared to visual searches of faces, visual searches of whole bodies and hands are understudied areas; and little is known about the accuracy method applied to visual searches of human bodies (including faces). The experiment based on the accuracy method is to assess the differences and similarities between hands, faces and whole bodies in terms of passive vision. The effects of human body visual stimuli on RT slopes are examined in Experiments 1 and 2. The visual search accuracy method in Experiments 3 and 4 is used to identify the proportions of correct visual search responses. In the visual search accuracy method, stimuli are presented rapidly (usually defined as less than 200 ms) to prevent any voluntary eye movements (Belopolsky & Theeuwes, 2010; Tyng, Amin, Saad, & Malik, 2017; Wieser, Mühlberger, Kenntner-Mabiala, & Pauli, 2006).

1.1.5 Is there evidence for the distinctions between the effects of hand and whole body images in eye movements?

Eye movements are partly governed by the properties of visual stimuli (Motter & Holsapple, 2007; Rolfs, 2015). Studies have shown that the neurological processes underlying attention involve activation in the extrastriate visual cortical and anterior temporal areas (Lane, Chua, & Dolan, 1999; Phan, Wager, Taylor, & Liberzon, 2002). These same areas may also be implicated in the gaze patterns observed during the viewing of human bodies (Geiger, Niessen, Bente, & Vogeley, 2017; Morand, Grosbras, Caldara, & Harvey, 2010; Sogo & Osaka, 2007). Accordingly, based on these eye movement studies, eye tracking is used to explore how stimuli related to the human body govern attention with regard to vision. This area has received increased attention because some studies have found that eye movements can be used to explain human behaviour in high-level cognition (Bonmassar, Pavani, & van Zoest, 2019; Orquin & Mueller Loose, 2013). However, there is a relatively small body of literature that is concerned with eye movements regarding hands and whole bodies. To date, despite extensive searches of eye movement studies, little has been found comparing hands with whole bodies. However, there is some literature comparing faces and nonface objects. According to earlier studies, eye movements can reveal attention shifts in cognitive control mechanisms with hands and whole bodies (Geiger et al., 2017; Schütz, Braun, & Gegenfurtner, 2011). In this thesis, to determine whether eye movements are affected by hands and whole bodies, saccade latencies and error rates were investigated. Saccade latencies and error rates, as viewers' reactions to visual stimuli, demonstrate attention shifts (Heyman, Montemayor, & Grisanzio, 2017; Hoffman & Subramaniam, 1995; Zhao, Gersch, Schnitzer, Dosher, & Kowler, 2012).

Currently, it is known that saccades are influenced by low-level factors (e.g., shape, colour, brightness or contrast) and high-level factors (e.g., identification of stimuli or use of stimuli with different affective reaction and arousal) (Rothkegel, Schütt, Trukenbrod, Wichmann, & Engbert, 2019; Schütt, Rothkegel, Trukenbrod, Engbert, & Wichmann, 2019). Studies on low-level influences are of great interest, and there is a highly active research community. Regarding eye movement control for parts of the human body, eye movements have been found to be related to attention bias and selective attention (Geiger et al., 2017; Schütz et al., 2011). It has also been found that attention bias and selective attention differ between emotional faces and neutral faces, and that attention bias and selective attention differ between hands and hand tools (Morrisey & Rutherford, 2013; Reinholdt-Dunne et al., 2012).

1.2 Are Distorted Finger Postures Salient? Why Might There Be Specific Responses to Distorted Finger Postures?

From previous sections, it is evident that hands are salient in human body perception. In this section, the topic is extended to compare distorted finger postures and natural finger postures (referred to as hands in the previous sections). Distorted finger postures are salient: that is, they attract considerable attention and cause unpleasant feelings. The saliency of distorted finger postures has been examined in physiological studies (Avikainen, Liuhanen, Schürmann, & Hari, 2003; Espírito Santo, Chen, & Schürmann, 2017; Schürmann, Hlushchuk, & Hari, 2011). However, distorted finger postures have been little studied in visual search and eye movements. Therefore, this section compares the different responses to distorted and natural finger postures in physiological evidence, visual search and eye movements. In the physiological evidence section, the synthesis and evaluation of distorted finger postures in brain research are described. In the visual search section, the visual search tasks used in the investigation of distorted finger postures are described. In the eye movement section, the eye tracking task used in the investigation of distorted finger postures is described.

1.2.1 Are distorted finger postures salient?

Figure 1-4 Examples of distorted finger postures following sports accidents
Image source: https://www.stack.com/a/gnarly-sports-fingers/

In social perception, distortions of parts of the human body caused by accidents are highly salient stimuli and can make the viewer feel uneasy (Schürmann et al., 2011). Four examples of real-world distorted finger postures are shown in the above pictures (Figure 1-4). This section extends the investigation from natural finger postures to a comparison with distorted finger postures. Reactions to distorted finger postures (computer-generated images with distorted fingers) evoking affective reaction and arousal were investigated. Some physiological studies have shown that distorted finger postures produce negative reaction and high arousal compared to natural finger postures (Avikainen et al., 2003; Espírito Santo, Chen, et al., 2017; Schürmann et al., 2011). In the MEG experiment, extrastriate occipital areas of both hemispheres were activated more strongly by distorted finger postures than by natural finger postures (Avikainen et al., 2003). In the fMRI experiment, cortical activation was more sensitive to distorted finger postures than natural finger postures with right lateralisation in the primary motor cortex, somatosensory cortex, amygdala, and insula (Schürmann et al., 2011). In the EEG experiment, the ERP amplitudes of distorted finger postures were stronger than those of natural finger postures (Espírito Santo, Chen, et al., 2017).

Although there is some physiological evidence to suggest that distorted finger postures evoke unique responses (Avikainen et al., 2003; Espírito Santo, Chen, et al., 2017; Schürmann et al., 2011), research investigating the topic of distorted finger postures in visual search or eye movements is scarce and suffers from a lack of clear and well-established literature, and the mechanisms underlying visual process and eye movements are still poorly understood. It is, therefore, currently difficult for researchers to predict and describe human behaviour responses to distorted finger postures. Although it is known that distorted finger postures are more salient than natural finger postures (Avikainen et al., 2003; Espírito Santo, Chen, et al., 2017; Schürmann et al., 2011), it is unknown how strong the salience of distorted finger postures is compared to other parts of the human body nor what the underlying mechanism of distorted finger posture perception is. Therefore, distorted and natural finger postures were investigated using visual search methods and pupillometry.

Over the last decade, distorted finger postures have been the focus of investigation in some literature, where it has been noted that there is different physiological evidence (MEG, fMRI and EEG evidence) for the different brain responses to distorted and natural finger postures (Avikainen et al., 2003; Espírito Santo, Chen, et al., 2017; Schürmann et al., 2011). More specifically, different brain regions respond to distorted and natural finger postures, and the ERPs of distorted and natural finger postures are different in the occipital cortex. Although many researchers have focused on the study of distorted finger postures to better understand the role of distorted finger postures in research on hand perception, most studies in the field of hand perception have focused only on physiological research and not on visual search research or eye movement research. This problem requires an alternative approach providing a fresh viewpoint and potentially shed light on the underlying factors influencing human behaviour in relation to distorted and natural finger postures.

1.2.2 Predictions for the response differences in visual perception between distorted and natural finger postures

This thesis set out to test the prediction that the response differences between distorted and natural finger postures are significant in visual search and eye movement tasks. The prediction regarding the visual search task was that the average RT and efficiency of visual search for distorted and natural finger postures would be different. The difference was thought to be caused by the varying degrees of attention given to distorted and natural finger postures in active and passive vision. The prediction was that saccade latencies and saccade error rates would vary depending on the direction of gaze shifts between finger postures in the eye movement tasks. Specifically, the anticipation is that saccade latencies and error rates would be higher when participants shifted their gaze from natural finger postures to distorted finger postures, compared to when shifting from distorted to natural finger postures. Active vision emphasises that visual perception is an active process involving continuous interaction between the observer and the environment. The role of cognitive resources in processing sensory information and how attentional allocation affects perception and action. When participants shift their gaze from a natural to a distorted finger posture, the unexpected visual and proprioceptive input conflicts with their prior expectations formed through everyday experiences with natural hand configurations. This mismatch requires additional cognitive processing to interpret the salient sensory information and demands increased attentional resources. Tasks involving higher perceptual load consume more attentional capacity, which can slow down processing and increase error rates. The distorted finger postures present a higher perceptual load due to their salience and complexity, necessitating greater attentional allocation. This increased demand on attention during the shift from natural to distorted postures contributes to longer saccade latencies and more errors.

In addition, regarding eye movement tasks, it was predicted that the index of fixations for distorted and natural finger postures would also be different. Finally, the prediction regarding the pupillometry underlying the eye movement tasks was that pupil dilation for distorted and natural finger postures would be different. An eye movement task was conducted in order to clarify whether there were differences of attention in active vision between distorted and natural finger postures, as this task excludes the effect of passive vision, which cannot be isolated in a visual search task.

1.2.3 Is there evidence for the distinctions between the effects of distorted and natural finger posture images in physiological studies?

It is known that the extrastriate body area is involved in whole body and hand perception and that the ERPs in response to viewing whole bodies and hands are different (Downing & Peelen, 2011; Espírito Santo, Maxim, et al., 2017). In addition, Santo et al. suggested that the visual processing in the brain for distorted finger postures was different from the visual processing for natural finger postures (Espírito Santo, Chen, et al., 2017). Stronger ERP amplitudes were found for distorted finger postures compared to those of natural finger postures but not for those of distorted chairs compared to standard chairs. Therefore, it was likely that the stronger ERP amplitudes were not indicative of a visuospatial process response to a distorted shape. Their findings suggest that body distortions, including distorted finger postures, lead to specific changes in brain activity. In particular, their findings suggested that the brain responds differently to body distortions compared to object distortions. This deduction was further supported by results showing that viewers processed the visual information from distorted finger postures differently to the visual information from natural finger postures. Although N1 modulation occurred in both hemispheres, it was strongly lateralised in the right hemisphere, which is often associated with emotional processing. This suggests that the distorted finger postures may have been emotionally charged stimuli. These results aligned with the privileged position of hands in visual processing as highly salient parts of the human body, with the distortions engaging neural resources that were specifically activated for stimuli related to the human body in social perception.

Some research suggests that a body-selective region is as powerful in generalising abstract image formats of whole bodies as a face-selective region is in generalising abstract image formats of faces (Engell & McCarthy, 2013, 2014). Functional magnetic resonance imaging (fMRI) studies have identified the fusiform face area, a region in the ventral occipitotemporal cortex specialised for facial processing. This neuroanatomical specificity suggests that facial features possess a unique neural representation distinct from other bodily features (Giabbiconi, Jurilj, Gruber, & Vocks, 2016; Kuniecki, Wołoszyn, Domagalik, & Pilarczyk, 2017). In the human brain, the visual processing of faces is separate from the visual processing of whole bodies. The former involves the fusiform face area; the latter involves the extrastriate body area. More specifically, the visual processing of faces involves the fusiform gyrus and part of the temporal lobe; the visual processing of whole bodies involves the inferior occipital gyrus and inferior temporal lobe. The anatomical differences between the regions responding to faces and whole bodies indicate a functional difference between these regions (Taylor, Wiggett, & Downing, 2007; Thierry et al., 2006). The extrastriate body area was originally assumed to be dedicated to the processing of visual information from human bodies (i.e., the parts of the body excluding the face) (Downing et al., 2001; Kuhn, Keizer, Rombouts, & Hommel, 2011; Urgesi, Berlucchi, & Aglioti, 2004). However, more recent research has found that the extrastriate body area is dedicated to the processing of visual information from the body as a whole and that this region is overlapped by the region dedicated to the processing of visual information from natural finger postures (Bracci et al., 2012; Bracci et al., 2010). This finding is supported by fMRI studies that show increased activation in this region when participants view images of hands and fingers in various postures compared to control images.

There is a growing body of literature that recognises that distorted finger postures evoke affective reaction and arousal in the same way that emotional faces evoke emotions (Arienzo et al., 2013; Madsen, Bohon, & Feusner, 2013). Previous studies on distorted finger postures have been conducted using electrophysiological responses and neurological research, such as magnetoencephalography (MEG), fMRI, and EEG (Avikainen et al., 2003; Espírito Santo, Chen, et al., 2017; Schürmann et al., 2011). Avikainen et al. compared the neuromagnetic cortical activation in MEG elicited by distorted and natural finger postures and found that the extrastriate occipital areas of both hemispheres were activated more strongly by distorted finger postures than by natural finger postures (Avikainen et al., 2003). Avikainen et al. (2003) indicated a top-down effect of emotional reaction on the processing of unusual hands (i.e., distorted finger postures) in the extrastriate visual cortex due to the enhanced extrastriate activation that was recorded. When enhanced extrastriate activation occurred, amygdalar activation occurred at the same time. Amygdalar activation could be expected to be analogous to the activation observed after viewing disturbing stimuli (Avikainen et al., 2003). It has been suggested that hand perception is related to social perception. Distorted finger postures are perceived as implausible, and this implausibility affects how visual information is processed in social perception (Schürmann et al., 2011). Activations in the primary motor cortex, the postcentral somatosensory area and the amygdala were higher in response to viewing distorted finger postures than when viewing natural finger postures (Schürmann et al., 2011). It has been demonstrated, in the aforementioned references, that implausibility, particularly physical implausibility, evokes stronger emotions in people. Thus, it can be deduced that perceptual salience is higher in response to distorted finger postures than to natural finger postures, as the viewers may instantaneously feel uneasy.

1.2.4 Is there evidence for the distinctions between the effects of distorted and natural finger posture images in visual search?

Hands contribute to the expression of emotion in human communication. When a speaker gives a lecture, humans notice not only the emotional expression on the speaker's face but also their emotional expression through their 'hand gestures' (Gullberg & Holmqvist, 2006; Gullberg & Kita, 2009). Hand gestures imply communicative gestures (Krauss, Chen, & Chawla, 1996; Krauss & Fussell, 1996). In addition, insulting hand gestures can evoke particular emotions (Flaisch, Hacker, Renner, & Schupp, 2011). In a study, emotional effects were reflected in distinct ERP modulations (Flaisch et al., 2011). Negative hand gestures, such as insults, appeared to be more potent than positive hand gestures, indicating approval, inducing a heightened state of attention during the processing stages implicated in stimulus recognition and focused attention. However, it is not only the insult hand gestures that evoke affective reaction and arousal in viewers. Distorted finger postures, as an implausible body configuration, also often induce an uncomfortable feeling. It is of interest whether distorted finger postures reflect particular patterns of distortion-related processing in visual search.

Affective reaction and arousal evoked by stimuli play a crucial role in the social perception of body images. Affective reaction rating in these experiments refers to the negative or positive reaction to the stimuli; arousal rating here refers to the emotional excitement that the stimuli evoke (Kurdi et al., 2017). For example, whilst it is commonly recognised that the human body, particularly facial expressions, can evoke emotions, one could underestimate the emotional responses triggered by hand gestures. However, not merely the gestures but the nature of the hand postures themselves, especially when distorted, can influence emotional reactions. This link between distorted hand postures and emotional response highlights nonverbal communication's subtle yet profound aspect.

Hands are processed in several brain regions, namely, occipital, parietal, and temporal. These regions include areas near the superior temporal and intraparietal sulci, which have been identified as being parts of the neuronal network involved in social perception (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Downing et al., 2001; Langton & Bruce, 2000). It has been shown that, like faces, hands play a critical role in the social perception of human bodies. This has led to the speculation that hands are important for social perception because viewers anticipate hand actions, or because viewers are prepared for hands to be used for gestures. Attention to static hands suggests that static hands also communicate important information (De Stefani & De Marco, 2019). In addition, like facial expressions, hands are important because parts of the body which are not covered reveal more communicative information than those which are. When uncovered, those parts which have more degrees of freedom of movement convey more information, for example, hands and faces compared to torsos (Bavelas & Chovil, 2006).

To measure attention, visual search tasks have been used which typically involve an active scan of the visual environment for a target object or feature among other distractor objects or features. One of the most well-known tools for assessing visual search is to measure RT. After a thorough literature search with the keyword 'distorted finger postures', no studies addressing distorted finger postures for visual search were found. The experiments in this PhD project will try to show the effect of distorted and natural finger postures on visual search based on previous studies which compared control conditions: faces and nonface objects in visual search (Goold & Meng, 2016; Hershler & Hochstein, 2005) and distorted and natural finger postures in brain research (Espírito Santo, Chen, et al., 2017).

Despite the lack of evidence to date regarding the distinctions between the effects of distorted and natural finger postures in visual search, it is possible to refer to the distinctions between the effects of hands and whole bodies in visual search, thus drawing on brain research methodology. In brain research methodology, the order of investigation is to first compare distinctions between the effects of hands and whole bodies and then those between distorted and natural finger postures. Therefore, it is possible to conduct experiments to obtain evidence of the distinctions between the effects of hands and whole bodies in visual search before conducting experiments to obtain evidence of the distinctions between the effects of distorted and natural finger postures in visual search. The approach to understanding the effects of visual search involves a strategic progression from broad to more specific research areas. Initially, the focus is on the effects involving hands and whole bodies, providing a foundational understanding before delving into more precise areas like the impact of distorted versus natural finger postures. Although similar effects might be observed with other body parts, such as broken, dislocated, or distorted legs, arms, or even necks, and this might be interesting and important, and could provide the subject of related follow-up studies, this thesis does not investigate them due to content limitations.

This layered approach, starting with broad categories and diving into their specifics, ensures that any findings in the focused areas are appreciated within the context of the broader categories. This sequence also aids in the elimination of confounding variables; by first investigating the impact of hands versus whole bodies, some baselines are established. Furthermore, this methodology allows for an incremental contribution to the knowledge. The insights gained from the first study can guide the design and interpretation of the second study, whilst the findings from the latter would incrementally enrich the understanding developed from the first study.

1.2.5 Is there evidence for the distinctions between the effects of distorted and natural finger posture images in eye movements?

Eye movements are partly governed by the property of the stimuli (Motter & Holsapple, 2007). Based on this statement, eye movement tracking is a suitable technique to explore the effects of distorted finger postures on perception. This experiment recorded ‘fixations’ and ‘saccades’. In an experimental setup, fixations provide information about how and when humans allocate their attention (Lin & Lin, 2014; Nelson & Mondloch, 2018), whilst saccades offer information regarding how rapidly humans move their eyes when presented with a novel stimulus (Walker, Deubel, Schneider, & Findlay, 1997). Saccades are rapid, ballistic movements of the eyes that abruptly change the fixation point of the eyes (Zirnsak & Moore, 2014). Understanding the relationship between eye movements and attention-capturing behaviour helps to understand the effects of human stimuli. Using eye tracking to understand the behavioural patterns of users in response to different stimuli can be beneficial for various applications. Eye movements, therefore, indicate the extent of the attention captured by stimuli.

Understanding this relationship helps recognise the nature of different human stimuli in visual processing.

It is thought that eye movements in the context of high-level visual processing (i.e., eye movements in object recognition rather than low-level visual processing for colour or orientation) indicate that hands are important targets in human in-person interactions (Schilbach, 2015). Here, hands as targets (i.e., high-level visual processing) can divert attention from other inanimate objects (Taylor, Pratt, & Witt, 2015). In addition, eye movements are altered by implausible human body stimuli (also high-level visual processing) (Geiger et al., 2017; Schütz et al., 2011). This issue is further investigated in this PhD project to confirm whether eye movements are determined by the physiological implausibility of distorted finger postures. Fixation and saccade were measured in these experiments. In terms of fixation, fixation duration and fixation counts were measured, these being defined as the number of fixations within an area of interest. Fixation durations and fixation counts can be used to identify the allocation of attention to different parts of the human body (Lin & Lin, 2014; Nelson & Mondloch, 2018). In terms of saccades, saccade latency and saccade amplitude were measured: this can demonstrate the shift of attention and the capturing of attention by different parts of the human body (Heyman et al., 2017; Hoffman & Subramaniam, 1995; Zhao et al., 2012). In the investigation of saccade latency, human implausibility (implausible human body stimuli) exerts an influence on saccade latency (Cajar, Schneeweiss, Engbert, & Laubrock, 2016; Khan, Heinen, & McPeek, 2010; Pratt & Trottier, 2005). These studies suggest that saccade latencies and amplitudes reflect attentional modulation and selective attention. Saccade latencies and amplitude modulations are enabled by gaze-contingent and attentional modulations. Thus, the saccade latencies and amplitude are examined to see whether the implausibility of stimuli related to the human body leads to attentional modulation. If saccade latencies and amplitudes change between implausibility and standard stimuli related to the human body, one could conclude that saccade latencies and amplitudes are specific to the heterogeneity of stimuli related to the human body.

Regarding eye movement saccades in this PhD project, an involuntary saccade task is used as part of an eye tracking experiment, where participants are instructed to fix their gaze on a specific target as in Taylor and Hutton (2009). This attention capture induces reflexive shifts of the saccade whenever new objects appear as in Pratt and Trottier (2005). These saccades are essentially overt responses instigated by new stimuli. In order to understand the allocation of attention, distorted and natural finger posture saccades were investigated. Experiments conducted for this purpose included the sequential display of several images as stimuli as in Strasburger, Rentschler, and Juttner (2011). Observations from these experiments indicate that when images with negative reaction and high arousal were presented, participants' gaze shifted to the next image more swiftly than when the images lacked negative reaction and high arousal, that is neutral images.

Regarding eye movement fixation in this PhD project, it was assumed that distorted finger postures would demand a greater cognitive capacity and allocation compared to natural finger postures, and as a result, there would be an increase in the fixation on distorted finger postures, either in terms of frequency or duration. Whilst the literature on the effects of distorted and natural finger postures on eye movements is sparse, existing references in terms of eye movements comparing faces and nonface objects provide substantial evidence that distorted finger postures systematically influence eye movements (Arizpe, Noles, Tsao, & Chan, 2019; Geringswald, Afyouni, Noblet, & Grosbras, 2020; Schütz et al., 2011).

1.2.6 Is there evidence for the distinctions between the effects of distorted and natural finger posture images in Pupillometry?

A considerable number of studies support the claim that the pupil is altered by emotional stimuli (Bradley, Miccoli, Escrig, & Lang, 2008; Kret, Stekelenburg, Roelofs, & de Gelder, 2013; Lang & Bradley, 2010; Piquado, Isaacowitz, & Wingfield, 2010; Snowden et al., 2016). Pupillary size can be modulated by emotional facial expressions (Harrison, Wilson, & Critchley, 2007). Psychosensory pupil response is driven by both sensory and psychological stimuli, which are affected by stimulation, thought and cognitive load (Beatty, 1982; Mathôt, 2018). Recording the pupil size to examine whether it is modulated by the distorted finger postures is one way of inspecting the visual processing of emotions (Bradley et al., 2008; Mathôt, 2018), and recording the modulation of the pupil size due to the emotional content of an image is a crucial paradigm for investigating changes in the visual processing of emotions (Laeng, Sirois, & Gredeback, 2012). In order to obtain evidence to support the prediction that distorted finger postures evoke affective reaction and arousal, pupillometry can be employed. The pupil size is recorded to examine if pupil size is modulated by distorted finger postures. Distorted and natural finger postures are presented, and the change in pupil size is recorded using the eye tracking method to explore whether the change in pupil size correlates with the distorted finger postures. The findings from the experiment in this PhD project led to the conclusion that distorted finger postures evoke an emotional response and modulate pupil size. This provides evidence for the prediction that distorted and natural finger postures evoke different affective reaction and arousal ratings.

1.3 How is Automatic Mental Simulation Involved in the Visual Perception of Hands?

From previous studies, it is known that automatic mental simulation occurs with hands. In addition, it is known that in behavioural experiments responses are affected by the degree of hand rotation due to the changes in automatic mental simulation. Based on earlier literature, this section investigates the Simon effect of hands and automatic mental simulation of hand stimuli. When a stimulus is presented on the same side as the response required, it leads to faster RTs and fewer errors, which is known as the Simon effect (Liepelt, 2014).

1.3.1 Is there a role of automatic mental simulation in the visual perception of hands?

The use of one's hands as a means of expression and communication is vital for humans (Mandal, 2014; Sagayam & Hemanth, 2016). As intrinsic parts of human behaviour, hands and their perception are associated with cognitive-motor processes. When viewing images of hands, humans are thought to use automatic mental simulation (Jeannerod, 2010; Parsons, 1994). The term 'automatic mental simulation' refers to the process in humans of self-projection into alternate temporal, spatial, social, or hypothetical realities (Klein, 2016; Waytz, Hershfield, & Tamir, 2015a). This process is characterised by its automaticity, occurring involuntarily and highlighting the unintentional nature of such mental simulations. Although it might seem like merely imagining, automatic mental simulation involves involuntary cognitive processes essential for planning and interpreting sensory information. Whilst evidence for this is strong with hand actions (Freeman, Dale, & Farmer, 2011), research on static hand images is limited. In addition, automatic mental simulation can broadly be defined as mental processing in which sensory information is used to plan and generate behaviour, as well as to anticipate, forecast, and interpret perceptions (Smith & Kosslyn, 2013).

A considerable number of studies into automatic mental simulation have focused on hands (Borra & Luppino, 2019; Hamada et al., 2018; Shenton, Schwoebel, & Coslett, 2004; Zhong & Zhang, 2021), and this trend began in the early 1980s (Parsons, 1987; Sekiyama, 1982). Participants were asked to quickly judge whether a left or a right hand was presented. These hand stimuli had different finger positions and wrist rotations. The RT of participants were affected by the different finger positions and wrist rotation angles. The participants responded faster to common finger positions and wrist rotation angles, those which occur in daily life.

A high number of right-lateralised responses to distorted finger postures might suggest an association between these stimuli and emotional processes, given that the right hemisphere of the brain is often involved in emotional processing, according to previous research (Borod et al., 1998; Gainotti, 2018). However, it is important to note that whilst this finding is suggestive, caution should be exercised against overgeneralising. Other potential explanations, such as the right hemisphere's role in spatial awareness, body schema representation, or attentional mechanisms need to be considered and discounted (Heilman, Valenstein, & Watson, 2000; Vallar & Ronchi, 2008). Further research is essential to conclusively determine whether distorted finger postures are emotionally charged stimuli across various contexts, elucidate the specific nature of this relationship, and explore any potential mediating factors or alternative explanations (Adolphs, 2002; Gainotti, 2018).

A currently widely debated topic in the field of cognitive-motor processes is the role of automatic mental simulation for hand postures. In cognitive-motor processes, automatic mental simulation is applied to interpret the actions of others (O'Shea & Moran, 2017; Smith & Kosslyn, 2013). Automatic mental simulation occurs with hand actions, hand movements, and hand postures. Many studies have shown that automatic mental simulation occurs with static hand images, hand actions or hand movements (Grosbras & Paus, 2006; Longo & Haggard, 2010). However, little is known about which other hand configurations (i.e., distorted finger postures) provoke automatic mental simulation or whether the visual stimuli are processed as individual fingers (as opposed to inseparable parts of the hand). Most research on hand perception addresses hand actions and movements rather than static hands. It would therefore be of interest to experiment with static hands in mental simulation rather than hand movements in cognitive-motor processes.

1.3.2 Predictions for automatic mental simulation in the visual perception of hands

Firstly, to confirm whether the Simon effect occurs during automatic mental simulation with hands, this thesis sets out to test the prediction that in a Simon task, the response differences for different responding hand positions are significant, depending on the position of the responding hand in a Simon task, where faster RTs and fewer errors happen when the stimulus and response are on the same side (Liepelt, 2014). Participants were asked to respond to images of left and right hands with their corresponding hands. Secondly, to confirm whether previous studies regarding the automatic mental simulation for hands remain valid and whether they can be extended to further relevant experiments (Parsons, 1987, 1994), this thesis sets out to duplicate those experiments and test the prediction that in a hand rotation behavioural experiment, RTs would be significantly faster when the degree of hand rotation is consistent with the hand used to press the response button, compared to when they are inconsistent. The research also tested the prediction that RTs would be faster when the hand stimuli were closer to the hand used to respond to the stimuli. This was examined by comparing performance in the normal hand position (left hand on the left-hand side and right hand on the right-hand side) with the crossed hand position (left hand on the right-hand side and right hand on the left-hand side) in a behavioural experiment.

Thirdly, to test whether automatic mental simulation occurs for individual fingers, this thesis sets out to test the prediction that the different marginal mean RTs between the different finger stimuli are significant. Furthermore, the automatic mental simulation process was investigated to ascertain whether it was automatic when there was a significant relationship between the participants' responding fingers and the response to the distorted and unusual finger images. To test the prediction for the individual finger experiment, participants were asked to respond to distorted or unusual finger images in a pilot experiment. This experiment investigated whether automatic mental simulation occurs for individual fingers in an explicit process. Given the observed phenomenon, wherein individual fingers exhibited faster responses to their corresponding counterparts during explicit processes, an additional experiment was carried out to further explore the automatic mental simulation of hands. In this experiment, participants were asked to respond to left- or right-hand images. These left- and right-hand image stimuli included distorted and unusual fingers. This experiment was to investigate whether mental simulation occurs in individual fingers in automatic processes.

The first purpose of this thesis regarding EEG analysis is to assess mu rhythm when observing hands. This assessment provides insights into how the brain processes visual information related to human body parts compared to inanimate objects. The possibility of whether the power of mu rhythm with hands is different to that with chairs is examined. The power of the mu rhythm is a parameter for determining the properties of event-related oscillations. Images of chairs, matching the geometric complexity of hands, serve as control stimuli. The first prediction to be tested is that the differences in EEG band power between the observation of hands and the observation of chairs are significantly different on specific time frequencies. Time-frequency analysis of EEG signals provides the visualisation of EEG signals from which the various rhythms, such as alpha, beta, and gamma rhythms, can be extracted (Bhardwaj, Gupta, Jain, Rani, & Yadav, 2015). The second purpose of this thesis regarding EEG analysis is to assess distorted and natural finger postures by comparing their mu rhythms with the control stimuli: distorted and standard chairs. The second prediction to be tested is that there are interactions between the factors of distortion and stimulus type on mu rhythm power.

1.3.3 How does automatic mental simulation process the visual perception of hands in behavioural experiments?

Previous studies have found that hand position significantly modulates the magnitude of the ‘Simon effect’ (also known as ‘spatial stimulus-response compatibility’) (Dolk et al., 2014; Liepelt, 2014) and that the Simon effect can be used to investigate how automatic mental simulation processes the visual information of hands. The Simon task is an interference behavioural test and can cause the Simon effect. In the Simon task, participants are asked to respond to position-indicating visual stimuli (e.g., left or right arrow). In the previous studies, when the participants' hands were located close to the objects on the monitor, the Simon effect was stronger than when they were further away (Dolk et al., 2014; Liepelt, 2014). The effect causing the time delay in automatic mental processing in this experiment is the Simon effect. The Simon effect is useful when studying how humans respond to the side on which the stimuli (here, hands) are presented, and the difference of spatial stimulus-response compatibility indicates automatic mental simulation of hands. Traditionally, the Simon effect has been used to investigate low-level visual features such as object shape, orientation and colour (Hommel, 2011; Scerrati, Lugli, Nicoletti, & Umiltà, 2017). However, some studies show that the Simon effect provides a method to investigate automatic mental simulation involving high-level visual features such as parts of the human body (Dolk et al., 2014; Sellaro, Dolk, Colzato, Liepelt, & Hommel, 2015). Thus, the Simon effect was used to measure the responses to hand images, one advantage being that the laterality of automatic mental simulation can be measured (Jones et al., 2021; Mellet, Mazoyer, Leroux, Joliot, & Tzourio-Mazoyer, 2016).

In addition to the Simon tasks, hand laterality (left or right) judgement tasks were used in this thesis. The hand laterality judgement task is defined here as a task involving the processing of judging the functional asymmetries of mentally simulated hands (Jones et al., 2021; Mellet et al., 2016). The functional asymmetry of hands is often used to investigate automatic mental simulation because it provokes automatic mental simulation when humans judge whether they are seeing a left or right hand. The role of automatic mental rotation for hands has received increased attention in the field of automatic mental simulation (Balasubramaniam, Ionta, Perruchoud, Draganski, & Blanke, 2012; Ionta & Blanke, 2009; Ionta, Fourkas, Fiorio, & Aglioti, 2007). Previous studies have demonstrated a strong and consistent association between mental simulation and hand postures, and that the automatic mental simulation was initiated by the hand.

Although previous studies showed that automatic mental simulation for single hands occurs and that humans use automatic mental simulation with hand rotation (Parsons, 1987, 1994), it was unknown whether automatic mental simulation occurred for both-hands stimuli nor what the role of both-hands rotation was in automatic mental simulation. In addition to studying how both hands participate in the automatic mental simulation, examining individual finger movements offers specific behavioural insights. For example, researchers can design tasks where participants are shown images of a single finger, such as the index, middle, or ring finger, in various orientations.

Participants might be asked to determine whether the depicted finger is from the left or right hand as quickly and accurately as possible. Measuring RTs and error rates in these tasks provides concrete data on how individuals mentally simulate the movement and positioning of specific fingers. This focus on individual digits is important because it reveals nuances in processing and planning fine motor actions. Such behavioural findings help us understand the intricacies of motor planning and mental simulation at the finger level, essential for improving skills in activities requiring precise finger movements. Therefore, the perception of individual fingers is now receiving more interest in the field of visual research. When humans receive visual information of hands, they also receive visual information of fingers. In the aforementioned studies, it was shown that automatic mental simulation occurs for hand postures (Parsons, 1987, 1994); however, before carrying out the experiments in this thesis, it had not been proved whether automatic mental simulation occurs for whole hands only or whether it occurs for individual fingers (i.e., automatic mental simulation for index, middle or ring fingers). Therefore, to extend the investigation of automatic mental simulation with simultaneous both-hand rotation and individual fingers, lateral hand recognition tasks were conducted.

1.3.4 Do hands suppress mu rhythm as a result of automatic mental simulation?

The use of EEG in studying action observation has significantly advanced our understanding of the neural mechanisms underlying social cognition and motor learning. A foundational study and meta-analytic findings have highlighted the central role of the mu rhythm and the mirror neuron system (MNS) in interpreting observed actions. Specifically, the meta-analysis study analysed 95 studies, of which 46 addressed mu suppression during action observation in adult participants (totalling 833 individuals), and 9 utilised static stimuli in the observation condition (involving 204 participants, with an effect size of 0.37) (Cochin, Barthelemy, Roux, & Martineau, 2008; Fox, Bakermans-Kranenburg, Yoo, Bowman, Cannon, Vanderwert, Ferrari, & van, 2016). These insights not only deepen our understanding of brain function but also open avenues for applications in therapeutic settings and educational practices.

Distorted finger postures, often a result of an accident and frequently arousing feelings of discomfort in the viewer, play a crucial role in the understanding of the hand in social interaction (Espírito Santo, Chen, et al., 2017; Schürmann et al., 2011). To date, there has been little agreement on the critical question of whether the extraordinary salience of distorted finger postures represents specific patterns of distortion-related processing within the brain of the viewer. Because distorted finger postures are rare in daily life and do not often occur in automatic mental simulation, studying them provides a good example to investigate whether such rare body parts involve automatic mental simulation. Motor representation is used to understand the meaning of observation-generated motor activity. This suggests that visual information of body distortion can influence brain activity related to the visual processing of hand postures and consequently alter the viewers' perception of their own bodies. A mismatch in the viewers' minds between distorted and natural finger postures is of interest because there is a conflict of automatic mental simulation, and this mismatch can inform understanding of the relationship between the visual mechanisms of human bodies and automatic mental simulation.

Mu rhythm is a type of brain oscillation involved in automatic mental simulation. The motor cortex, which is the region of the cerebral cortex involved in automatic mental simulation and which contains mirror neurons driven by visual input, is still activated when the final part of the viewed action is hidden. This shows that the motor cortex can be activated even when the information received does not include a complete action (Umiltà et al., 2001). A key aspect of brain oscillations in automatic mental simulation is mu rhythm (Haufe et al., 2014). Mu rhythm is a band of oscillations between 8 and 13 Hz, and suppression of mu rhythm is related to automatic mental simulation (Cabrera, Novak, Foti, Voyles, & Wachs, 2020; Sakihara & Inagaki, 2015). It can be seen that when automatic mental simulation occurs, the viewers' mu rhythm is suppressed. Mu rhythm desynchronisation is a widely used measure of motor cortex activation that has been identified as a possible measure of the MNS (Hobson & Bishop, 2017). Mu rhythm is an alpha frequency oscillation of the EEG reported over central scalp regions. Mu rhythm is predominantly produced in resting conditions and is attenuated or reduced immediately before or during motor events, then known as mu desynchronisation. The mu desynchronisation pattern is considered a reliable indicator of motor cortex activation and correlates electrophysiologically with motor cortex activation.

Recent evidence suggests that EEG activity in the mu frequency band is suppressed during both gesture performance and observation (Hobson & Bishop, 2017). Particular characteristics during the kinematic execution of gestures showed dynamic changes in mu activity when gestures aid in the communication intent (Cabrera et al., 2020). The reduction in the mu wave (a pattern of brain activity detected by EEG) that is observed in an individual when they are watching an action take place is a fundamental and consistent phenomenon. In other words, body movement explains the attenuation of the mu wave in the viewer (Bernier, Dawson, Webb, & Murias, 2007; Hobson & Bishop, 2017). In addition, overt hand actions explain decreased attenuation in the viewer when looking at human gestures (Uhlmann et al., 2020). However, it is unclear whether attenuation is suppressed in the viewer when showing images of static hands (Bernier et al., 2007). Therefore, it is reasonable to expect that images of hands elicit mu rhythm.

Data from a previous study (Espírito Santo, Chen, et al., 2017), in which the data were collected using EEG and the ERPs were analysed, was used to analyse event-related oscillations. It was of interest to explore whether the automatic mental simulation of brain oscillations was evoked by hands due to the fact that mu rhythm desynchronisation revealed the interaction of motor skills between hand action and object recognition (Kumar, Riddoch, & Humphreys, 2013). The term 'mu rhythm desynchronisation' is used in its broadest sense to refer to event-related desynchronisation of mu rhythms. Event-related desynchronisation designates a short-lasting and localised amplitude attenuation of rhythms. Conversely, event-related synchronisation describes a short-lasting amplitude enhancement (Pfurtscheller, 1991). Desynchronisation is an active state and involves the suppression or disappearance of a spontaneous rhythm. Conversely, synchronisation is a resting state, with tens of thousands of pyramidal cells in synchrony with each other (Gomez-Ramirez, Freedman, Mateos, Perez Velazquez, & Valiante, 2017). Of particular interest is the primary sensorimotor area where these electrical responses to distorted finger postures occur. It has been experimentally demonstrated by movement observation that the mu rhythm desynchronisation in the primary sensorimotor area is concomitant with mirror neuron activation (Sakihara & Inagaki, 2015).

1.4 Thesis Outline: Stimulus Categories and Experiments

1.4.1 Overview of stimulus categories

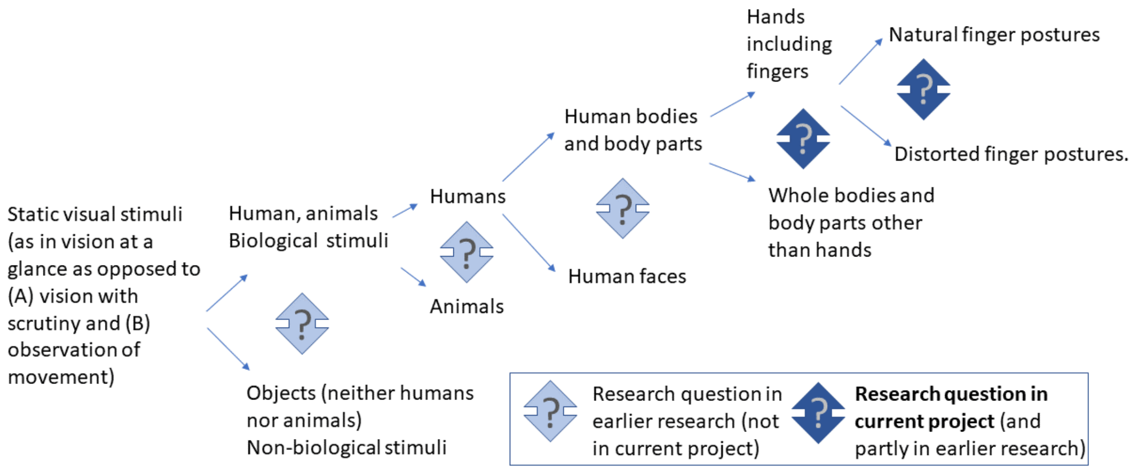


Figure 1-5 Overview of stimulus categories and related questions in research using visual search experiments and eye movement experiments.
The purpose is to illustrate the wider context of the questions in this thesis.

The overview of stimulus categories puts the research in this thesis in the context of other research on higher-order visual perception (Figure 1-5). There are six levels in the hierarchy. At the first level is static visual stimuli, which does not involve vision with scrutiny or observation of movements (this thesis concerns itself with static visual stimuli, not dynamic visual stimuli). At the second level, stimuli can be classified as biological stimuli or nonbiological stimuli. Biological stimuli include human body, animal, and even plant stimuli, whereas nonbiological stimuli involve objects such as furniture, appliances, and geometric shapes. At the third level, human body, animal and plant stimuli feature This thesis focuses on human body stimuli, animal and plant stimuli are excluded from this research. In this thesis, from the fourth level and above the stimuli are investigated. At the fourth level, the stimuli are classified as human bodies (excluding faces) and human faces. This thesis compares these two sets of stimuli. At the fifth level, hands are compared with whole bodies (without heads) and with body parts other than hands. At the sixth level, distorted and natural finger postures are compared. There are two main areas of interest in this thesis: the differences in the related perceptual processes; and the investigation of perceptual differences between distorted finger postures and natural finger postures.

This thesis is composed of four themed experiments: visual search experiments, eye tracking experiments (including pupillometric methods), motor cognition behavioural experiments and the analysis of an EEG experiment. These experiments (including the EEG analysis) were carried out to investigate the perceptual processes for hands and to complement earlier studies on the perception of faces and whole bodies. Furthermore, these experiments were used to explore whether there were differences in perceptual processes between distorted and natural finger postures and to complement the distorted and natural finger posture experiments of earlier studies. The applications of these methods are detailed below.

1.4.2 Experiments conducted in this thesis

1.4.2.1 Visual search experiments

The visual search task experiments were conducted to investigate the differences in perceptual processes for hands, faces, and whole bodies. Because these experiments were successful in identifying differences in perceptual processes for these three stimulus types, the visual search experiments were expanded to test and distinguish differences between the perceptual processes for distorted and natural finger postures. The visual search experiments with RT measurements were used to understand the allocation of visual attention in the perception of various stimuli (Experiments 1, 2, 3, 4). In addition, a second set of visual search task experiments were adjusted to take accuracy measurements. These accuracy measurement experiments were used to understand whether the visual properties of various stimuli and the efficiency of visual search of these stimuli were different in the visual processing of passive vision. In addition, the visual properties of distorted and natural finger postures and the efficiency of visual search of distorted and natural finger postures were also found to be different in the visual processing of passive vision.

1.4.2.2 Eye tracking experiments

Two eye tracking experiments were carried out: one was used to understand the allocation of visual attention and visual inhibition in the perception of hands, faces and whole bodies; the other was conducted to investigate the differences between the perceptual processes for distorted finger postures and those for natural finger postures. The pupillometric method, based on the data from the eye tracking experiment with distorted finger postures, was used to investigate the difference between the perceptual processes for distorted finger postures and those for natural finger postures. Furthermore, the pupillometric method was used to understand the affective reaction and arousal and the cognitive load of hands with distorted finger postures.

1.4.2.3 Behavioural experiments with automatic mental simulation

Behavioural experiments underlying automatic mental simulation were used to explore the cognitive-motor processes for hands with distorted finger postures. These underlying behavioural experiments consisted of two main experiments: a Simon task (Experiments 7 and 8) and a hand laterality recognition task (Experiments 9, 10 and 11).

1.4.2.4 EEG experiment

Using the EEG experiment from the preceding study (Espírito Santo, Chen, et al., 2017), which was reanalysed for this current PhD project, the brain processes that govern the mu rhythms for distorted and natural finger postures could be identified and compared.

1.4.2.5 Summary

Drawing upon these four research methods into hand perception, this thesis investigates the perception of hands and determines the extent to which hands and distorted finger postures are allocated more attention. Additionally, this thesis considers the automatic mental simulation of hands and distorted finger postures and whether they elicit unusual responses (e.g., suppress mu oscillations). In this thesis, the stimulus categories can be classified as (1) stimuli related to the human body (Figure 1-6) and (2) stimuli related to nonhuman objects. The stimuli related to the human body comprise the following categories: hands, faces, whole bodies and feet. The stimulus categories related to nonhuman objects include chairs, cars and other inanimate objects (Figure 1-7). The selection of control stimuli in the project, including chairs, cars, and other inanimate objects, serves as a baseline to compare against human body distortions. To examine emotional effects, threatening and neutral objects similar in shape were chosen, ensuring that any observed differences are due to emotional content rather than shape. Threatening stimuli were considered appropriate for this purpose; however, overly intense images that might overshadow the finger distortions being investigated were avoided.

1.4.3 Stimuli related to the human body and to nonhuman objects

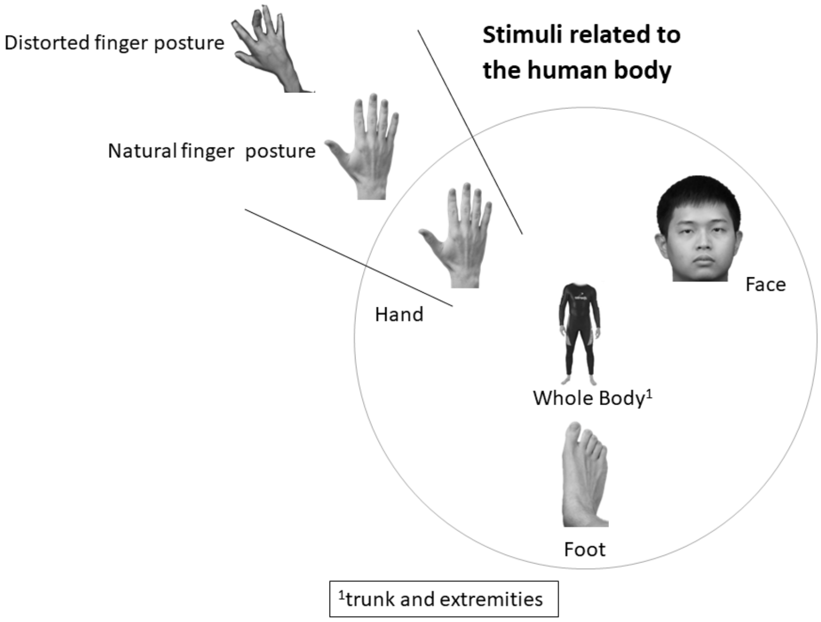


Figure 1-6 Overview of stimuli related to the human body, as used in this PhD project The project compares hand stimuli with face, whole body (1trunk and extremities, no head) and foot stimuli. Distorted finger posture stimuli and natural finger posture stimuli were also compared.

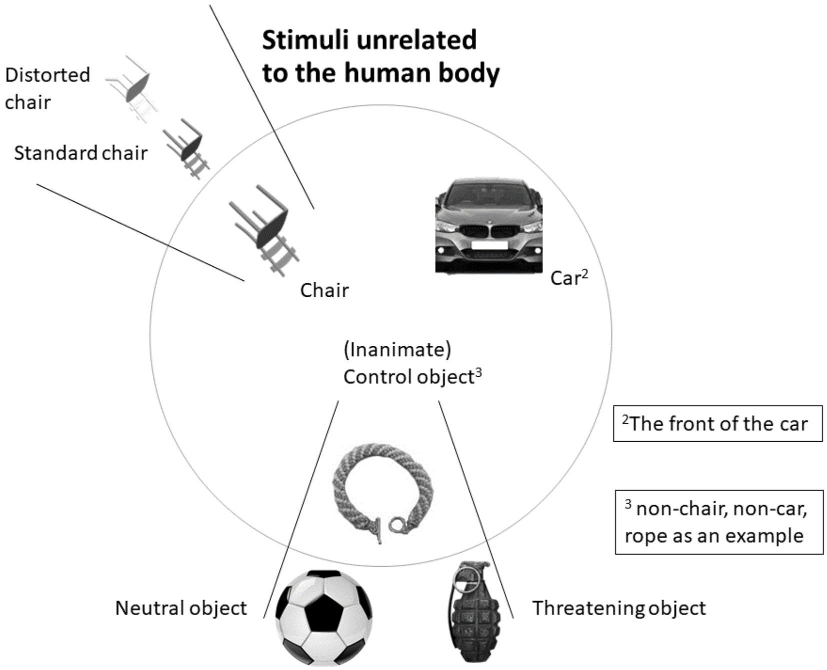


Figure 1-7 Overview of stimuli unrelated to the human body, as used in this PhD project
In different experiments, this project uses three control stimulus types: chair, car (front view), and other inanimate control objects (non-chair, non-car). As controls for the comparison between distorted and natural finger postures, this project uses the comparison between distorted and standard chairs and the comparison between threatening and neutral objects.

1.5 Research Aims

The aim of this thesis is to examine the impact of hands and, in particular, distorted finger postures, on the underlying mechanisms of visual search and eye movement. Furthermore, this thesis aims to utilise images of hands and individual fingers as stimuli to investigate the mechanism of automatic mental simulation. By presenting these visual cues, the study seeks to evaluate how the brain processes and mentally simulates hand and finger postures. Finally, this thesis aims to investigate whether and how humans pay more attention to hands than to other parts of the human body, in particular to distorted finger postures, and whether automated mental simulation is involved. To achieve this, several questions are posed.

First, are hands salient in visual search and eye movements? Previous studies have shown that physiological evidence indicates differences between the responses to hands and to whole bodies. In addition, previous studies have also shown differences between the responses to faces and to nonface objects in visual search and eye movements. However, hands and whole bodies have not yet been compared using visual search and eye movements. Therefore, in this PhD project, visual search tasks and eye tracking methods are used to explore the specificity of hands by comparing them to other parts of the human body.

Second, this thesis attempts to confirm whether distorted finger postures are more salient than natural finger postures in visual search and eye movements. Previous studies have shown that physiological evidence indicates differences between the responses to distorted and natural finger postures. However, distorted finger postures have not yet been compared using visual search and eye movements. Therefore, in this PhD project, visual search tasks and eye tracking methods are used to explore the specificity of distorted finger postures by comparing them to natural finger postures.

Third, based on the above questions, this thesis attempts to understand how affective reaction and arousal affect visual behaviours in visual search and eye movements. Previous studies have shown that emotional faces, whose affective reaction and arousal differ from those of neutral faces, influence visual behaviour. At this point, it is worth clarifying whether the different responses to distorted and to natural finger postures are caused by the differences in affective reaction and arousal ratings. Therefore, in this PhD project, the affective reaction and arousal ratings in visual search of distorted and natural finger postures are measured and subsequently compared to those of inanimate objects with similar distorted and natural finger posture affective reaction and arousal ratings.

Fourth, this thesis extends previous studies on the automatic mental simulation of the visual perception of hands by incorporating a new paradigm (Simon task) that has not yet been used with the automatic mental simulation of hands. In addition, this thesis uses hand laterality tasks to examine whether automatic mental simulation occurs not only with a single hand but also with both hands when presented together; whether automatic mental simulation can be used with individual fingers; and whether automatic mental simulation for hands is an automatic process.

Finally, this thesis sets out to investigate the occurrence of automatic mental simulation based on existing brain research evidence. To achieve this, event-related oscillations were measured to determine the presence of mu desynchronisation (serving as an indicator of automatic mental simulation).

1.6 Changes Made to Experiments and Thesis Content Due to COVID-19 Pandemic Restrictions

After the COVID-19 pandemic was declared in March 2020, the EEG experiments that had been prepared over the previous 3 months had to be suspended. The preparation had consisted of reviewing the literature, designing experiments, generating the PsychoPy files for executing the experiments, and developing stimulus material for the experiments. The EEG laboratories were closed as EEG experiments were subject to COVID-19 related risks: (1) the distance between the researchers and the participants in EEG experiments is less than two metres, and (2) EEG experiments last more than 45 minutes. Once the EEG laboratories had been closed, it was immediately evident that EEG experiments could not be run in the near future. Therefore, alternative experiments had to be devised based on the EEG experiments already planned. Although it had been decided to conduct face-to-face behavioural experiments based on automatic mental simulation, as the risks were not as high as those of EEG experiments, it soon became clear that it was too dangerous to conduct experiments in person at all. After discussions with the supervising team evaluating the risks, it was decided to run online behavioural experiments until the laboratories reopened, with the option of remote testing. This method had a distinct advantage over EEG methods under the conditions at that time. However, there were numerous challenges in generating online behavioural experiments and recruitment of participants (see Appendix 1: Online experiment setting and participants recruitment for online experiments). Although not a novel technique, online behavioural experiments were not popular at that time and were in their infancy, and there were not many tried and tested examples. 2 months were required to devise them. As a result, this thesis includes more content on motor cognition and behavioural experiments based on motor cognition (Experiments 9, 10 and 11) and less EEG content. Only the analysis of limited previously published EEG data are included (Experiment 12) rather than new data from specifically conducted experiments.

Chapter 2 Investigating the Salience of Hands Compared To Faces and Whole Bodies Using Visual Search Methods

This chapter describes visual search relating to human body perception (including faces, whole bodies and hands) and is subdivided into seven sections. The first section describes Experiment 1, which addressed whether there were different RTs for the hands, faces and whole bodies; the second section describes Experiment 2, which addressed whether there were different RTs for the distorted and natural finger postures; the third section describes Experiment 3, which examined whether there were different proportions of correct responses for the hands, faces and whole bodies; the fourth section describes Experiment 4, which addressed whether there were different proportions of correct responses for the distorted and natural finger postures; the fifth section describes Control Experiment 1, an evaluation questionnaire, which measured the affective reaction and arousal ratings of the stimuli used in this thesis; the sixth section describes Control Experiment 2, which addressed whether there were different RTs for the distorted and natural finger postures, grenades and balls; the last section describes Control Experiment 3, which addressed whether there were different RTs for the distorted finger postures, natural finger postures, distorted toe postures and natural toe postures. For Experiments 1 and 2, participants were present in a lab; all other experiments were performed online because of COVID-19 (see Appendix 1: Online experiment setting and participants recruitment for online experiments). Overall, these experiments were performed to uncover insights into visual search processes related to human body perception, assessing RT, accuracy, and the effects of various stimuli on perceptual judgements. The tasks involve the identification and discrimination of body-related stimuli within a group of other stimuli, investigating the pop-out effect of these body-related stimuli.

2.1 Experiment 1: Is Visual Search Different for Hands, Faces and Whole Bodies? (An RT Measurement)

2.1.1 Introduction

Faces are considered the most important visual stimuli in social interaction, and have a special status over most other stimulus types (Salvato, De Maio, & Bottini, 2017). In contrast to most other objects, faces spontaneously capture humans' attention from a set of distractors (Downing, Bray, Rogers, & Childs, 2004). Whilst a considerable number of studies have focused on facial expressions in social communication, less is known about the attentional capture by other body parts, despite evidence of neural responses (such as amygdala activation to fearful body postures) to certain bodily cues (Atkinson, Heberlein, & Adolphs, 2007). It remains unclear whether various parts of the human body, beyond the face, spontaneously capture attention in social contexts.

Visual search is a ubiquitous behaviour, and an efficient distinction of different stimuli in visual search is vital for human survival (Cazzato, Mele, & Urgesi, 2014; Eckstein, 2011; Palmer, Verghese, & Pavel, 2000). Attention to hands is crucial for social and cognitive processes. There is some discussion about whether the visual perception of hands can be dissociated from the visual perception of human bodies (Bracci et al., 2010). It has been found that there are two distinct regions in the human brain that are involved in the processing of hands and bodies (Bracci et al., 2010). The first region, located in the left lateral occipitotemporal cortex, is specifically responsive to hands. The second region, located in the extrastriate body area, is responsive to both hands and bodies. By identifying specific regions responsive to hands and bodies, insight is gained into the brain's compartmentalised processing abilities. This ties in with the principle observed in holistic face perception, where a 'parallel search' strategy facilitates quick recognition. Such rapid processing might similarly benefit the perception of hands and entire bodies, contrasting with the slower 'serial search' approach. Visual search studies indicate that holistic face perception has ‘parallel search’ rather than ‘serial search’ (Hershler & Hochstein, 2005, 2006).

One of the most well-known tools for assessing visual search is to measure RT. RT measurements provide insights into the efficiency and effectiveness of a visual search system or interface. By analysing the RT data, researchers can obtain a comprehensive understanding of the visual search performance. Typically, observers search for a target among a variable number of distractor items. The stimulus is usually present until a response is made. Observers judge the presence or absence of the target stimuli (Wolfe, 2018). If all items are processed in parallel unaccompanied by capacity limitations, the slope of the RT × set size functions would be expected to be near 0 ms/item (Treisman, 1985; Wolfe, 2018). Therefore an RT slope of around 0 ms/item is considered a ‘parallel search’ (Treisman, 1985; Wolfe, 2018), whereas an RT slope of around 20 ms/item or above is considered to be a serial search. If the items were processed in series, the RTs would increase linearly with the number of distractors. However, researchers have not categorised their results into absolute parallel search or absolute serial search in recent years, as this distinction is considered too rigid, and some visual searches can show an overlap between parallel search and serial search (Wolfe, 2018; Wolfe & Horowitz, 2017). Therefore, parallel and serial search are now being considered as high and low extremes of a continuum.

Compared with using parallel or serial search as the criterion for judging visual search, using visual search efficiency can more broadly explain the features of different objects as visual search targets (Wolfe, 2018; Wolfe et al., 2011). Visual search efficiency refers to the ability to efficiently and accurately locate a specific target within a visual scene or display. It is a measure of how quickly and accurately individuals can identify a target among distractors in a visual search task. The pop-out effect is indicative of high visual search efficiency. The effect was termed the ‘pop-out effect’ when the RT for detecting the unusual component was dissociated from the number of distractors (i.e., RT slopes is 0 ms/item) (Treisman, 1985; Treisman & Gormican, 1988). High visual search efficiency in visual search happens under various circumstances. In this study, it was observed that visual search exhibited high efficiency, characterised by the pop-out effect.

In visual search tasks involving faces, the RT slope is typically flat, indicating a parallel search process in which all items are processed simultaneously. The efficiency of face detection and recognition in visual search tasks is supported by numerous studies demonstrating a near-zero RT slope. This flat slope indicates that the RT remains relatively constant regardless of the number of distractor items present. For example, in a classic study, participants were tasked with finding a target face among varying numbers of distractor faces (Treisman & Gelade, 1980). The results showed that the time it took to find the target face did not increase significantly as the number of distractors increased, suggesting a parallel search process in which all items are processed simultaneously. This efficient parallel processing is likely due to the specialised neural mechanisms dedicated to face perception. The human brain has evolved to rapidly and accurately detect and recognise faces, a skill crucial for social interaction and survival. This specialised processing allows for the location and identification of faces even in complex visual environments.

This further implies that all faces within a field of view are processed simultaneously, a phenomenon showcasing the remarkable capabilities of the human visual system for face detection. Similar to the human face, the human body is a rich source of socially relevant information about other individuals (Goold & Meng, 2016). Different cognitive models could be explained by the speed and accuracy of the search based on the dynamics of attention and the similarity of item representations defined as items present in the display (Kotowicz et al., 2010).

The visual processing of human bodies and stimuli unrelated to the human body is different (Cho, 2018). Evidence from studies of perceiving human bodies points to part of the higher-level visual cortex being dedicated to the visual perception of human bodies (de Gelder, de Borst, & Watson, 2015; Peelen & Downing, 2007). RT methods of visual search are known to clarify our understanding of human body stimuli. Depending on the diverse attributes of the visual perception of human bodies, the visual search task in this experiment was conducted to investigate the pop-out effect comparing parts of the human body and stimuli unrelated to the human body.

To measure attention, researchers have used visual search tasks that typically involve passive vision and an active scan of the visual environment for an object or feature as the target among other objects or features as the distractors (Treisman & Gormican, 1988; Treisman & Gelade, 1980). The visual search experiment was conducted in order to measure the difference of attention given to the different parts of the human body (hands, faces and whole bodies). Here, the term ‘whole body’ refers to ‘human bodies without heads’ (Thierry et al., 2006).

One purpose of this visual search task experiment was to investigate the difference in RTs to visual stimuli related to the human body and those unrelated to the human body (i.e. inanimate objects, e.g. a rock, a chair or a book), and to understand whether visual search has higher visual search efficiency (slope value can be used as an indicator of visual search efficiency) for visual stimuli related to the human body compared to those unrelated to the human body. Additionally, a further purpose of the experiment was to examine the different RTs to the different parts of the human body. This prediction is based on the idea that hands are more frequently involved in fine motor tasks and tool use, leading to more specialised and efficient neural processing for hands compared to whole bodies. Research has shown that expert tool users, for example, have distinct neural representations for hands and tools, suggesting a higher degree of differentiation and possibly faster RTs for hand-related stimuli (Kessler & Miellet, 2013; Schone, Maimon-Mor, Baker, & Makin, 2021). Additionally, hands are often perceived and processed as individual entities rather than as part of a whole body, which could contribute to quicker and more efficient recognition and RTs. The reason for this prediction is that there were differences in average RTs and RT slopes between faces and nonfaces in visual search tasks from previous studies.

2.1.2 Method

2.1.2.1 Participants

Thirty-one students from the University of Nottingham Malaysia, 22 females and 9 males (18-45 years, *M* = 25.10, *SD* = 3.31) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment. All participants gave written, informed consent and had normal or corrected to normal visual acuity by self-report, and all received either course credits or inconvenience allowances. The participants were all judged to be right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971; Veale, 2014). The number of participants in Experiment 1 was greater than the number of participants in comparable visual search paradigms (Goold & Meng, 2016; Hershler & Hochstein, 2005). In addition, G*Power 3.1.3 a priori analysis was used to determine which sample size would be adequate, and the GPower 3.0 default setting was chosen (Faul, Erdfelder, Buchner, & Lang, 2009). For the calculation, a small effect size was set at a value of 0.25 (Brydges, 2019). Assuming 3 (set size 2, 4 and 6) × 4 (hand, face, whole body and car) within-subject factors, the a priori power analysis indicated that in the experiment, a sample size of 18 would be sufficient to detect a significant interaction with α: 0.05, power: 0.95; a number of groups of 2 and a number of measurements of 12 in repeated measures of within-subjects ANOVA were chosen (Faul et al., 2009; Faul, Erdfelder, Lang, & Buchner, 2007). The procedures for this study received approval from the Science and Engineering Research Ethics Committee (SEREC) at the University of Nottingham Malaysia. The committee assigned the application number HYC150221 to this research project.

2.1.2.2 Materials and apparatus

The experiment comprised five target conditions: four target-present conditions and one target-absent condition. The target item in target-present conditions was a hand (30 images, 3 × 10 different images), a face (30 images, 3 × 10 different images), a whole body (30 images, 3 × 10 different images) and a car (30 images, 3 × 10 different images); whereas items in the target-absent condition (i.e. no target item) was combined with distractors only, which were inanimate objects excluding cars. These visual items were 3 × 3 cm greyscale images (Figure 2-1). The whole body and hand images (first-person perspective, dorsal view) were computer-generated images from Espírito Santo, Maxim, et al. (2017), with the authors' permission. The face images, which included different races and frontward facing female and male faces inclusive of hair and ears, were obtained from the School of Psychology University of Nottingham Malaysia Face Database. The car images (front view) were downloaded from Google Search (labelled for reuse). Distractors were selected randomly from a database of 360 photographs of inanimate objects, such as a bag, a bracelet, a button etc. from Espírito Santo, Maxim, et al. (2017), with the authors' permission.

The visual search display was akin to an earlier published design (Goold & Meng, 2016), with a black fixation cross in the centre of a white screen together with 2, 4, 6 items. For displays with two items, these were positioned opposite each other around the fixation point at 0° and 180°; for four items, these were positioned around the fixation point at 0°, 90°, 180° and 270°. For six items, these were positioned around the fixation point at 30°, 90°, 150°, 210°, 270° and 330°. For each set size (2, 4 and 6), there was a target item, and the rest were distractors. The target item was either a hand, a face, a whole body or a car image; each target item and each distractor measured 3 × 3 cm (3° × 3° visual angle) on the visual search display. The size of the black fixation cross was 0.5 × 0.5 cm (0.5° × 0.5° visual angle). The distance from the black fixation cross to the centres of the target items and the distractors was 5 cm (5° × 5° visual angle); the visual search display had a resolution of 1280×720 pixels (Figure 2-1).

In a block of 240 visual displays (shown in random order), in target-present conditions, 120 visual displays were distributed equally across the three set sizes (2, 4 and 6). In target-absent conditions, 120 visual displays, also distributed equally across the three set sizes, served as controls (Table 1). After 240 visual displays had been shown to the participants, another three blocks of 240 visual displays were repeated in random order to make up 960 (across the four blocks).

The participants were sitting 57 cm away from a monitor. The experiment was presented and coded using PsychoPy (Peirce, 2007, 2008) on a 14-inch HP EliteBook 840 with a refresh rate of 60 Hz and a spatial resolution of 1366 × 768 pixels, which was set to 1280×720 pixels to appropriately display images, with luminance levels in candelas per square metre, 124 cd/m^2. All visual displays were presented on a white background.

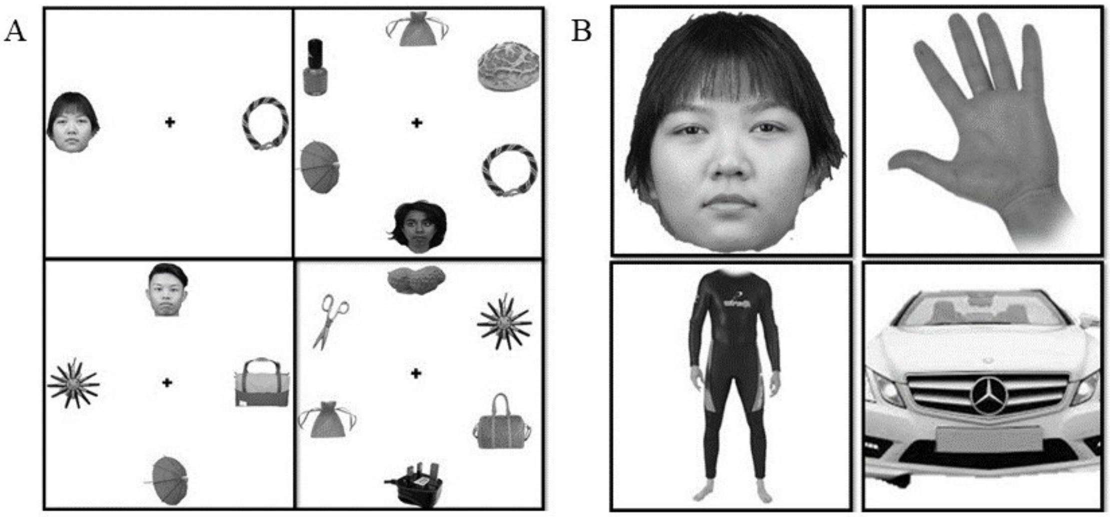


Figure 2-1 Examples of visual displays and examples of target items in Experiment 1 (A) Examples of visual displays containing set sizes 2, 4 and 6 visual items, out of the four examples, three contain a target item (face) whilst one contains no target item, each example of a target stimulus and one or more distractors. (B) Examples of visual target items from top left to bottom right: face, hand whole body and car.

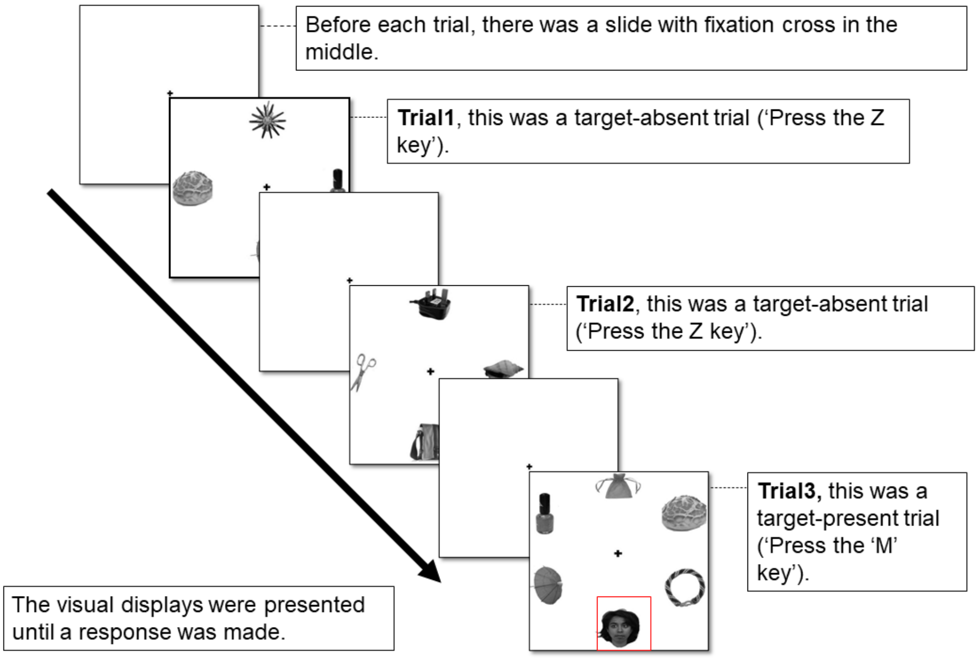
Table 1 The stimuli of Experiment 1
The experimental structure of one block of 240 trials in Experiment 1. The experiment comprised four blocks.

Group	Set size	Stimuli	Number of trials
Absent group (120 stimuli)	2	All distractors	40
	4	All distractors	40
	6	All distractors	40
Target group (120 stimuli)	2	Hand with distractors	10
		Face with distractors	10
		Whole body with distractors	10
		Car with distractors	10
	4	Hand with distractors	10
		Face with distractors	10
		Whole body with distractors	10
		Car with distractors	10
	6	Hand with distractors	10
		Face with distractors	10
		Whole body with distractors	10
		Car with distractors	10

2.1.2.3 Design and procedure

In a randomised mixed design, each participant underwent 960 trials composed of 480 target-present trials (120 trials including hand target items, 120 trials including face target items, 120 trials including whole body target items and 120 trials including car target items) and 480 target-absent trials. In addition, there were an initial 20 practice trials, the results of which were disregarded. The trials were separated into four blocks, with 240 trials in each block. In each block, there were 120 target-present trials (30 trials including hand target items, 30 trials including face target item, 30 trials including whole body target items and 30 trials including car target item) and 120 target-absent trials. Each stimulus type had an equal number of trials with 2, 4 or 6 visual items in the display (Figure 2-2).

Each trial started with a 500 ms blank screen with a fixation cross at the centre of the screen followed by the target screen. Participants were instructed to maintain fixation on the central fixation cross. A blank screen was followed by a target screen. Before the presentation of each target screen, participants were instructed to fixate at the centre of the screen. Once the stimuli appeared, participants were to search for a hand, a face, a whole body, or a car in each trial. They were told to press as quickly as possible the ‘M’ key if a hand, a face, a whole body or a car, was present and the ‘Z’ key if neither hand, face, whole body or car were present, whilst aiming for consistently high levels of accuracy (Figure 2-2). The stimulus remained until a response was made. In order to maintain high levels of accuracy in this study and consistent speed of response, participants were encouraged to respond as quickly as possible to avoid the effect of working memory and to maintain high levels of accuracy (Olmos-Solis, van Loon, Los, & Olivers, 2017; Olmos-Solis, van Loon, & Olivers, 2018). Participants were informed that the top 3 performers in terms of accuracy (excluding long-RT outlier trials) would receive a bonus.



Before each trial, there was a slide with fixation cross in the middle.

Trial1, this was a target-absent trial ('Press the Z key').

Trial2, this was a target-absent trial ('Press the Z key').

Trial3, this was a target-present trial ('Press the 'M' key').

The visual displays were presented until a response was made.

Figure 2-2 Experiment 1 Stimulus Timeline
Stimulus timeline of visual displays in Experiment 1, showing 3 trials (2 target-absent trials, correct answer 'Z' and one target-present trial, correct answer 'M').

2.1.3 Results

Accuracy rates ranged from 86 to 99% in Experiment 1. Accuracy was tracked to ensure that the accuracy rates were not too low (above 80 %), which would have rendered the RTs questionable (Wolfe, 2018). Prior to conducting a two-way repeated measures ANOVA to examine the effects of stimulus type (hands, faces, whole bodies, cars, and absence) and set size (2, 4, and 6) on average RTs (Figure 2-3), the RT data were preprocessed. This preprocessing involved the removal of anticipatory responses (RTs < 150 ms) and outlying slow responses (RTs > 1000 ms standard deviations from the participant's mean). These steps were taken to ensure the data's quality and reliability for subsequent analyses. There was a statistically significant interaction between stimulus type and set size [F(8, 240) = 32.460, p < 0.001, η_p^2 = 0.521]. There was a statistically significant main effect of both stimulus type [F(4, 120) = 47.680, p < 0.001, η_p^2 = 0.614] and set size [F(2, 60) = 83.386, p < 0.001, η_p^2 = 0.735] on average RTs across set sizes. Pairwise comparisons revealed that there were statistically significant differences between hand and face (t = -5.349, p < 0.001, *d* = -0.253) and between hand and whole body (t = 3.906, p = 0.005, *d* = 0.209). In addition, there were statistically significant differences between hand and car (t = 3.906, p = 0.005, *d* = 0.209), between face and car (t = 3.906, p = 0.005, *d* = 0.209), and between whole body and car (t = -5.111, p < 0.001, *d* = -0.336).

The RT slopes for hands, faces, bodies, cars and absence were 13 ms/item, 6 ms/item, 32 ms/item, 33 ms/item and 62 ms/item, respectively. The results showed that the ranking of RT is faces, followed by hands and bodies, with cars being the last. The RT slopes for stimulus types were analysed by ANOVA. The results of the analysis showed a significant main effect of RT slopes [F(4, 120) = 55.140, p < 0.001, η_p^2 = 0.648] (Figure 2-3). Pairwise comparisons revealed that RT slopes were not significantly different when comparing hands and faces ($p = 0.081$); the RT slopes for hands and whole bodies were significantly different ($p < 0.001$); the RT slopes for faces and whole bodies were significantly different ($p < 0.001$), suggesting that visual search for faces is more efficient and parallel, whilst search for whole bodies is less efficient and more serial. The RT slopes for whole bodies and cars were not significantly different ($p = 1.000$), indicating that visual search for these two stimulus types is similarly efficient, falling somewhere between a parallel and serial process.

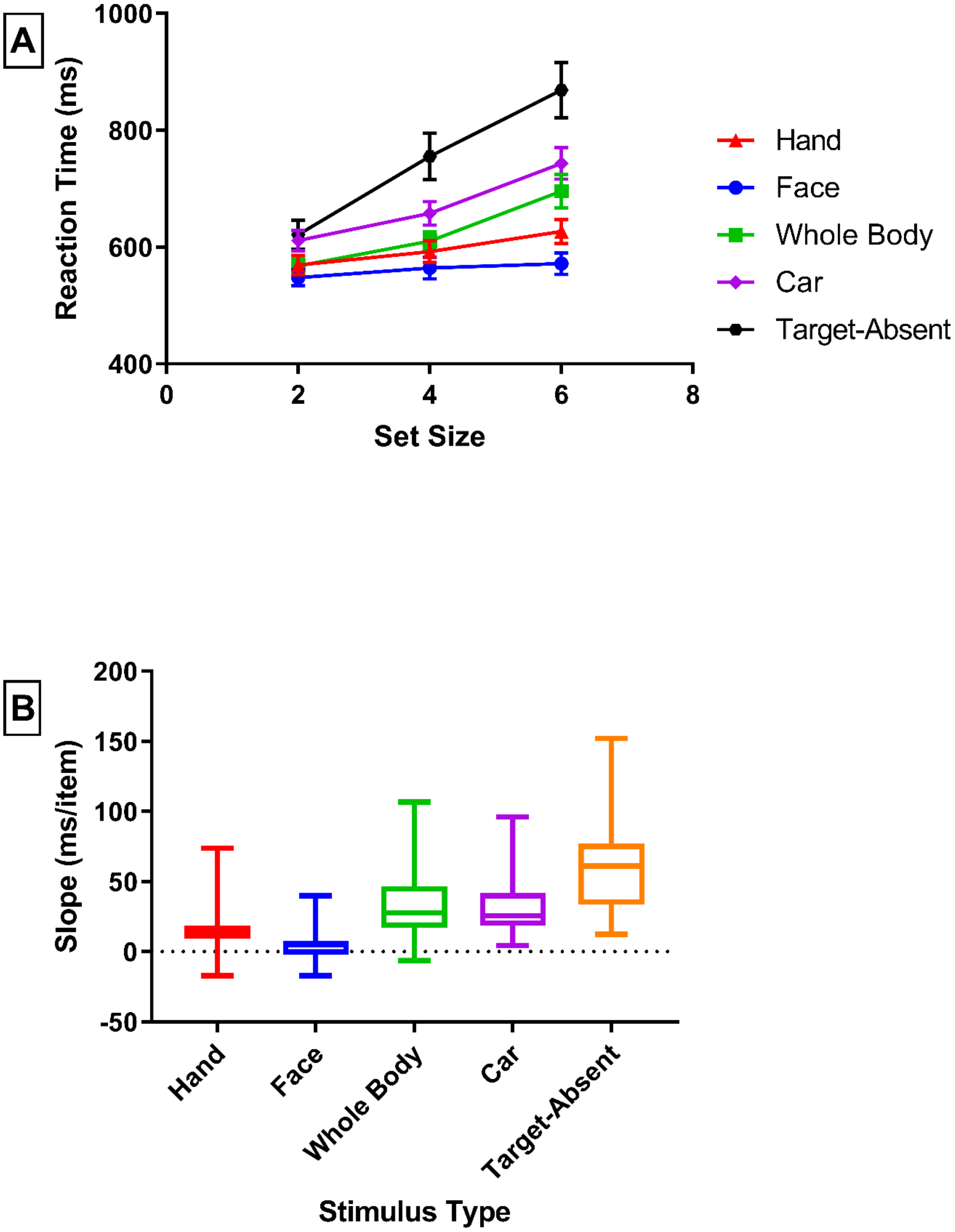


Figure 2-3 Experiment 1 results
(A) Average RTs across set sizes on search set size and stimulus type. (B) RT slopes. The box plot shows 2.5%, 25%, 50% (median), 75% and 97.5% percentiles. There is a significant difference between the hand and the whole bodies.

2.1.4 Discussion

Participants were asked to identify hands, faces, whole bodies, and nonhuman body objects (in this experiment, cars) out of different sets of distractors to see whether average RTs across set sizes (mean RTs) and RT slopes changed dependent on the interaction between stimulus type and set size.

Regarding RTs across set sizes, the results showed that the average RTs across set sizes for hands, faces and whole bodies were significantly smaller than for cars across set sizes. These results implied that, in addition to faces, stimuli of other parts of the human body spontaneously capture attention and are relevant for models of social perception. The research reviewed here supported the prediction of Experiment 1, namely, that the average RT across set sizes for hands was different from that for whole bodies. This observation suggests that despite hands, faces, and whole bodies all being components of the human form, they are processed distinctly by the visual system. The differential response patterns indicate that these body parts, though related, likely engage separate cognitive mechanisms or neural pathways during visual recognition tasks. The visual properties of the different stimuli related to the human body were different in visual search. This study also showed that the visual property of hands was more salient than that for whole bodies because the average RT across set size for hands was higher than that for whole bodies (Crostella, Carducci, & Aglioti, 2009; Geiger et al., 2017).

Regarding RT slopes, the results showed that the RT slope for hand stimuli was less steep than that for whole body stimuli. Although the hand did not generate the pop-out effect, which is defined as an RT slope of zero ms/item, the result still indicated that participants had a higher visual search efficiency for hand stimuli than for whole body stimuli. In addition, the RT slope for hand stimuli was not significantly different from that for face stimuli. This indicates that participant visual search efficiency for hand stimuli did not differ from that for face stimuli. As expected, the RT slope for the face stimuli was the least steep of all the stimulus types, and they generated a pop-out effect in visual search. This result corroborates the findings of a considerable amount of previous work in visual search for face stimuli (Goold & Meng, 2016; Hershler & Hochstein, 2005, 2006). Surprisingly, the slope for whole body stimuli was not significantly different from that for car stimuli.

These results confirmed that the visual search for hands could be a high-level phenomenon such as occurs for faces, and demonstrated that gist information contributed significantly to rapid hand detection, but these results did not reveal why the RT slope for hand stimuli was less steep than that for whole body stimuli (Goold & Meng, 2016; Hershler & Hochstein, 2005, 2006).

The results in this experiment were supported by Kanwisher's fMRI results and Perrett's single-unit recordings results (Kanwisher, Tong, & Nakayama, 1998; Perrett, Rolls, & Caan, 1982), the latter indicating that the effective category of faces was represented by specialised 'face cells'. These neuronal populations (face cells) could form a feature map for face detection (Borji, Sihite, & Itti, 2013). In addition, studies have revealed that some neurons respond selectively to the shapes of individual body stimuli (de Gelder et al., 2010; Peelen & Downing, 2007), and hand-selective cells respond strongly to human hand stimuli of different orientations and sizes (Clark & Colombo, 2018). The different selective cells can be seen in the variety of RTs in visual search for different parts of the human body.

The findings in this experiment indicated that hand stimuli have a high visual search efficiency when among a variety of distractors. The difference in RT slopes can be explained by feature integration theory. Feature integration theory suggests that when perceiving a stimulus, features are “registered early, automatically, and in parallel, whilst objects are identified separately” and at a later stage in processing (Wolfe, 1994b). When RT is set size independent, the distinctive feature is detected in parallel by a preattentive mechanism (Treisman, 1985; Treisman & Gormican, 1988). It is necessary here to clarify what is meant by a preattentive mechanism. ‘A preattentive mechanism’, also called ‘spread-attention’, is when a feature search (pop-out) is performed to find the odd element out of a series of distractors.

The experiment highlights that visual search mechanisms should not classify faces as simple low-level visual elements, but rather as holistic, 'face-like' features. This approach is supported by the feature interaction theory, where visual search involves explicit neuronal representations of target features distinct from distractors (Treisman, 1985; Treisman & Gormican, 1988). Separate perceptual dimensions, such as 'colour' or 'orientation', are represented on individual maps, enabling the detection of objects like 'red' or 'green', and 'vertical' or 'horizontal', respectively. Focused attention retrieves location information from these maps, although objects matching the feature maps can be detected without focused attention on a master map (Dumoulin, 2015; Somers & Sheremata, 2013). The concept of search asymmetry, particularly for faces, suggests the presence of a specialised feature map for faces (Hershler & Hochstein, 2005, 2006). Detection without attention occurs when object features align with those on the feature maps, not affecting RTs despite the number of distractors. Focused attention is consolidated on a master map to initiate perception processing, which consumes significant attention resources (Cavanagh, 2011; Geng & Behrmann, 2003).

Specialised neurons in the high-level visual cortex enable parallel search for face stimuli through a pop-out mechanism in preattentive processing, recognising 'face' features distinctively (Grill-Spector, Weiner, Gomez, Stigliani, & Natu, 2018; Grill-

Spector, Weiner, Kay, & Gomez, 2017). Studies show that RT slopes for human versus animal faces differ significantly despite their physical similarities like eye symmetry (Hershler & Hochstein, 2005, 2006). This highlights that high-level facial features are not uniformly processed in parallel categorisation, suggesting different visual processing for stimuli related to human and nonhuman bodies.

Experiment 1 examined whether human body stimuli were a feature in preattention early perception. If human body stimuli can be considered a feature, the RT slopes between hands, faces and whole bodies would not be significantly different. The results in this experiment did not support the prediction that the RT slopes between hand stimuli, face stimuli and whole body stimuli were significantly different, and the visual search efficiency for hand and face stimuli were greater than for whole body stimuli. The low visual search efficiency of the whole body, indicated by the RT slope, was surprising due to the anatomical similarities between faces and whole bodies. Thus, it can be deduced that human body stimuli cannot be considered a feature based on anatomical factors but can be considered a feature based on neural similarities. Regarding the different RT slopes associated with human body stimuli, neural similarity across different parts of the human body could explain these differences (Bracci, Caramazza, & Peelen, 2015; Bracci et al., 2012). Neural similarity is a concept using fMRI to construct a map representing the correlation between discrete objects. The RT of visual search in human body features correlates with the neural familiarity of parts of the human body (Bracci, Ritchie, & de Beeck, 2017; Cohen, Alvarez, Nakayama, & Konkle, 2017). In an experiment by Bracci, the different regions of the brain responding to hand, face, whole body stimuli were delineated in the occipitotemporal cortex (Bracci et al., 2015; Bracci et al., 2012), and a matrix was used to compare the neural similarities between the different parts of the human body. Faces were found to have a higher correlation with hands than whole bodies, and the gap between hands and whole bodies was larger than the gap between faces and hands. This probably implied why the visual search efficiency of visual search between hands and faces was not significantly different.

In summary, Experiment 1 indicates that hand perception demonstrates a high degree of visual search efficiency for hands compared to whole bodies, as evidenced by the average RT across set sizes and RT slope. However, this efficiency does not appear to align with a purely parallel search mechanism. Whilst hands may be processed more efficiently than bodies or objects, their search efficiency may not be as distinct as that of faces. These findings suggest that the processing of hands occupies a unique position on the parallel-to-serial continuum, warranting further investigation to elucidate the specific mechanisms underlying hand perception.

2.2 Experiment 2: Is Visual Search Different for Finger Postures (Distorted or Natural) vs Chairs (Distorted or Standard) As Control Images? (An RT Measurement)

2.2.1 Introduction

Experiment 1 revealed differences in both average RTs across set sizes and RT slopes across various body part stimuli. Specifically, it is found significant differences in average RTs between hands and faces, as well as between hands and whole bodies. Regarding RT slopes, there was a significant difference between whole bodies and hands, but no significant difference between hands and faces. These findings suggest that both the overall speed of processing (reflected in average RTs) and the efficiency of visual search (indicated by RT slopes) vary depending on the type of body part stimulus, with hands showing distinct patterns compared to both faces and whole bodies. The RT method for the visual search task was employed in this experiment, and participants were requested to detect a target in an arrangement of distractors and respond by pressing the button as quickly and accurately as possible. The visual search task was conducted to investigate the average RTs across set sizes and RT slopes among the various body stimuli. The average RTs across set sizes of stimuli represent the time to detect the target among its distractors (Wolfe et al., 2010).

Additionally, the RT slopes are a manifestation of visual search efficiency in detecting the targets (Horstmann, Becker, & Grubert, 2020; Wolfe, 2018). Given that hands are a biologically and socially significant stimulus, further investigation into their processing is warranted. Specifically, examining distorted finger postures is relevant for several reasons. First, it allows for the exploration of the boundaries of the perceptual system in processing hand configurations. Second, it can provide insights into how the system adapts to variations in stimuli. Lastly, understanding the perception of distorted hands has practical implications, such as informing the design of prosthetics or virtual reality interfaces. Therefore, differences between distorted and natural finger postures in this study could reflect the unique geometric properties of the distorted stimuli and shed light on the adaptability of the visual processing system.

The purpose of this experiment was to investigate (1) the visual property between distorted and natural finger postures by comparing the difference in average RT across set sizes and (2) the visual search efficiencies between distorted finger postures and natural finger postures by comparing the difference in RT slopes. This research tested two predictions: (1) that the average RT across set sizes for distorted finger postures would be smaller than that for natural finger postures, and (2) that the RT slope for both distorted and natural finger postures would be smaller than that for chairs (both distorted and standard).

2.2.2 Method

2.2.2.1 Participants

Forty-six students from the University of Nottingham Malaysia, 22 females and 24 males (18-45 years, $M = 22.80$, $SD = 2.62$) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment. The recruitment requirements for this experiment were the same as for Experiment 1. One participant's data was excluded from the analysis as it met the criteria for an outlier. An outlier was defined as any data point that fell more than 3 standard deviations away from the mean of the sample or had a z-score greater than ±3.29 (Leys, Ley, Klein, Bernard, & Licata, 2013). Based on assuming 3 (set size 2, 4 and 6) x 2 (hands and chairs) x 2 (distorted and natural) within-subject factors and keeping the same other parameters as in Experiment 1 in a priori analysis for G*Power, a sample size of 18 was sufficient. The SEREC evaluated and endorsed this study. The research project was assigned the identifier HYC150221, and the committee provided ethical approval for the experimental protocols.

2.2.2.2 Materials and apparatus.

The visual items were used in the same way as in Experiment 1. The stimuli in target-present conditions were replaced by distorted finger postures, natural finger postures, distorted chairs and standard chairs (Figure 2-4). Distorted finger postures and natural finger postures (first-person perspective, dorsal view) were computer-generated images from Espírito Santo, Chen, et al. (2017), used with the authors' permission. 'Distorted finger postures' refers to hands with the middle finger bent at the second joint from the knuckle. Chairs, also modelled after Espírito Santo, Chen, et al. (2017), were the control stimuli that corresponded to the hands in terms of geometrical complexity. 'Distorted chairs' refers to chairs with a leg bent two thirds from the bottom of the leg. The distractors were the same as in Experiment 1 as was the visual search display. The distance between each item in this experiment was the same as in Experiment 1. The number of target and absent stimuli was the same as in Experiment 1. The stimuli in target-present conditions were replaced by either distorted finger postures, natural finger postures, distorted chairs or standard chairs (Table 2). The experiment was demonstrated in the same manner as Experiment 1.

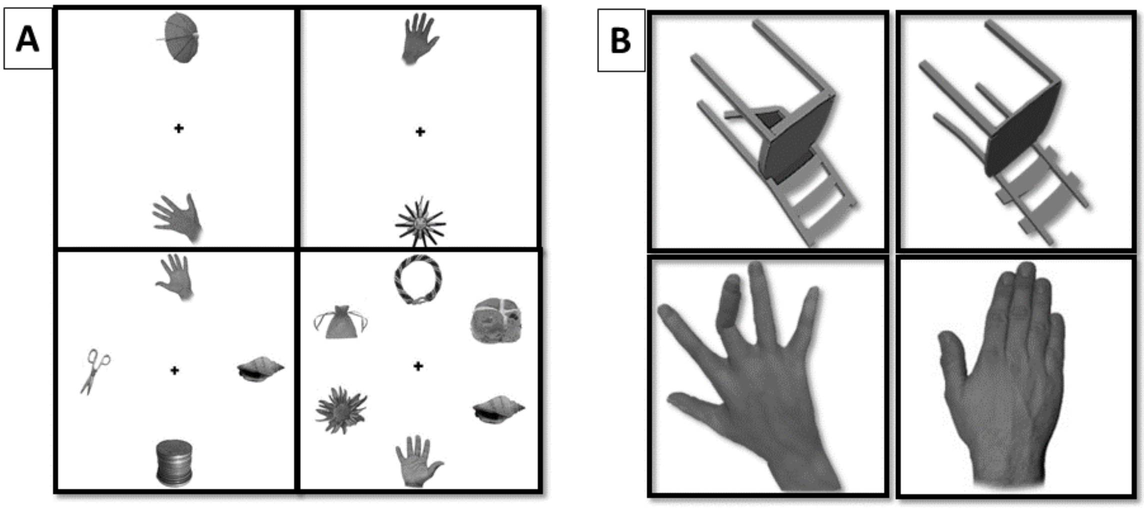


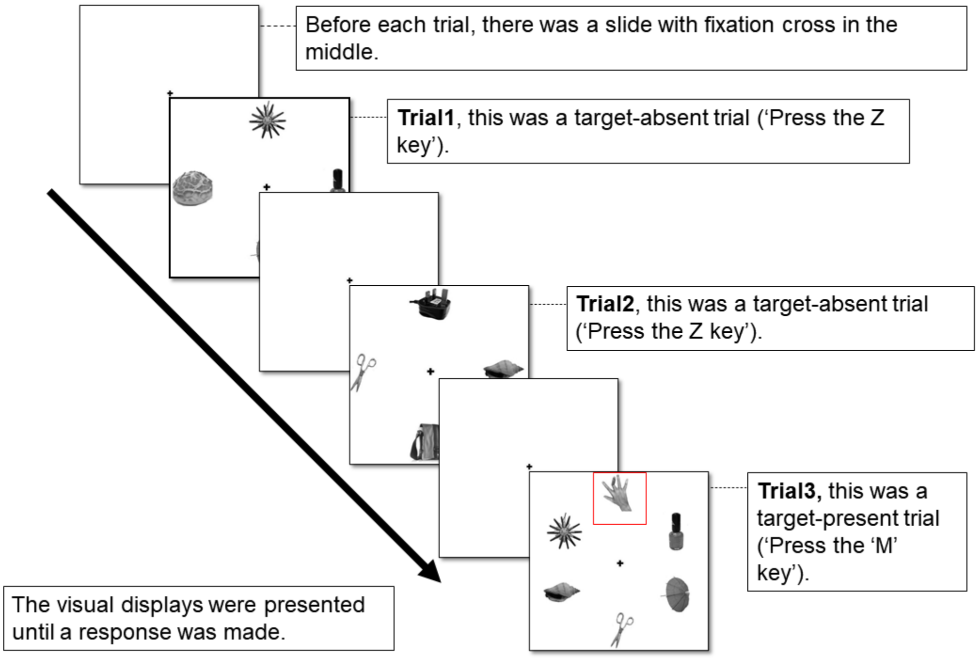
Figure 2-4 Examples of visual displays and examples of target items in Experiment 2 (A) Examples of visual displays containing set sizes 2, 4 and 6 visual items, each example of a target stimulus and one or more distractors. Distractors only displays were not shown in the figure. (B) Examples of target stimuli from top left to bottom right: distorted chair, standard chair, distorted finger posture and natural finger posture.

Table 2 The stimuli of Experiment 2
The experimental structure of one block of 240 trials in Experiment 1. The experiment comprised four blocks.

Group	Set size	Stimuli	Number of trials
Absent condition (120 stimuli)	2	All distractors	40
	4	All distractors	40
	6	All distractors	40
Target condition (120 stimuli)	2	Distorted finger posture with distractors	10
		Natural finger posture with distractors	10
		Distorted chair with distractors	10
		Standard chair with distractors	10
	4	Distorted finger posture with distractors	10
		Natural finger posture with distractors	10
		Distorted chair with distractors	10
		Standard chair with distractors	10
	6	Distorted finger posture with distractors	10
		Natural finger posture with distractors	10
		Distorted chair with distractors	10
		Standard chair with distractors	10

2.2.2.3 Design and procedure

The experimental design and procedure were the same as in Experiment 1. The target stimuli were replaced by either distorted finger postures, natural finger postures, distorted chairs or standard chairs (Figure 2-5).



Before each trial, there was a slide with fixation cross in the middle.

Trial1, this was a target-absent trial ('Press the Z key').

Trial2, this was a target-absent trial ('Press the Z key').

Trial3, this was a target-present trial ('Press the 'M' key').

The visual displays were presented until a response was made.

Figure 2-5 Experiment 2 Stimulus Timeline
Stimulus timeline of visual displays in Experiment 2, showing 3 trials (2 target-absent trials, correct answer 'Z' and 1 target-present trial, correct answer 'M').

2.2.3 Results

Accuracy rates ranged from 87% to 99% in Experiment 2. Accuracy was recorded to ensure that the error rates were not too high, rendering RT questionable (Wolfe, 2018). In contrast to Experiment 1, the data of target-absent trials were excluded from the results because they were not relevant to the specific research question of interest, which focused solely on the hands and chairs data.

The average RTs across set sizes were analysed using a three-way repeated measures ANOVA over configuration (distorted and natural), the stimulus types (hands and chairs), and the set sizes of the search array (2, 4 and 6 items) (Figure 2-6). There was no significant three-way interaction between stimulus type, configuration and set size [$F(2, 88) = 1.602$, $p = 0.207$, $\eta_p^2 = 0.035$]. For the two-way interactions, there was a significant two-way interaction between stimulus type and set size [$F(2, 88) = 14.869$, $p < 0.001$, $\eta_p^2 = 0.253$]. None of the other two-way interactions were significant. There was a significant main effect of configuration [$F(1, 44) = 6.533$, $p = 0.014$, $\eta_p^2 = 0.130$]; stimulus type [$F(1, 44) = 58.901$, $p < 0.001$, $\eta_p^2 = 0.572$] and set size [$F(2, 88) = 160.162$, $p < 0.001$, $\eta_p^2 = 0.784$]. For further analysis of average RTs across set sizes for hands only to remove the effect of chairs in the statistical analysis, a two-way ANOVA was conducted with two within-participant factors of condition (configuration and set sizes). There was a significant main effect of configuration [$F(1, 44) = 15.843$, $p < 0.001$, $\eta_p^2 = 0.265$].

The RT slopes for stimulus types were analysed by two-way repeated measures ANOVA (Figure 2-6). There was a main effect of configuration [$F(1, 44) = 29.380$, $p < 0.001$, $\eta_p^2 = 0.400$]. The results of the analysis showed an interaction of RT slopes between configuration and stimulus types [$F(1, 44) = 5.703$, $p = 0.021$, $\eta_p^2 = 0.115$]. The RT slopes for distorted finger postures tended to be smaller than RT slopes for natural finger postures [$t(44) = -2.029$, $p = 0.049$]. In addition, there was no significant difference between the RT slopes for distorted chairs and the RT slopes for standard chairs [$t(44) = 0.785$, $p = 0.437$].

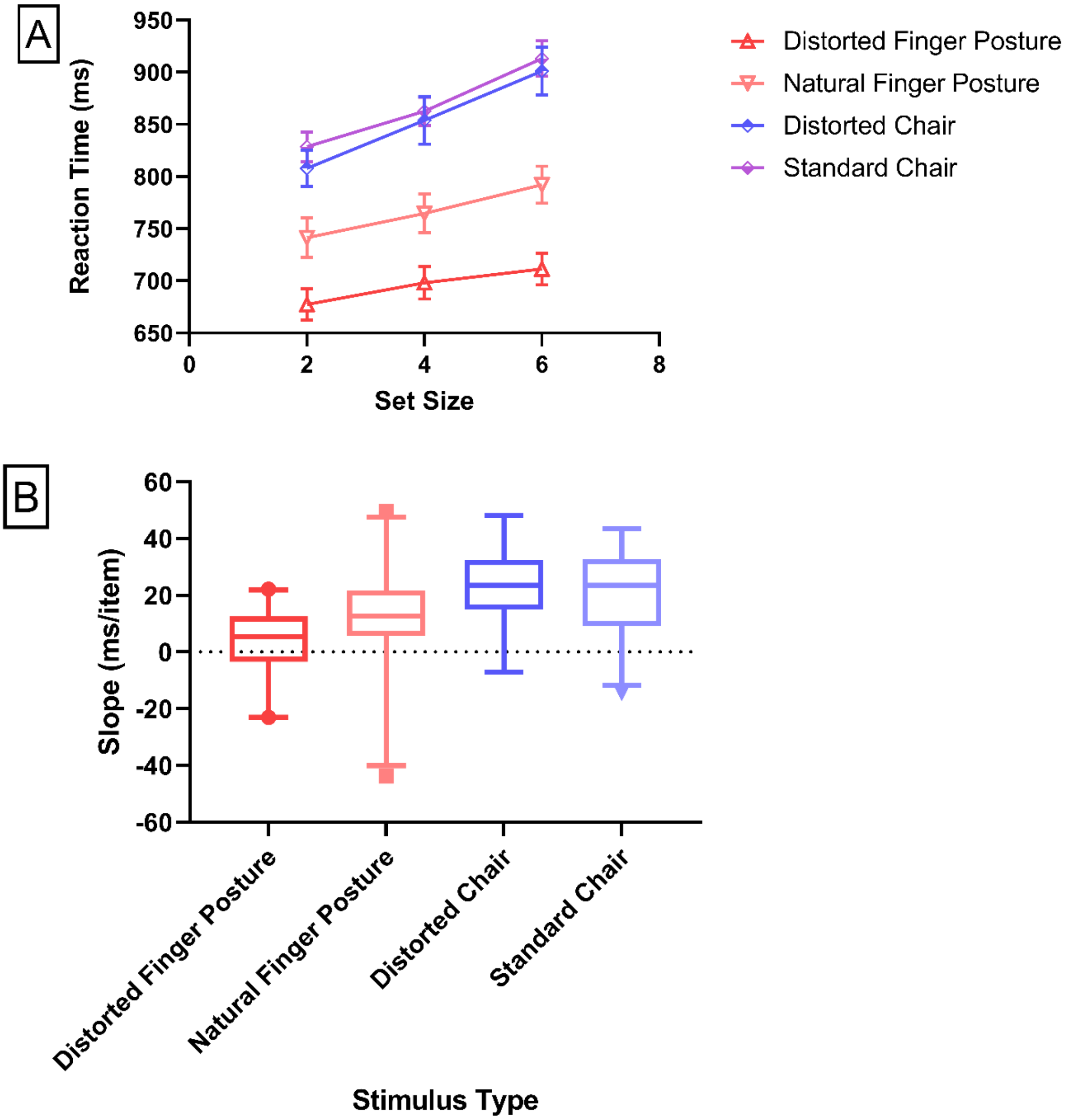


Figure 2-6 Experiment 2 results
(A) Average RTs across set sizes on search set size and stimulus type (distorted finger post) with SE bars. (B) RT slopes taken from panel A represent either parallel or serial search in Experiment 2. The box plot shows 2.5%, 25%, 50% (median), 75% and 97.5% percentiles. There is a significant difference between the distorted and natural finger postures. The high slope in the box plot for the natural finger posture condition, whilst notable, do not necessarily indicate a problem with the data or the experimental design. Rather, they provide valuable information about the broader distribution of response times in this condition, potentially reflecting natural variability in how participants process these stimuli.

2.2.4 Discussion

Experiment 1 showed that the average RT across set sizes and the RT slope for hand stimuli compared to whole body stimuli were significantly different. The question in this experiment was to determine whether the RTs for distorted finger posture stimuli differed significantly from the RTs for natural finger posture stimuli. Interestingly, the average RTs across set sizes for distorted finger posture stimuli differed significantly from the RTs for natural finger posture stimuli. In addition, the RT slope for distorted finger posture stimuli was flatter than that for natural finger postures, but the RT slope for distorted chairs was the same as that for standard chairs.

A possible explanation for the difference in average RTs across set sizes between distorted finger posture stimuli and natural finger posture stimuli in visual search would be that the various selective cells (each part of the human body has a specific brain cell attributed to it for visual processing) respond differently to different configurations of hands (e.g. distorted and natural finger postures) (Perrett et al., 1989).

Previous research showed fMRI results and single-unit recordings which indicated that the category of hands was represented by specialised 'hand cells', which responded to the shape of hands (Kanwisher et al., 1998; Perrett et al., 1982). Additional studies have confirmed that hand-selective cells respond strongly to human hand stimuli of different orientations and sizes and also that specific neurons respond selectively to the shapes of individual whole bodies (Peelen & Downing, 2007; Perruchoud, Michels, Piccirelli, Gassert, & Ionta, 2016). Therefore, a speculative interpretation based on these findings could be that there are two different populations of hand cells, one responding to distorted finger postures and the other to natural finger postures.

The results for distorted and natural finger postures as shown in the slopes may be explained by the fact that distorted finger postures are not considered as a single holistic feature (i.e. ‘distorted finger postures feature’); instead, the distorted finger postures were broken down into feature maps of natural finger postures and distorted human body, according to feature integration theory (Nakayama & Martini, 2011). On the other hand, the specialised cell prediction suggests that there may be neurons specifically tuned to recognise distorted finger postures as a whole. This theory posits that the brain has dedicated neural pathways for processing unique or frequently encountered stimuli(Gross, 2016). When RT is independent of set size, a distinctive feature like a distorted finger is detected in parallel by a preattentive mechanism (Treisman, 1985; Treisman & Gormican, 1988). Each feature map represents a specific attribute, such as colour or orientation. In this case, the distorted finger is preferentially processed as an individual feature, rather than the entire distorted hand popping out as a holistic entity.

Attention is necessary to retrieve feature location information from these maps, but the presence and amount of visual items can be detected without focusing attention on the feature map (Dumoulin, 2015; Somers & Sheremata, 2013). Search asymmetry is typically accounted for by the feature map encoding the features. If there is no difference in the RT slopes between distorted and natural finger postures, there is no effect of the search asymmetry. If there is a difference in the RT slopes between distorted and natural finger postures, there is an effect of search asymmetry. In the results, there is little evidence of the effects of search asymmetry, so the features of the maps are not conclusive (Hershler & Hochstein, 2005, 2006).

There is a possible explanation based on feature integration theory for the interaction between stimulus type, configuration and set size. The RT slopes for similar objects are not different. Therefore, the RT slopes for distorted and natural finger postures, which are similar objects, logically should not be different; the RT slopes for distorted and standard chairs, which are similar objects, logically should not be different, either. However, the RT slopes for distorted and natural finger postures were different. The reason is that if (1) a feature map is an essential map (e.g., colour or orientation feature map) in the master feature map of humans (the hand feature map is an essential feature map) and (2) this feature map is a proper subset of a feature map of another object (e.g., the hand feature map of natural finger postures is a proper subset of the hand feature map of distorted finger postures), the RT slopes for these two objects are different (Itti, Koch, & Niebur, 1998; Kristjánsson & Egeth, 2019; Schade & Meinecke, 2013). This is because the brains are more attuned to detecting unusual or unexpected features, such as those found in distorted finger postures, leading to faster RTs. The reason is that the mutual exclusivity of a shared feature facilitates the detection of objects from the remaining gist information.

Thus, the distorted finger postures shared the hand feature (an essential feature map in the master feature map), with the natural finger postures. Therefore, the RT slope for the distorted finger postures differed from that for the natural finger postures because the remaining gist information (distorted human body feature) facilitated the detection of the distorted finger postures. Another possible explanation for the result in this experiment is that the hand feature maps are combined into a conspicuity map where the stimuli related to unusual human body will be encoded using preattentive processing without any attention (Itti et al., 1998). Such encoding does not occur for distorted chairs. In other words, the distorted chairs are not considered salient compared to the distorted finger postures.

Hence, it could conceivably be observed that the average RTs across set sizes for hands differed from chairs among the different set sizes, even though the shape of hands and chairs are similar. In addition, the RT slope for distorted finger postures differed from natural finger postures, but the RT slopes for distorted chairs are not different from standard chairs. This result confirms that the effect of distortion occurs only on the hands rather than on chairs. This demonstrates that gist information contributes significantly to rapid distorted hand detection, rather than distorted chairs (Goold & Meng, 2016; Hershler & Hochstein, 2005). The results coincide with some neuronal populations that may constitute a feature map of sorts for the distorted finger posture (Borji et al., 2013; Clark & Colombo, 2018).

Further work must be done to understand the mechanisms which contribute to the difference in average RTs across set sizes between distorted finger postures and natural finger postures. In particular, it is necessary to separate the contributions of active vision and passive vision. In typical accuracy measurements, a way to exclude a contribution from active vision is to run accuracy measurements with stimuli presented for less than 200 ms, avoiding participant eye movements (Wolfe, 2018). It was considered that accuracy measurements, taken after stimulus presentation when participants were no longer required to maintain fixation, would usefully supplement and extend the result from RT measurements, given that accuracy does not suffer from the issues of eye movement (Findlay & Gilchrist, 2003). The accuracy measurements can overcome the limitations of RT measurements in visual search tasks, with the latter whose source of processing information is not only from passive vision but also from active vision (Degno & Liversedge, 2020; Kornrumpf et al., 2016). In contrast, the accuracy method collects data from the passive vision only. This difference is crucial for accurately interpreting results and drawing valid inferences about visual perception.

In summary, the slope of the RT × set size function is flatter for distorted finger postures than for natural finger postures. It is evidently clear from the findings that visual and cognitive processes are not caused by the fact of geometric complexity. These findings can contribute to a better understanding of distorted human bodies in visual and cognitive processes.

2.3 Experiment 3: Is Visual Search Different for Hands, Faces and Whole Bodies When Viewed at a Glance? (An Accuracy Measurement)

2.3.1 Introduction

Visual perception plays a crucial role in how humans interact with the world around us. Whilst researchers have extensively studied various aspects of visual processing, some areas remain unexplored. Although prior studies have noted the importance of hand perception in RTs of visual search, little was found in the literature on whether there were differences between faces, whole bodies and hands in the proportion of correct response as indices of passive vision in performing RSVP with the limitations of time, where a sequence of stimuli is shown to an observer in a specific visual field. The participant must detect a visual target stimulus out of these stimuli. This experiment sets out to investigate differences in visual processing of faces, whole bodies, and hands in passive vision.

Attention selects and limits information available at various levels of processing. Visual search tasks provide a structured window into the vast world of attentional phenomena (Jiang, 2018; Kruse et al., 2016). Two behavioural measures are of concern in classic visual search tasks: RT and accuracy (Wolfe, 2018). Accuracy here is defined as the proportion of correct responses in visual search (Porter et al., 2007). In typical visual search tasks with RT measurements, stimuli are presented until participants respond. The RTs are indices of visual search, and accuracy is also recorded, but only to ensure that error rates are not so high that they would influence the RTs (Heitz, 2014). Visual search tasks using accuracy measurements present stimuli for <200 ms to prevent eye movement (Findlay & Gilchrist, 2003; Wolfe, 2018). This method overcomes limitations of RT measurements by focusing solely on passive vision, whilst RT methods involve both active and passive vision (Degno & Liversedge, 2020;

Kornrumpf et al., 2016). By contrast, the accuracy method collects data from passive vision only. Human body perception plays a crucial role in visual search. Human body perception in visual search is well known for effective and fast visual processing of hands and distortions in observed finger postures from Experiment 2. Little is known about this occurrence and whether it is caused by active or passive vision. Experiment 3 examined whether this occurrence is caused by active vision or passive vision.

Compared to visual searches of faces, visual searches of whole bodies and hands are understudied areas; and little is known about the accuracy method applied in the visual search of human bodies. Here, the effects of human body visual stimuli on RT slopes were examined in Experiment 1. Visual search with accuracy measurement was used to evaluate the proportions of correct visual search responses. Visual search with accurate measurement is a method of studying the timing of vision. In RSVP, the paradigm of visual search, stimuli are presented rapidly (usually defined as less than about 200 ms) to prevent any voluntary eye movements (Belopolsky & Theeuwes, 2010; Tyng et al., 2017; Wieser et al., 2006).

This experiment investigates the differences in visual search accuracy slopes between hands and whole bodies. Building upon previous research in this thesis that showed significant differences in RT slopes for these stimuli, the prediction was that the visual search accuracy slopes for hands would be smaller than those for whole bodies, suggesting more efficient processing for hand images in RSVP tasks. By examining this relationship, the research intends to expand the understanding of RSVP processing for hands versus whole bodies. The results of this experiment contribute valuable insights into the distinct perceptual mechanisms involved in recognising these different body-related stimuli, furthering the comprehension of how the visual system processes hands and whole bodies differently. These insights reveal a more complex picture of hand perception than previously understood. A critical insight is the confirmation that hands are processed more efficiently than whole bodies in RSVP tasks, as evidenced by smaller accuracy slopes. Another crucial insight extends beyond this, demonstrating that the perceptual advantage of hands over whole bodies is not limited to RTs but also encompasses accuracy measures. This dual advantage in both speed and precision offers the insight that there is a robust, multi-faceted processing priority for hand stimuli in the visual system.

2.3.2 Method

2.3.2.1 Participants

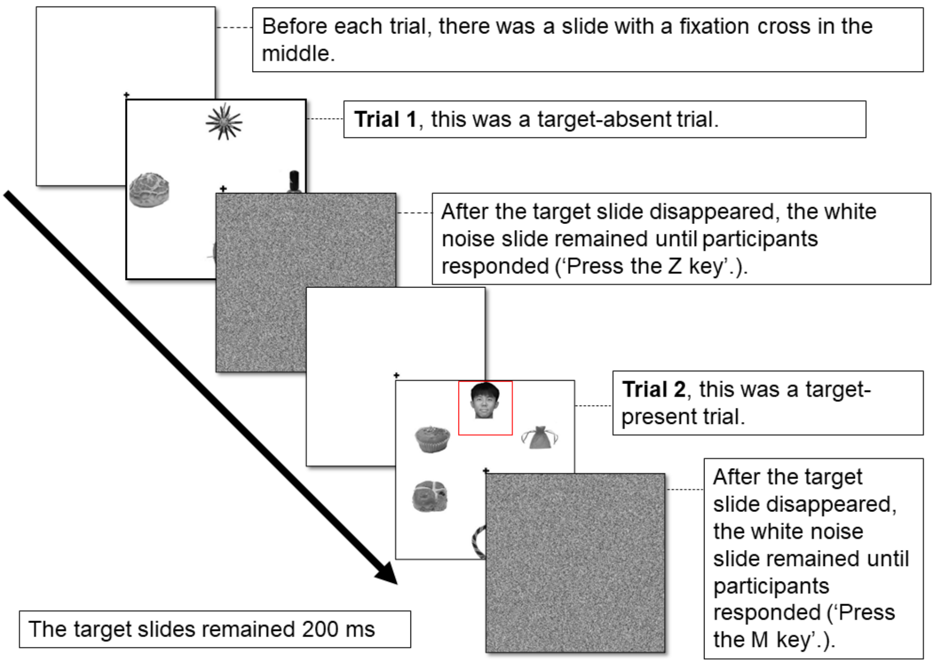
Thirty-seven students from the University of Nottingham Malaysia, 25 females and 12 males (18-45 years, *M* = 22.80, *SD* = 2.62) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment. The recruitment requirements for this experiment were the same as for Experiment 1. Based on assuming 3 (set size 2, 4 and 6) x 4 (hand, face, whole body and car) within-subject factors and keeping the same other parameters as in Experiment 1 in a priori analysis for G*Power, a sample size of 18 was sufficient. This research project, identified by the application number HYC150221, was reviewed and approved by the University of Nottingham Malaysia's SEREC. The committee granted ethical clearance for the study's procedures.

2.3.2.2 Materials and apparatus

The visual items were used in the same way as in Experiment 1. All items were altered to have the same luminance and contrast using the SHINE toolbox (Willenbockel et al., 2010). The visual search display in this experiment was the same as in Experiment 1. The distance between each item in this experiment was the same as in Experiment 1. The number of target and absent stimuli was the same as in Experiment 1. The visual search display was 35 cm horizontally and 18 cm vertically. Participants were asked to sit 57 cm away from a monitor. The experiment was presented and coded using Pavlovia online, which is an online hosting service that accommodates different types of JavaScript experiments (Grootswagers, 2020; Sauter, Draschkow, & Mack, 2020).

2.3.2.3 Design and procedure

The experimental design was the same as in Experiment 1. Each trial started with a 500 ms blank screen with a fixation cross at the centre of the screen followed by the target screen. Participants were instructed to maintain fixation on the central fixation cross for the duration of the trial. The target screen remained visible for 200 ms, followed by a white noise slide. The purpose of the white noise slide is to prevent participants from using any residual visual information from the target screen, ensuring that their responses are based solely on their perception during the brief presentation of the target. Participants were instructed to detect a particular kind of stimulus, e.g. a hand, a face, a whole body or a car in each trial. They were told to press the 'm' key if a hand, a face, a whole body, or a car, was present, and the 'z' key if other stimuli were present (Figure 2-7). The white noise screen remained until a response was made. In order to maintain high levels of accuracy in this study and consistent speed of response, participants were encouraged to respond as quickly as possible to avoid the effect of working memory and maintain high levels of accuracy (Olmos-Solis et al., 2017, 2018). The top 3 participants whose accuracies were not outliers with the highest RT would receive a bonus.



Before each trial, there was a slide with a fixation cross in the middle.

Trial 1, this was a target-absent trial.

After the target slide disappeared, the white noise slide remained until participants responded ('Press the Z key'.).

Trial 2, this was a target-present trial.

After the target slide disappeared, the white noise slide remained until participants responded ('Press the M key'.).

The target slides remained 200 ms

Figure 2-7 Experiment 3 Stimulus Timeline
Stimulus timeline of visual displays in Experiment 3, showing 2 trials (1 target-absent trial, correct answer 'Z' and 1 target-present trial, correct answer 'M').

2.3.3 Results

The average proportions of correct responses across set sizes were analysed using a two-way repeated measures ANOVA over the stimulus types (face, whole bodies, hands and cars), and the set sizes (2, 4 and 6 items) (Figure 2-8). There was a significant main effect of stimulus type [$F(3, 69) = 68.838$, $p < 0.001$, $\eta_p^2 = 0.750$] and set size [$F(2, 46) = 90.539$, $p < 0.001$, $\eta_p^2 = 0.\ 0.797$]. For the two-way interactions, there was a significant two-way interaction between stimulus types and set sizes ($F(6, 138) = 32.621$, $p < 0.001$, $\eta_p^2 = 0.586$). Pairwise comparisons revealed that the proportions of correct response slopes were significantly different between faces and cars ($p < 0.001$); between hands and cars ($p < 0.001$); between whole bodies and cars ($p < 0.001$). Additionally, there was a significant difference between hands and whole bodies ($p = 0.003$), but there was no significant difference between hands and faces ($p = 0.134$).

The proportions of correct response slopes were analysed by ANOVA (Figure 2-8). There was a significant main effect of stimulus types [$F(3, 69) = 50.918$, $p < 0.001$, $\eta_p^2 = 0.689$]. Pairwise comparisons revealed that the proportions of correct response slopes were significantly different between faces and cars ($p < 0.001$); between hands and cars ($p < 0.001$), but they were not significantly different between whole bodies and cars ($p = 0.219$).

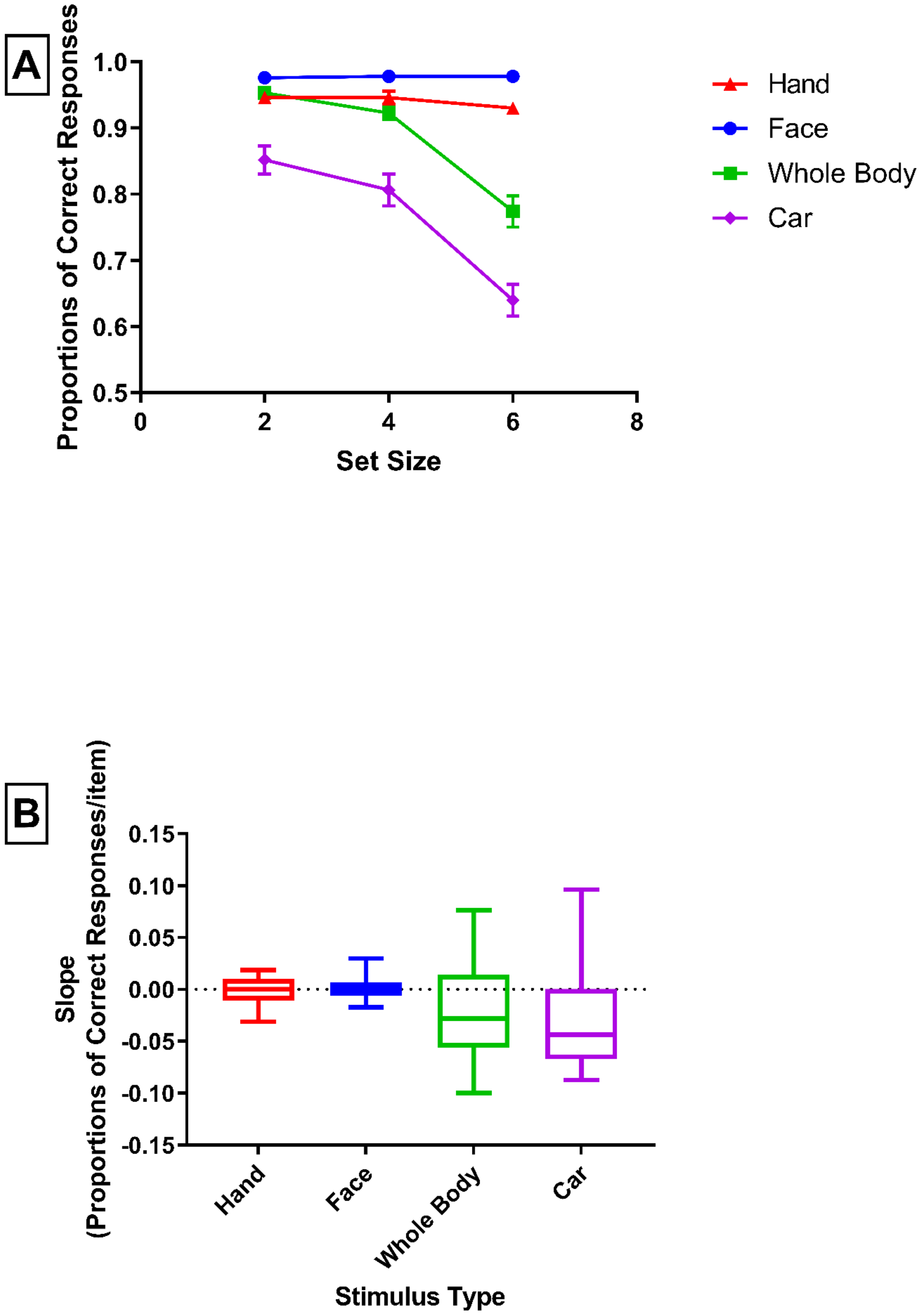


Figure 2-8 Experiment 3 results
(A) Average proportion of correct response across set sizes on search set size and stimulus type. (B) The slopes of the proportion of correct responses. The box plot shows 2.5%, 25%, 50% (median), 75% and 97.5% percentiles. There is a significant difference between the hand and the whole body.

2.3.4 Discussion

This experiment found that the average proportions of correct response across set sizes between hands and faces were not significantly different but for hands and whole bodies they were. In addition, the results of this experiment indicate that the proportion of correct response slopes between hands and faces were not significantly different but that for hands and whole bodies they were. One unexpected finding was that there was no significant difference between whole bodies and cars.

There are similarities in performing the visual search between hands, faces and whole bodies in Experiment 1. This result may be explained by the fact that high-level activity with generalisation over spatial and other property details for human body stimuli occurs not only in active vision (voluntary eye movement) but also in passive vision (involuntary eye movements). Despite this, possible interference with eye movements cannot be ruled out. The results probably can only confirm that high-level activity of visual search for the features of hands and faces is performed regardless of whether in the mechanism of active vision or passive vision.

These findings suggest that hands, like faces, benefit from efficient processing even without active eye movements, whereas headless bodies do not share this advantage. This study employed passive vision, i.e., visual search without involuntary eye movement, to reveal the unique 'pop-out' effect of hands. Passive vision was crucial in this context as it allowed us to demonstrate the automatic processing of hands without the potential confounds introduced by saccades. This highlights the importance of controlled visual search paradigms in uncovering the special status of biologically relevant stimuli, such as hands and faces, in visual processing.

2.4 Experiment 4: Is Visual Search Different for Finger Postures (Distorted or Natural) vs Chairs (Distorted or Standard) As Control Images When Viewed for Short Durations? (An Accuracy Measurement)

2.4.1 Introduction

Attention to distorted finger postures is vital for social and cognitive processes because these postures can impact fine motor skills and dexterity, thereby affecting performance in tasks that require precise hand movements and coordination. Visual search tasks are available for exploring perceptual salience (Jiang, 2018; Kruse et al., 2016). In Experiment 2, it was found that the average RT across set sizes and RT slopes are different between the distorted finger postures and natural finger postures in active vision (with eye movements). Additionally, in Experiment 3, it was shown that the average proportion of correct responses and the slope of the proportion of correct responses between the hand and the whole body stimuli are different in passive vision (without eye movement).

Experiments 1 and 2 have shown the difference in visual search between distorted finger and natural finger postures in active vision and the difference in visual search between hand and whole body; this new study investigates the impact of distorted versus natural finger postures on passive visual perception, an area previously unexamined in the literature. By exploring this novel topic, researchers aim to provide foundational insights to inform future research and applications in fields such as human-computer interaction and cognitive neuroscience. This work is a logical extension of our previous research, which has progressively delved into the complexities of visual perception. By addressing how finger posture influences visual processing, researchers seek to uncover new principles that enhance our understanding of how the brain processes visual information. This research could contribute to the development of more intuitive and effective technologies, further advancing our understanding of human perception and its societal implications.

The purpose of this investigation was to explore the relationship between distorted and natural finger posture in passive vision using RSVP, extending understanding beyond active vision scenarios. Based on previous research, it was predicted that in passive vision, the average proportion of correct responses for distorted finger postures would be higher than for natural finger postures, and the slope of the proportion of correct responses for distorted finger postures would be smaller. These predictions stemmed from the prediction that distorted finger postures might capture attention more effectively due to their unusual nature, potentially leading to enhanced visual processing and more consistent attention across presentation durations. It is predicted that there would be no significant difference between active and passive vision effects, anticipating that underlying mechanisms of visual attention and processing might operate similarly regardless of visual input control. By investigating these relationships in a passive vision context, the study sought to determine whether the influence of finger posture on visual processing is a generalisable phenomenon, potentially providing valuable insights into broader cognitive processes underlying visual perception and attention.

2.4.2 Method

2.4.2.1 Participants

Twenty-seven students from the University of Nottingham Malaysia,18 females and 9 males (18-45 years, *M* = 24.30 years, *SD* = 3.52) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment. The recruitment requirements for this experiment were the same as for Experiment 1. The data of 2 participants were removed because the accuracy of the participants was much lower than the group mean. Based on assuming 3 (set size 2, 4 and 6) x 2 (hands and chairs) x 2 (distorted and natural) within-subject factors and keeping the same other parameters as in Experiment 1 in a priori analysis for G*Power, a sample size of 18 was sufficient. The procedure followed the university research ethics. The SEREC at the University of Nottingham Malaysia reviewed this research project, designated as HYC150221. Following their assessment, the committee granted ethical approval for the study's methodology.

2.4.2.2 Materials and apparatus

The visual items were used in the same way as in Experiment 2. The visual search display in this experiment was the same as in Experiment 2. The number of target and absent stimuli was the same as in Experiment 2. The experiment was presented online in the same manner as in Experiment 3.

2.4.2.3 Design and procedure

The experimental design was the same as in Experiment 1. The online experiment procedure was the same as in Experiment 3 (Figure 2-9).

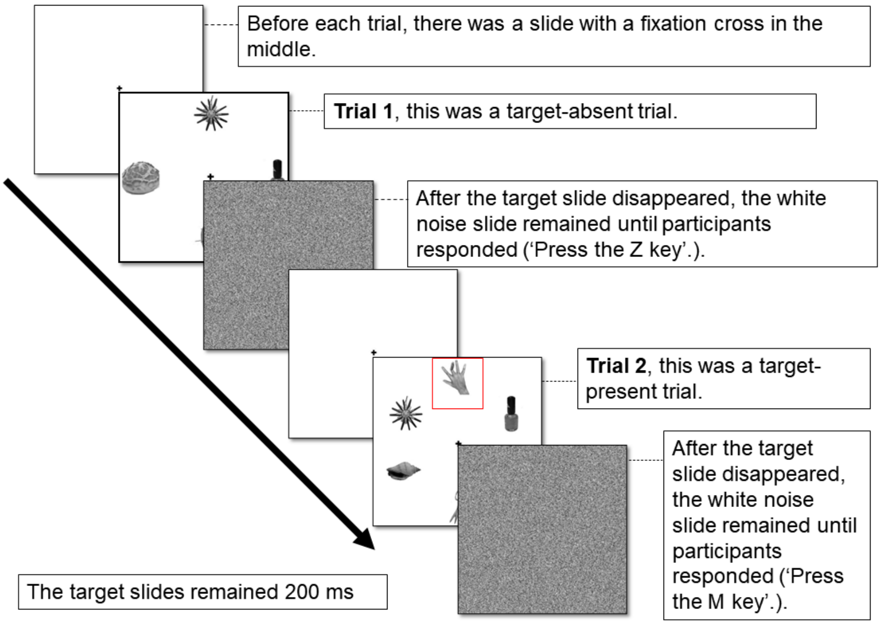


Figure 2-9 Experiment 4 Stimulus Timeline
Stimulus timeline of visual displays in Experiment 4, showing 2 trials (1 target-absent trial, correct answer 'Z' and 1 target-present trial, correct answer 'M').

2.4.3 Results

A three-way repeated measures ANOVA was conducted using the factors: distortion (distorted, natural), stimulus type (hand, chair) and set size (2,.4, and 6), all within subject. There was no three-way interaction between distortion, stimuli and set size [F(2, 48) = 0.377, p = 0.688, $\eta_p^2 = 0.015$]. There was a two-way interaction between distortion and stimulus types [F(1, 24) = 10.215, p = 0.004, $\eta_p^2 = 0.299$]. Specifically, the effect of distortion differed depending on the type of stimulus, with hand of stimulus showing a greater impact of distortion compared to the chair. There was a main effect of stimulus type [F(1, 24) = 50.031, p < 0.001, $\eta_p^2 = 0.676$]. This indicates that the type of stimulus significantly influenced the outcome, with hand stimulus leading to higher performance than chair. There was also a main effect of set size [F(2, 48) = 5.166, p = 0.009, $\eta_p^2 = 0.177$]. This suggests that the size of the set had a significant impact on the results, with larger set sizes generally associated with poorer performance.

A two-way repeated measures ANOVA was conducted to determine the effects of distortion and stimuli on slopes. There was no two-way interaction between distortion and stimulus type [F(1, 24) = 0.479, p = 0.495, $\eta_p^2 = 0.020$]. There was no main effect of distortion [F(1, 24) = 0.367, p = 0.550, $\eta_p^2 = 0.015$] or of stimulus type [(F(1, 24) = 2.584, p = 0.121, $\eta_p^2 = 0.097$].

Experiment 2 suggests that some distortions do not significantly impact recognition speed within a category (chairs). Experiment 3 reveals that accuracy is more susceptible to distortions of certain features, even for objects within the same category. This discrepancy could be due to different features. Experiment 4 reinforces this idea by showing no difference in accuracy when distorting certain chair features, suggesting that these features are less critical for accurate recognition compared to other features.

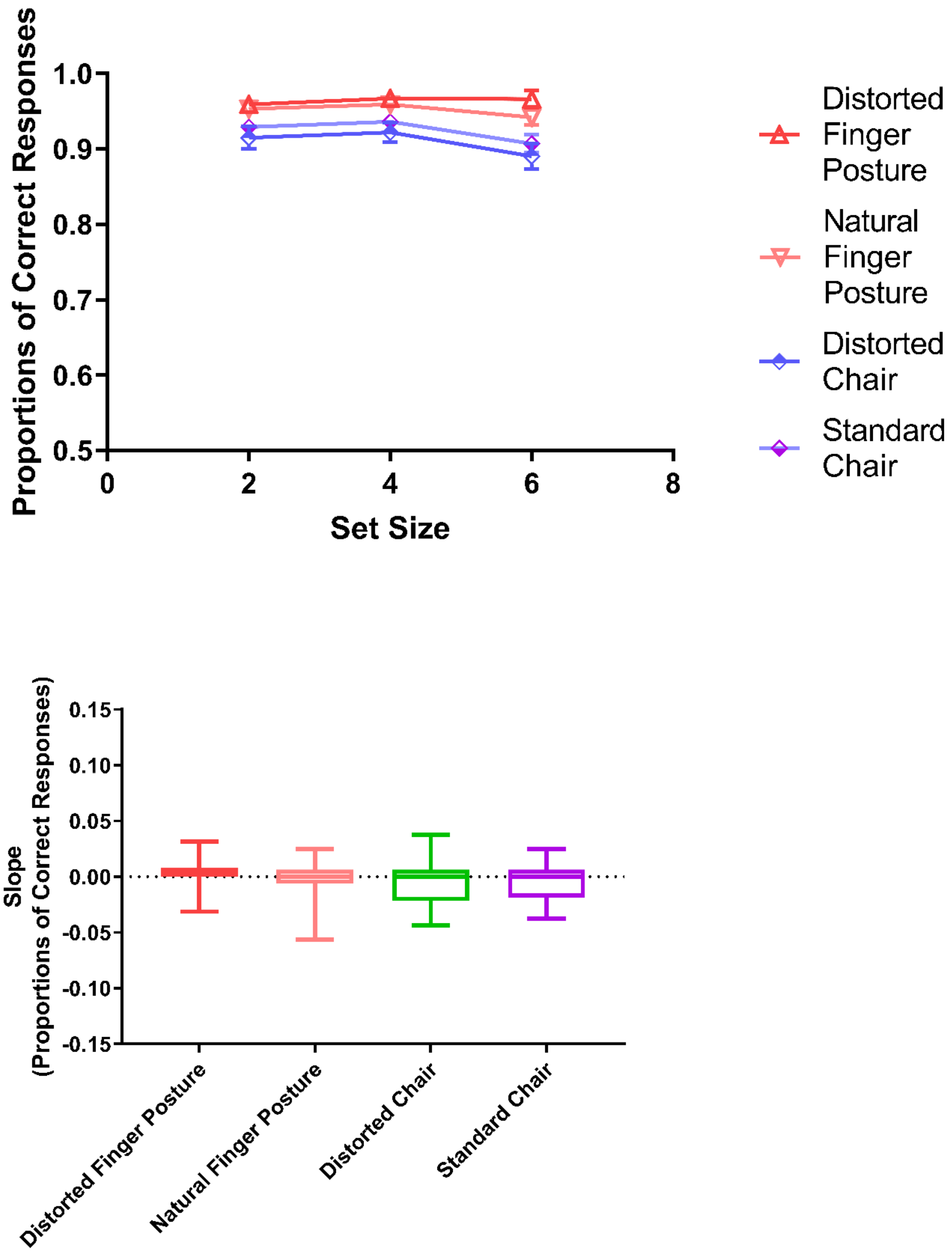


Figure 2-10 Experiment 4 results
(A) Average proportion of correct response across set sizes on search set size and stimulus type. (B) The slopes of the proportion of correct responses. The box plot shows 2.5%, 25%, 50% (median), 75% and 97.5% percentiles.

2.4.4 Discussion

In the previous section, it was known that the proportions of correct response between hands and whole bodies were significantly different, but not between hands and faces. This experiment was designed to determine the effects of stimulus types and configuration on hands. The results of this research provided insights into the differences between distorted finger postures and the interplay of stimulus types and configurations. Specifically, the experiment uncovered the main effect of stimulus type on the average proportion of correct responses, as well as an interaction between stimulus type and configuration in this measure. These findings might be attributed to the significant differences in visual properties between hand and chair stimuli when observed through passive vision without eye movement. Such distinctions in passive visual processing could explain the observed variations in response accuracy across different stimulus types and configurations, highlighting the complex nature of visual perception in this context.

This experiment found a main effect of stimulus type on the average proportion of correct response and interaction between stimulus type and configuration in the average proportion of correct response. This means that the type of stimulus (hand or chair) influenced the overall accuracy of responses, and the way this influence occurred depended on the specific configuration of the stimulus. These results indicate that participants' accuracy in identifying hands differed significantly from their accuracy in identifying chairs. Moreover, the effect of distortion on response accuracy varied depending on whether the stimulus was a hand or a chair. These findings highlight the complexity of visual perception processes, suggesting that different categories of objects (body parts versus inanimate objects) may be processed differently in the visual system. They also indicate that our visual recognition abilities may be differentially affected by configural changes depending on the category of object being viewed. One possible explanation for this is that the visual properties of hand stimuli and chair stimuli differ significantly when viewed passively without eye movement. However, it remains unclear whether participants can detect these differences in peripheral vision or if they are merely identifying the presence of a stimulus with protruding features (e.g., a hand or a chair). To address this uncertainty, a follow-up experiment is proposed to test participants' ability to distinguish between natural and distorted stimuli in peripheral vision. In this experiment, participants would be instructed to press 'M' if the stimulus appears natural and 'Z' if it appears distorted. This would help elucidate whether the observed effects are due to the detection of specific stimulus differences or simply the presence of a stimulus with salient features.

It is somewhat surprising that this experiment detected no evidence of stimulus types and configuration effects in a proportion of correct response slopes. A possible explanation for this is that in rapid serial visual search without eye movement in the passive vision situation, for hand and chair stimuli, the difference cannot be detected, so there was no significant main effect of stimulus types. Another possible explanation for this result would be the lack of appropriate difficulties in this task. The possibility of similarity of the proportion of correct response between distorted and natural finger postures is that the number of items is not large enough, so the difference in the proportion of correct response between different set sizes was not significantly different. On the other hand, if the number of distractors increases and the resources of visual search are exploited more, the difference in the proportion of correct responses across set sizes gets more.

2.5 Control Experiment 1: Affect Rating of the Visual Stimuli

2.5.1 Introduction

Previous findings showed differences in visual search between distorted and natural finger postures. This could be due to emotional affective reaction differences, as emotion often influences visual search for body-related stimuli (Calvo, Nummenmaa, & Avero, 2008; Wolfe, 2017). The emotional affective reactions of different finger postures likely vary, with natural finger postures generally perceived as neutral, whilst distorted finger postures may evoke negative emotions such as discomfort. These emotional associations could potentially influence attention allocation and search efficiency. For instance, distorted finger postures might capture attention more readily, leading to faster detection times. There are differences in (1) average RTs across set sizes and (2) visual search efficiencies, between distorted and natural finger postures in visual search. However, little is known about whether the differences between them are caused by (1) the visual properties of stimuli related to the human body in particular or (2) stimuli related to any uncommon objects which evoke feelings associated with negative-surprising stimuli. In other words, little is known about whether the different affective reaction and arousal ratings are a contributing factor to the average RTs across set sizes and to the visual search efficiencies, in visual search in these experiments. In order to test whether the results were caused by the visual properties of parts of the human body or by parts of the human body which evoke feelings of surprise, a visual search task for comparing negative-surprising and nonnegative-surprising stimuli must be conducted.

Before comparing the differences between negative-surprising and nonnegative- surprising stimuli in visual search, the negative-surprising stimuli must first be defined. Measuring the emotion evoked by negative-surprising stimuli in this situation is problematic because the emotional perception evoked by negative-surprising stimuli is subjective. Nevertheless, it can be quantified to a certain extent using affect ratings, measuring its intensity in response to a stimulus. This can be done by measuring the affective reaction and arousal ratings of affect ratings for visual stimuli which commonly evoke feelings. Affective reaction rating in these experiments refers to the negative or positive reaction to the stimuli; arousal rating here refers to the emotional excitement that the stimuli evoke (Kurdi et al., 2017).

This experiment was conducted with two main purposes: to confirm the ratings of hand stimuli (in both distorted and natural positions), and to identify appropriate control stimuli, including chairs and additional objects, that correspond to the distorted and natural finger postures. These purposes intend to establish a robust foundation for further investigation into the perception of distorted biological and nonbiological forms in subsequent visual search tasks.

This section seeks to assess the affective reaction and arousal ratings of images. The experiment examined the ratings of images in two categories: (1) distorted finger and natural finger postures seen from the first perspective and (2) negative-surprising and nonnegative-surprising stimuli. Three pairs of comparable stimuli (one negative-surprising and one nonnegative-surprising) are then compared to the pair of distorted finger and natural finger posture stimuli. The pair whose ‘provocative’ object rating was closest to the distorted finger posture rating (potential feeling of negative surprise) and whose ‘nonprovocative’ object rating was closest to the natural finger posture rating (no potential feeling of negative surprise) was chosen. In order to avoid the effect of different shapes in visual search, the shapes of these pairs of objects were similar to each other (Dickinson, Haley, Bowden, & Badcock, 2018; Green, Dickinson, & Badcock, 2018).

2.5.2 Method

2.5.2.1 Participants

Fifty-three students from the University of Nottingham Malaysia, 32 females, 20 males and 1 (18-45 years, $M = 21.91$, $SD = 3.20$) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment. The recruitment requirements for this experiment were the same as for Experiment 1. None of the participants had seen the images in the experiments in order to avoid the influence of learning or memory effects (Tyng et al., 2017). The number of participants in the experiment was greater than in a comparable earlier affective reaction and arousal rating experiment (Korovina, Baez, & Casati, 2019). The procedures for this study received approval from the SEREC at the University of Nottingham Malaysia. The committee assigned the application number HYC150221 to this research project.

2.5.2.2 Materials and apparatus

This experiment was (1) to confirm the ratings of hands and chair stimuli (including distorted and natural positions) and (2) to find stimuli of additional objects (other than chairs) corresponding to distorted and natural finger postures (Figure 2-11). There were five images of hands: in each of four of the images, one finger was distorted (by turning the index, middle, ring and little finger); in the fifth image, all the fingers were positioned naturally. There were five images of a chair: in each of four of the images, one leg was distorted; in the fifth image, all the legs were standard. The additional objects selected to correspond to the distorted and natural finger posture pair were (1) a real gun and a toy gun, (2) a knife and a toothbrush and (3) a grenade and a ball, all of which are pairs of similar shapes. Ethical approval was secured for using potentially unsettling images, though not all specific images were shown to the ethics committee, only described. The informed consent form clearly stated the possible discomfort from viewing such images, ensuring transparency with participants (Figure 2-12).

Qualtrics was used to collect data for this experiment. It is a web-based survey creation and distribution platform that enables the design and customisation options of surveys (Qualtrics, Provo, UT). The participants who needed credits accessed the experiment via the SONA system, which is a cloud-based research software and participant management solution for universities.

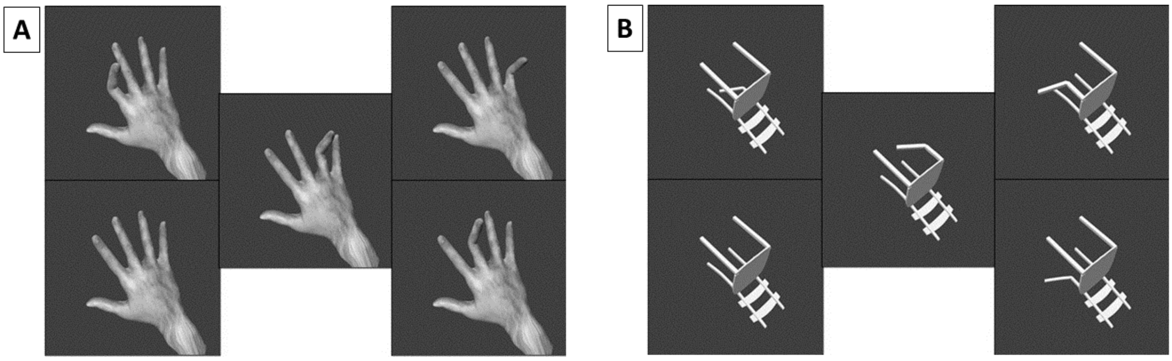


Figure 2-11 Examples of (A) hands and (B) chairs in Control Experiment 1.

Figure 2-12 Control Experiment 1 image selection
From top left to bottom right, the chosen images correspond to both distorted and natural finger postures, showing a real gun, knife, grenade, toy gun, tooth brush, and ball.

2.5.2.3 Design and procedure

This experiment was organised as follows. (1) An ANOVA was used to compare the affective reaction and arousal ratings between the different distorted finger postures, i.e. to compare each of the four distorted finger postures with one another. (2) Where there was no significant difference in (1), t-tests were used to compare the affective reaction and arousal ratings between the average rating of the distorted finger postures with the single natural finger posture. (3) T-tests were used to compare the affective reaction and arousal ratings of the average rating of the distorted finger postures with the other surprising stimuli (grenades, etc.) and to compare between the single natural finger posture and the nonnegative-surprising stimuli (ball, etc.).

Participants were asked for affective reaction and arousal ratings for (1) distorted finger postures and natural finger postures, (2) distorted and standard chairs, and (3) the three sets of images (grenade and ball, etc.). Following previous research, a

7-point Likert scale was used to conceptualise the affective responses and their measurement (Kurdi et al., 2017; Zhang & Savalei, 2016). There were 7 ratings each for affective reaction and arousal. The 1 to 7 affective reaction ratings were: Very Negative, Moderately Negative, Somewhat Negative, Neutral, Somewhat Positive, Moderately Positive, and Very Positive. The 1 to 7 arousal ratings were: Very Low, Moderately Low, Somewhat Low, Neither Low or High, Somewhat High, Moderately High, and Very High. Each image was only shown once. The affective reaction and arousal rating prompts appeared randomly and separately to ensure that each was considered independently.

2.5.3 Results

The ANOVA comparing the affective reaction and arousal ratings between the four different distorted finger postures did not show any significant differences in affective reaction and arousal, [F(3, 128) = 1.061, p = 0.368, $\eta_p^2 = 0.024$] and [F(3, 128) = 0.141, p = 0.935, $\eta_p^2 = 0.003$] respectively. This result suggests that the different distorted finger postures can evoke the same affective reaction and arousal ratings. The t-tests comparing the affective reaction and the arousal ratings between the average rating of the distorted finger postures and the single natural finger posture showed significant differences in affective reaction and in arousal, (t(52) = 4.23, p < 0.001) and (t(52) = 2.47, p = 0.017), respectively.

The result shows that the affective reaction and arousal ratings for the grenade are closer to the distorted finger postures than the comparable stimuli (real gun or knife), and those for the ball are closer to the natural finger postures than the comparable stimuli (toy gun or toothbrush) therefore only the affective reaction and arousal ratings between the distorted/natural finger postures and grenade/ball stimuli were selected (Figure 2-13). The t-tests to compare the distorted finger postures with the grenades did not show a significant difference in affective reaction (t(52) = 0.044, p = 0.965) or arousal (t(52) = -0.395, p = 0.694). The t-tests to compare the natural finger postures with the ball did not show a significant difference in affective reaction (t(52) = 1.055, p = 0.297) or arousal (t(52) = 0.000, p = 1.000). The similarity of the affective reaction and arousal ratings suggests that the grenade and ball images are valid control stimuli.

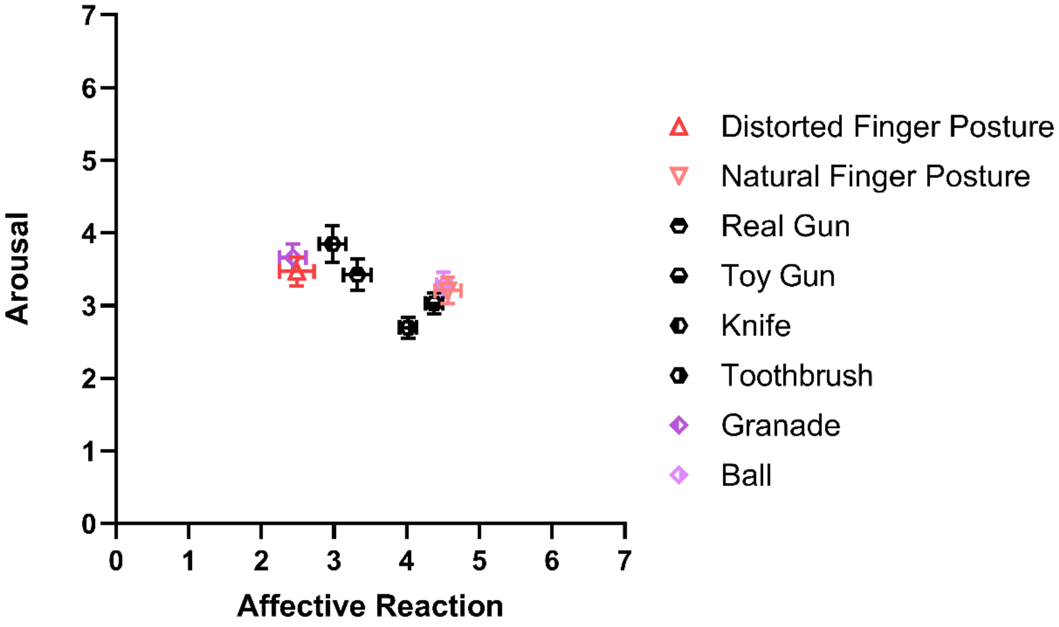


Figure 2-13 Control stimuli image ratings in Control Experiment 1.
Image ratings of the three pairs of control stimuli with distorted and natural finger postures with affective reaction (measured on a 1–7 Likert scale) on the x-axis and arousal (also measured on a 1–7 Likert scale) on the y-axis. Error bars show the average standard error of measurement across all subjects for each stimulus.

2.5.4 Discussion

This experiment set out to find the pair of images which could be used as control stimuli for comparing the distorted and natural finger postures. The results were encouraging. According to the rationale of using a pair of similarly shaped objects for the control stimuli, grenades and balls were the most appropriate combination, given the insignificant difference in affective reaction and arousal values, to compare with the target stimuli set of the distorted and natural finger postures in the visual search task. These findings suggest that the grenade and the ball images are appropriate images to use as control stimuli in visual search to examine whether the low RT and high visual search efficiency on distorted finger postures is caused by distorted finger postures specifically or just by stimuli with particular affective reaction and arousal values. Specifically, whilst the grenade and ball images are similar in arousal levels, the grenade image is more negative in affective reaction compared to the ball image.

Further studies, which take the grenade and ball images in visual search tasks as the control stimuli to compare with the distorted finger postures and natural finger postures as target stimuli, will need to be undertaken. If there was a significant interaction between configuration (surprising negative stimuli vs nonnegative-surprising) and stimulus types (human body stimuli vs stimuli unrelated to the human body) either in the average reaction times across set sizes or the slope of the RT × set size function, it would be inferred that the difference between distorted and natural finger postures is caused by negative-surprising stimuli vice versa.

2.6 Control Experiment 2: Is Visual Search Different for Negative-Surprising and Nonnegative-Surprising Stimuli (Using an RT Measurement)?

2.6.1 Introduction

From previous experiments, distorted finger postures are generally regarded as the main cause of the difference of the average RTs across set sizes and the RT × set size slopes in visual search. The experiment in the previous section showed that the RT slope for distorted finger postures is smaller than that for the whole body. In addition, the distorted finger posture slope is smaller than the natural finger posture slope; the distorted finger posture RT is lower than the RT of natural finger posture RT.

Despite the significant interaction between stimulus types (hands and chairs) and configuration (distorted and natural), it was still unclear and debated which factors caused the results. Although some evidence suggested that it was probably caused by the nature of salient human bodies, other evidence suggested that it was probably caused by surprising negative stimuli, which came with negative affective reactions and high arousal values (Calvo et al., 2008; Wolfe & Horowitz, 2017).

In this experiment, the grenade and ball images were used as control stimuli as they have the nature of surprising negative stimuli and nonnegative-surprising stimuli based on the results in the previous section. According to the definition in the previous section, surprising negative stimuli refer to visual stimuli that can evoke a surprising negative feeling in humans. The negative-surprising stimuli were selected based on the standard of the surprising negative stimuli proposed in Control Experiment 1. The grenades and balls had specific affective reactions and arousal values which helped to identify whether these ratings were one factor that contributed to the different RTs and slopes in the visual search.

The purpose of the experiment was to assess the extent to which, in visual search, these factors (affect ratings or the nature of salient human bodies) were caused by the differences in the average RTs across set sizes, and those in the RT × set size slopes, particularly whether there was an interaction between stimulus types (human and nonhuman body) and configurations (surprising negative stimuli and nonnegative-surprising stimuli) on (1) the average RTs across set sizes and (2) RT × set size slopes.

2.6.2 Method

2.6.2.1 Participants

Thirty-seven students from the University of Nottingham Malaysia, 25 females and 12 males (18-45 years, *M* = 22.80, *SD* = 2.62) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment. The recruitment requirements for this experiment were the same as for Experiment 1. Based on assuming 3 (set size 2, 4 and 6) x 2 (human and nonhuman) × 2 (negative-surprising stimuli and nonnegative-surprising stimuli) within-subject factors and keeping the same other parameters as in Experiment 1 in a priori analysis for G*Power, a sample size of 18 was sufficient. The procedure followed the university research ethics. The University of Nottingham Malaysia's SEREC approved these procedures, assigning application number HYC150221.

2.6.2.2 Materials and apparatus

The visual items were used in the same way as in Experiment 2 (Figure 2-14). The target stimuli were replaced by either distorted finger postures, natural finger postures, grenades or balls. The visual search display in this experiment was the same as in Experiment 2. The number of target and absent stimuli was the same as in Experiment 2. The target stimuli were replaced by either distorted finger postures, natural finger postures, grenades or balls (Table 3). The experiment was performed online in the same manner as Experiment 3.

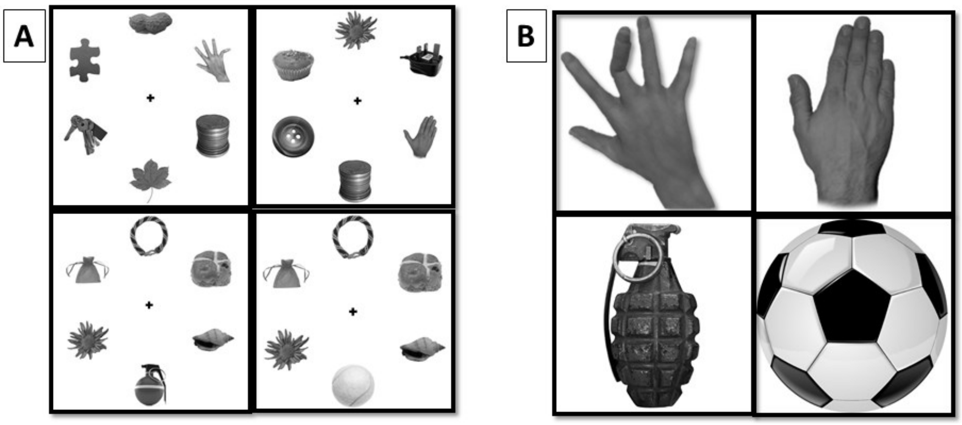


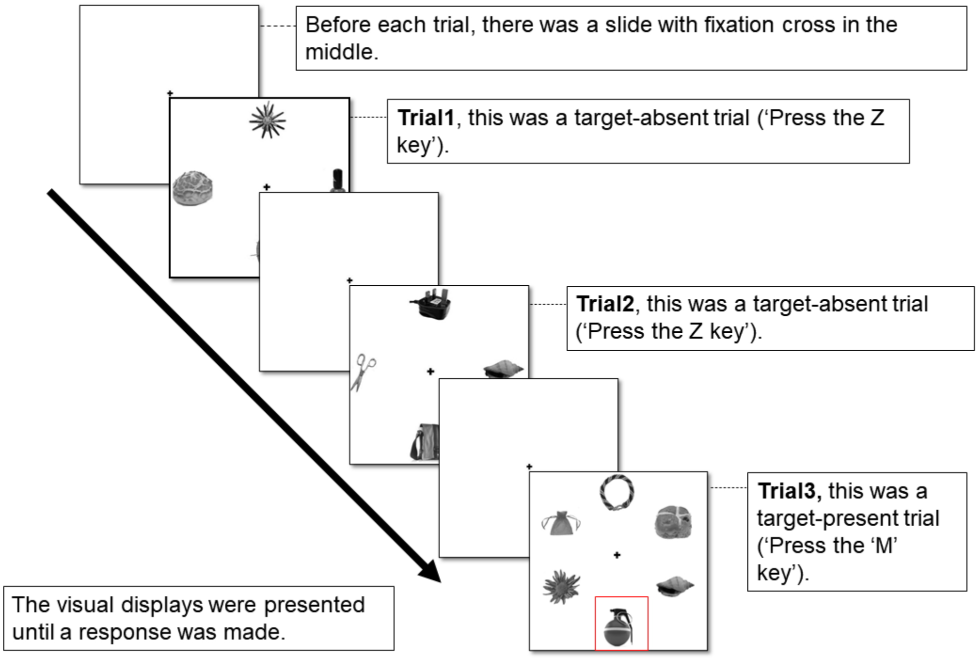
Figure 2-14 Examples of visual displays and examples of target items in Control Experiment 2.
(A) Examples of visual displays containing set sizes 2, 4 and 6 items, contain a distorted finger posture, a natural finger posture, a grenade and a ball. (B) Examples of visual target items from top left to bottom right: distorted finger posture, natural finger posture, grenade and ball.

Table 3 The stimuli of Control Experiment 2
The experimental structure of one block of 240 trials in Control Experiment 2. The experiment comprised four blocks.

Group	Set size	Stimuli	Number of trials
Absent condition (120 stimuli)	2	All distractors	40
	4	All distractors	40
	6	All distractors	40
Target condition (120 stimuli)	2	Distorted finger posture with distractors	10
		Natural finger posture with distractors	10
		Grenade with distractors	10
		Ball with distractors	10
	4	Distorted finger postures with distractors	10
		Natural finger postures with distractors	10
		Grenade with distractors	10
		Ball with distractors	10
	6	Distorted finger postures with distractors	10
		Natural finger postures with distractors	10
		Grenade with distractors	10
		Ball with distractors	10

2.6.2.3 Design and procedure

The experimental design was the same as in Experiment 1, but the visual items were distorted finger postures, natural finger postures, grenades or balls (Figure 2-15). The online experiment procedure was the same as in Experiment 3.


Before each trial, there was a slide with fixation cross in the middle.

Trial1, this was a target-absent trial ('Press the Z key').

Trial2, this was a target-absent trial ('Press the Z key').

Trial3, this was a target-present trial ('Press the 'M' key').

The visual displays were presented until a response was made.

Figure 2-15 Experiment 2 Stimulus Timeline
Stimulus timeline of visual displays in Experiment 2, showing 3 trials (2 target-absent trials, correct answer 'Z' and 1 target-present trial, correct answer 'M').

2.6.3 Results

Accuracy rates ranged from 84% to 99% in Control Experiment 2. Accuracy was measured to confirm that error rates remained sufficiently low, thus validating the RT data (Wolfe, 2018). In this analysis, data from target-absent trials were deliberately omitted, aligning with the specific focus of our study. The decision to concentrate solely on target-present trials was premised on the particular interest and relevance of these instances within the context of our exploration into the dynamics of hands and grenades and balls.

The average RTs across set sizes were analysed using a three-way repeated measures ANOVA over stimulus type (hands and nonhand), configuration (negative-surprising and nonnegative-surprising), and set size (2, 4 and 6 items) (Figure 2-16). There was a three-way interaction between stimulus type, configuration and set size [$F(2, 40) = 9.462$, $p < 0.001$, $\eta_p^2 = 0.321$]. For the two-way interactions, there was a significant two-way interaction between stimulus types and set sizes [$F(2, 40) = 30.571$, $p < 0.001$, $\eta_p^2 = 0.605$]. There was a significant main effect of stimulus types [$F(1, 20) = 98.494$, $p < 0.001$, $\eta_p^2 = 0.831$] and set size [$F(2, 40) = 157.218$, $p < 0.001$, $\eta_p^2 = 0.887$].

The RT slopes for stimulus types were analysed by two-way repeated measures ANOVA over stimulus types (hands and nonhand) and configurations (negative-surprising and nonnegative-surprising) (Figure 2-16). There was a main effect of stimulus type [$F(1, 20) = 86.512$, $p < 0.001$, $\eta_p^2 = 0.812$]. There was a significant two-way interaction between stimulus types and configurations [$F(1, 20) = 10.915$, $p = 0.004$, $\eta_p^2 = 0.353$].

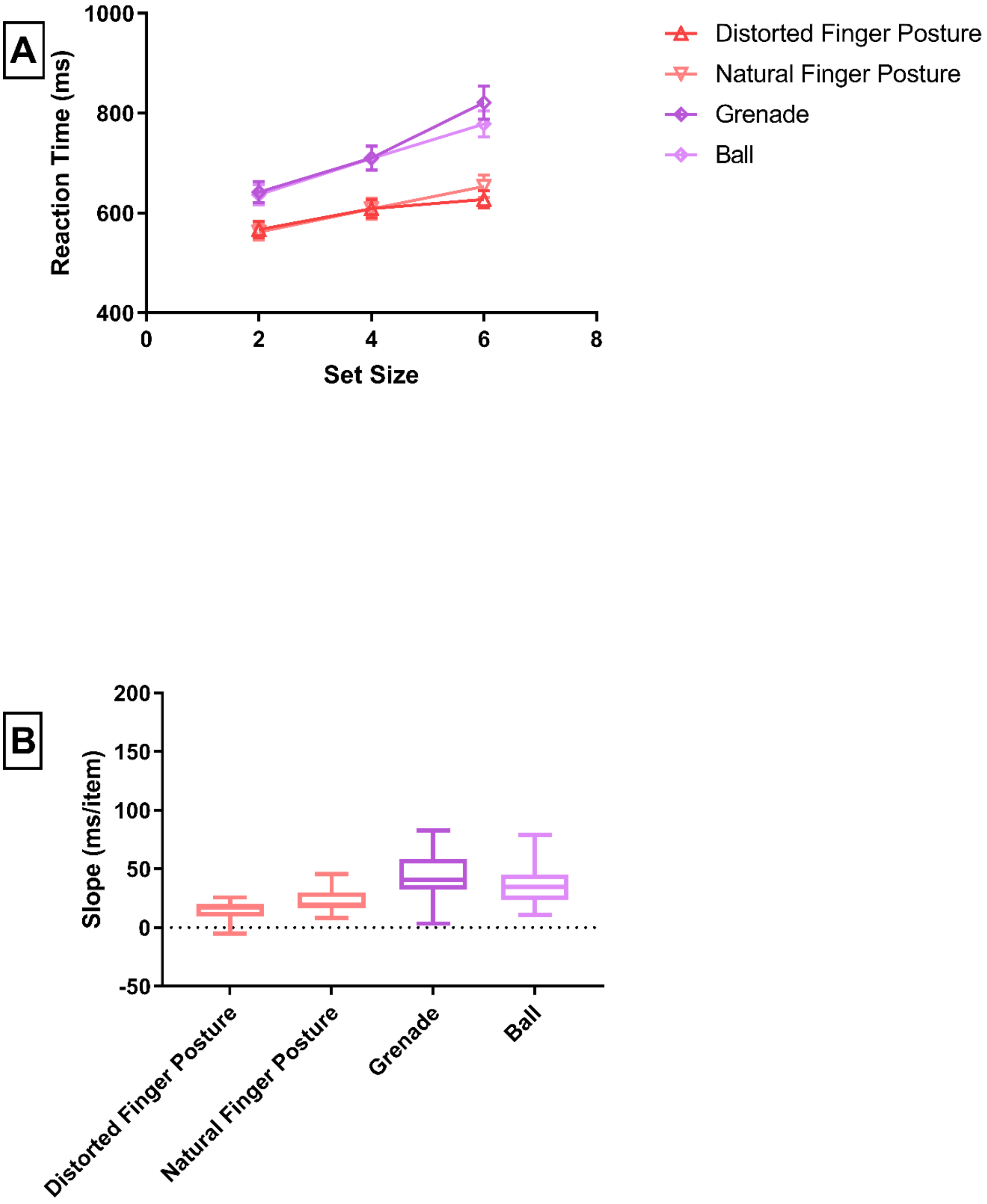


Figure 2-16 Control Experiment 2 results
(A) Average RTs across set sizes on search set size and stimulus type. (B) RT slopes. The box plot shows 2.5%, 25%, 50% (median), 75% and 97.5% percentiles.

2.6.4 Discussion

Experiments 1 and 2 have noted the importance of the effects of stimulus types between faces, whole bodies, and hands and interactions between stimulus types, including hands and chairs and configuration including distortion and nondistortion, have indicated that visual property and visual search efficiencies between hands and whole bodies differed significantly. The established findings indicate that both visual properties in visual search and search efficiencies are influenced by the difference between hands and whole bodies, as well as by the difference between distorted and natural finger postures. Despite these discoveries, the impact of emotional intensity (affective reaction) and physiological activation (arousal) on visual properties and search efficiencies remains unclear.

This experiment was designed to determine the effects of affective reaction and arousal in visual search. With respect to this question, it was found the main effect of average RTs across set sizes in stimulus types and the interactions of average RTs across set between stimulus types and set sizes. In addition, it was found the main effect of RT slope in stimulus types and an interaction between stimulus types and configuration.

This noteworthy finding provides critical insight into the complex interplay between various factors influencing the efficacy of visual search. Specifically, it highlights the significance of a three-way interaction involving stimulus type, configuration, and set size. Stimulus type, encompassing categories such as human hands and inanimate objects, emerged as a consequential factor, underpinning the differential patterns observed in the visual search process. It suggests that the nature of the object under focus significantly steers the direction of our visual attention and subsequently influences the search efficiency. Meanwhile, the configuration, whether the stimulus is surprising or non-surprising, introduces an additional layer of complexity. This component might tap into the cognitive and emotional dimensions of visual processing, suggesting that unexpected or surprising elements may disrupt standard visual search patterns, potentially causing delays or enhancements in object recognition. Finally, set size, the quantity of elements presented in the visual field, emerged as a critical determinant. It implicates the role of visual clutter and information overload in affecting the efficiency of the visual search. Larger set sizes might increase the complexity of the visual scene, thereby extending the time required to locate a particular object or detail.

These findings can potentially be understood by considering that the visual attributes used when searching for hands compared to an inanimate object (which holds no significant difference in emotional intensity or excitement level) were significantly different. This factor might also explain why there is a noticeable difference between distorted and natural finger postures. Rather than being influenced by any surprising negative stimuli, this difference seems to be caused by the specific visual characteristics of the human body.

2.7 Control Experiment 3: Is Visual Search Different for Finger Postures and Toe Postures (Using an RT Measurement)?

2.7.1 Introduction

The visual characteristics of implausible human bodies, as derived from previous experiments in this thesis, potentially hold an impact, lending credence to their instrumental role in influencing (1) the difference of average RTs across set sizes, and (2) the efficiencies of the visual search. The research in this section was carried out to investigate whether there is a difference in visual search between hands and feet in implausible human bodies.

This research is intended to clarify whether the distinction between distorted and natural postures is specific to fingers or extends to toes, chosen as a control due to their structural similarity but reduced social and communicative relevance. The conceptual underpinning of this selection arises from the anatomical parallels between feet, inclusive of their toes, and hands with their corresponding fingers. By comparing finger and toe postures, isolating the effect of posture distortion from confounding factors related to social importance, whilst using a more appropriate biological control than non-body objects. This experiment defines distorted finger postures as distorted hands and distorted toe postures as distorted feet, as established in Experiment 1. Through this comparison, researchers seek to understand whether the perceptual differences observed are unique to fingers, possibly due to their crucial role in human interaction, or represent a more general phenomenon of body part distortion, potentially illuminating the cognitive mechanisms underlying body perception and the special status of hands and fingers in human cognition.

Despite the importance of understanding the interrelationships between distinct parts of the human body regarding their visual properties in visual search, little information exists to shed light on this subject. To bridge this knowledge gap, researchers designed and implemented an experiment to comprehend these intricate interconnections. As a result, this work has validated its utility in broadening our understanding of these relationships, thus propelling the field of study forward with these findings.

2.7.2 Methods

2.7.2.1 Participants

Thirty-seven students from the University of Nottingham Malaysia, 25 females and 12 males (18-45 years, $M = 22.80$, $SD = 2.62$) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment. The recruitment requirements for this experiment were the same as for Experiment 1. Based on assuming 3 (set size 2, 4 and 6) x 2 (finger posture and toe posture) × 2 (distorted and natural) within-subject factors and keeping the same other parameters as in Experiment 1 in a priori analysis for G*Power, a sample size of 18 was sufficient. These procedures were approved by the SEREC at the University of Nottingham Malaysia under application number HYC150221.

2.7.2.2 Materials and apparatus

The visual items were used in the same way as in Experiment 2. The target stimuli were replaced by either distorted finger postures, natural finger postures, distorted toes or natural toes (Figure 2-17). The visual search display in this experiment was the same as in Experiment 2. The number of target and absent stimuli was the same as in Experiment 2. The target stimuli were replaced by either distorted finger postures, natural finger postures, distorted toe postures or natural toe postures (Table 4). The experiment was demonstrated online in the same manner as Experiment 3.

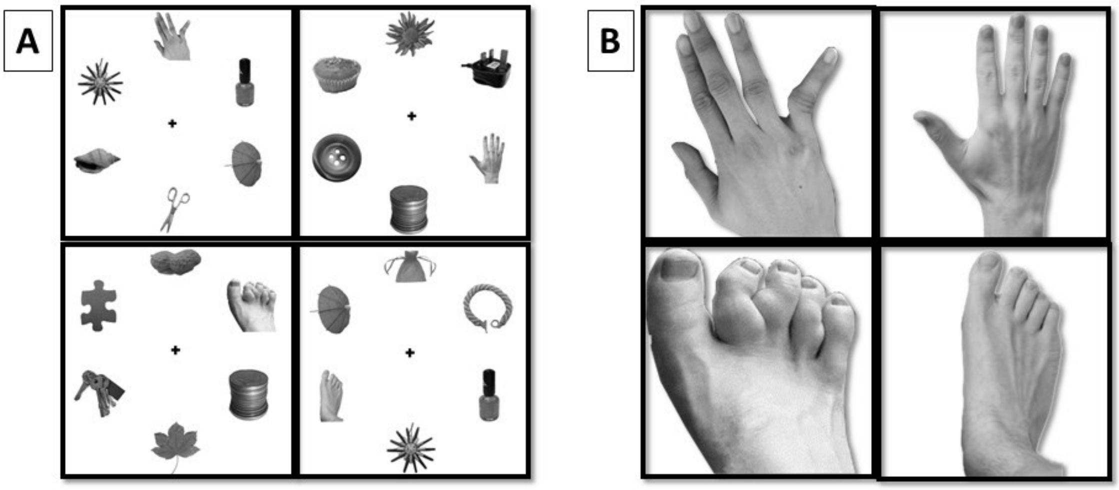
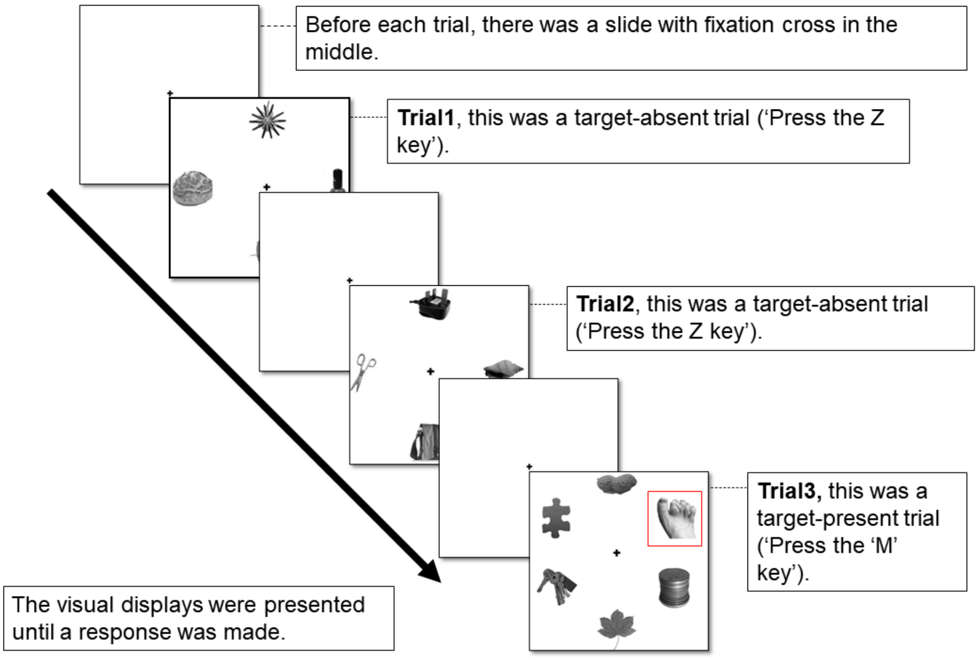


Figure 2-17 Examples of visual displays and examples of target items in Control Experiment 3
(A) Examples of visual displays containing set sizes 2, 4 and 6 visual items, contain a distorted finger posture, natural finger postures, distorted toe posture and natural finger posture, each example of a target stimulus and one or more distractors.

2.7.2.3 Design and procedure

The experimental design was the same as in Experiment 1. The online experiment procedure was the same as in Experiment 3 (Figure 2-18).



Before each trial, there was a slide with fixation cross in the middle.

Trial1, this was a target-absent trial ('Press the Z key').

Trial2, this was a target-absent trial ('Press the Z key').

Trial3, this was a target-present trial ('Press the 'M' key').

The visual displays were presented until a response was made.

Figure 2-18 Control experiment stimulus timeline
Stimulus timeline of visual displays in Control Experiment, showing 3 trials (2 target-absent trials, correct answer 'Z' and 1 target-present trial, correct answer 'M').

Table 4 The stimuli of Control Experiment 3.
The experimental structure of one block of 240 trials in Control Experiment 3. The experiment comprised four blocks.

Group	Set size	Stimuli	Number of trials
Absent condition (120 stimuli)	2	All distractors	40
	4	All distractors	40
	6	All distractors	40
Target condition (120 stimuli)	2	Distorted finger posture with distractors	10
		Natural finger posture with distractors	10
		Distorted toe with distractors	10
		Standard toe with distractors	10
	4	Distorted finger posture with distractors	10
		Natural finger posture with distractors	10
		Distorted toe with distractors	10
		Standard toe with distractors	10
	6	Distorted finger posture with distractors	10
		Natural finger posture with distractors	10
		Distorted toe with distractors	10
		Standard toe with distractors	10

2.7.3 Results

Accuracy rates ranged from 85% to 99% in Control Experiment 3. Response accuracy was monitored to verify that error rates remained low enough to ensure the reliability of RT data (Wolfe, 2018). In this analysis, data from target-absent trials were deliberately omitted, aligning with the specific focus of our study. The decision to concentrate solely on target-present trials was premised on the particular interest and relevance of these instances within the context of our exploration into the dynamics of hands and feet.

The average RTs across set sizes were analysed using a three-way repeated measures ANOVA over stimulus types (hands and feet), configurations (distorted and natural), and set sizes (2, 4 and 6 items) (Figure 2-19). No three-way interactions were significant. For the two-way interactions, there was no two-way interaction between configuration and set sizes. There was a significant main effect of stimulus types (F(1, 28) = 6.511, p = 0.016, $\eta_p^2 = 0.188$); configuration [F(1, 28) = 5.947, p = 0.021, $\eta_p^2 = 0.175$]; set size [F(2, 56) = 27.895, $p < 0.001$, $\eta_p^2 = 0.499$]. For the two-way interactions, there was no a significant two-way interaction between configuration and set sizes. None of the other three-way interactions were significant.

The RT slopes for stimulus types were analysed by two-way repeated measures ANOVA over stimulus types (hands and feet) and configurations (negative-surprising and nonnegative-surprising) (Figure 2-19). There was no significant main effect of stimulus types [F(1, 28) = 0.505, p = 0.483, $\eta_p^2 = 0.018$] and configuration [F(1, 28) = 0.003, p = 0.958, $\eta_p^2 = 0.000$]. For the two-way interactions, there was no significant interaction between stimulus types and configuration [F(1, 28) = 1.699, p = 0.203, $\eta_p^2 = 0.057$].

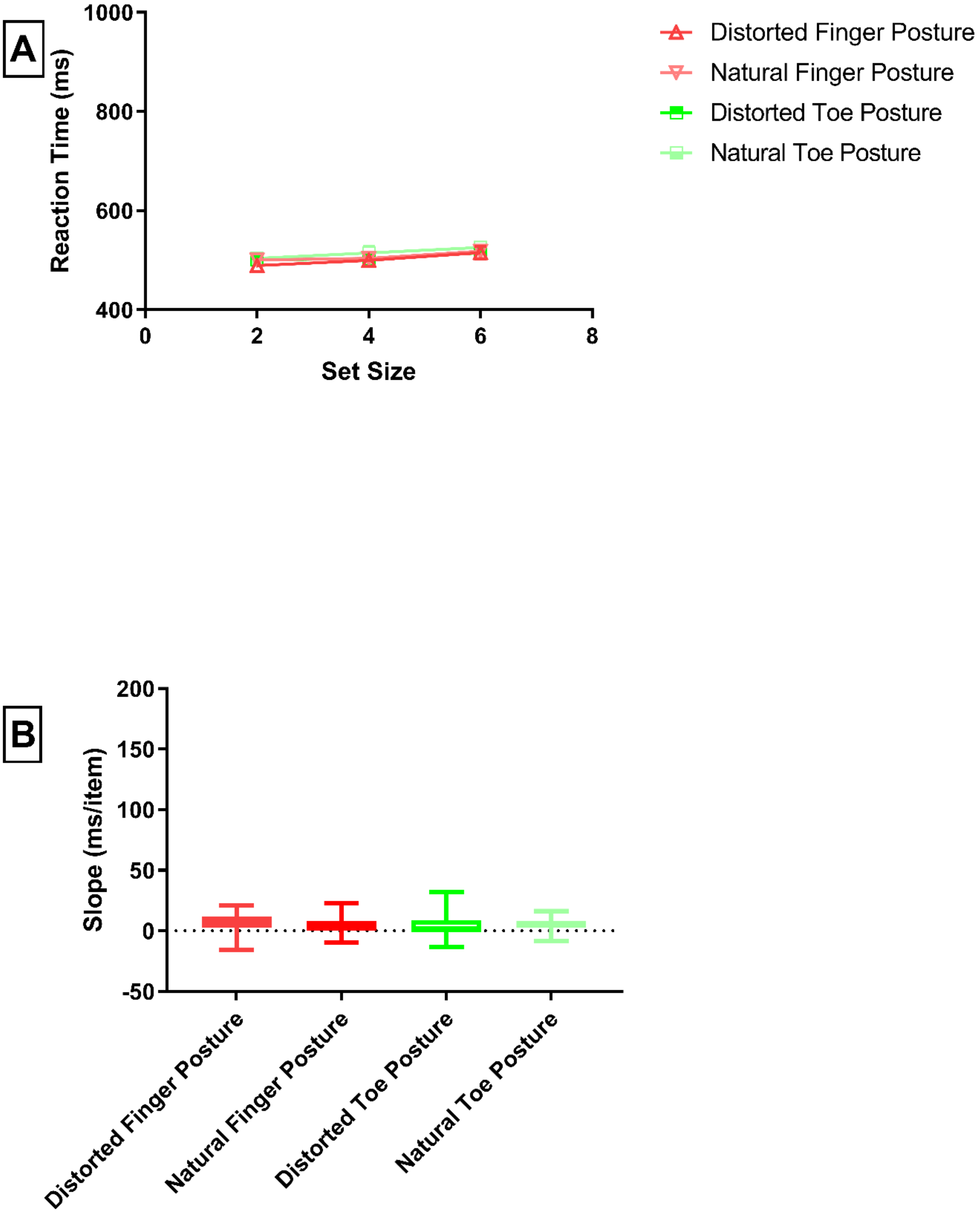


Figure 2-19 Control Experiment 3 results
(A) Average RTs across set sizes on search set size and stimulus type. (B) RT slopes. The box plot shows 2.5%, 25%, 50% (median), 75% and 97.5% percentiles.

2.7.4 Discussion

This experiment was designed to investigate the influence of feet on visual search patterns. Toe distortions may be less visually striking, potentially introducing bias. However, using feet as a control remains a valuable compromise to explore whether the distinction between distorted and natural postures extends beyond the hands. Regarding the primary question of the research, the data indicated a difference in average RTs across set sizes, contingent on the type of stimulus. Further, a discrepancy in average RTs across set sizes was observed between the distorted and natural conditions across the same set sizes. The RTs across set size is smallest for faces, followed by hands, then whole bodies, and largest for cars. This experiment did not reveal any evidence that the slope of RTs influenced either the type of stimulus or the configuration of the stimulus Furthermore, no interaction effect was found between the kind of stimulus and configuration. The findings indicate that the presumed similarity between hands and feet, due to their anatomical features, does not necessarily translate to cognitive processes related to visual search tasks. These results, showing no significant difference in visual search efficiencies between the hands and the feet, challenge the assumption that such differences are fundamental to social communication. This finding necessitates a revaluation of current theories and encourages further research to identify the specific mechanisms underlying social signalling and interaction.

2.8 General Discussion for Chapter 2

Previous research has demonstrated the significance of hands in social communication, tool use, and object manipulation, as well as their role as highly salient stimuli in visual search tasks. However, a comparative analysis of hands with other body parts, such as faces or whole bodies, in terms of salience remains unclear. To address this gap, a series of experiments were conducted to investigate the identification and discrimination of specific body parts within a group of stimuli. Participants were presented with arrays of images comprising hands, faces, or whole bodies, accompanied by distractor images. The purpose was to swiftly and accurately identify the target image. The results of the experiments revealed that hands exhibited greater salience than faces or whole bodies in visual search tasks. Participants displayed enhanced speed and accuracy in identifying hands compared to other body parts. These findings underscore the critical role played by hands in human perception. The implications of these findings extend to the realm of visual information processing in everyday life.

A key component of the experiments involved comparing natural and distorted images of body parts and objects. Interestingly, the RT for distorted finger postures was faster than for natural finger postures, indicating that distorted hand configurations may be more salient. However, this effect was not observed with chairs, as there was no significant difference in RT between distorted chairs and standard chairs. This highlights the unique salience of hands in visual search tasks. It is important to acknowledge certain limitations of the study. The investigation solely focused on a restricted set of body parts (hands, faces, and whole bodies). Future research endeavours could explore additional body parts or combinations thereof to attain a more comprehensive understanding of human body perception. Another limitation pertains to the absence of an examination into individual differences in hand perception. It is plausible that certain individuals may exhibit greater sensitivity to hand stimuli owing to factors such as experience or genetic predispositions. Despite these limitations, the findings of this study hold significant implications for academic fields including psychology, neuroscience and even neuropsychology. Furthermore, the results provide insights into the processing of social information, as hands are crucial for social communication and are indicated to be particularly salient in this context. Future research endeavours could delve into the relationship between hand perception and social cognition and behaviour. In addition to its practical applications, this study contributes to the advancement of our theoretical comprehension of human body perception. The findings underscore the highly salient nature of hands as stimuli in visual search tasks.

Chapter 3 Perception of Hands, Faces, and Whole Bodies Using Eye Tracking, Including Pupillometry

This chapter describes behavioural experiments, involving eye tracking, including pupillometry, on human body perception and is subdivided into two sections. The first section describes Experiment 5, which examined the behavioural effect of distorted and natural finger postures. The second section describes Experiment 6, which extended from Experiment 5 to investigate whether there was a difference between distorted and natural finger postures on fixation and saccade using eye tracking, including pupillometry which can examine mental effort for distorted and natural finger postures by measuring changes in pupil dilation.

3.1 Experiment 5: Inhibiting Saccade to Hand, Face and Whole Body Perception: High-Level Visual Processing via Modulation of Oculomotor Control

3.1.1 Introduction

In vision, attention is partly driven by the individual and partly governed by the properties of the received stimuli (Motter & Holsapple, 2007; Rolfs, 2015). Endogenous attention, also called top-down attention, is goal-directed and is allocated voluntarily. Exogenous attention, also called bottom-up attention, is stimulus-driven and evoked automatically or involuntarily. Importantly, top-down attention is relatively sustained. Visual attention functions through two main processes known as top-down and bottom-up attention. With top-down attention, individuals consciously direct their focus towards particular objects, attributes, or spatial locations for prolonged periods. Bottom-up attention, on the other hand, refers to the brief and automatic capture of one's focus by external stimuli in the environment. Generally, in visual search task using RT measures, the experiments' focus is on endogenous, top-down, attention (Carrasco, 2011; Pinto, van der Leij, Sligte, Lamme, & Scholte, 2013). In Chapter 2, visual search tasks measuring reaction time were also used to investigate endogenous attention and it was found that there was a significant difference between hand and whole body average RT across set sizes and RT slopes. The average RT for hand movements is smaller than for whole body movements, and the RT slopes for the hand are flatter than those for the whole body.

Previous studies have demonstrated that certain brain regions, including the extrastriate visual cortex and anterior temporal areas, show independent activation in response to attentional tasks involving visual stimuli with varied sensory features presented (Lane et al., 1999; Reinholdt-Dunne et al., 2012). Additionally, when study participants viewed images of human bodies, activation was observed in these same regions. This overlap in activation suggests these same regions may play a dual role in both general attentional processing attentional processing and the body-specific perceptual processing associated with viewing human forms, such as images of bodies (Crouzet, Kirchner, & Thorpe, 2010; Geringswald et al., 2020). This thesis examines hand perception processes, drawing from previous research that has observed increased activity in the extrastriate visual cortex and anterior temporal areas during attention-modulated body perception. To further explore this relationship between attention, perception, and body-specific processing, this thesis used eye gaze tracking to investigate hand perception tasks. By tracking eye gaze patterns during hand stimulus viewing, changes in overt attention can be measured, and this can serve as an index of perceptual and evaluative processing driven by these higher-order sensory regions. Characterising both the attentional and perceptual signals reflected in gaze control during hand perception will shed new light on how body representations are constructed across the ventral visual stream. In particular, predictable relationships between activation timecourses in body-sensitive areas and real-time shifts in gaze position help elucidate dynamic signalling related to perceptual binding for meaningful body part stimuli.

Recent research into saccadic eye movements using parts of the human body as visual stimuli has received increased attention in publications across several disciplines (Born, Ansorge, & Kerzel, 2012; Kowler, 2011; Zhao et al., 2012). Researchers know from previous studies that, when an eye movement is programmed, covert attention to human faces or whole human bodies is forced to transfer to the saccade target, and the programming of the eye movement can reveal cognitive control mechanisms (Geiger et al., 2017; Schütz et al., 2011). In addition, emotional affective reaction has been included in eye tracking experiments on face and whole body stimuli (Schurgin et al., 2014; Shields, Engelhardt, & Ietswaart, 2012).

Based on observers' eye movements to visual stimuli, it can be seen that saccades demonstrate attentional shifts and capture (Heyman et al., 2017; Hoffman & Subramaniam, 1995; Zhao et al., 2012). This attention capture leads to reflexive shifts in saccade occurrence, and response latency can reflect visual properties of parts of the human body (Cazzato et al., 2014; Reinholdt-Dunne et al., 2012). These studies focus on how these shifts in attention and saccade response are uniquely manifested in the perception of hands and their distortions. The important aspects of attention in this experiment are visual selective attention, attentional inhibition and attentional bias. Visual selective attention is the brain function that modulates the ongoing processing of retinal input for selected representations to gain privileged access to perceptual awareness and to guide behaviour (Anderson et al., 2021; Chelazzi, Perlato, Santandrea, & Della Libera, 2013). Saccade target selection is a measure of visual selective attention (Deubel & Schneider, 1996; Kristjánsson, 2007). This is shown through experiments like visual search tasks, where faster and more accurate saccades towards a target suggest pre-allocation of attention. Pre-cueing tasks, where a cue directs attention, also support this – saccades are faster when the target aligns with the cue. Further, dual-task paradigms, where participants plan a saccade whilst discriminating a flashed stimulus, show better discrimination when the stimulus and saccade target locations coincide, indicating attention shifts to the planned eye movement location. This experiment applies these insights to hand perception, analysing how the visual system selectively attends to hand images, especially when they are distorted.

Attentional inhibition refers to a process in which individuals avert their gaze towards targets and limit their attention to distracting information (Chelazzi, Marini, Pascucci, & Turatto, 2019; Moorselaar & Slagter, 2020). Antisaccades can be used to measure attentional inhibition, and antisaccade tasks serve as effective tools for assessing attentional inhibition. These tasks require individuals to resist the instinctive urge to look directly at a stimulus appearing in their peripheral vision. Instead, participants must consciously direct their gaze to the opposite side. This process involves both suppressing an automatic response and initiating a deliberate eye movement, making it particularly useful for measuring one's ability to control attention. (Chen, Clarke, Watson, Macleod, & Guastella, 2014). Compared to prosaccade tasks requiring participants to saccade to targets, antisaccade tasks require participants to resist the reflexive urge to stare at a visual object that appears in their peripheral vision and instead saccade towards targets that emerge in the opposite direction. Cognitive psychologists often use this test to assess inhibition (Calanchini, Rivers, Klauer, & Sherman, 2018). Attentional bias refers to a condition in which individuals distribute attention to distinct aspects of neutral and threatening stimuli to varying degrees (Li, Liu, Yu, Tang, & Liu, 2020). Attentional bias is often calculated by subtracting the mean difference in saccade latency between antisaccade and prosaccade trials (also known as antisaccade cost) (Reinholdt-Dunne et al., 2012). Evidence from numerous studies suggest that saccade latencies reflect attentional modulation and selective attention (Cajar et al., 2016; Crouzet et al., 2010; Khan et al., 2010; Pratt & Trottier, 2005; Senturk, Greenberg, & Liu, 2016).

Currently, it is known saccades can be driven by low-level (e.g., colour, brightness or contrast) and high-level (e.g., the position, semantic category of objects) features of stimuli (Schütt et al., 2019). Research on the influence of low-level features is of great interest and has a very active research community. Still, there is little published research on high-level features, especially on body parts, in particular, hands. In terms of human bodies in the eye tracking experiment, eye movements have been studied in that attentional bias, and selective attention between emotional faces and natural faces are different, and that attentional bias and selective attention between hands and hand tools are distinct (Morrisey & Rutherford, 2013; Reinholdt-Dunne et al., 2012). One of the main challenges in understanding the visual processing of body parts is the limited research on eye movements during the simultaneous perception of hands, faces, and whole bodies. By employing antisaccade tasks in this study, we aim to investigate the underlying attentional and inhibitory control mechanisms specific to hand perception. Antisaccade tasks require participants to suppress automatic eye movements toward a stimulus and instead direct their gaze away from it, providing a measure of cognitive control and attentional allocation. By comparing antisaccade performance across different stimuli, we can determine whether hands elicit unique patterns of eye movements and cognitive processing compared to faces and whole bodies. This approach reveals how hand perception may involve distinct neural and cognitive pathways, enhancing our understanding of the specialised processing of hands in the visual system.

The first purpose of Experiment 5 was to explore differences in selective attention, attentional inhibition, and attentional bias among hands, faces, whole bodies, and cars for horizontal saccade. This was measured using saccade onset latencies in both prosaccade and antisaccade tasks, based on the theoretical framework that acknowledges specialised neural pathways for processing these distinct visual stimuli. It was predicted that prosaccade latencies for hands would be longer than for faces, but shorter than for whole bodies. Additionally, antisaccade latencies for hands were predicted to be shorter than for faces but longer than for whole bodies. Finally, it was predicted that antisaccade latency cost (the difference between antisaccade and prosaccade) for hands would be lower than for faces but higher than for whole bodies and cars. This prediction stems from the specialisation of the neural system in processing the hand, faces, whole body, and cars in neuroimaging and behavioural studies (Berlucchi, 2011; Conson et al., 2020a; Op de Beeck et al., 2013; Van den Stock et al., 2014).

The second purposes investigated vertical saccade using saccade latencies and in prosaccade and antisaccade tasks. Predictions mirrored those of horizontal saccades, with expected differences in attention based on stimulus type (hands, faces, bodies, cars). This aligns with known neural specialisation (Berlucchi, 2011; Conson et al., 2020a; Op de Beeck et al., 2013; Van den Stock et al., 2014). The research explores attentional engagement and its link to specialised processing of these stimuli.

The third purpose of the experiment was to explore whether there is interaction between the saccade conditions (prosaccade and antisaccade), stimulus type (hand, face, whole body and car) and saccade type (horizontal and vertical) on saccade latency and error rate. This prediction is that horizontal and vertical saccades elicited different cognitive processes based on varying stimulus type and saccade conditions. This prediction stems from the complex interplay between attentional control mechanisms, specialised neural pathways, and the distinct ways humans process horizontal and vertical visual information. Investigating such interactions could shed light on the flexibility and limits of our attentional systems (Greene, Diwadkar, & Brown, 2023; Irving & Lillakas, 2019).

3.1.2 Methods

3.1.2.1 Participants

Thirty students from the University of Nottingham Malaysia, 12 females and 18 males, (18–45 years, *M* = 24.80 years, SD = 3.51) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment. All participants gave written, informed consent and had normal or corrected to normal visual acuity by self-report, and all received either course credits or inconvenience allowances. The participants were all judged to be right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971; Veale, 2014). The number of participants in the experiments was larger than in comparable earlier studies using eye movement recordings (Bradley et al., 2008; Deubel, 2008; Sandoval & McIntosh, 2015). Using G*Power 3.1.9.7 with default settings, it was determined that a sample size of 24 would be sufficient to detect a significant interaction with a power of 0.95 and an alpha of 0.05 in a repeated measures within-subjects ANOVA (Faul et al., 2009; Faul et al., 2007). All participants gave written, informed consent and had normal or corrected to normal visual acuity. All participants received either course credit or an inconvenience allowance. These procedures received approval from the SEREC of the University of Nottingham Malaysia under application number HYC150221.

3.1.2.2 Materials and apparatus

Eye tracking experiments have been employed to investigate whether saccade durations would be altered by faces, bodies and hands (Pratt & Trottier, 2005). The eye tracking experiment in this study reported here is a task, including antisaccade and prosaccade, that asks participants to saccade to a specific target, including images of faces, bodies, hands and car stimuli, following instructions using a factorial design. Four stimulus types (hands, faces, whole bodies and cars) were used in the experiment (Figure 3-1B). For each type of stimulus, there were five unique example images. These images were in greyscale (average RGB: 128, 128, 128). The size of each image was 100 pixels × 100 pixels (viewed at 2.95° × 2.95° visual angle). In each trial, one of the 20 images was shown as a target image at 310 pixels (9.15°) from the centre of the screen, either at 0° (horizontal midline and to the right-hand side of the centre), 90°, 180° and 270°. Simultaneously with the target, a blank square (blank inside) was shown (same size as the target) at 180° relative to the target. Fifty percent of all trials showed the target and the square in a horizontal arrangement, whilst in the other 50%, the arrangement was vertical (see Figure 3-1A for examples of horizontal and vertical arrangements). In each trial, one stimulus was always a target stimulus, and the other was always an empty square.

Chin and forehead rests were used to limited head movements. The stimuli were displayed on a 24-inch BenQ monitor with a temporal frequency of 144 Hz, at a spatial resolution of 1024 × 768 pixels (340 × 270 mm). A desktop-mounted eye tracker (EyeLink 1000 Plus) from SR Research was used to monitor participants' eye movements at a sampling rate of 1000 Hz throughout the experiment. The viewing distance was set at 57 cm. Stimuli were presented with a programme called SR Research Experiment Builder, running on a 64-bit Windows 7 computer connected to an EyeLink 1000 Plus (SR Research, Ontario, Canada) and an eye tracking host computer used to record eye tracking data. All eye movement data were recorded by SR Research Experiment Builder and analysed using SR Research Data Viewer.

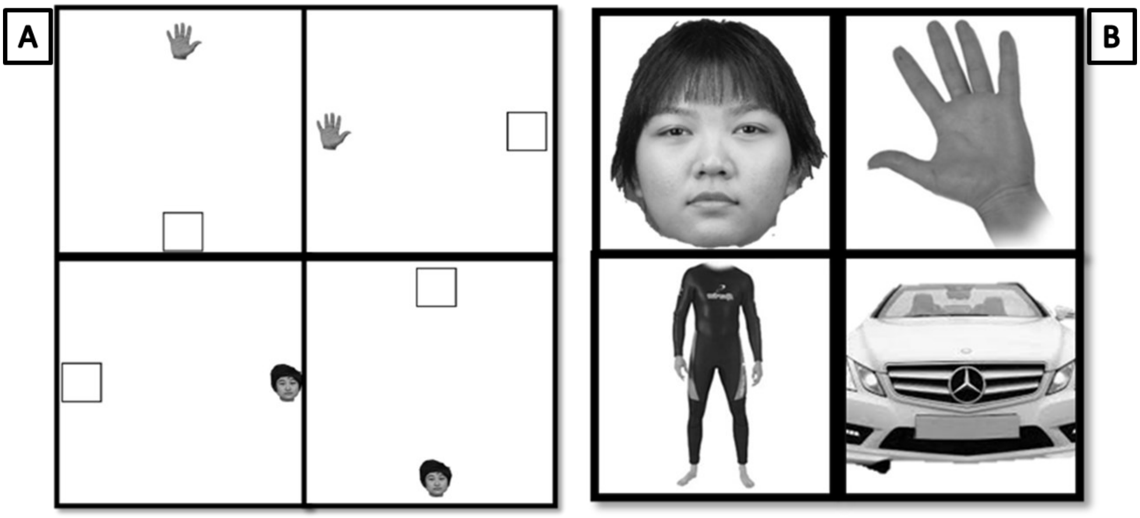
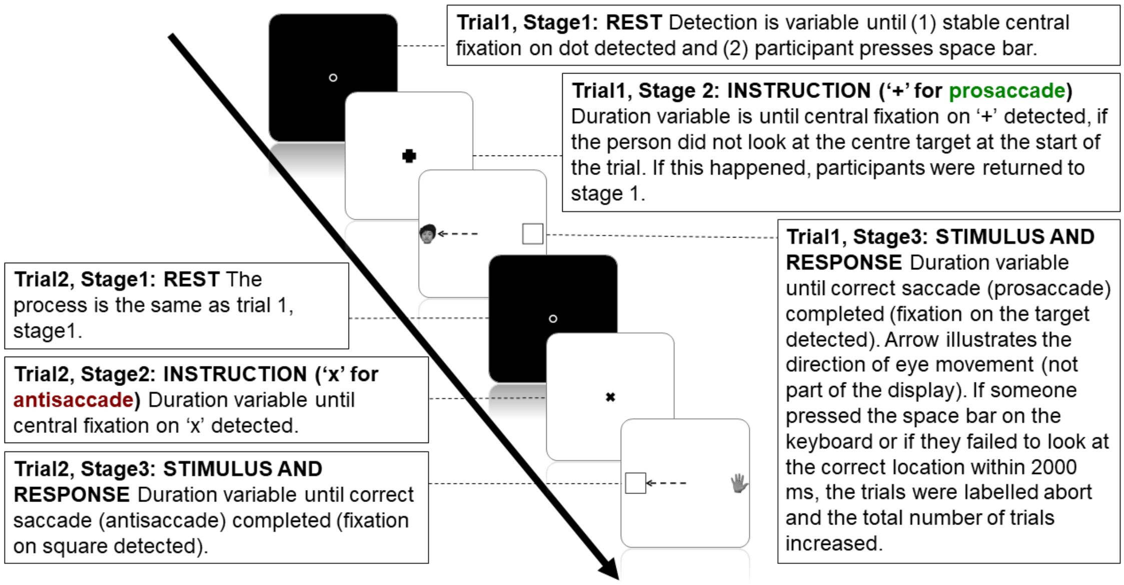


Figure 3-1 Example of visual displays and examples of visual target stimuli in Experiment 5
(A) Each example of a visual display containing a target stimulus and a square. (B) Examples of visual target stimuli, each trial was one of the stimuli.

3.1.2.3 Procedure

Successful calibration using a 9-point calibration and 9-point validation was required before starting the experimental trials (Mathôt, Grainger, & Strijkers, 2017; Wang, Yuval-Greenberg, & Heeger, 2016). Before starting experimental trials, participants performed several practice trials after receiving approximately two minutes of instructions from the experimenter. Each participant was tested with 800 trials, in five blocks of 160 trials each, in a pseudorandom order. Each block took approximately 7 minutes to complete. Each trial was repeated if the participants did not respond correctly; the screen would not move on to the next trial until they got it right. Each trial began with a drift correction, where the participants fixated on a white dot on a black background to allow the eye tracker to correct any drift errors (Figure 3-2). The trials would not continue unless the participants looked at the white dot for 100 ms. Once stable fixation on the white dot was detected, the fixation cross was replaced by a cue (either a '+' or an 'x'). Cue '+' indicated a prosaccade trial and 'x' indicated an antisaccade trial. Once fixation on the cue was detected, the target stimuli appeared in either the top, bottom, left side or the right side of the screen, and the square appeared in the position opposite to the target stimuli. In the prosaccade trials, participants had to fixate at the target stimulus, and in the antisaccade trials, participants had to fixate the square. Within each block, prosaccade and antisaccade trials and stimulus types were fully randomised. The trial ended when the participants detected the target stimuli.



Trial1, Stage1: REST Detection is variable until (1) stable central fixation on dot detected and (2) participant presses space bar.

Trial1, Stage 2: INSTRUCTION ('+' for prosaccade) Duration variable is until central fixation on '+' detected, if the person did not look at the centre target at the start of the trial. If this happened, participants were returned to stage 1.

Trial1, Stage3: STIMULUS AND RESPONSE Duration variable until correct saccade (prosaccade) completed (fixation on the target detected). Arrow illustrates the direction of eye movement (not part of the display). If someone pressed the space bar on the keyboard or if they failed to look at the correct location within 2000 ms, the trials were labelled abort and the total number of trials increased.

Trial2, Stage1: REST The process is the same as trial 1, stage1.

Trial2, Stage2: INSTRUCTION ('x' for antisaccade) Duration variable until central fixation on 'x' detected.

Trial2, Stage3: STIMULUS AND RESPONSE Duration variable until correct saccade (antisaccade) completed (fixation on square detected).

Figure 3-2 Stimulus timeline for Experiment 5, showing 2 trials.

3.1.2.4 Data preprocessing

There are horizontal and vertical saccades. 400 trials are horizontal saccades, and 400 trials are vertical saccades. Data preprocessing and statistical tests were carried out using JASP (https://jasp-stats.org/). Trials were discarded if (1) the saccade latency was less than 80 ms because these saccades probably reflected anticipatory responses (Geringswald et al., 2020), (2) the saccade amplitude was less than 1° of visual angle (Geringswald et al., 2020), or (3) the distance between the saccade start point and the screen centre exceeded 1° of visual angle (Geringswald et al., 2020). Participants' data were discarded if (1) a participant's error rates were too high (>20%), (2) participants did not finish the experiment (Geringswald et al., 2020). After the application of these criteria, the final sample size was 20 participants.

3.1.3 Results

3.1.3.1 Horizontal saccade latency

All values are reported as the mean and standard errors of the mean of each participant and each variable. The mean prosaccade latency was 191 ms (SD = 8 ms). The mean antisaccade latency was 211 ms (SD = 10 ms) (Figure 3-3). The mean antisaccade cost latencies (mean difference between antisaccade and prosaccade latencies) was 20 ms (SD = 30 ms) (Figure 3-3). A two-way repeated measures ANOVA was conducted to determine the effects of saccade conditions (prosaccade and antisaccade) and stimulus (Figure 3-3). There was no a statistically significant main effect of condition [F(3, 57) = 0.644, p = 0.590, η_p^2 = 0.033]. There was a statistically significant main effect of condition [F(1, 19) = 26.499, p < 0.001, η_p^2 = 0.582]. There was a statistically significant two-way interaction between condition and stimuli [F(3, 57) = 11.252, p < 0.001, η_p^2 = 0.372].

Pairwise comparisons were run between the different stimulus type for prosaccade-only trial. There was a statistically significant difference between face and whole body [t(19) = -3.101, p = 0.006, *d* = -0.711], between face and car [t(19) = -2.667, p = 0.015, *d* = -0.609]. There was no statistically significant difference between hand and face [t(19) = -1.653, p = 0.115, *d* = -0.517] and hand and whole body [t(19) = -1.653, p = 0.115, *d* = 0.194]. Pairwise comparisons were run between the different stimulus type for antisaccade-only trial. There was a statistically significant difference between hand and whole body [t(19) = -2.638, p = 0.016, *d* = -0.428] and between hand and car [t(19) = 3.094, p = 0.006, *d* = 0.537]. Interestingly, there was no statistically significant difference between hand and face [t(19) = 2.077, p = 0.052, *d* = 0.360]. Paired-samples t-tests were used to determine whether there was a statistically significant difference in mean saccade latency on antisaccade cost latency between hand, face, whole body and car. For follow-up analysis, the factor of directions was excluded by averaging between saccade towards the left direction and right direction. There was a statistically significant mean difference between hand and face [t(19) = 2.275, p =0.035, *d* = 0.509], hand and whole body [t(19) = -2.375, p = 0.028, *d* = -0.531] and between hand and car [t(19) = 2.411, p = 0.026, *d* = 0.539]. There was no statistically significant difference between whole body and car [t(19) = 0.031, p = 0.976, *d* = 0.006].

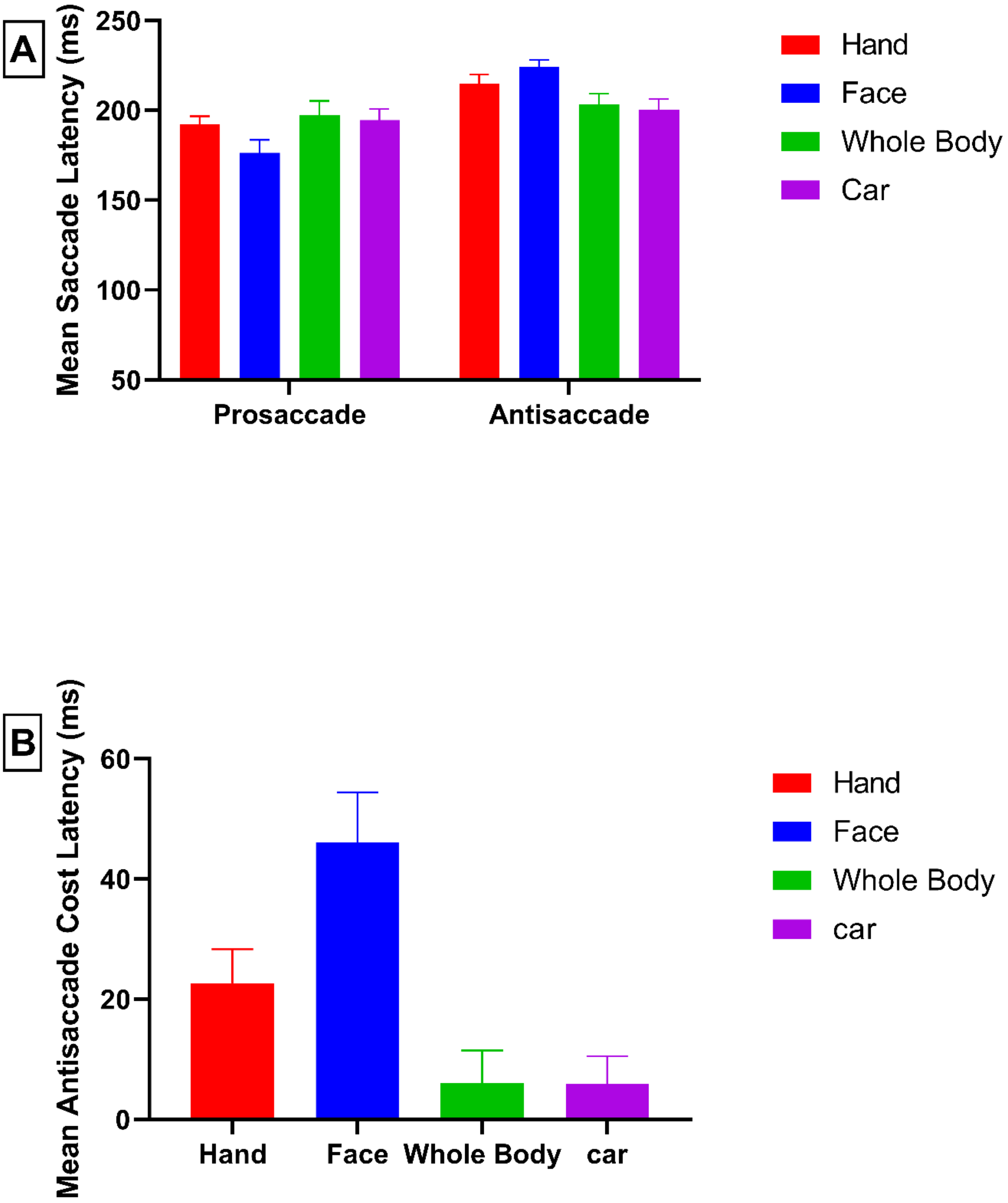


Figure 3-3 Results of horizontal saccade latencies in Experiment 5
(A) Mean horizontal prosaccade and antisaccade latency. Participants instructed to look in target direction, targets appeared randomly left or right. (B) Mean horizontal antisaccade cost latency.

3.1.3.2 Vertical saccade latencies

All values are reported as the mean and standard errors of the mean of each participant and each variable. The mean prosaccade latency was 214 ms (SD = 24 ms). The mean antisaccade latency was 216 ms (SD = 19 ms) (Figure 3-4). The mean antisaccade cost latencies (mean difference between antisaccade and prosaccade latencies) was 3 ms (SD = 5 ms) (Figure 3-4). A two-way repeated measures ANOVA was conducted to determine the effects of conditions (prosaccade and antisaccade) and stimulus type (hand, face, whole body and car). There was a statistically significant main effect of stimulus type [F(3, 57) = 7.359, $p < 0.001$, $\eta_p^2 = 0.279$]. There was no statistically significant two-way interaction between saccade condition and stimulus type [F(3, 57) = 1.490, p = 0.227, $\eta_p^2 = 0.073$]. Pairwise comparisons were run between the different stimulus type for prosaccade-only trial. There was a statistically significant difference between hand and face [t(19) = 3.679, p = 0.002, $\eta_p^2 = 0.554$]. Pairwise comparisons were run between the different stimulus type for antisaccade-only trial. There was not a statistically significant difference between each other.

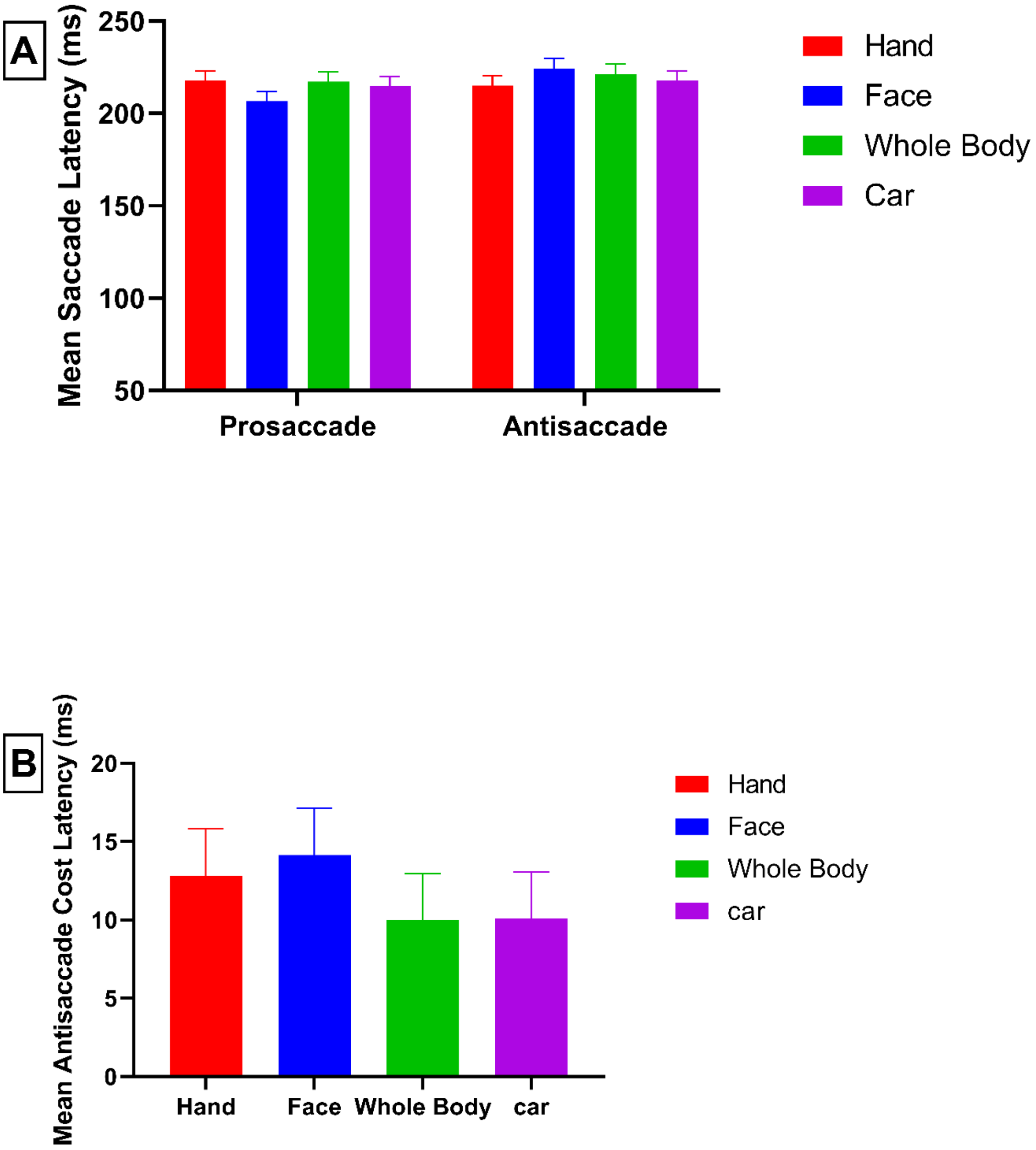


Figure 3-4 Mean vertical saccades in Experiment 5
(A) Mean vertical prosaccade and antisaccade latency. (B) Mean vertical antisaccade cost latency.

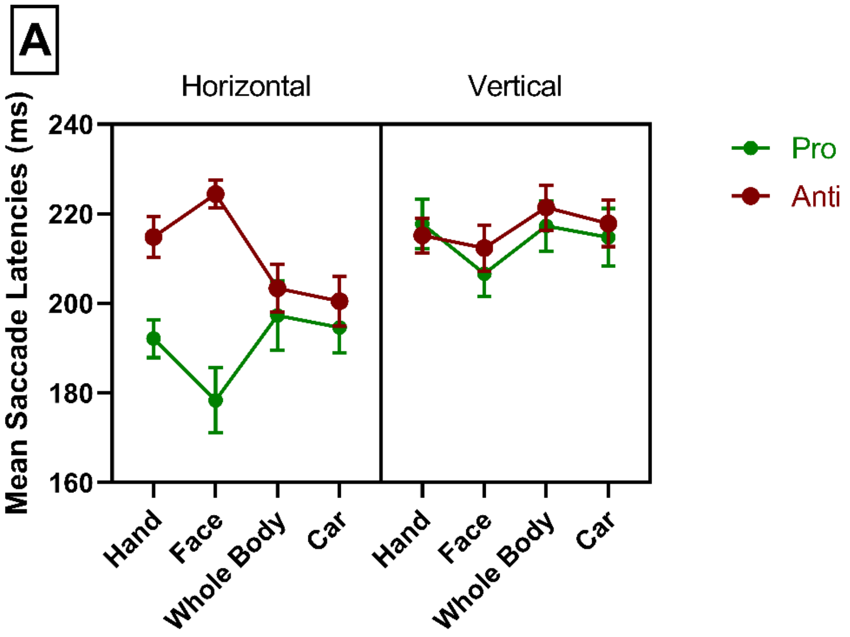
3.1.3.3 Horizontal and vertical saccade latency and error rate

A three-way repeated measures ANOVA was conducted to determine the effects of conditions (prosaccade and antisaccade), stimulus type (hand, face, whole body and car) and saccade type (horizontal and vertical) on saccade latency (Figure 3-5). There was a statistically significant main effect of conditions [$F(1, 19) = 18.974$, $p < 0.001$, $\eta_p^2 = 0.500$]. There was a statistically significant two-way interaction between condition and saccade type [$F(3, 57) = 23.591$, $p < 0.001$, $\eta_p^2 = 0.554$]. There was a statistically significant two-way interaction between stimuli and condition [$F(3, 57) = 8.983$, $p < 0.001$, $\eta_p^2 = 0.321$]. There was a statistically significant three-way interaction between condition, stimulus type and style [$F(3, 57) = 9.347$, $p < 0.001$, $\eta_p^2 = 0.330$].

A two-way repeated measures ANOVA was conducted to determine the effects of stimulus type (hand, face, whole body, and car) and saccade type (horizontal and vertical) on the antisaccade cost (antisaccade minus prosaccade) on saccade latency (Figure 3-5). There was a statistically significant main effect of saccade types [$F(1, 19) = 5.928$, $p = 0.025$, $\eta_p^2 = 0.238$]. There was a statistically significant two-way interaction between stimulus type and saccade type [$F(3, 57) = 17.664$, $p < 0.001$, $\eta_p^2 = 0.482$]. Pairwise comparisons were run on the interaction between stimulus type and style. There was a statistically significant difference between horizontal and vertical saccades for face stimuli [$t(19) = 6.486$, $p < 0.001$, $d = 0.355$].

A three-way repeated measures ANOVA was conducted to determine the effects of conditions (prosaccades and antisaccades), stimulus type (hand, face, whole body and car) and saccade type (horizontal and vertical) on saccade error rate (Figure 3-6). There was a main effect of condition [$F(1, 19) = 23.286$, $p < 0.001$, $\eta_p^2 = 0.551$]. There was a significant two-way interaction between condition and style [$F(3, 57) = 26.122$, $p < 0.001$, $\eta_p^2 = 0.579$]. There was a significant two-way interaction between condition and stimulus type [F(3, 57) = 14.045, $p < 0.001$, $\eta_p^2 = 0.425$]. There was a statistically significant three-way interaction between conditions, stimulus type and style [F (3, 57) = 10.739, $p < 0.001$, $\eta_p^2 = 0.361$].

A two-way repeated measures ANOVA was run to determine the effect of stimuli (hands, faces, whole body, and cars) and style (horizontal and vertical) on the antisaccade cost error rate (antisaccade minus prosaccade) (Figure 3-6). There was a statistically significant main effect of style [F (1, 19) = 32.622, $p < 0.001$, $\eta_p^2 = 0.632$]. There was a statistically significant two-way interaction between stimulus type and style [F(3, 57) = 13.900, $p < 0.001$, $\eta_p^2 = 0.422$]. Pairwise comparisons were run on the interaction between stimulus type and style. There was a statistically significant difference between horizontal and vertical on hand [t(19) = 7.640, $p < 0.001$, $\eta_p^2 = 0.141$]. There was a statistically significant difference between horizontal and vertical on face [t(19) = 4.591, $p < 0.001$, $\eta_p^2 = 0.241$].



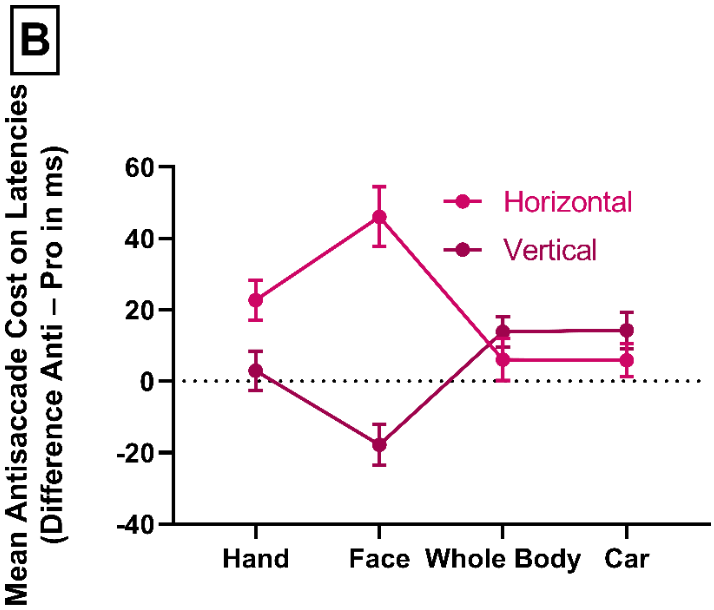


Figure 3-5 Results of horizontal and vertical saccade latency in Experiment 5. (A) Mean saccade latency as a function of stimulus type. (B) Difference in saccade latency between antisaccade and prosaccade.

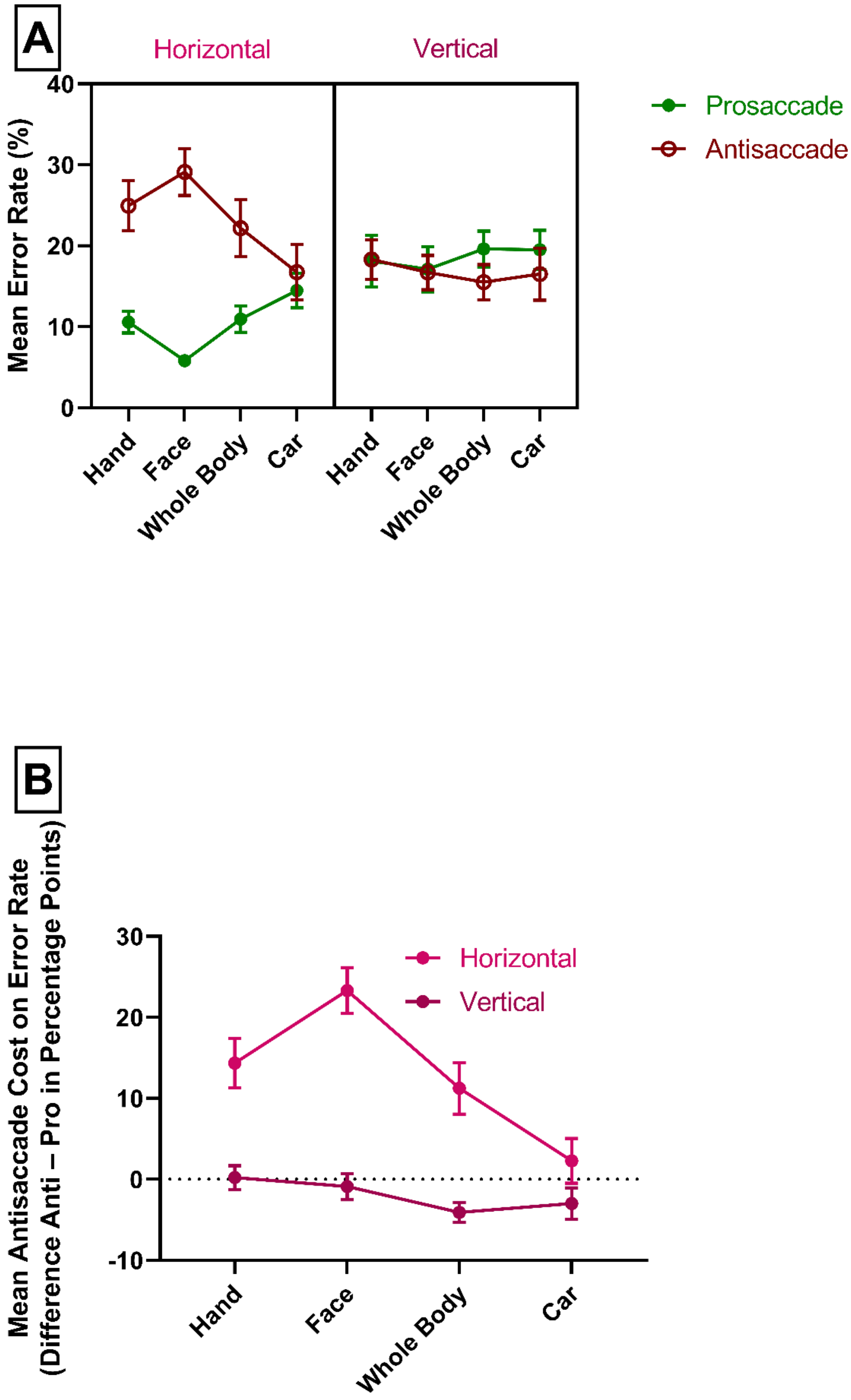


Figure 3-6 Results of horizontal and vertical saccade error rate in Experiment 5. (A) Mean error rate as a function of stimulus type. (B) Mean antisaccade cost on error rate.

3.1.4 Discussion

First, for horizontal saccade, the experiment findings that prosaccade latency, were slightly longer for hands compared to faces, but still shorter than for whole bodies or cars. Conversely, antisaccade latency was significantly longer for hands than whole bodies or cars. The antisaccade cost was higher for hands compared to whole bodies or cars. There was not statistically significant between hands and faces (Figure 3-3). Second, for vertical saccade, hand stimuli elicited significantly faster prosaccade latencies compared to face stimuli. However, there was no significant difference in antisaccade latencies between hand and other stimulus types (Figure 3-4). Third, hand stimuli, there was a statistically significant difference between horizontal and vertical saccades on the antisaccade cost error rate. Specifically, the result showed a significant difference between horizontal and vertical saccades for hand stimuli, indicating that the antisaccade cost error rate differed significantly between horizontal and vertical saccades (Figure 3-5).

Prior studies have used prosaccade and antisaccade tasks to investigate attention to human bodies (Morand et al., 2010; Morrisey & Rutherford, 2013; Reinholdt-Dunne et al., 2012). This finding is pertinent as it underscores the contrast in cognitive processing times for attentional inhibition (antisaccade) versus selective attention (prosaccade) tasks, reflecting the intricacies of cognitive processes involved in hand perception. In accordance with the present results, previous studies have demonstrated that prosaccade latencies in principle are lower than antisaccade for the same stimuli (Abegg, Manoach, & Barton, 2011; Reinholdt-Dunne et al., 2012). Prior studies have used prosaccade and antisaccade tasks to investigate attention to human bodies (Morand et al., 2010; Morrisey & Rutherford, 2013; Reinholdt-Dunne et al., 2012). This study found that the antisaccade latencies are higher than the prosaccade latencies. In accordance with the present results, previous studies have demonstrated that prosaccade latencies in principle are lower than antisaccade for the same stimuli (Abegg et al., 2011; Edelman, Valenzuela, & Barton, 2006; Reinholdt-Dunne et al., 2012). One interesting finding is that the prosaccade latencies of hands are the same as the faces. These results of prosaccade corroborate the findings of much of the previous work conducted in Chapter 2 in visual search for the different parts of the human body that the slopes of visual search in faces and hands are not significantly different.

The current study found that antisaccade latencies of faces differ from whole bodies and hands. A possible explanation for this might be that faces have lower attentional inhibition (Chen et al., 2014; Hutton & Ettinger, 2006; Reinholdt-Dunne et al., 2012). Another important yet surprising finding is that vertical antisaccade cost on saccade latency for faces was significantly higher than for hands, whole bodies and cars. Regarding the difference between the parts of the human body, a possible explanation for this is that antisaccade of hands has a stronger attentional bias (Chen et al., 2014; Hutton & Ettinger, 2006). Therefore, the properties of faces and hands could be a major factor, if not the only one, causing the difference between prosaccades and antisaccades.

The present results are significant for three reasons. First, the lack of significant difference in prosaccade latencies towards faces versus hands suggests that both categories of biologically relevant stimuli elicit comparable levels of visual attention orienting and selection efficiency. This finding is notable because it provides behavioural evidence that hands, as platforms for vital physical and social interaction, may be encoded with similar visual priority in the brain as facial cues during scene processing. Comparable saccade reaction times imply shared neurocognitive resources allocated preferentially to shifting gaze towards these highly informative human appendages. Determining if equivalent oculomotor drive extends to other body parts can shed further light on the attentional prioritisation of form, motion, and interaction signals dynamically transmitted through human body configurations. Overall, equivalent prosaccade metrics align with evolutionary perspectives on how selective pressures may have specialised systems guiding visual attention to rapidly detect social affordances. Second, results from antisaccade indicated that the visual inhibition of faces differed significantly from that of bodies and hands. Third, the results of the antisaccade cost latencies indicated that the visual attentional bias of hands differs significantly from faces and bodies. An implication of this research is that saccade latencies may be modulated by perceptual attributes related to representation of human bodies in the visual system.

The findings in this experiment highlight an interplay between saccade condition, stimulus type, and saccade type, emphasising the complexity of visual perception and saccadic eye movement control. The significant three-way interaction among saccade condition (prosaccade and antisaccade), stimulus type (hand, face, whole body, and car), and saccade type (horizontal and vertical) points to the ways in which the visual systems respond to different visual stimuli, with hand perception being particularly notable for its relevance in motor control and communication. Moreover, the distinct latency differences between horizontal and vertical saccades, especially for face stimuli, underscore the tailored nature of visual processing. These findings not only illuminate the multifaceted nature of saccade in response to various stimuli but also suggest a rich area of exploration in understanding the specific perceptual and cognitive mechanisms involved in hand perception and its interaction with eye movement control. The comparative analysis of horizontal and vertical saccade latencies revealed a notable contrast: horizontal latencies exhibited an opposite trend between antisaccade and prosaccade movements, a phenomenon not observed in vertical saccades. This outcome suggests the presence of an attentional bias specific to horizontal latencies, as opposed to vertical ones (Figure 3-5).

Some reports have shown that antisaccade experiments investigate horizontal saccades only because compared to vertical saccades, horizontal saccades are more representative of the cognitive mechanism of visual recognition of stimuli related to the human body (Geringswald et al., 2020; Salvia, Harvey, Nazarian, & Grosbras, 2020). Although it has commonly been assumed that vertical saccades are not representative of the cognitive mechanism of the stimuli related to the human body and previous studies have failed to the role played by vertical saccade, the possible interference of vertical saccade cannot be ruled out, because some literature still includes the analysis of vertical saccade, despite the fact that the results of these experiments did not show the strong significance between horizontal and vertical saccade (Crouzet et al., 2010; Kauffmann, Khazaz, Peyrin, & Guyader, 2021; Morand et al., 2010). In order to consider another source of uncertainty of saccade, the analysis of vertical saccade was conducted to compare whether there was a difference between horizontal and vertical saccades on the stimuli related to the human body.

The results of this study intriguingly reveal a notable main effect of stimulus type on vertical saccade latency during prosaccade tasks (Figure 3-5). Specifically, the latency for recognising faces was significantly shorter compared to other stimuli, resonating with the findings of prior research (Crouzet et al., 2010; Rossion & Caharel, 2011) which underscored faster saccade responses to faces than to nonanimated objects like cars or natural scenes. This aligns with the overarching theme of this research, which centralises on the nuanced cognitive processes underpinning hand perception. Whilst the vertical saccade latency for hands in prosaccade did not significantly differ from the latency for whole bodies and cars (Figure 3-5). The results of this study intriguingly reveal a notable main effect of stimulus type on vertical saccade latency during prosaccade tasks (Figure 3-5). Specifically, the latency for recognising faces was significantly shorter compared to other stimuli, resonating with the findings of prior research (Crouzet et al., 2010; Rossion & Caharel, 2011), which underscored faster saccade responses to faces than to nonanimated objects like cars or natural scenes. This aligns with the overarching theme of this research, which centralises on the nuanced cognitive processes underpinning hand perception. Whilst the vertical saccade latency for hands in prosaccade did not significantly differ from the latency for whole bodies and cars (Figure 3-5), this subtle disparity underscores the complex interplay between visual attention and hand perception.

The absence of significant variance in vertical saccade latency for faces during antisaccade tasks further corroborates the nuanced cognitive processing involved in hand perception, as it suggests a uniformity in response latency across various stimuli. Consequently, this indicates that the differential processing speeds observed in prosaccade tasks are not merely a function of stimulus type but are intricately tied to the cognitive mechanisms governing hand perception. Despite these insights, the lack of significant differences in vertical saccade latency for antisaccade tasks suggests that the intricacies of hand perception are more subtly reflected in these measures, warranting a focused exploration in future studies to unravel the specific cognitive processes involved.

A possible explanation for vertical prosaccade latency for hand might be that in the vertical saccade, humans still pay attention selectively to stimuli related to human body, especially for the face. It can thus be suggested that the selective attention of stimuli related to the human body occurs not only in horizontal saccades but also in vertical saccade. A possible explanation for vertical saccade latency for the hand might be that the strength of selective attention for the hand was not as strong as that of selective attention for the face. Despite this, very little has been found in the literature on the question of the difference between different parts of the human body from each other. This limitation of lack of literature means that the study findings must be interpreted with caution. A possible explanation for vertical antisaccade latency might be that humans do not have selective attention for human body in vertical saccade. Comparison of the findings with those of other studies confirms that the difference of saccade latency between different parts of the human do not occur in antisaccades.

3.2 Experiment 6: An Eye Tracking and Pupillometry Study into the Perception of Distorted Finger Postures

3.2.1 Introduction

Antisaccades for faces, whole bodies and hands have been studied extensively in Experiment 5, using an eye tracking method. Different antisaccades have been found to be related to different types of body and body parts stimuli. However, there are few studies on eye movements on the visual processing of hands with emotional affective reaction. In Experiment 5, antisaccades were extensively studied for hands, faces and whole bodies using an eye tracking method. This experiment found that different antisaccades are associated with various types of body and body part stimuli. Notably, few studies have focused on eye movements in the visual processing of hands with emotional affective reaction. Participants were asked to view a sequence of distorted and natural finger posture images. To discern if the observed phenomena were specific to hands rather than general shapes, researchers included similar geometric shapes and images of chairs as control stimuli (Espírito Santo, Chen, et al., 2017). These control stimuli, chosen for their novelty, saliency, and visuospatial processing demands, aimed to isolate the effect of human versus nonhuman bodies. Whilst the results are not universally applicable to all human body stimuli beyond hands, it is possible that factors other than the human versus nonhuman body distinction influenced the outcomes.

Eye movements and pupil dilations were tested under various colours to ensure that the result was not influenced by background colour (Cherng, Baird, Chen, & Wang, 2020) because compared with the pupil’s response to light, the pupil’s responses to other stimuli are slight (Mathôt, 2018). Eye movements and pupil dilations, assessed under various colours to mitigate background colour influence, were central to this experiment. The results of these experiments enhance the understanding of how the brain processes hands. In addition, understanding the processing of distorted finger postures helps to comprehend the processes when people perceive abnormal body parts with emotional affective reaction. Moreover, the research evidence can be used to inspect whether the nature of the hand is akin to the nature of faces or bodies. The research applied the pupil dilation measurement to assist emotion research (Feng et al., 2009). Pupil diameter can be monitored during picture viewing to assess the effects of hedonic affective reaction and arousal values of stimuli on pupillary responses (Bradley et al., 2008), and pupil size can modulate the processing of emotional facial expressions (Harrison et al., 2007). This highlights the significant role of pupil size in modulating the perception of sadness and its correlation with empathy. It reveals that variations in observed pupil size can enhance the intensity and affective reaction judgements of sad expressions, emphasising the importance of autonomic signals in emotional communication and empathy. The demonstration of the change in pupil size and the analysis method was the same as in the eye tracking experiment.

The purpose of Experiment 6 was to investigate variations in fixation duration, saccade amplitude and latency, and pupil dilation responses. It is predicted that distorted finger postures cause longer fixation durations or a higher frequency of fixations compared to natural finger postures. This phenomenon does not occur with distorted and standard chairs. Additionally, it is predicted that saccade amplitudes are longer when transitioning from natural to distorted finger postures than from natural finger postures to other natural finger postures. Conversely, it is predicted that that saccade amplitudes are shorter when moving from distorted finger postures to distorted finger postures, compared to transitions from distorted finger postures to other distorted finger postures. This phenomenon does not occur with distorted and standard chairs. Furthermore, saccade latency is predicted to be shorter for transitions from natural finger postures to distorted finger postures than from natural finger postures to other natural finger postures. In contrast, saccade latency is predicted to be longer when transitioning from distorted finger postures to distorted finger postures, compared to movements from distorted finger postures to distorted finger postures. This phenomenon does not occur with distorted and standard chairs. Lastly, Experiment 6 predicted that the impact of distorted finger postures on pupil size is greater than that of natural finger postures.

The prediction of Experiment 6 on eye movements has been queried regarding fixation and saccade. It is predicted that distorted finger postures will be fixated for a longer duration or with a greater frequency of fixations than natural finger postures. The human visual system is particularly attuned to anomalies, prompting extended cognitive processing to interpret such irregularities. Measuring fixation time in this context can reveal crucial insights into attentional mechanisms, with longer fixation times on distorted postures possibly indicating deeper cognitive engagement, heightened attentional allocation due to the novelty or complexity of the stimulus, or an empathetic or emotional response to perceived discomfort. This, in turn, enhances our understanding of the intricate interplay between visual perception, cognitive processing, and motor imagery or planning in response to unusual visual stimuli (Acik, Bartel, & Konig, 2014; Avikainen et al., 2003; Zhou, Xie, Wang, Ma, & Hao, 2023). This aspect was crucial since pupil responses to stimuli are subtle compared to light responses (Mathôt, 2018). These experiments contribute to our understanding of hand processing in the brain, particularly how distorted finger postures are perceived and the emotional processing of abnormal body parts. Additionally, the experiments explore if hands share similar processing characteristics with faces or other body parts. Notably, pupil dilation measurement played a role in assessing emotional processing (Feng et al., 2009), with pupil diameter during picture viewing indicating the effects of stimuli’s hedonic affective reaction and arousal (Bradley et al., 2008), and even modulating the processing of emotional facial expressions (Harrison et al., 2007).

This highlights the significant role of pupil size in modulating the perception of sadness and its correlation with empathy. It reveals that variations in observed pupil size can enhance the intensity and affective reaction judgements of sad expressions, emphasising the importance of autonomic signals in emotional communication and empathy. The methodology for monitoring pupil size changes was consistent with the eye tracking experiment. The predictions for Experiment 6, however, raise questions about fixation and saccade in eye movements. It is predicted that distorted finger postures will attract longer or more frequent fixations than natural postures, and that they will also influence saccade amplitude and latency. For pupil dilation, the expectation is that distorted finger postures will have a more significant effect on pupil size compared to natural postures. In essence, this section dissects the intricate relationship between visual stimuli, particularly of hands, and the corresponding eye movement and pupil dilation responses, setting the stage for further exploration in Experiment 6. The prediction that distorted finger postures have a larger effect on pupil size than natural finger postures is likely based on the understanding that such stimuli require more cognitive effort to process and may elicit stronger emotional responses, both of which are known to influence pupil dilation (Harrison, Singer, Rotshtein, Dolan, & Critchley, 2006; Mitre-Hernandez, Covarrubias Carrillo, & Lara-Alvarez, 2021; van der Wel & van Steenbergen, 2018).

3.2.2 Methods

3.2.2.1 Participants

There were two parts for this experiment. In Experiment 6A, 35 students from the University of Nottingham Malaysia, 17 females and 18 males (18–45 years, *M* = 22.59 years, SD = 3.41) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment, participated. In Experiment 6B, 17 students from the University of Nottingham Malaysia, 8 females and 9 males (18–45 years. *M* = 24.10 years, SD = 2.56) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment, participated. The recruitment requirements for this experiment were the same as for Experiment 5. The numbers of participants in Experiments 6A and 6B were greater than those used by previous studies measuring eye movements and pupil dilations (Bradley et al., 2008; Deubel, 2008; Sandoval & McIntosh, 2015). All participants gave written, informed consent and had normal or corrected to normal visual acuity. All participants received either course credits or monetary compensation. Using G*Power 3.1.3, it was determined that a sample size of 30 would be sufficient to detect a significant interaction with a power of 0.90 and an alpha of 0.05 in repeated measures for within-subjects ANOVA (Faul et al., 2009; Faul et al., 2007). These procedures received approval from the SEREC of the University of Nottingham Malaysia under application number HYC150221.

3.2.2.2 Materials and apparatus

Four images, which were distorted finger postures, natural finger postures, distorted chairs, and standard chairs, were used in the experiment. The same images for each category were used throughout the experiment. These images were in greyscale. In Experiment 6A, only images of hands (distorted and natural) were shown. The size of the images was 160 pixels × 120 pixels (4.72° × 3.54°). Nine images of hands were arranged with 310 pixels (9.15°) from each other (Figure 3-7). Three shades of grey characterised by pixel intensities were used as backgrounds, specifically, black (RGB: 0, 0, 0), grey (RGB: 128, 128, 128), and white (RGB: 255, 255, 255). Experiment 6A did not include dark-skinned or palm-up hands, as the study's focus was on examining the effects of different background colours, black, grey, and whit, rather than the colour or orientation of the hands. In Experiment 6B, there were 16 images of hands and chairs in one layout. The size of the images used was 100 pixels x 100 pixels. Two different layouts of hands and chairs were arranged as shown (Figure 3-8). As there was no centre image in this experiment, the top left image was used to align the rest of the images, with a pixel coordinate of 204, 105. The horizontal distance between the two images was 204 pixels (6.77°), whereas the vertical distance was 145 pixels (4.81°). Three shades of grey were used as the background, specifically which were 25% grey (RGB: 188, 188, 188), 50% grey (RGB: 128,128,128), and 75% grey (RGB: 64, 64, 64).

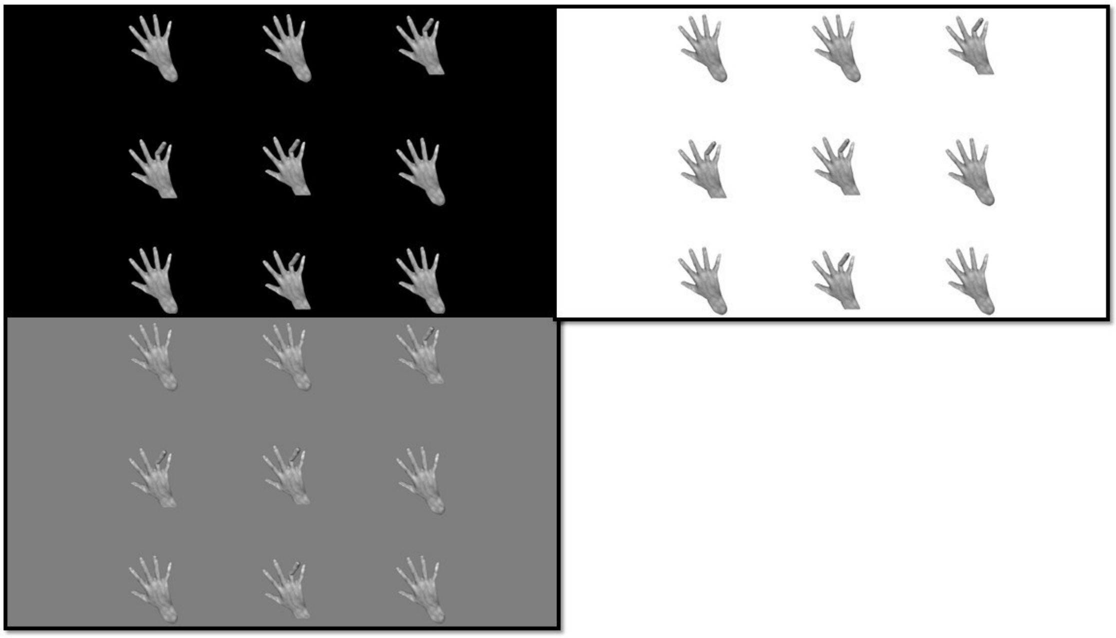


Figure 3-7 Experiment 6A Configurations with Monochromatic Backgrounds
Experiment 6A configuration with black (RGB: 0, 0, 0), grey (RGB: 128, 128, 128) and white (RGB: 255, 255, 255) background.

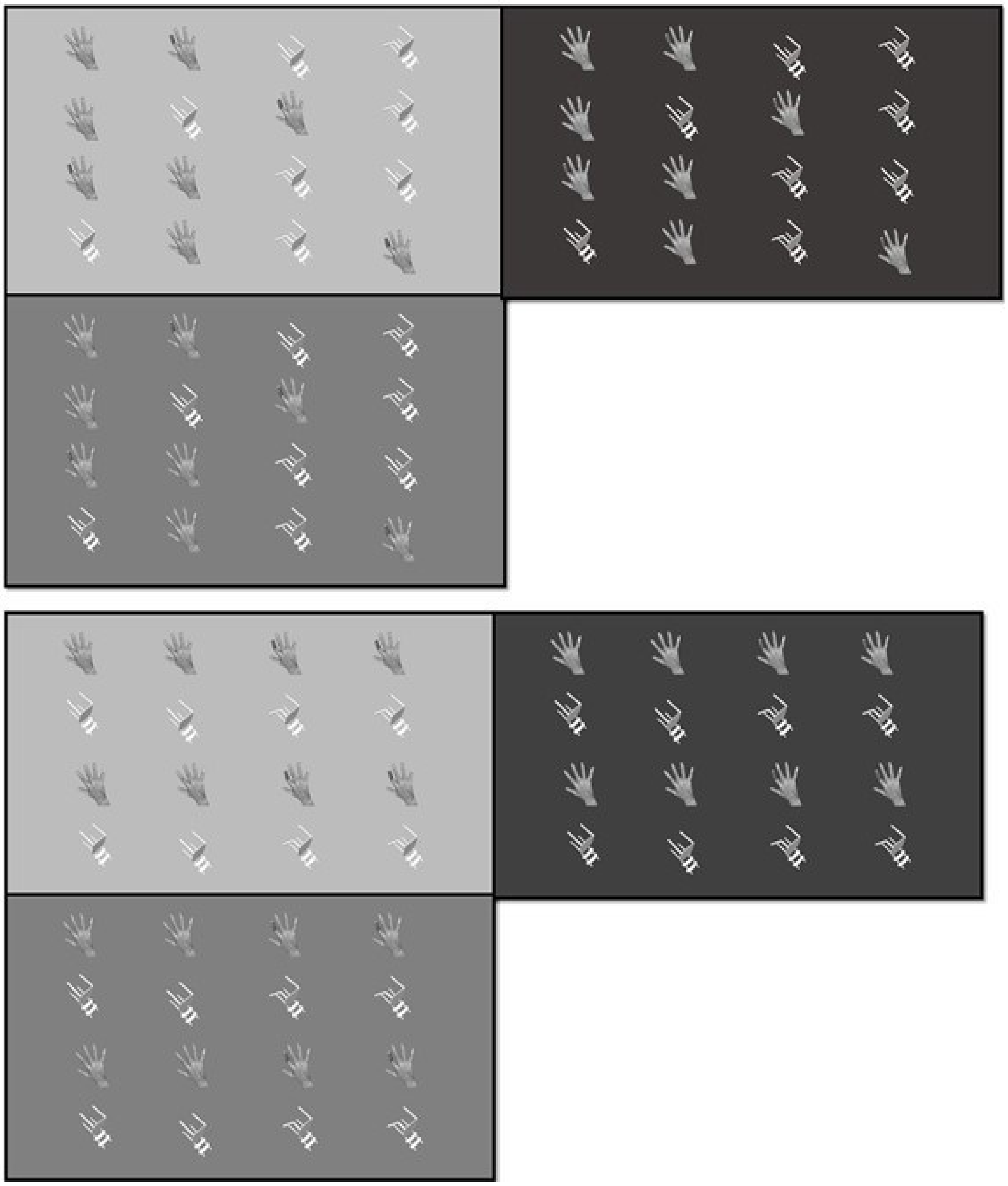


Figure 3-8 Visual layout configurations in Experiment 6B
The configuration of layout A (upper part) and B (lower part) in the eye movement in Experiment 6B

Head movements were limited by a chin and forehead rest. The stimuli were displayed on a 24-inch BenQ monitor with a frame frequency of 144 Hz, at a spatial resolution of 1024 × 768 pixels. A desktop-mounted eye tracking system (EyeLink 1000 Plus) from SR Research was used to monitor participants' eye movements throughout the experiment at a sampling rate of 1000 Hz. Eye movements to targets were recorded using the eye tracker. The screen display was extended to full-screen mode, and the viewing distance was set at 57 cm. Stimuli were randomly drawn with a programme running on a 64-bit Windows 7 computer with a 3.4-GHz CPU and 8 GB of RAM connected to an EyeLink 1000 Plus (SR Research, Ontario, Canada) and an eye tracking host computer. The desktop-mounted eye tracker was used to monitor participants' eye movements and pupil size during the trials. All eye movement and pupil dilation data were created by Experiment Builder and analysed using Data Viewer. Data analyses were performed using JASP statistical software.

3.2.2.3 Design and procedure

Nine images were presented consecutively on the display screen. The participants were asked to gaze at these images, and the fixation, saccade, and pupil size were measured and recorded. The participants were seated in a dimly illuminated room. The eye tracker was calibrated and validated for each participant before each experiment, using a nine-point calibration screen and a nine-point validation.

Experiment 6A: The arrangement of nine images with hands in one layout was identical regardless of the background colour. The layout was shown to the participants three times (9 × 3), each time with a different background shade. The images were displayed sequentially from top left to bottom right, starting from the image on the left in every row and back to the top left again in the subsequent layout. Images appeared for 1000 milliseconds (ms) and then disappeared, with no inter-stimuli interval (ISI)

(Figure 3-9). The background colours were shown in random order. Experiment 6B: In one layout, the images with hands and chairs were displayed the same as Experiment 6A. Images appeared for 1000 ms and then disappeared, with no ISI (Figure 3-9). Images were arranged differently in two layouts (Figure 3-8). Layout A was always followed by layout B with the same tone of a grey background. These were repeated twice with another two hues of grey as the background, appearing in random order. With three tones of grey, each layout is shown in 16 trials individually. Layouts A and B were shown three times each, showing 96 consecutive images (16 × 2 × 3), repeatedly over five blocks.

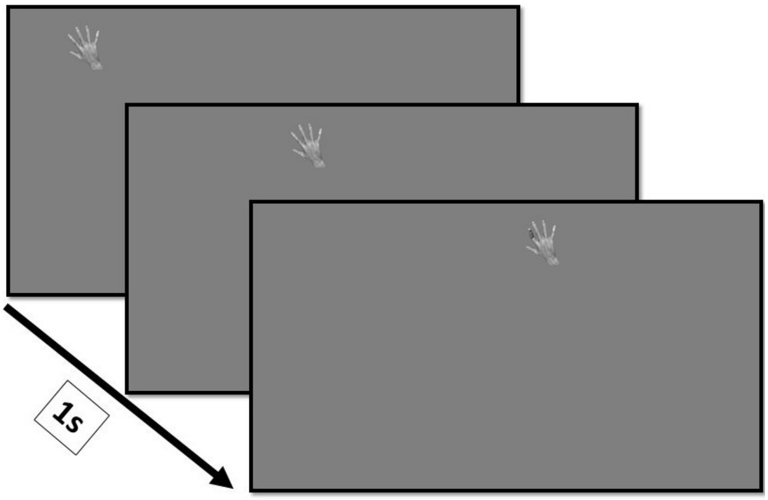


Figure 3-9 Experimental procedure in Experiments 6A and 6B

3.2.3 Results

3.2.3.1 Experiment 6A

The stimuli the participants observed were categorised into distorted finger postures, natural finger postures, distorted chairs and standard chairs (natural chairs).

The mean fixation count across all types of stimuli presented to the participants was 2.06 (SD = 0.803). A two-way within-subjects ANOVA with the interaction between configuration and colour (white, grey and black) revealed no interaction [$F(2, 68) = 1.000$, $p = 0.373$, $\eta_p^2 = 0.028$] (Figure 3-10). There was no significant main effect of colour [F(2, 68) = 2.458, p = 0.093, $\eta_p^2 = 0.067$]. The effect between distorted finger posture and natural finger postures was highly significant [F(1, 34) = 69.032, p < 0.001, $\eta_p^2 = 0.670$]. As expected, the mean fixation counts and mean fixation duration were inversely related at a fixed presentation time. However, a higher fixation count or duration when one of these parameters was fixed on a trial suggests that more cognitive capacity for processing information on a specific area was required (Lin & Lin, 2014).

The mean fixation duration of the trials was 418 ms (SD = 225 ms). A two-way repeated measures ANOVA was run to determine the effect of different colours over stimulus types on fixation duration. There was no statistically significant interaction between stimulus types and colour on fixation duration [F(2, 68) = 0.512, p =0.602, $\eta_p^2 = 0.015$] (Figure 3-11). The results showed no significant difference in colour [F(1, 34) = 0.799, p = 0.378, $\eta_p^2 = 0.023$]. As expected, the main effect of stimulus type was highly significant [F(1, 34) = 9.986, p = 0.003, $\eta_p^2 = 0.227$].

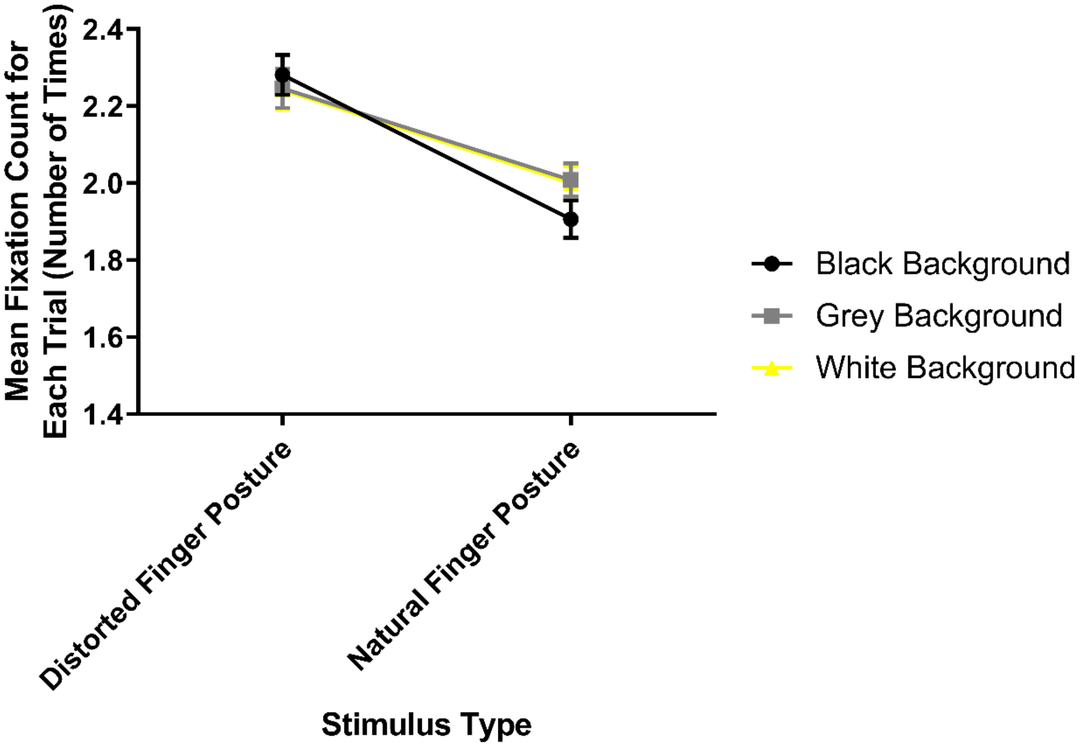


Figure 3-10 Fixation counts in Experiment 6A

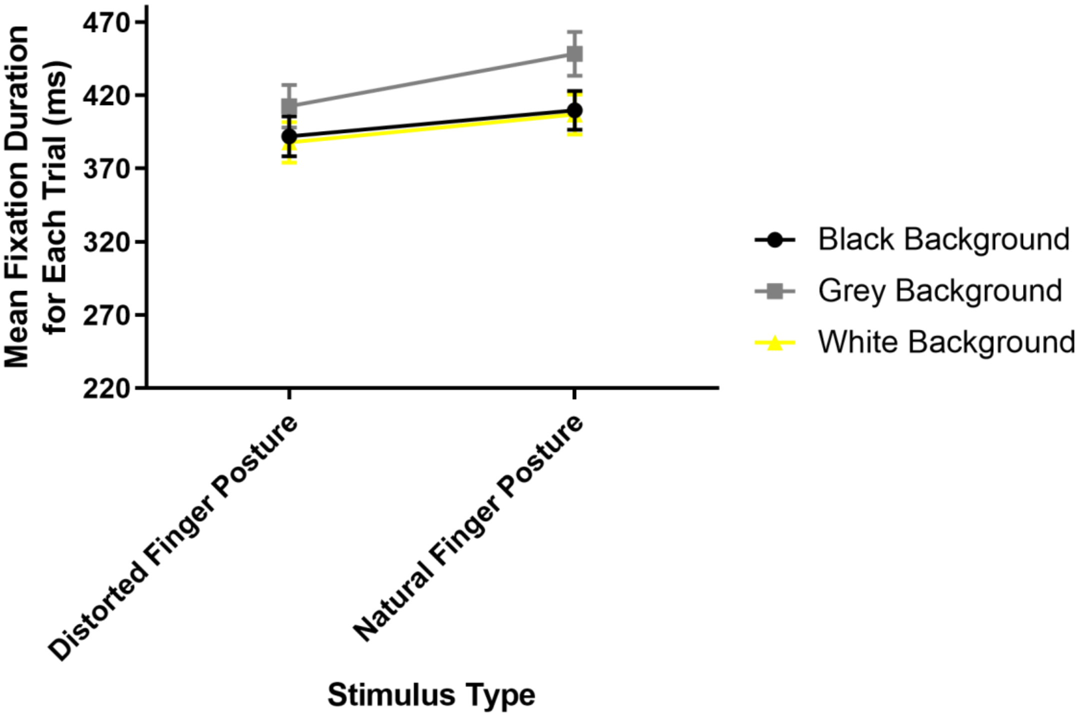


Figure 3-11 Fixation duration in Experiment 6A.

The mean saccade amplitude for each stimulus was 10.6° (SD = 1.209°). The saccade amplitude between the centres of the two stimuli was 9.15°. These saccadic stimuli were labelled depending on the start and end of the area of interest. The stimulus types of saccades were natural finger postures to natural finger postures, natural finger postures to distorted finger postures, distorted finger postures to distorted finger postures and distorted finger postures to natural finger postures. They were standard chairs to standard chairs, standard chairs to distorted chairs, distorted chairs to distorted chairs, and distorted chairs to standard chairs.

The two-way repeated measures ANOVA demonstrated no interaction between types of stimuli of saccade and colour [$F(6, 204) = 1.017$, $p = 0.415$, $\eta_p^2 = 0.029$] (Figure 3-12). Furthermore, there was no significant difference in colour [$F(2, 68) = 0.819$, $p = 0.445$, $\eta_p^2 = 0.024$]. The main effect of the stimuli was significant [$F(3, 102) = 7.808$, $p < 0.001$, $\eta_p^2 = 0.187$]. Pairwise comparisons showed that the saccade amplitude of distorted finger posture to distorted finger posture was significantly higher than natural finger posture to natural finger posture and distorted finger posture to natural finger posture, but not natural finger posture to distorted finger posture ($p = 0.051$) (Figure 3-12).

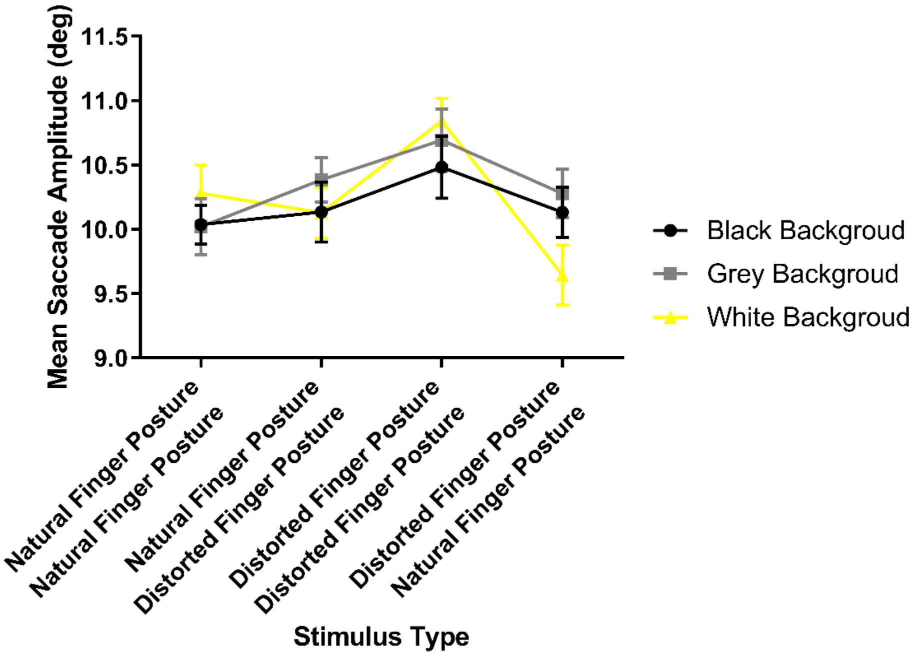


Figure 3-12 Saccade amplitude in Experiment 6A

The mean pupil size was 4.31 mm (SD = 0.95 mm). A two-way repeated measures ANOVA with the stimulus types and colour revealed no interaction [F(2, 68) = 1.593, p =0.211, η_p^2 = 0.045] (Figure 3-13). The results of the analyses showed a high significance with different background colours expectedly [F(2, 68) = 1065.951, p < 0.001, η_p^2 = 0.969]. Interestingly, the main effect of stimulus type was significant [F(1, 34) = 10.094, p = 0.003, η_p^2 = 0.229] (Figure 3-12).

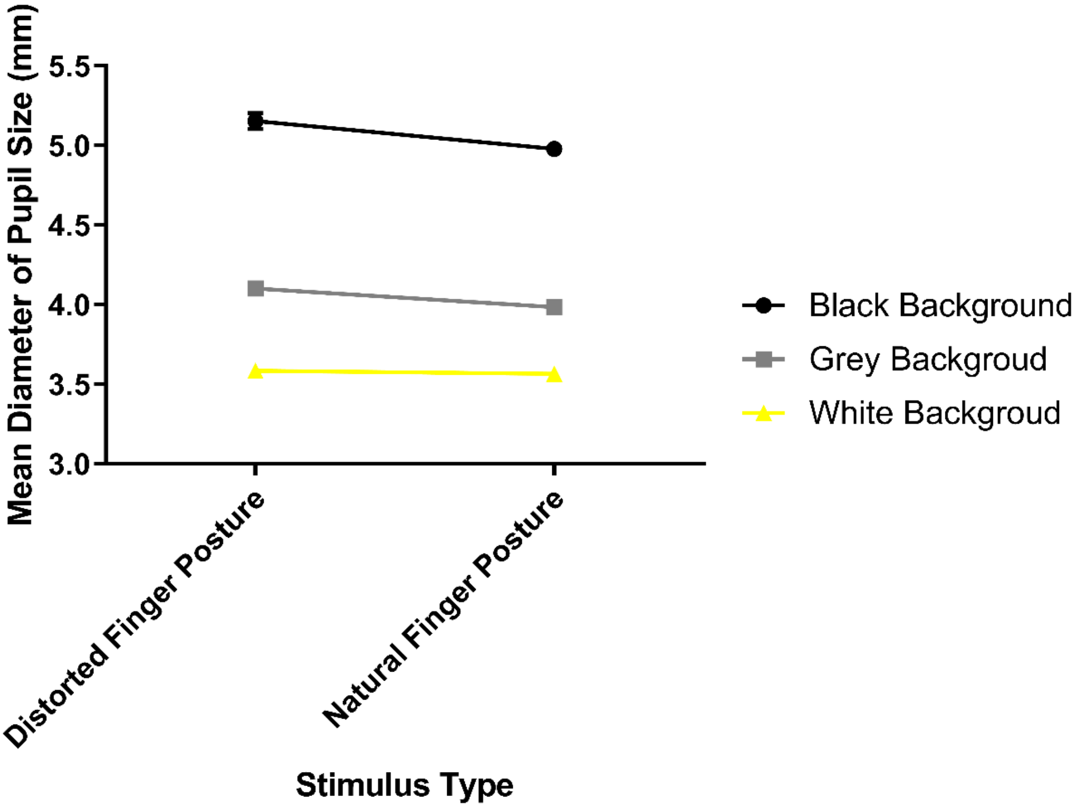


Figure 3-13 Pupil size in Experiment 6A

3.2.3.2 Experiment 6B

The mean fixation counts were 1.68 times (SD = 0.268). A two-way repeated measures ANOVA with the interaction between different types of stimuli (distorted finger posture, natural finger posture, distorted chair and natural chair) and colour (grey 25, grey 50 and grey 75) revealed no significant interaction between stimulus type and colour [F(6, 96) = 0.473, p = 0.827, $\eta_p^2 = 0.029$] and no significant main effect of colour [F(2, 32) = 2.999, p = 0.064, $\eta_p^2 = 0.158$] (Figure 3-14). As expected, the main effect of stimulus type was significant [F(3, 48) = 10.903, p < 0.001, $\eta_p^2 = 0.405$]. Pairwise comparisons of the different stimuli showed that the only significant difference was between distorted finger posture and natural finger posture, t = 4.947, p < 0.001. The mean fixation duration of each stimulus was 255.30 ms (SD = 31.453 ms). A two-way repeated measures ANOVA demonstrated the significant interaction between types of stimuli and colour [F(6, 96) = 2.548, p =0.025, $\eta_p^2 = 0.137$] (Figure 3-14). There was no main effect on difference using a distinct background colour [F(2, 32) = 0.568, p = 0.572, $\eta_p^2 = 0.034$] and no main effect of stimulus types [F(3, 48) = 0.386, p = 0.764, $\eta_p^2 = 0.024$].

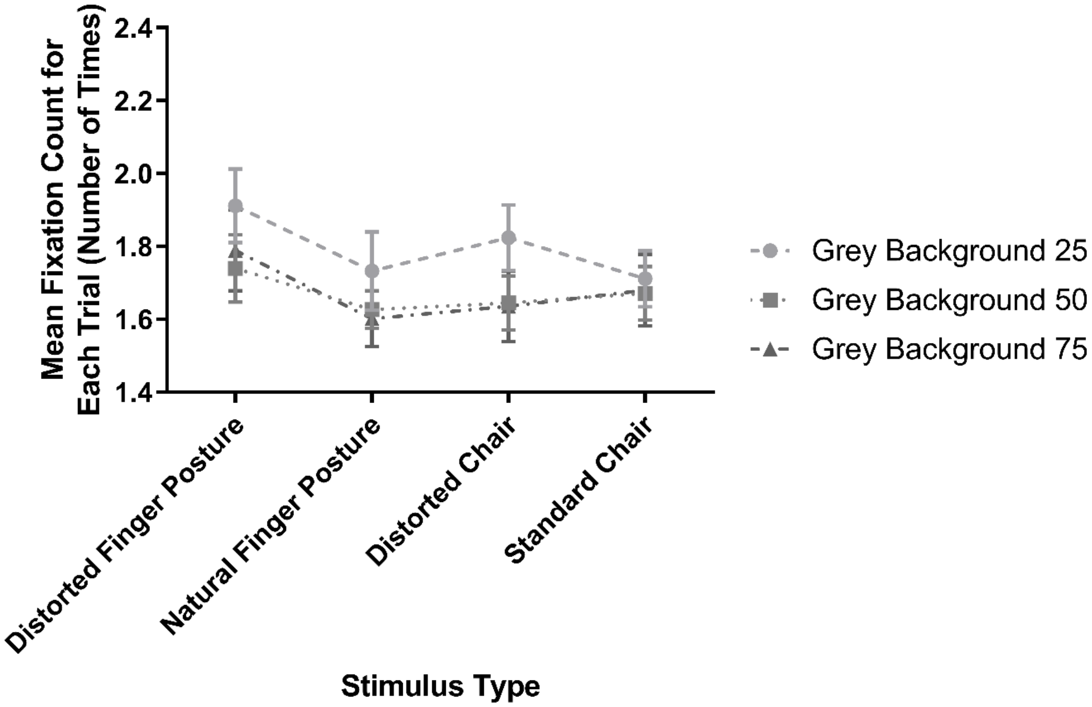


Figure 3-14 Fixation count in Experiment 6B

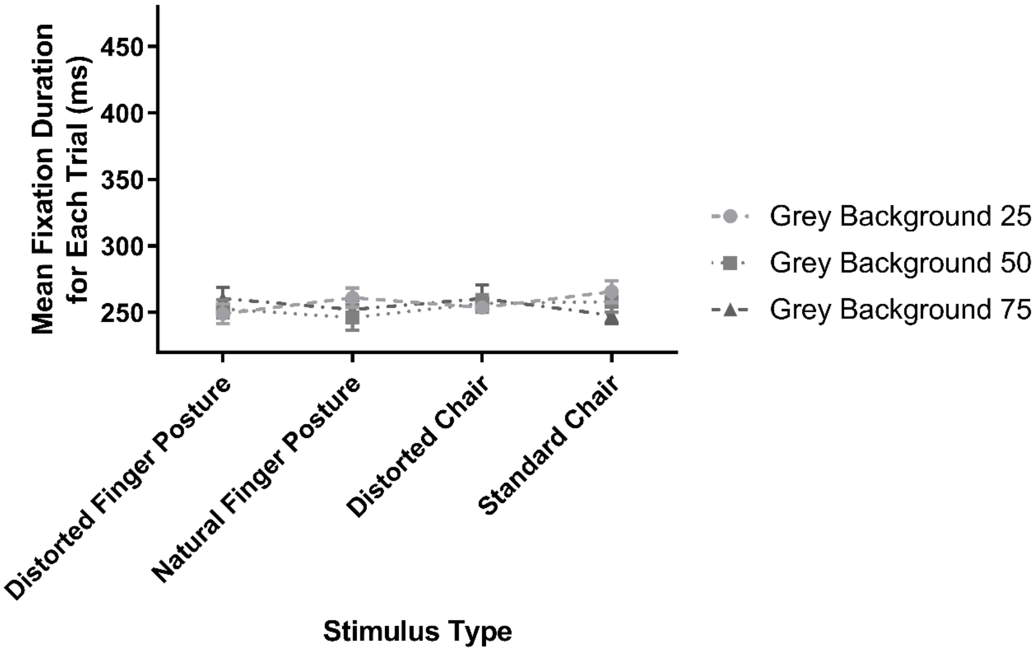


Figure 3-15 Fixation duration in Experiment 6B

The mean saccade amplitude for each stimulus in the hand stimuli was 6.7° (SD =1.13°). A two-way repeated measures ANOVA was used with the factors types of saccade landing across different discrete stimuli. Analysis of the data showed no interaction between types of stimuli and achromatic colour on the saccade amplitude of hands [F(6, 96) = 1.408, p = 0.220, η_p^2 = 0.080] and no significant difference in background colours [F(2, 32) = 0.426, p = 0.657, η_p^2 = 0.026] (Figure 3-16). The effect of different stimuli was significant [F(3, 48) = 26.528, p < 0.001, η_p^2 = 0.623]. Surprisingly, pairwise comparisons of the different stimuli showed that distorted finger postures to natural finger postures were significantly different from the other stimuli. The result is unlike the result in Experiment 6A. Experimental control scripts in PsychoPy and raw data have been checked to exclude potential mix-up of variable labels in statistical analysis.

The mean saccade amplitude of each stimulus in the chair stimuli was 6.78° (SD =1.086 °). A two-way repeated measures ANOVA with the factors of chairs and colours did not reveal a significance between them [F(6, 96) = 0.483, p = 0.820, η_p^2 = 0.029] (Figure 3-17). Moreover, the effect of types of chairs was not significant [F(3, 48) = 3.271, p = 0.029, η_p^2 = 0.170]. The analysis also showed no significant main effect of colour [F(2, 32) = 0.229, p = 0.796, η_p^2 = 0.014].

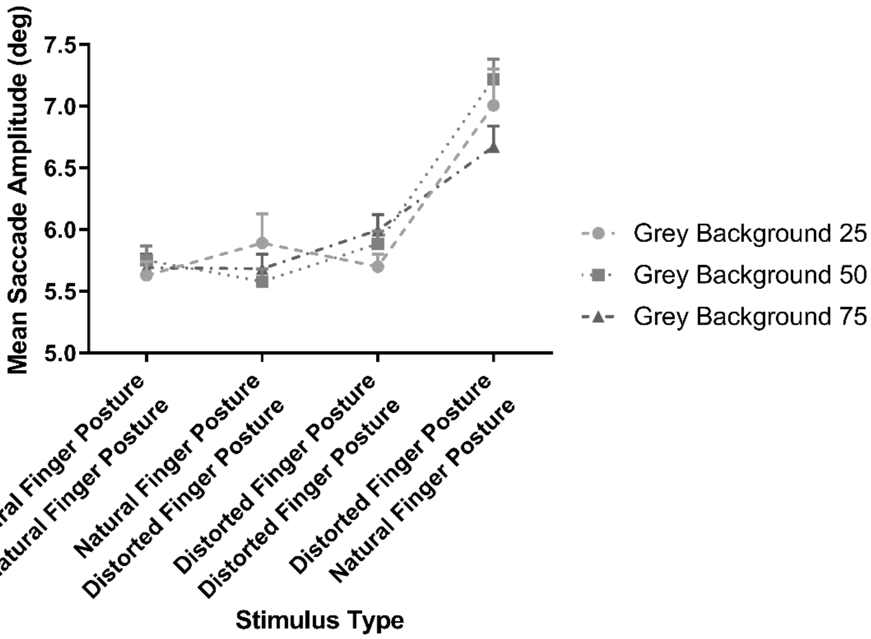


Figure 3-16 Hand saccade amplitude in Experiment 6B

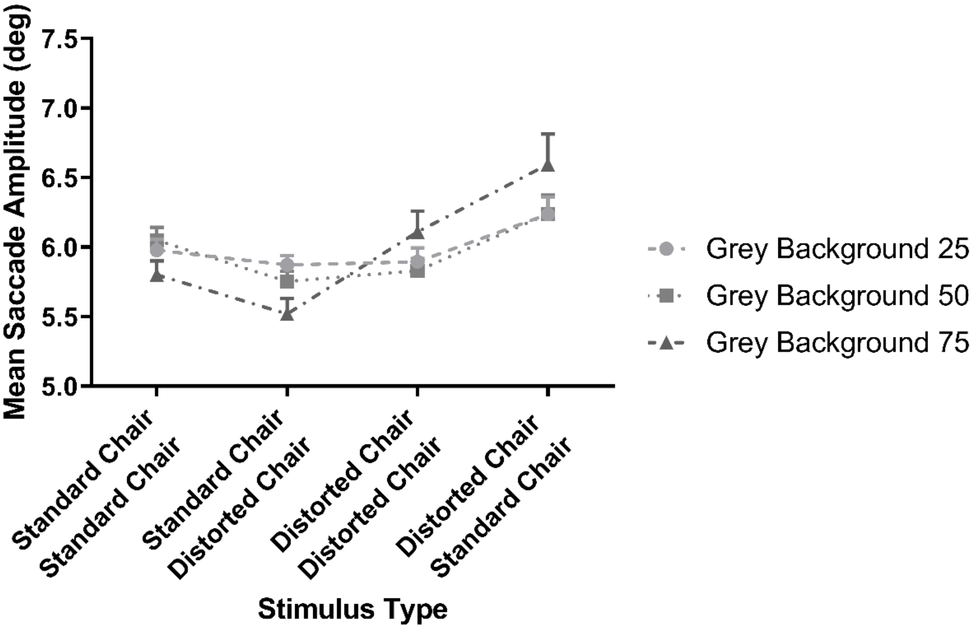


Figure 3-17 Chair saccade amplitude in Experiment 6B

The mean saccade latency for hand stimuli was 138 ms (SD = 73 ms). A two-way repeated measures ANOVA confirmed that the interaction between types of stimuli of saccade latency for hands and colour was significant [F(6, 96) = 0.884, p =0.510, η_p^2 = 0.052] (Figure 3-18). There was no significant difference in colour [F(2, 32) = 0.443, p = 0.646, η_p^2 = 0.031]. The main effect of types of stimuli was significant [F(3, 48) = 5.742, p = 0.002, η_p^2 =0.264]. Pairwise comparisons showed no difference between stimulus types of saccade latency.

The mean saccade latency for the chair stimuli was 144 ms (SD = 55 ms). A two-way repeated measures ANOVA with the interaction between types of stimuli of saccade latency and the colour was not significant [F(6, 96) = 1.067, p =0.388, η_p^2 = 0.063] (Figure 3-19). There was no significant difference in colour [F(2, 32) = 0.477, p = 0.625, η_p^2 = 0.029]. On the other hand, the main effect of different stimuli was significant [F(3, 48) = 12.250, p < 0.001, η_p^2 =0.434]. Pairwise comparisons showed a significant difference between standard chairs to standard chairs and distorted chairs to standard chairs and between distorted chairs to distorted chairs and distorted chairs.

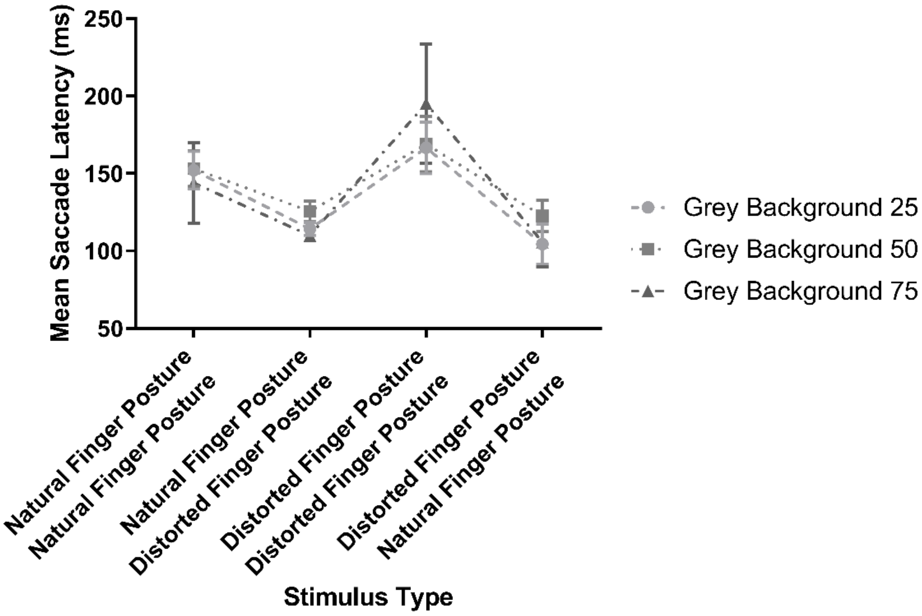


Figure 3-18 Hand saccade latency in Experiment 6B

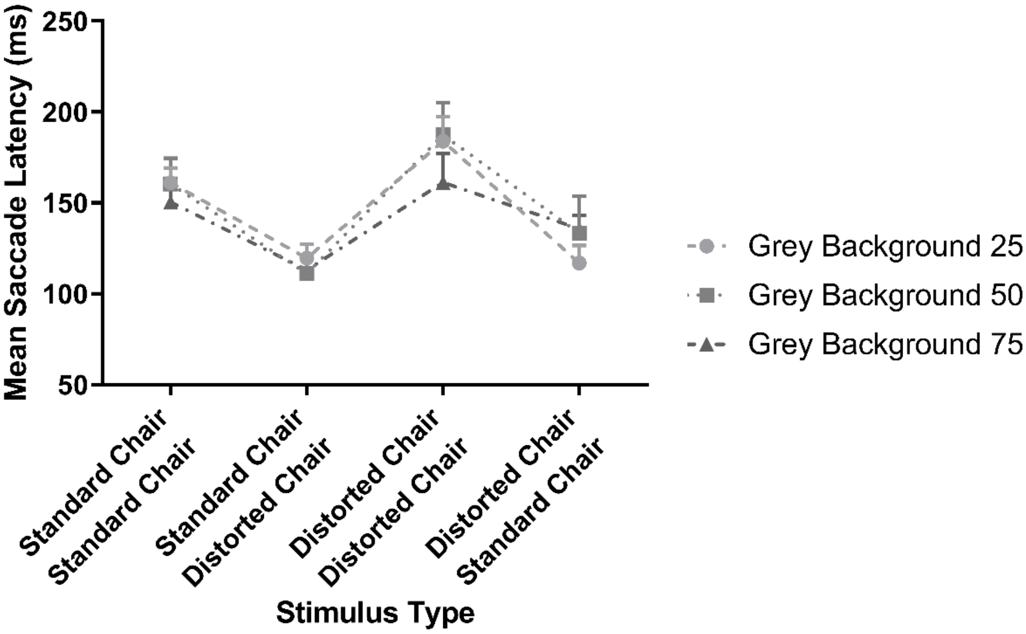


Figure 3-19 Chair saccade latency in Experiment 6B

The mean pupil size was 4.7 mm (SD = 0.9 mm). A two-way repeated measures ANOVA with the factors types of stimuli and colour revealed a significance of the condition [F(6, 96) = 3.982, p = 0.001, η_p^2 = 0.199] (Figure 3-20). Using different colours showed a significant difference [F(2, 32) = 134.532, p < 0.001, η_p^2 = 0.894] whilst the effect of pupil size of each type of stimuli was significant [F(3, 48) = 24.194, p < 0.001, η_p^2 =0.602]. Pairwise comparisons of the different stimuli showed that distorted finger posture was significantly different from natural finger posture. The pupil size of distorted finger posture was bigger than natural finger posture. Pairwise comparisons of the different stimuli showed that distorted chair was significantly different from standard chair. The pupil size of standard chair was bigger than distorted chair.

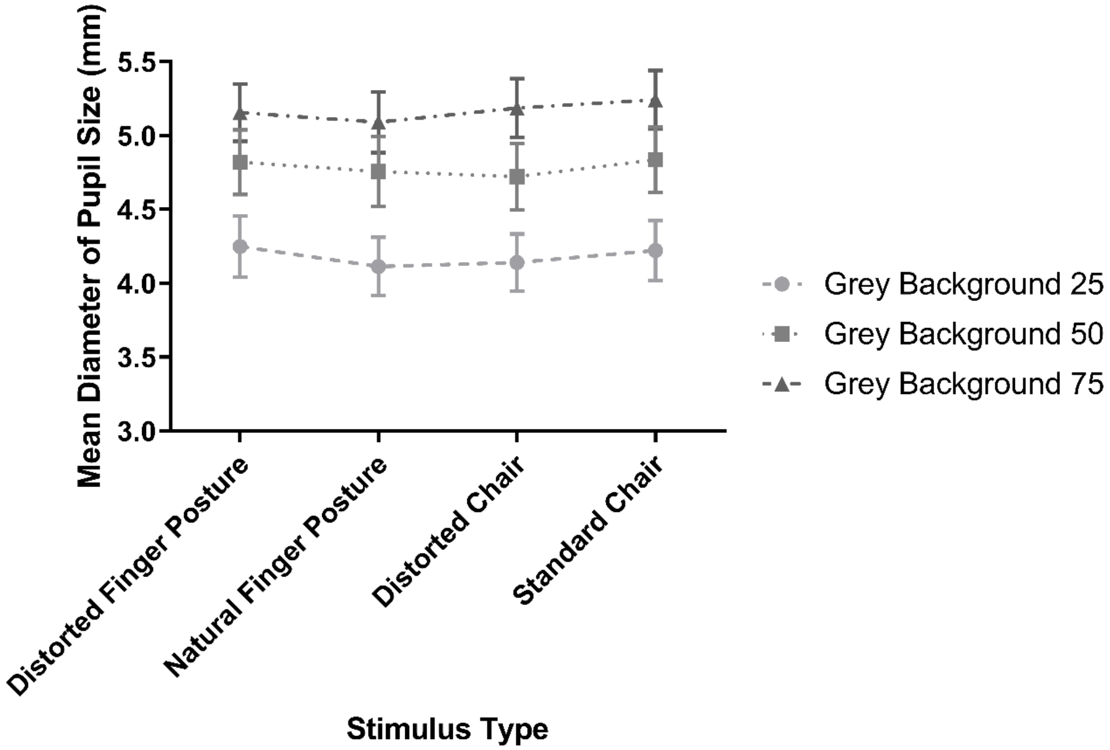


Figure 3-20 Pupil size in Experiment 6B

3.2.4 Discussion

Experiment 6A employed various background settings to demonstrate consistent results. Experiment 6B expanded this validation by using additional monochromatic backgrounds. The comparison of fixation durations between distorted and natural finger postures revealed that distorted postures attracted longer or more frequent fixations than natural postures (Figure 3-10 and Figure 3-11). In the comparison of saccade amplitude and latency between distorted and natural fingers, there was no significant impact of distorted postures on either saccade amplitude or latency (Figure 3-12). Lastly, the comparison between distorted and natural fingers regarding pupil dilation confirmed that distorted postures induced greater pupil dilation than natural postures (Figure 3-13). More comprehensively, the result of Experiment 6B shows that the fixation counts on the distorted finger postures were more than on natural finger postures (Figure 3-14). However, the result of Experiment 6B rejects the prediction that saccade amplitude or saccade latency was affected by distorted finger postures (Figure 3-16, Figure 3-17, Figure 3-18 and Figure 3-19). The results of Experiment 6B presented thus far provide evidence that pupil dilation on the distorted finger postures was bigger than on natural finger postures (Figure 3-20). The experiment corroborated the prediction that distorted finger postures manifest a distinct effect on visual and cognitive processing relative to natural finger postures, as observed through increased fixation durations, differential saccade amplitude trends, and increased pupil sizes. However, the results were inconclusive on the predicted trends in saccade latency and between the comparison of distorted and standard chairs. It appears that the differences observed in distorted finger postures from natural postures were significant, in accordance with the prediction that distorted finger postures are more mentally taxing, according to the visual attention measures and physiological ones measured.

The findings from the experiments indicated a lack of difference in the fixation counts between natural and distorted chairs. The noticeable difference in fixation counts between distorted and natural finger postures stands in contrast to the lack of significant differences in vertical saccade latencies across both human and nonhuman stimuli categories. This discrepancy suggests that the underlying factor driving increased attention towards the distorted finger postures may be related to their perceived association with actual human body configurations. In particular, the distortions could conceivably be registering as unexpected or ‘impossible’ hand configurations in the viewer's internal body representation mapped through lifelong sensorimotor experience. This would result in greater cognitive effort to reconcile the distorted postures with expectations, consequently attracting more fixations. On the other hand, attributes inherent to the other nonhuman categories of stimuli, like salience or feature congestion, cannot fully account for the variance in fixation counts if they do not impact a core oculomotor metric like saccade latencies. In summary, the relation of the stimuli to the perceiver's internal body schema emerges as a potential factor that could explain why distortion draws fixations beyond effects of low-level stimulus attributes. However, further controlled experiments are needed to conclusively investigate the underlying mechanisms driving differential attention towards body distortions.

Consequently, it seems that the human-related nature of the stimuli, rather than the distortion, may play a more significant role in influencing fixation counts. It implies that the allocation of attention with the fixation counts was specialised for stimuli related to human body. Most of the results in Experiments 6A and 6B showed no significant interaction between types of stimuli and colour. This means that results can be interpreted as independent of background colour. The purpose of Experiment 6A is to demonstrate consistent results across different backgrounds. Experiment 6B is to further validate these findings by utilising additional monochromatic backgrounds.

The fixation counts can reveal the allocation of attention (Nelson & Mondloch, 2018). From the results in Experiment 6A, it was found that the fixation duration in distorted finger posture was significantly less than in natural finger postures. Conversely, the fixation counts in distorted finger postures were higher than normal. Interestingly, the result showed that the fixation duration does not significantly differ between distorted finger posture and natural finger posture in Experiment 6B. However, the fixation counts of distorted finger postures were higher than that of natural finger postures. Furthermore, the results in Experiment 6B for distorted chairs and standard chairs showed no significant differences, for both fixation counts and fixation duration. The evidence supports the claim that individuals need more cognitive capacity to process distorted finger posture, and more attention should be allocated to natural finger posture.

The experimental findings revealed a pattern in saccade latencies (the time it takes for the eye to move from one point to another). The latencies were longer when the eye moved between similar stimuli - either two natural finger postures or two distorted finger postures. Two key inferences can be drawn from these observations. First, saccade latencies are not influenced by whether or not the stimuli are related to human bodies. The results indicate that the type of stimulus, whether human -related or not, does not impact the latency time for vertical saccades. Specifically, no significant difference was found in how quickly gaze shifts occurred between faces and nonhuman-human stimuli. Secondly, it was observed that saccade latencies were longer when the eyes moved between two similar stimuli, regardless of whether they were natural or distorted. This may indicate that an attentional shift does not occur between similar stimuli.

The eyes take longer to move between two similar objects, perhaps because the brain does not perceive a need to shift attention as quickly. Therefore, these findings suggest that it is the shape of the stimuli, rather than their relation to human bodies, which affects saccade latencies. In other words, the type of stimuli, whether they are related to human bodies or not would not have resulted in different outcomes in this experiment. The primary factor influencing the speed of eye movements appears to be the similarity in shape between the two stimuli, rather than their specific content. A previous study has provided evidence that the shift of attention towards the location of different stimuli can influence the speed of saccades, which are rapid eye movements. Simply, how quickly our eyes move to focus on different things can be affected by where the attention is directed (Barnas & Greenberg, 2019; Senturk et al., 2016). Moreover, further studies have suggested that unexpected targets elicit faster saccade latencies than expected targets (Irwin, Colcombe, Kramer, & Hahn, 2000). These studies support the prediction that with different stimuli attentional shift elicits a shorter saccade latency than with identical stimuli.

Regarding the saccade amplitude, an unexpected result was observed in both Experiments 6A and 6B. In Experiment 6A, the saccade amplitude between distorted finger postures was higher compared to other combinations, such as between two natural finger postures. Similarly, in Experiment 6B, the saccade amplitude from distorted finger posture to natural finger posture, as well as between distorted and standard chairs, resulted in larger saccade amplitudes compared to other conditions. These findings indicate that the type and combination of stimuli presented significantly influence the saccade amplitude. Transitions involving distorted stimuli consistently provoke larger saccade amplitudes compared to other combinations, whether they are finger postures or chairs. This pattern suggests that distorted stimuli may elicit a stronger visual processing response, resulting in larger saccadic eye movements.

However, an inconsistency arose between the outcomes of Experiments 6A and 6B, raising uncertainty regarding the impact on saccade amplitude. Experiment 6B suggested that stimuli related to the human body did not have a discernible effect on saccade amplitude. Instead, it is possible that the amplitude variance may have been caused by a saccade transition from a distorted to a normal shape, leading to an increased saccade amplitude. Currently, there is no established theoretical framework to comprehensively explain these outcomes. Further investigation is necessary to address the discrepancies and gain a deeper understanding of these complex processes. Factors such as differing methodologies, participant responses, and unknown variables should be thoroughly examined to shed light on the root of this inconsistency. This highlights the need for continued research in this field to advance our knowledge and guide future experimental design and theoretical development.

The pupil can be regarded as a readily accessible portal for probing the intricate mechanisms of emotional affective reaction. An exhaustive analysis of the obtained results unveils substantial differences among the diverse categories of stimuli under examination. A specific finding of significance is the prominent influence of distorted finger postures on inducing emotional affective reaction. The correlation observed in this context provides robust evidence in support of the initial prediction, the premise that manipulated finger postures can evoke emotional responses. To specify, this research revealed that upon exposure to distorted finger postures, the subjects exhibited a heightened level of pupil dilation compared to their reactions to natural finger postures. This suggests an effect direction wherein distorted finger postures trigger a more potent emotional, as indicated by the dilation of pupils. Importantly, pupil dilation is indicative of heightened emotional or cognitive states, such as increased arousal or cognitive load. This suggests that observing distorted finger postures may trigger a complex emotional or cognitive reaction in the viewer. The variability in the intensity of this reaction, along with the underlying processes driving it, presents intriguing opportunities for further investigation. The findings suggest a potential relationship between pupil dilation and ERP responses to visual stimuli. This relationship could imply that they both reflect similar underlying cognitive processes or neural activity. Pupil dilation, governed by the autonomic nervous system, is sensitive to cognitive load and emotional arousal, mirroring the brain's effort to process stimuli. Similarly, ERPs provide a direct measure of neuronal activity, offering insights into the brain's electrical response to sensory and cognitive events. Whilst ERPs highlight specific cognitive processes, pupil responses add a layer of understanding regarding emotional and arousal states. The correlation between pupil dilation and ERPs in response to visual stimuli is rooted in their shared neurophysiological mechanisms, both reflecting aspects of cognitive processing and neural activity. Pupil dilation, governed by the autonomic nervous system, is sensitive to cognitive load and emotional arousal, mirroring the brain's effort to process stimuli.

Similarly, ERPs provide a direct measure of neuronal activity, offering insights into the brain's electrical response to sensory and cognitive events. Whilst ERPs highlight specific cognitive processes, pupil responses add a layer of understanding regarding emotional and arousal states. The graph for the ERP has been redrawn from the article (Espírito Santo, Chen, et al., 2017) (Figure 3-21). From the statistics derived from the results for ERPs, a significant interaction between stimulus types and configuration [$F(1, 13) = 7.009$, $p = 0.020$, $\eta_p^2 = 0.350$] reflected a distortion effect of the opposite direction for hands vs chairs. From the pupillometry, pairwise comparisons showed that the significant distorted finger posture vs natural finger postures difference matches the corresponding ERP results. In the ANOVA for hands only in the ERPs study, the result with p below 0.1 was a main effect of the configuration [F(1, 13) = 3.624, p = 0.079, $\eta_p{}^2 = 0.218$], reflecting the trend of higher N1 amplitudes for distorted finger postures. That was rather a good match with the pupillometry data. However, the significant difference between distorted chairs and standard chair in pupillometry does not directly match any ERP result because the ERP amplitude between distorted chairs and standard chairs was not significantly different. Even the trend of the result in pupillometry was consistent with the ERP amplitude of chairs.

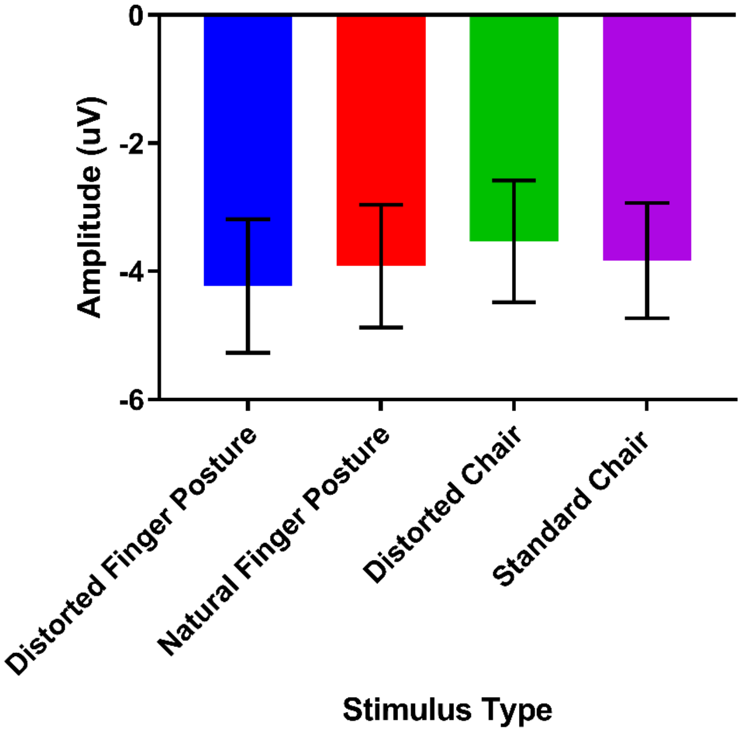


Figure 3-21 Modulation of ERP amplitude
The ERP amplitude of distorted and natural finger and chair posture. Panels modified, with permission from Espírito Santo, Chen, et al. (2017).

3.3 General Discussion for Chapter 3

This chapter presents two experiments that examine the impact of distorted and natural finger postures on human body perception, employing eye tracking and pupillometry as research methods. Experiment 5 focuses on investigating the behavioural consequences of hands and whole bodies, whilst Experiment 6 extends this investigation to explore the behavioural consequences of distorted and natural finger postures. The results obtained from these experiments yield significant insights into high-level visual processing on eye saccade and eye fixation and the role of pupillometry in comprehending mental effort. Notably, the findings indicate that processing distorted finger postures necessitates greater mental effort compared to natural finger postures.

The observed increase in pupil dilation during the viewing of distorted images, indicating heightened cognitive load, is further substantiated by the biological relevance of these distortions, especially in the context of hand with distorted finger postures. This response stems from the fact that hands are biologically and functionally significant to humans, playing a crucial role in everyday interactions and tasks (El Haj, M. J. Janssen, Gallouj, & Lenoble, 2019; Espírito Santo, Chen, et al., 2017). Therefore, when images of finger postures are distorted, they become particularly unexpected and startling, leading to a more pronounced cognitive reaction compared to less familiar or less biologically relevant objects like chairs (El Haj et al., 2019; Espírito Santo, Chen, et al., 2017). The surprising nature of these distorted images of familiar objects incites a stronger cognitive response, as indicated by increased pupil dilation, highlighting the mental processes' intensified engagement to interpret and comprehend these unusual visual stimuli. Furthermore, the results suggest that different categories of body stimuli may entail varying levels of cognitive processing, underscoring the importance of considering affect in future studies. The experiments in high-level visual processing have significantly advanced the understanding of how the eye movement interprets complex visual stimuli. This suggests the intricacies of visual recognition, the varying cognitive load required for processing different visual inputs of human bodies.

This thesis details the findings from two experiments focused on the perception of distorted versus natural finger postures. Through the use of eye tracking and pupillometry, we have identified specific patterns in how such stimuli are processed by the human visual system. The results of Experiments 5 and 6 elucidate the differential cognitive efforts required to interpret distorted as opposed to natural body postures, shedding light on the complexities of high-level visual processing. They enhance the understanding of how the eye movements response complex visual information, particularly in recognising and interpreting varied body shapes. These findings are pivotal in assessing cognitive load, understanding perceptual and psychological research. The experiments in high-level visual processing have significantly revealed how our eyes and brain work together to interpret complex visual stimuli, particularly involving human bodies. We have learned that eye movements are not random but are closely linked to cognitive processes during visual recognition. When we view complex images, our eyes follow specific patterns that reflect how we process and understand the visual information. The outcomes of these experiments offer valuable insights into high-level visual processing and the cognitive effort required to process diverse body stimuli. Specifically, the findings reveal that participants exhibited longer fixation times and increased eye movement patterns when observing salient body shapes, indicating a higher cognitive load. Eye-tracking data showed that the visual system allocates more attention to certain features of the body stimuli, enhancing our understanding of how eye movements respond to complex visual information. These findings are pivotal in assessing cognitive load and contribute significantly to perceptual and psychological research by elucidating how we recognise and interpret varied body shapes.

Chapter 4 Investigating Motor-Cognitive Processes in Hand Perception

This chapter describes motor-cognitive behavioural experiments into human body perception and is subdivided into five sections. The first section describes Experiment 7, which addressed spatial stimulus-response compatibility and automatic mental simulation modulating manual responses to stimuli in the hand category. The second section describes Experiment 8, which builds on Experiment 7 and examined whether the modulation of automatic mental simulation was caused by spatial stimulus-response compatibility by using another experimental paradigm, i.e., responding with wrists crossed. The third section describes Experiment 9, which addressed the automatic mental simulation of hand rotation and, in addition, examined whether automatic mental simulation of hands only applied to a single hand or to both hands simultaneously. The fourth section describes Experiment 10, which examined whether the nonautomatic mental simulation of hands applied not only to hands but also to individual fingers; the fifth section describes Experiment 11, which built on Experiment 10 and examined whether mental simulation of hands was caused by implicit (automatic) or explicit (nonautomatic) features.

4.1 Automatic Mental Simulation in Hand Perception and Recognition

Automatic mental simulation, defined as the cognitive process whereby actions are mentally envisioned without being physically enacted, holds a crucial role in a multitude of cognitive tasks (Cole, Smith, Ragan, Suurmond, & Armitage, 2021). The initial theoretical foundation to contemplate revolves around automatic mental simulation involving hands. There exists an inherent capability within human cognition to perceive, decode, and interpret hand postures, absent explicit directives or conscious exertion (Brockmole, Davoli, Abrams, & Witt, 2013). The study's focus is on the speed and automaticity of hand posture recognition, rather than its evolutionary origins. Therefore, the term ‘inherent’ might describe a fundamental aspect of human cognition that is present early in development and operates without conscious effort, but not necessarily an evolved trait specific to hand postures. This automatic mental simulation coincides with the cognitive processes associated with comprehending and predicting actions, thus constituting a key component of social cognition (Hooker, Mair, Germine, & Lincoln, 2020).

Expanding this theory to the intricacies of finger postures, a distinction arises between natural and distorted postures (Schürmann et al., 2011). Due to their common occurrence in daily life, natural finger postures are readily recognised and processed. In contrast, distorted finger postures, being more salient, trigger more intense automatic mental simulations. This contrast sheds light on the impact of salience on cognitive processing, where salient entities are typically processed with increased ease. Furthermore, automatic mental simulation is exemplified in the Simon task (Ellinghaus, Karlbauer, Bausenhart, & Ulrich, 2017). The paper demonstrates that the Simon effect, where irrelevant stimulus location impacts response speed, is consistent across stimulus durations due to brief, pulse-like automatic activation. In this cognitive task, stimuli appear in varying locations, yet the response is dependent not on the location, but on the stimuli's attributes. For example, participants might be asked to press a left button when they see a red circle or a right button when they see a blue circle, regardless of whether the circle appears on the left or right side of the screen. The Simon effect occurs when responses are faster when the stimulus location matches the response side, even though location is irrelevant to the task. Performing the task with hands triggers an automatic mental simulation, revealing how physical actions and perceptions are linked and influence our cognitive responses.

As the discussion transitions to the hand laterality judgement task, automatic mental simulation once more surfaces as a central element (Parsons, 1987, 1994). In this task, the laterality of images depicting hands in diverse postures is judged by participants. The task goes beyond mere identification and engages in the mental simulation of aligning one's own hand with the posture depicted. This process occurs regardless of whether the image shows a single hand or both hands, even though the cognitive processing complexity may vary. Lastly, the exploration of automatic mental simulation is further advanced by the individual finger laterality judgement task (Parsons, 1987, 1994). Although the article is on hand laterality judgement, the principles and findings apply to finger laterality judgement tasks. The mental rotation and imagery processes used to determine the laterality of hands naturally extend to tasks involving specific fingers, as both require similar cognitive and motor imagery mechanisms. Instead of focusing on the entire hand, this task targets individual fingers. Despite the increased complexity, mental simulation persists as a tool for reaching judgements. This approach underscores the impressive adaptability of mental simulations to a wide range of detail and complexity. Hand and finger laterality judgements involve mapping perceived stimuli onto internal body representations. The Simon effect links faster responses to matching stimulus and response locations.

Studying these judgements in individuals with hand dystonia could reveal if impairments are specific or reflect broader body representation issues. Examining how distorted finger postures impact judgements could show the adaptability of these simulations, potentially informing rehabilitation by helping us understand the relationship between motor deficits and mental body representations in dystonia.

4.2 Experiment 7: Spatial Stimulus-Response Compatibility and Automatic Mental Simulation Modulating Manual Responses to Images of Hands

4.2.1 Introduction

One approach to studying the process of automatic mental simulation is to present images of hands on a computer screen to which participants give left- and right-hand side keyboard responses depending on the instructions for various stimulus features. Responses could potentially be influenced by the Simon effect, which suggests that reaction times might be quicker when there is a spatial match between the stimulus and the response hand.

This experiment seeks to determine the extent to which spatial stimulus-response compatibility impacts the perception of distorted and natural finger postures, particularly focusing on how compatibility may modulate automatic mental simulation during hand perception tasks and potentially confound research findings. Many researchers have used the Simon task to measure the difference in RT across trials, i.e., those in which RTs are quicker when stimuli and response are on the same side and those trials in which they are on opposite sides to each other. The RTs in the latter group are generally slower (Dolk et al., 2014) (Figure 4-1).

Experiment 7 compared the Simon effect for hand images with chair images as controls (comparable to hands in geometric shape but without automatic mental simulation). A motor strategy is adopted by the motor cortex whilst doing hand laterality tasks (Cabinio et al., 2010). One of the assumptions made in this research is that identifying the laterality of hands depends on a motor strategy. Other studies, however, have said that identifying the laterality of hands depends on a visuo-spatial strategy (Jones et al., 2021; Mellet et al., 2016). The prediction involves the Simon effect, where it is anticipated that the right hand will respond faster to images on the right, and the left hand will respond faster to images on the left. This effect is expected to occur when the orientation of a chair's legs mimics the position of the fingers on either the left or right hand.

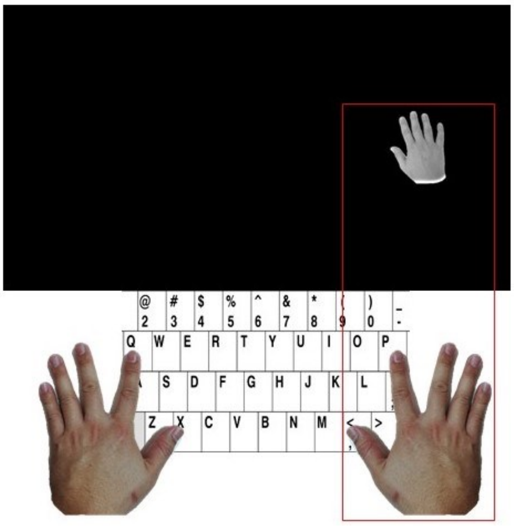


Figure 4-1 A schematic illustration of response hands with a keyboard, from Experiment 7
The right hand presses the P key and the left hand presses the Q key. Participants were instructed to use their right hand to press the P key when they detected a right hand; they were instructed to use their left hand to press the Q key when they detected a left hand.

4.2.2 Method

4.2.2.1 Participants

Thirty-eight students from the University of Nottingham Malaysia, 12 females and 26 males (18-45 years, *M* = 23.40 years, *SD* = 3.22) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment. All participants gave written, informed consent and had normal or corrected to normal visual acuity, and all received either course credits or an inconvenience allowance as per ethics approval. The number of participants in this experiment was higher than in earlier studies examining the Simon effect (Lleras, Moore, & Mordkoff, 2004). In addition, an a priori analysis by G*Power 3.1.9.4 (Faul et al., 2009) was used to determine what sample size would be adequate, and the default setting as specified in GPower 3.0 was chosen. G*Power is a statistical software tool used for power analysis and sample size calculation. A correlation coefficient of $\rho = 0.5$ has been used to estimate sample size requirements. For a study with 2 × 2 × 2 × 2 within-subjects factorial design, an a priori power analysis was conducted using G*Power. A small effect size was set at a value of 0.25 (Brydges, 2019).. The results indicated that a sample size of 16 participants would be sufficient to detect a significant interaction effect in a repeated measures within-subjects ANOVA, with a statistical power of 0.95 and an alpha level of 0.05 (Faul et al., 2009; Faul et al., 2007). The experiment was approved by the Ethics Committee of the School of Psychology, University of Nottingham, ethics code HYC150221.

4.2.2.2 Materials and apparatus

The greyscale images used in this experiment were stimuli from hand and chair categories. All hand images were in the first-person perspective and consisted of left and right hands. Chairs were chosen as control stimuli because their overall shape resembles hands (Figure 4-2). The size of the images used was 2° × 2° visual angle (2 cm × 2 cm). All chair images were comparable to hands in geometrical configuration and complexity. There were 15 images each of 15 different single hands and chairs, which were as in Espírito Santo, Chen, et al. (2017), with the authors' permission.

Participants sat 57 cm from the monitor. The distance between the centre of the screen and the stimuli was 18 cm (18° visual angle) along a horizontal line. There were six blocks in the experiment. In the first three blocks, only images of hands (distorted and natural) were shown to participants in two separate locations (on the screen) in random order. There were 120 trials in each block. Of the 120 stimuli in each block, 15 images were presented for each combination: configuration (distorted and normal), hand laterality (left or right), and location (left or right), resulting in 120 images. In the second three blocks, only images of chairs (distorted and natural) were shown. There were 120 trials in each block. Of the 120 stimuli in each block, 15 images were presented for each combination: configuration (distorted and normal), chair orientation (left or right), and location (left or right), resulting in 60 images.

The experiment was presented and coded using PsychoPy 3.1.0 (Peirce, 2007, 2008) on a 14-inch HP EliteBook 840 with a refresh rate of 60 Hz and a spatial resolution of 1366 × 768 pixels. All stimuli were presented on a black background.

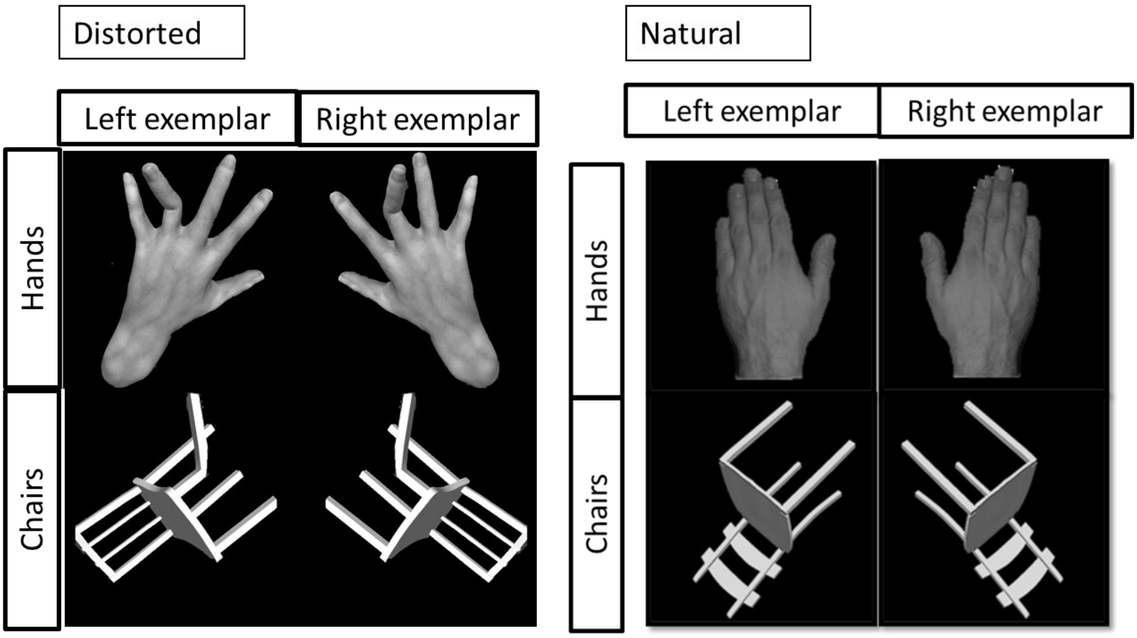


Figure 4-2 Stimulus setup in Experiment 7
Stimulus categories: 4 exemplars per category (distorted and natural), each in left and right configurations. Top row shows hands (distorted and natural), bottom row shows chairs (distorted and standard). Stimuli are computer-generated using an in-house protocol.

4.2.2.3 Design and procedure

This behavioural study used computer-generated images of hands (left and right) and chairs (rotated so that the legs were oriented like the fingers of either left or right hands). Stimuli were presented on either the left or right half of a computer screen. A perceptual decision task required left- or right-hand responses on a keyboard (Figure 4-3). There were 20 practice trials prior to the formal trials. In a randomised mixed design, each participant did a total of 720 trials divided equally across the first three blocks, and 360 trials divided equally across the second three blocks.

Participants were instructed to maintain fixation in the centre of the screen until the stimuli were displayed. Stimuli were presented on either the left or right half of the computer screen. Before stimuli were presented, a white fixation cross was presented in the centre of the screen. Participants were told to press the ‘P’ key if a right hand or a chair (with legs oriented like the fingers of the right hand) was presented; the ‘Q’ key if a left hand or a chair (with legs oriented like the fingers of the left hand) was presented. For chairs, the orientation of the legs was manipulated. Some chairs had legs arranged to mimic the finger orientation of a right hand, whilst others had legs arranged to mimic the finger orientation of a left hand. Participants were asked to imagine rotating their hand until their fingers aligned with the chair legs. Then, they pressed the ‘P’ key if this imagined rotation matched a right hand or the ‘Q’ key if it matched a left hand. The stimulus remained until a response was made with a response-stimulus interval (RSI) of 500 ms. The left or right and hand locations were independent variables. The RT was used as a dependent variable.

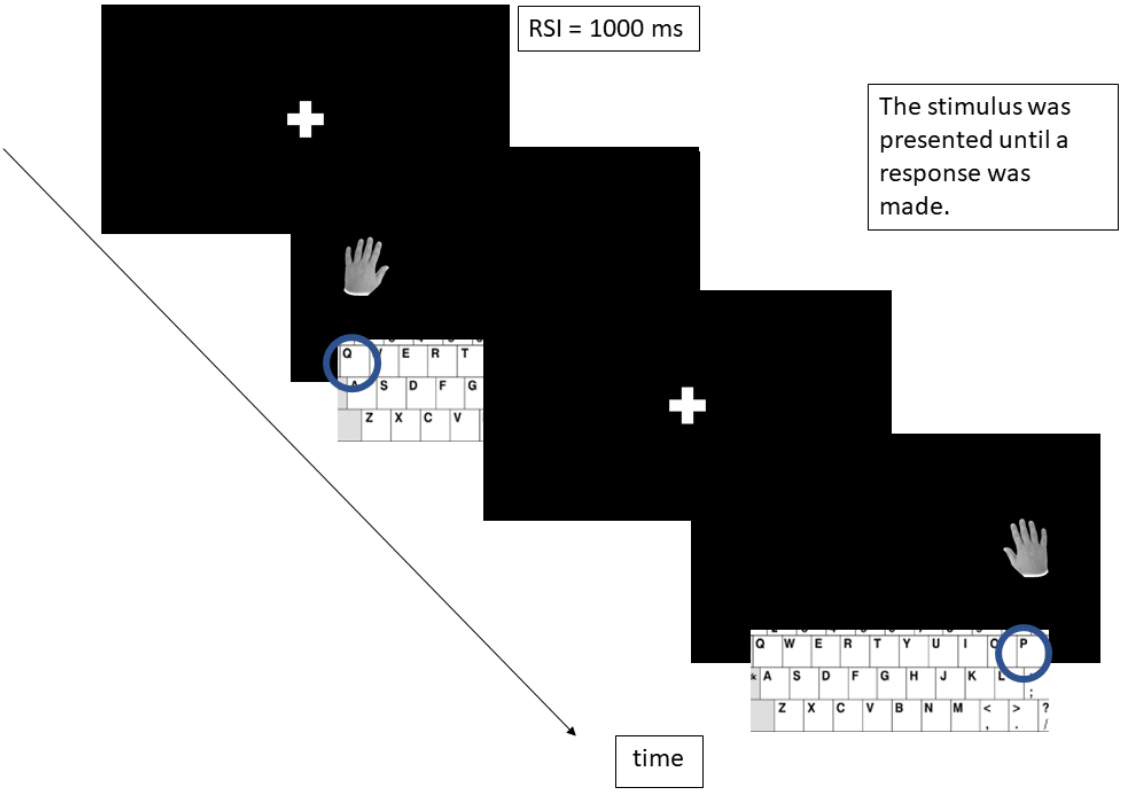


Figure 4-3 Stimulus timeline in Experiment 7.
Only left and right hands (natural finger posture) stimuli (two out of the eight stimulus exemplars), first and second trials, respectively. Stimuli not shown to scale (actual distance 18° between the centre of the screen and the stimuli).

4.2.3 Results

Accuracy rates in the experiment ranged from 88% to 99%. Accuracy was monitored to ensure error rates remained low enough to maintain the validity of RT data (Hilchey, Ivanoff, Taylor, & Klein, 2011; Ivanoff, Klein, & Lupianez, 2002). To encourage participants to answer as quickly as possible, whilst focusing on accuracy, a bonus is offered to the top 3 participants with the highest RTs whose accuracies are not outliers. The RT of the hand (mean = 803 ms, SE = 15 ms) is slower than that of the chair (mean = 714 ms, SE = 15 ms). RTs were analysed using factorial repeated measures ANOVA over the configuration (distorted and natural), hand laterality (left or right), stimulus type (hand and chair), and stimulus location (left or right). For hands, responses by the right hand were 100 ms faster than responses by the left hand. For chairs, right-hand responses were 30 ms faster than left-hand responses. Stimulus type showed a significant main effect [$F(1, 37) = 48.478$, $p < 0.001$, $\eta_p^2 = 0.567$]. Responses to hands were 89 ms slower than responses to chairs. In terms of responses between distorted hands (distorted finger postures) and natural hands (natural finger postures), configuration showed a significant main effect [$F(1, 37) = 48.478$, $p < 0.001$,. $\eta_p^2 = 0.567$]. This suggests that participants' responses differed significantly depending on whether the hand stimuli were presented in a distorted or natural posture. The RT for distorted hands is 45 ms slower than for natural hands. There was also a significant interaction between hand laterality, stimulus type, and location [$F(1, 37) = 13.676$, $p < 0.001$, $\eta_p^2 = 0.270$]. The results of the analysis did not disclose any factorial repeated measures interaction between configuration, hand laterality, hand laterality, and location [$F(1, 37) = 2.513$, $p = 0.121$, $\eta_p^2 = 0.064$].

If only natural and standard stimuli were taken and reduced factorial repeated measures ANOVA to three-way repeated measures ANOVA to combine the Simon effect and automatic mental simulation for natural finger postures and standard chairs only and remove the factor of distortion, there was a significant interaction between hand laterality and location [F(1, 37) = 15.337, $p < 0.001$, $\eta_p^2 = 0.293$]. One of the critical findings of this task was that the Simon effect was strong for natural finger postures and weak for standard chairs, as manifested in a significant interaction. There was a significant interaction between hand laterality, stimulus type, and stimulus location [F(1, 37) = 6.846, $p = 0.013$, $\eta_p^2 = 0.156$]) (Figure 4-4).

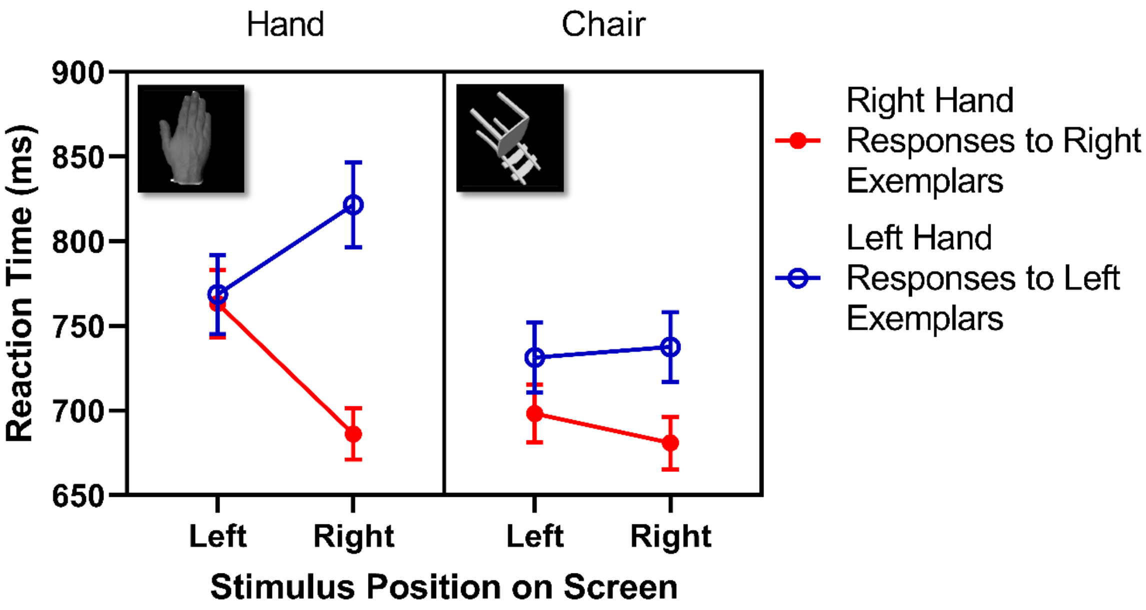


Figure 4-4 Experiment 7 results
RT of different stimulus types (hand and chair), hand laterality (left and right) and stimulus location (left and right). Results exclude configuration factors (distorted and natural).

4.2.4 Discussion

This experiment introduces a novel approach to examine how spatial stimulus-response compatibility influences automatic mental simulation, a key component in understanding hand perception. This experiment contributes to the overall thesis by addressing a fundamental methodological concern in the study of automatic mental simulation. By elucidating the role of spatial stimulus-response compatibility in this context, the research enhances the validity and reliability of future studies, allowing for a more accurate understanding of the mechanisms underlying automatic mental simulation and its implications for social cognition, motor control, and related fields. The results suggested an effect of spatial stimulus-response compatibility on RTs, facilitated by automatic mental simulation in the case of hand stimuli. From these results, it can be concluded that the Simon effect is only significant in hands, and not chairs, when analysing neutral stimuli (i.e., natural finger postures and standard chairs). The Simon effect is more pronounced with stimuli linked directly to actions, as these automatically trigger corresponding motor responses. In contrast, for non-action-related stimuli like green circles or red squares, which do not inherently suggest specific actions, this automatic activation of motor programmes might be weaker, leading to a less pronounced or absent Simon effect.

The occurrence of automatic mental simulation for hands explains these findings. The spatial stimulus-response compatibility showed the different responses to hand stimuli presented on one side or the other of the monitor. The RTs differed depending on which side of the monitor the stimuli were presented. When right-hand stimuli appeared on the right-hand side, the right hand responded faster than when the right-hand stimuli appeared on the left-hand side of the monitor. The spatial stimulus-response compatibility was expected to be the same for the chair stimuli because the hand and chair stimuli appeared in the same positions on the monitor and were responded to with the same responding hand. The hand and chair stimuli were similar in geometric form as the images of the chairs, the control stimuli, were with legs pointing left, replicating the posture of the right-hand stimuli. However, the RTs for the chair stimuli were almost the same, irrespective of the side on which the chair stimuli were presented.

The results showed spatial stimulus-response compatibility was higher with hand stimuli and responding hands, indicating a stronger Simon effect, compared to lower compatibility and effect with chair stimuli. It can be inferred that there was a stronger Simon effect between hand stimuli and responding hands and a lower Simon effect between chair stimuli and responding hands. This could be due to automatic mental simulation, where participants associate hand stimuli with their hands, leading to faster responses when the stimulus and response locations align. This is supported by the significant difference in RTs between right-hand stimuli appearing on the right side versus the left side (Nagashima, Takeda, Shimoda, Harada, & Mochizuki, 2019; Zhong & Zhang, 2021). This suggests that hands are automatically processed as action-relevant objects. Future research could investigate whether this effect persists with distorted hand stimuli, shedding light on the boundaries of automatic hand processing and its impact on the Simon effect.

Participant feedback in the pilot study recorded that the instructions were hard to understand when the hands and chairs appeared in random order. Consequently, the hands were presented in the first two blocks and the chairs were presented in the second two blocks. However, the experiment subsequently suffered from a design limitation due to this revised sequence of experiments (hand stimuli followed by chair stimuli), as the Simon effect is sometimes found to be stronger at the beginning of a session. In order to enhance internal validity and mitigate this limitation, it would be beneficial to design the experiment such that each stimulus is presented in a randomised order. Alternatively, another approach could be to present the stimuli in blocks, ensuring that the order of these blocks is varied across participants, a method known as counterbalancing.

Chairs, unlike hands, minimally inhibit the Simon effect when stimuli are presented opposite the responding hand, despite their similar shape. Although the shape of the chairs was similar to that of the hands, the chairs did not show the same result as the hands. In the following experiment, Experiment 8, modifications were made to identify potential inhibition for a mismatch between stimulus location and responding hands (Verghese, Mattingley, Palmer, & Dux, 2018). In Experiment 7, the findings are inconclusive as to whether participants showed longer RTs when they crossed hands to respond to the stimuli than when they responded with hands in the normal response position (left hand on the left-hand side and right hand on the right-hand side).

4.3 Experiment 8: Spatial Stimulus-Response Compatibility and Automatic Mental Simulation Modulate Manual Responses to Images with Responding Hand Located on the Opposite Side

4.3.1 Introduction

The Simon effect has been shown to occur in motor-cognitive processing of hands, in Experiment 7. In Experiment 8, it can be inferred from the different RTs of the different spatial response-stimulus compatibility recordings that automatic mental simulation occurs with hands but not chairs (of similar geometric complexity) due to the hand stimuli being closely associated with the responding hand. One notable example is the study, which demonstrated that the Simon effect persists even when the hands are crossed, indicating that the effect is driven by the compatibility between the stimulus and response locations rather than the responding hand (Seibold, Chen, & Proctor, 2015). This study suggests that the spatial compatibility between the stimulus and response locations is a crucial factor in the Simon effect, regardless of the position of the responding hand. Incorporating this study would strengthen the introduction by providing a more comprehensive background and context for the current experiment.

However, this is not a certitude as it was unclear whether the Simon effect for hands was caused by automatic mental simulation. To clarify the issue, it was necessary to confirm whether automatic mental simulation was engaged because (1) the hand stimuli and the responding hand were in close proximity, irrespective of the side of the body or screen involved (the right or left-hand side) or because (2) the stimuli and responding hand appeared in proximity on the same side. The purpose of this experiment was to gain a further understanding of the Simon effect on hands and to identify the factors influencing it. The key research question of this experiment was whether the Simon effect was driven by mental simulation or other factors. This experiment drew on the framework of the Simon task but was a variant of the Simon task. The position of the responding hands was switched; that is, the participants crossed their wrists, thus pressing the key on the opposite side of the keyboard. This was to eliminate the influence of key positions on RT. The RT was used as a dependent variable (Figure 4-5).

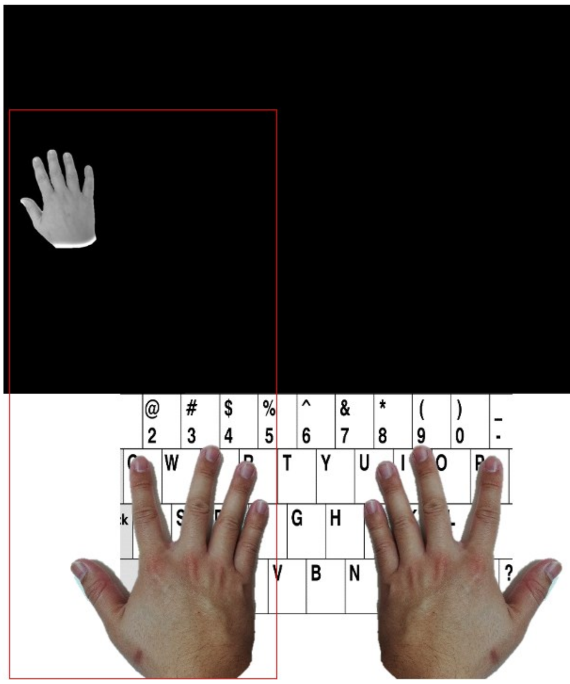


Figure 4-5 A schematic illustration of crossed-responding hands with keyboard, from Experiment 8
In this experiment, the right hand presses the Q key and the left hand presses the P key. When participants detected a right-hand image on the screen; they were instructed to use their right hand to press the Q key. When they detected a left-hand image, they were instructed to use their left hand to press the P key.

4.3.2 Methods

4.3.2.1 Participants

23 students from the University of Nottingham Malaysia, 12 females and 11 males (18-45 years, *M* = 21.10 years, *SD* = 2.24) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment. The recruitment requirements for this experiment were the same as for Experiment 7. The data of one participant was removed because the participants' accuracy was much lower than the group mean. Based on assuming stimulus type (left hand and right hand) x 2 (without and with wrists crossed) within-subject factors and keeping the same other parameters as in Experiment 1 in a priori analysis for G*Power, a sample size of 18 was sufficient. The experiment was conducted under the approval of the Ethics Committee of the School of Psychology at the University of Nottingham, adhering to ethics code HYC150221.

4.3.2.2 Materials and apparatus

The materials used in this experiment were greyscale stimuli from the hand category. The hand images used in this experiment were the same hand images as in Experiment 7. Participants sat 57 cm from the monitor. The distance from the centre of the screen to the centre of the stimuli was 18 cm (18° visual angle) along a horizontal line. There were six blocks in this experiment. There were 120 trials in each block presented in random order. Out of the 120 stimuli in each block, 15 images were presented for each combination: left or right hand and hand location (left or right), resulting in 120 images. The visual search display size was 35 cm horizontally and 18 cm vertically. The experiment was presented and coded using Pavlovia online, which is an online hosting service that accommodates different types of JavaScript experiments (Grootswagers, 2020; Sauter et al., 2020).

4.3.2.3 Design and procedure

The design and procedure of Experiment 8 were based on Experiment 7, and the standard for selecting the data was also based on Experiment 7. In this randomised mixed design, each participant underwent 960 trials. In the first three blocks, participants were asked to place their hands as normal on the keyboard, wrists not crossed. They were told to press the P key if a right hand was presented on the screen, the Q key if a left hand was presented. In the second three blocks, participants were asked to place their hands on the keyboard, wrists crossed (Figure 4-6). They were told to press the P key if a left hand was presented, the Q key if a right hand was presented. The stimulus remained until a response was made with a RSI of 500 ms. The RT was used as a dependent variable.

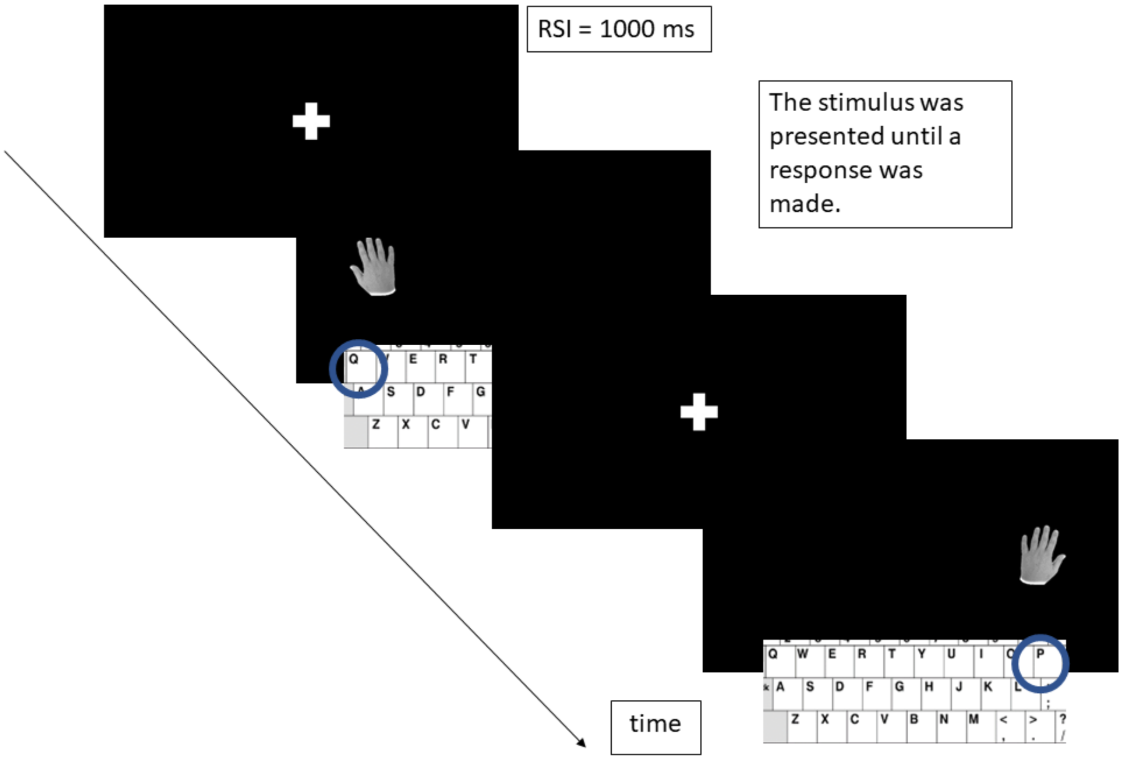


Figure 4-6 Stimulus timeline in Experiment 8
There were left and right natural finger posture stimuli, in the first and the second trials, respectively. Stimuli not shown to scale (actual distance 18° from the centre of the screen and the centre of stimuli).

4.3.3 Results

The standard for selecting the data were the same as for Experiment 7. The RT of the cross configuration (mean = 756 ms, SE = 26 ms) is slower than that of the normal configuration (mean = 585 ms, SE = 20 ms). RTs were analysed using three-way repeated measures ANOVA over the hand position configuration (without and with wrists crossed), hand laterality (left and right hand) and hand location (left or right position). The hand position configuration showed a significant main effect (F(1,22) = 128.931, $p < 0.001$, $\eta_p^2 = 0.854$) (Figure 4-7). Stimulus types showed a significant main effect (F(1,22) = 4.864, p = 0.038, $\eta_p^2 = 0.181$). There was a significant interaction between hand positions and stimulus types (F(1,22) = 9.921, p = 0.005, $\eta_p^2 = 0.311$). There was a significant interaction between layout, hand positions and stimulus types (F(1,22) = 62.723, $p < 0.001$, $\eta_p^2 = 0.060$).

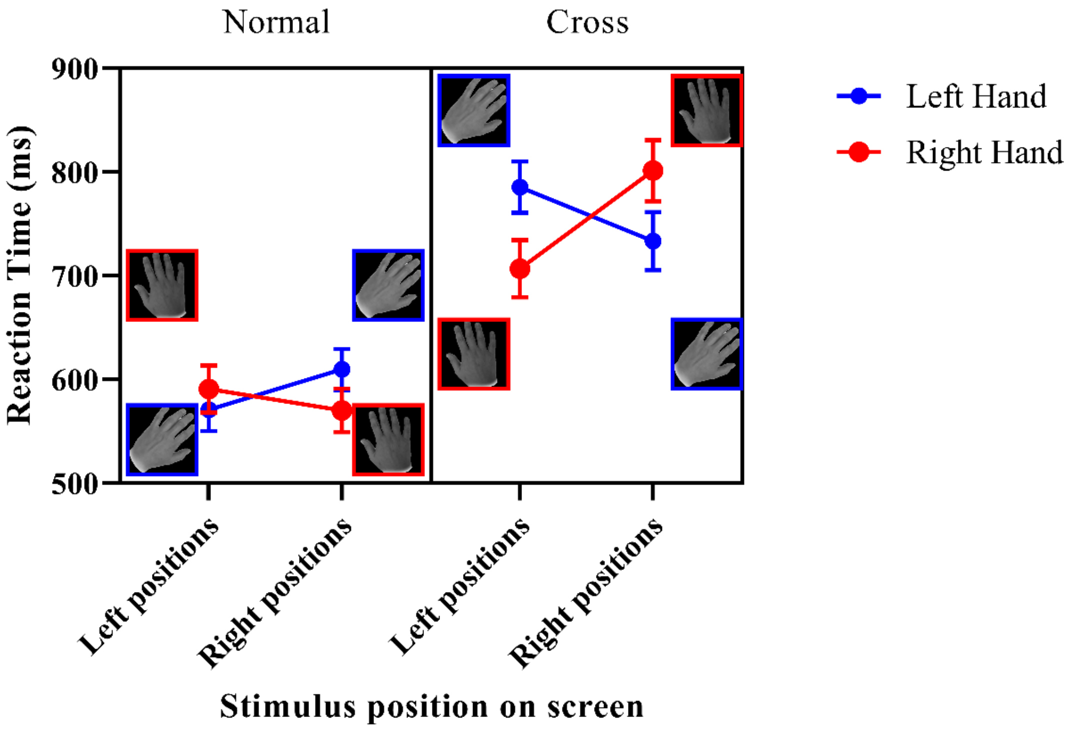


Figure 4-7 Experiment 8 results
RTs of different hand configurations (with and without wrists crossed), hand location on screen (left or right side), and left and right hands.

4.3.4 Discussion

In Experiment 7, the importance of automatic mental simulation for hands was highlighted and there was uncertainty about whether the results of the Simon effect for hands were caused by the Simon effect or by the location of the stimuli. Experiment 8, a modification of Experiment 7, found that the results were caused by the Simon effect and that this latter indicated there was automatic mental simulation for hands. The instructions in Experiment 7 were altered in Experiment 8 to make it easier to isolate the role of mental simulation. The results of Experiment 8 confirmed that the results in Experiment 7 were caused by mental simulation rather than the location of stimuli as a result of the crossed-wrist responding hand instruction which removed the impact of location of stimuli. This further suggests that spatial stimulus-response compatibility can significantly modulate automatic mental simulation, supporting the theory that such simulations are not purely mechanical but involve higher cognitive processes. Including the crossed-wrist condition helped disable the effects of spatial compatibility from those of mental simulation, strengthening the validity of the findings (Seibold et al., 2015). The results of Experiment 7 suggested a Simon effect, as faster response times occurred when stimulus and response were on the same side, potentially due to automatic mental simulation of hand movements. Experiment 8, with the crossed-wrist condition, further emphasised this, showing a Simon effect even when stimulus and response locations were mismatched. This indicates that mental simulations of hand movements are robust and not merely dependent on spatial compatibility, highlighting their significance in cognitive processing.

The purpose of this experiment was to determine whether the Simon effect for hands was caused by (1) spatial proximity, i.e., whether the crossed-responding hand was on the same side as the hand stimuli or whether the crossed-responding hand was on the opposite side to the hand stimuli, the hand stimuli being placed on its own side or the opposing side respectively; or (2) by the position of hand image (responding hands not crossed), i.e., right responding hand reacting to the stimuli on the right-hand side of the screen and vice versa. In this experiment, it was found that the hand position (with wrists crossed) did not cause the time delay between responding hand position and hand stimuli, even though the responding hands were not one the normal position. When spatial proximity between hand stimuli and responding hands was close, no delay conditions were found between them. The results in this experiment may be explained by the fact that the Simon effect for hands was driven by automatic mental simulation. The automatic mental simulation of the hand position was instantaneous and thus, there was no delay in response time. The Simon effect for hands may result from automatic mental simulation, not hand image or response position (Bardi, Schiff, Basso, & Mapelli, 2015). This is supported by the absence of a Simon effect for chairs, which are not human body stimuli and therefore do not trigger the same automatic mental simulation processes. The inclusion of distorted hands in Experiment 7 was to further investigate the role of mental simulation, as chairs do not provide a comparable basis for such an assessment (Cespón, Hommel, Korsch, & Galashan, 2020; Waytz, Hershfield, & Tamir, 2015b).

In summary, these results in Experiment 8 also showed that the Simon effect was not only influenced by the directional cue, as discussed in the general previous paradigm of this chapter, but also by automatic mental simulation (i.e. when responding hand and stimulus were matched). The findings of this research can help better understand the automatic mental simulation that occurs when responding hands are closed to hand stimuli. In Experiments 7 and 8, the investigation focused solely on one hand, either the left or the right. Considering the thesis' aim to ascertain if viewed hands, especially those with distorted finger postures, are exceptionally salient, in the Experiment 9, further research was examined whether automatic mental simulations occur exclusively with single hands or in both hands simultaneously. This is crucial for understanding if there are distinct cognitive processes or brain activation patterns involved in processing distorted versus natural finger postures.

4.4 Experiment 9: Hand Laterality Judgement Task - Perception of Thumb Side View

4.4.1 Introduction

The role of mental rotation for hands has received increased attention in the study of automatic mental simulation (Balasubramaniam et al., 2012; Ionta & Blanke, 2009; Ionta et al., 2007). Results from the two previous experiments in this chapter demonstrated a strong and consistent association between mental simulation and hand postures and that the mental simulation was initiated by the hand postures rather than the chair image.

Although these two previous experiments showed that mental simulation for single hand stimuli occurred, it is unknown whether mental simulation would occur for both-hand stimuli. Previous research has shown that humans do use mental simulation on hand rotation, however, little is still known about the role of both-hand rotation in motor imagery. There remain questions about the validity of simultaneous both-hands rotation.

One of the purposes of this experiment was to duplicate the experiments in the aforementioned literature review, in which mental simulation of hands was investigated by presenting hands positioned at different angles. The first prediction was that RTs would differ for the differently rotated hand positions. This prediction was based on the hypothesis that mental simulation occurs for hands, which would be consistent with the results observed in the literature review experiments. The second prediction, based on previous research, posits that mental simulation occurs not only for single hands but also for both hands together. Previous investigations have shown that individuals can mentally simulate hand movements, engaging similar neural mechanisms as actual movement. Our predictions build on these findings and aim to explore whether the same principles apply to both hands simultaneously. This experiment advances our understanding by examining mental simulation with distorted hand representations, potentially revealing new insights into cognitive and neural flexibility (Bek, Humphries, Poliakoff, & Brady, 2022). To examine the first prediction, hands positioned at different angles were shown to participants in Experiment 9A and the RTs were measured to assess whether they differed for the altered hand rotations. To examine the second prediction, that mental simulation occurs for single hands and both hands together, a hand laterality judgement task was conducted in Experiment 9B.

4.4.2 Methods

4.4.2.1 Participants

Thirty-one students from the University of Nottingham Malaysia, 15 females and 16 males (18-45 years, $M = 21.80$, $SD = 2.34$) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment. The recruitment requirements for this experiment were the same as for Experiment 7. The data of 10 participants were removed because their accuracies were substantially lower than the group mean. These participants fell more than two standard deviations below the average accuracy. Based on assuming 2 (left and right hand) × 8 (-180°, -108°, -72°, -36°, 36°, 72°, 108°, and 180°) within-subject factors and keeping the same other parameters as in Experiment 7 in a priori analysis for G*Power, a sample size of 16 was sufficient. These procedures received approval from the SEREC of the University of Nottingham Malaysia under application number HYC150221.

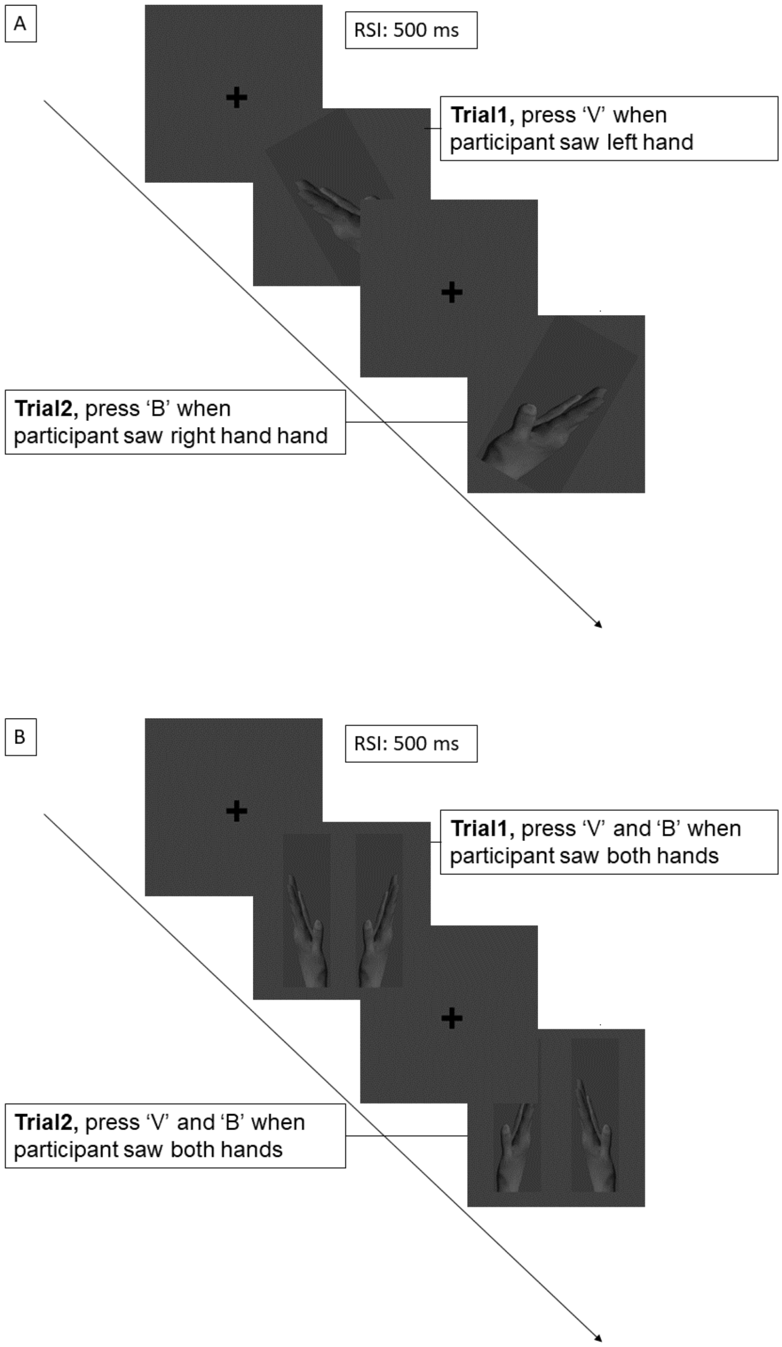
4.4.2.2 Materials and apparatus

The greyscale images in the hand category used in this experiment were 5 cm long and 3cm wide. All hand images were presented vertically from the thumb perspective. This choice was made for two primary reasons. First, thumbs are simple, easily recognisable stimuli, allowing easier identification and processing of hand images. Second, observation of thumbs can activate motor areas related to hand movement, which may facilitate the processing of hand images and enhance understanding of hand postures and gestures. There were five images of five different hands. The hand images were generated by Blender which is a computer graphics software toolset (see Appendix 2: Stimuli creation for hand model in motor-cognitive task). In Experiment 9A, there were three blocks and there were 120 trials in each block. Of the 120 stimuli in each block, 5 images were presented for each combination: hand laterality (left or right) and degree of rotation (0°, 36°, 72°, 108°, 180). In Experiment 9B, there were also three blocks each with 120 trials. 60 of the 120 trials in each block showed five different hand images presented either palm to palm or back of hand to back of hand. The other 60 trials showed the same five hand images presented as parallel left pairs or parallel right pairs.

The visual search display was 35 cm horizontally and 18 cm vertically. The experiment was presented and coded using Pavlovia online, which is an online hosting service that accommodates different types of JavaScript experiments (Grootswagers, 2020; Sauter et al., 2020).

4.4.2.3 Design and procedure

Participants sat 57 cm from the monitor and selected keys on the keyboard as instructed in response to the stimuli. Experiment 9A task: when the participant saw the left hand, they were instructed to use the ring finger on the left hand to press the ‘G’ button on the keyboard. When the participants saw a right hand, they were instructed to use the ring finger on the right hand to press the ‘H’ button on the keyboard. Experiment 9B Task: when participants saw a pair of left hands, they were instructed to use the ring finger on the left hand to press the ‘G’ button. The previous Simon task experiments in this thesis maximised the Simon effect (slower responses when stimulus and response locations are incompatible) by using widely spaced keys. This experiment intentionally places the 'H' and 'G' keys closer together to investigate the impact of spatial proximity on automatic mental simulation and response selection. When participants saw a pair of right hands, they were instructed to use the ring finger on the right hand to press the 'H' button on the keyboard. When they saw both hands, they were instructed to use the left and right ring fingers simultaneously to press the buttons 'G' and 'H' buttons, respectively (Figure 4-8). The RT was used as the dependent variable.



Trial1, press ‘V’ when participant saw left hand

Trial2, press ‘B’ when participant saw right hand hand

Trial1, press ‘V’ and ‘B’ when participant saw both hands

Trial2, press ‘V’ and ‘B’ when participant saw both hands

Figure 4-8 Stimulus timeline in Experiment 9A and 9B.
(A) Stimuli timeline in Experiment 9A. (B) Experiment timeline 9B.

4.4.3 Results

The standard for selecting the data were the same as for Experiment 7.

In Experiment 9A, the RT of the left hand (mean = 841 ms, SE = 37 ms) is slower than that of the right hand (mean = 818 ms, SE = 35 ms). RTs were analysed using two-way repeated measures ANOVA over the hand stimuli (left and right hands) and rotation degree (left or right position). The rotation degree showed a significant main effect (F(7,147) = 6.649, $p < 0.001$, $\eta_p^2 = 0.240$) (Figure 4-9). There was a significant interaction between hand stimuli and rotation degree (F(7,147) = 54.038, $p < 0.001$, $\eta_p^2 = 0.720$).

In Experiment 9B, The RT of the normal layout (mean = 728 ms, SE = 34 ms) is slower than that of the abnormal layout (mean = 802 ms, SE = 33 ms). RTs were analysed using t-test for normal (hands uncrossed) and abnormal (hand crossed) layout hand stimuli. The results showed a significantly different between normal and abnormal layout hand stimuli (t(21) = -5.098, $p < 0.001$, $d = -1.087$). The RT of the normal layout hand stimuli is 74 ms faster than the abnormal hand layout stimuli.

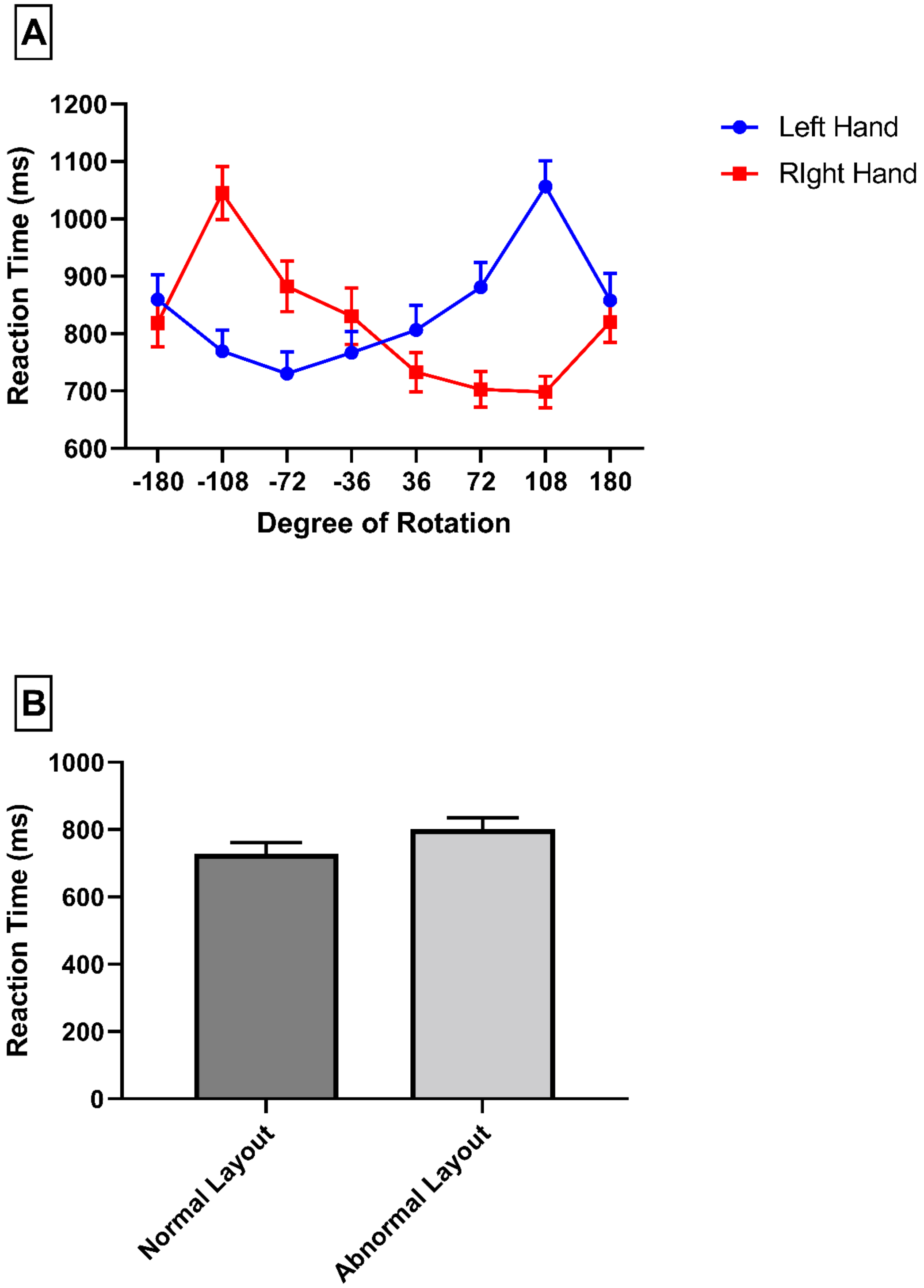


Figure 4-9 Experiment 9A and 9B results.
(A) The RTs of hand stimuli and degree of rotation in Experiment 9A. The RTs of normal layout and abnormal layout in Experiment 9B.

4.4.4 Discussion

As mentioned in the literature review, automatic mental simulation occurs when experiment participants look at hands (Parsons, 1994; Wohlschlager, 2001). In Experiment 9A, it was predicted that previous experiments could be duplicated (Parsons, 1994; Wohlschlager, 2001). The results of Experiment 9A indicated that the degree of hand rotation affected the RTs and the results were not different from the results of the previous experiments in the literature review (Figure 4-9). This pattern of results aligns with previous experiments discussed in the literature review, which consistently demonstrated that the mental rotation of hands is influenced by the biomechanical constraints of real hand movements (Parsons, 1987; "<Sekiyama - 1983 - Mental and physical movements of hands.pdf>," ; Sekiyama, 1982). The current study extends these findings by showing that the plausibility of the hand rotations also plays a role in the RTs. Specifically, the RTs for the left hand 108 and right hand -108° conditions were disproportionately longer than the others, suggesting that participants had more difficulty mentally rotating their hands to these less natural positions. This is consistent with the idea that the automatic mental rotation of body parts is not only affected by the angular disparity between the stimulus and the participant's body position but also by the feasibility of the imagined movement (Parsons, 1994). Experiment 9A supports evidence from previous experimental observations that RTs are affected by the degree of hand rotation. A possible explanation for this is that sensorimotor structures are integral to the mental simulation of hands, as they are responsible for processing sensory information and controlling hand movements, both in reality and in mental simulations.

Based on the results in Experiment 9A, Experiment 9B was executed. This experiment set out to assess whether mental simulation occurred for a single hand or for both hands together. The results of this experiment showed that the RTs in the palm facing/palm facing condition were significantly faster than the back of hand/back of hand condition. A possible explanation for this might be that mental simulation does not occur only for a single hand, but also for both hands together (Figure 4-9).

4.5 Experiment 10: Hand Laterality Judgement Task - Responses to Specific Fingers

4.5.1 Introduction

Mental simulations of hands were found in Experiments 9A and 9B for hand rotation and for single hands and both hands together. Based on the results of Experiments 9A and 9B that found that mental simulation occurs in humans when they look at hands, Experiment 10 was conducted to examine whether there is nonautomatic mental simulation for individual fingers alone.

The perception of individual fingers is now receiving more interest in the field of visual research. When humans receive the visual information of hands, they also of course receive the visual information of fingers. From previous experiments described in this thesis, it has been shown that mental simulation occurred for hand postures. However, it was debatable whether mental simulation occurred for individual fingers.

This study therefore set out to examine whether or not nonautomatic mental simulation for individual fingers occurs. In order to clarify this issue, a motor-cognitive experiment was conducted to examine whether participants responded faster when the responding finger was the same digit as the bent finger which they were viewing. For example, responding index finger reacting to index finger image compared to responding index finger reacting to middle finger image or ring finger image. This experiment sought to investigate the deliberate and nonautomatic mental simulation of individual fingers, focusing on participants' ability to visualise bent fingers upon explicit instruction.

4.5.2 Methods

4.5.2.1 Participants

22 students from the University of Nottingham Malaysia, 16 females and 15 males (18-45 years, *M* = 23.80 years, *SD* = 2.12) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment. The recruitment requirements for this experiment were the same as for Experiment 7. The accuracy of eight participants was significantly below the group average, leading to their data being excluded from further analysis. These participants were more than two standard deviations away from the mean accuracy. Based on assuming 3 (block 1, block 2 and block 3) × 3 (invisible dorsal and visible palm view; visible dorsal and invisible palm view; invisible dorsal and invisible palm) ×2 (distorted and normal) ×3 (index, middle and ring) within-subject factors and keeping the same other parameters as in Experiment 7 in a priori analysis for G*Power, a sample size of eight was sufficient. The a priori power analysis, even with a small sample, suggested a sufficient effect size to detect meaningful differences within the experimental conditions. This gives confidence in the validity of the results, even with a limited sample size. These procedures received approval from the SEREC of the University of Nottingham Malaysia under application number HYC150221.

4.5.2.2 Materials and apparatus

The stimuli in the experiment were images of hands with different fingers in distorted finger postures. The stimuli were 7.5 cm long and 7.5 cm wide, reduced to half of the real size. The hands were presented at a 30° angle from horizontal and rotated 15° on a diagonal with the palm (or the back of hand) facing the viewer.

The visual search display was 35 cm horizontally and 18 cm vertically. Participants were asked to sit 57 cm away from a monitor. The experiment was presented and coded using Pavlovia online, which is an online hosting service that accommodates different types of JavaScript experiments (Grootswagers, 2020; Sauter et al., 2020).

4.5.2.3 Design and procedure

In this experiment, the participants saw different fingers in twisted finger postures. In block 1, when they saw a bent (distorted or unusual) finger posture, they were instructed to use the right index finger to press the 'V' button on the keyboard (Figure 4-10). In block 2, when they saw a bent (distorted or unusual) finger posture, they were instructed to use the right middle finger to press the 'B' button. In block 3, when they saw a bent (distorted and unusual) finger posture, they were instructed to use the right ring finger to press the 'N' button. In blocks 1, 2 and 3, when they saw a natural hand, they were instructed to use the right thumb to press the 'space bar'. The RT was used as a dependent variable.

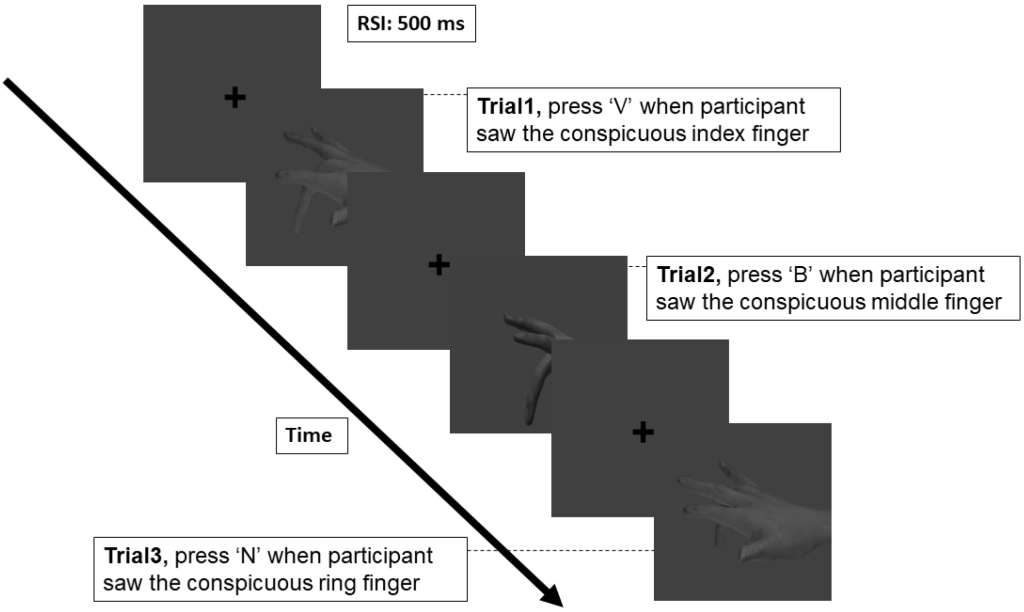


Figure 4-10 Stimulus timeline in Experiment 10

4.5.3 Results

The standard for selecting the data was the same as for Experiment 7. RTs were analysed using factorial repeated measures ANOVA over the responding finger (responding index, responding middle and responding ring), views (invisible dorsal and visible palm view; visible dorsal and invisible palm view; invisible dorsal and invisible palm), configuration (distorted and normal), bent finger (index, middle and ring) (Figure 4-11). This factorial repeated measures ANOVA design permits a comprehensive analysis of how RT is influenced by the different viewing conditions, hand configurations, specific fingers bent, and potential changes across repeated blocks, as well as any interactions between these factors (Figure 4-11). The block showed a significant main effect ($F(2,42) = 3.970$, $p = 0.026$, $\eta_p^2 = 0.159$). The configuration showed a significant main effect ($F(2,42) = 15.140$, $p < 0.001$, $\eta_p^2 = 0.419$). There was a significant interaction between views and configuration ($F(2,42) = 4.196$, $p = 0.022$, $\eta_p^2 = 0.167$). There was a significant interaction between views and bent finger ($F(2,42) = 4.196$, $p = 0.022$, $\eta_p^2 = 0.167$). There was no significant interaction between blocks, views, configuration and bended finger ($F(8,168) = 1.119$, $p = 0.353$, $\eta_p^2 = 0.051$).

From marginal mean of both distorted and unusual finger postures, the RT of the index finger (mean = 697 ms, SE = 24 ms) in block 1 was faster than the middle finger (mean = 737 ms, SE = 29 ms) and the ring finger (mean = 734 ms, SE = 30 ms), the RT of the middle finger (mean = 651 ms, SE = 26 ms) in block 2 is faster than the index finger (mean = 673 ms, SE = 26) and the ring finger (mean = 673, SE = 29 ms); the RT of the ring finger (mean = 694 ms, SE = 33 ms) in block 3 was faster than the index finger (mean = 725 ms, SE = 42) and the middle finger (mean = 702, SE = 37 ms). The manipulation of blocks, in which participants were instructed to respond with a specific finger, reveals a significant interaction between the responding finger and the stimulus finger. The fastest reaction times were consistently observed when the responding finger matched the stimulus finger. This suggests a form of finger-specific priming, where the preparation to use a particular finger facilitates the response to a stimulus on that same finger.

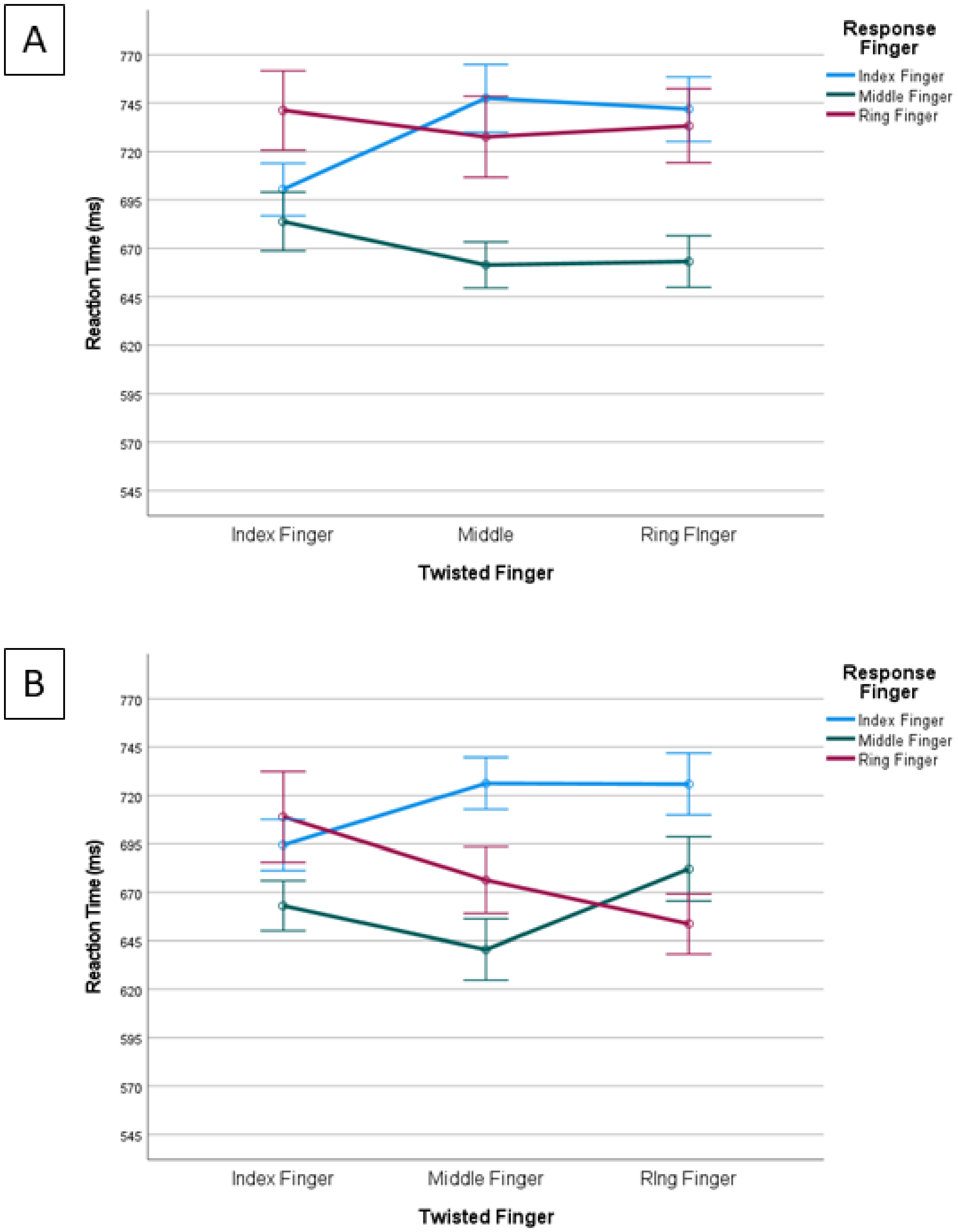


Figure 4-11 Experiment 10 results
(A) Distorted finger postures results, (B) Unusual finger postures results.

4.5.4 Discussion

Whilst the existing literature offers limited insights on mental simulation with individual fingers, recent research using transcranial magnetic stimulation (TMS) suggests its potential for inducing and refining mental simulation of specific finger movements (Mihelj, Bächinger, Kikkert, Ruddy, & Wenderoth, 2021). Additionally, the precise mapping of motor representations in the brain with TMS lays a foundation for understanding how such simulations might occur. Whilst not directly focused on individual finger simulation, the work on the MNS provides a framework for understanding how the brain might represent and simulate actions, potentially including those of individual fingers (Rizzolatti & Craighero, 2004; Rizzolatti & Sinigaglia, 2016). This experiment was designed to determine the existence of mental simulation of individual fingers. The results of this experiment showed that the RTs were faster when each responding finger was the same digit as the twisted stimulus finger (either index, middle, or ring fingers). It can be predicted that the mental simulation did occur with individual fingers. So, when participants' responding finger (e.g., index finger) was the same digit as the twisted stimulus finger (e.g., index finger), automatic mental simulation was indicated.

The effect of finger bending on response time is intriguing. Contrary to what one might expect, the distorted finger posture led to slower responses, potentially due to the absence of automatic mental simulation. This suggests that our brains struggle to process and react to salient finger positions, as humans lack an automatic mental model for such distortions. The concept of automatic mental simulation helps explain why humans respond more quickly to salient postures. The brains can easily simulate and understand positions humans frequently encounter. These findings may have been somewhat influenced by the experiment instructions, which brought to the attention of the participants the twisted positions of the stimuli. It is possible that these results are only valid for situations in which participants allocate their attention to this. The findings of this experiment suggested that mental simulation does occur with individual fingers as well as hands. A question that remained unanswered was whether the results were caused by explicitness or not. In order to clarify this issue, further research should be undertaken to investigate what triggers automatic simulation with individual fingers.

This can only explain that in allocate their attention but cannot explain the situation in automatic mental simulation because automatic mental simulation is spontaneous. The current study's findings are limited in their ability to fully explain the phenomenon of automatic mental simulation. Whilst the experiment instructions directed participants' attention to the twisted positions of the stimuli, thereby potentially influencing the results, it does not account for the spontaneous nature of automatic mental simulation. Automatic mental simulation is thought to occur without explicit effort or intention (Grush, 2004). It is a process that happens spontaneously, often in response to observed actions or stimuli. The current study's design, which explicitly drew attention to the stimuli, may not accurately capture the automatic and spontaneous aspects of mental simulation. Moreover, previous research has shown that automatic mental simulation can occur even when attention is not explicitly directed towards the stimuli. Viewers automatically simulated observed actions, even when they were not instructed to do so. This suggests that automatic mental simulation is a fundamental cognitive process that occurs independently of conscious attention allocation (Brass, Bekkering, Wohlschläger, & Prinz, 2000). To better understand the mechanisms underlying automatic mental simulation with individual fingers, future research should employ designs that capture the spontaneous nature of this process. This could involve paradigms that measure implicit responses or use distractor tasks to ensure that participants' attention is not explicitly directed towards the stimuli (Sebanz, Knoblich, & Prinz, 2003). By investigating automatic mental simulation under conditions that more closely resemble real-world scenarios, researchers can gain deeper insights into the triggers and neural underpinnings of this phenomenon.

4.6 Experiment 11: Hand Laterality Judgement Task: Left- or Right- Hand Recognition

4.6.1 Introduction

In Experiment 10, participants were asked to respond to bent distorted finger postures which were ‘explicit’ features. In order to test the difference of compatibility between the responding hands and the hand stimuli, Experiment 11 was performed to investigate bent finger postures as ‘implicit’ features.

In Experiment 10, the role of explicit features in a finger-response task was investigated. Participants were instructed to use a designated finger (index, middle or ring) to respond to a corresponding bent finger image, including distorted and unusual variations. The phrase ‘a bent finger’ was included to potentially prime explicit awareness of the task. By analysing response times and accuracy, the purpose was to determine whether the mechanism driving their finger selection was primarily explicit (involving deliberate decision-making based on the instruction and image) or implicit (triggered by automatic mental simulation of the viewed finger position) (Brusa, Erden, & Sedda, 2023).

The prediction in Experiment 11 was that RTs would be faster when the responding finger was the same digit as the bent stimulus finger, for either left or right hand. To clarify the conscious response issue, the task and the instructions given to participants were altered in Experiment 11; the behaviour method used in Experiment 10, to collect left and right recognition RTs, was also used in Experiment 11. Participants in Experiment 11 were asked to look at images of a left or a right hand and were instructed to use the same responding hand as they saw on the screen, i.e., to use the left hand when a left hand was shown and the right hand when a right hand was shown. However, in each block, participants were instructed to use different fingers to respond on the keyboard. The experimental design was used to remove the effect of recognising explicit features (here referring to bent individual fingers) and as predicted participants did not consciously respond to the ‘bent’ aspect of the finger postures.

4.6.2 Methods

4.6.2.1 Participants

Nineteen students from the University of Nottingham Malaysia 15 females and 16 males (18-45 years, *M* = 22.80, *SD* = 2.62) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in the experiment. The data from 7 participants were rejected because their accuracy scores were notably low compared to their peers, falling outside the range of two standard deviations from the mean. Based on assuming 2 (left and right hand) × 8 (-180°, -108°, -72°, -36°, 36°, 72°, 108°, and 180°) within-subject factors and keeping the same other parameters as in Experiment 7 in a priori analysis for G*Power, a sample size of 16 was sufficient. These procedures received approval from the SEREC of the University of Nottingham Malaysia under application number HYC150221.

4.6.2.2 Materials and apparatus

The stimuli in this experiment were images of different fingers in bent (distorted or unusual) finger postures, as in Experiment 10, but included both left- and right-hand images and there were no standard hand images.

The visual search display was 35 cm horizontally and 18 cm vertically. Participants were asked to sit 57 cm away from the monitor. The experiment was presented and coded using Pavlovia online, which is an online hosting service that accommodates different types of JavaScript experiments (Grootswagers, 2020; Sauter et al., 2020).

4.6.2.3 Design and procedure

In block 1, participants were instructed to press the ‘E’ button with left index finger when they saw a left-hand image; to press the ‘I’ button with the right index finger when they saw a right-hand image (Figure 4-12). In block 2, participants were instructed to press the button ‘E’ with the left middle finger when they saw a left-hand image; to press the button ‘I’ with the right middle finger when they saw a right hand. In block 3, participants were instructed to press the ‘E’ button with the left ring finger when they saw a left-hand image; to press the ‘I’ button with the right ring finger when they saw a right hand. The RT was used as the dependent variable.

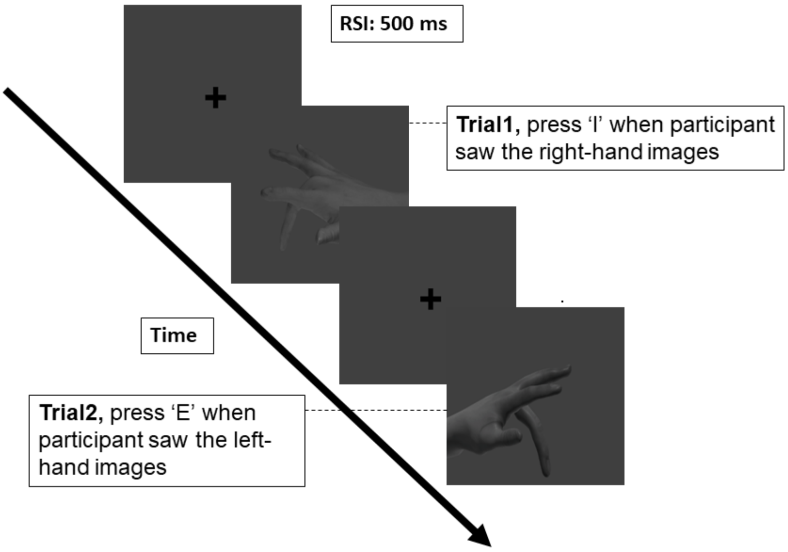


Figure 4-12 Stimulus timeline in Experiment 11

4.6.3 Results

The standard for selecting the data was the same as for Experiment 7. RTs were analysed using factorial repeated measures ANOVA over the response finger (index finger, middle finger and ring finger), views (invisible dorsal and visible palm view; visible dorsal and invisible palm view; invisible dorsal and invisible palm), configuration (distorted and unusual), bent fingers (index, middle and ring ringers) and stimulus types (left and right hands). In contrast to Experiment 10, where bent finger was an explicit feature directly manipulated in the experimental design, the current experiment incorporates bent finger as an implicit feature. This means that whilst the bent finger factor is still analysed, it is not a primary manipulation but rather an inherent characteristic of the hand stimuli used. The response finger showed a significant main effect ($F(2,36) = 30.386$, $p < 0.001$, $\eta_p^2 = 0.628$) (Figure 4-13). There was a significant interaction between stimulus types, configuration and bent fingers ($F(2,36) = 3.809$, $p = 0.032$, $\eta_p^2 = 0.175$). There was no significant interaction between response finger, configuration, bent fingers and stimulus types ($F(8,144) = 1.081$, $p = 0.380$, $\eta_p^2 = 0.057$).

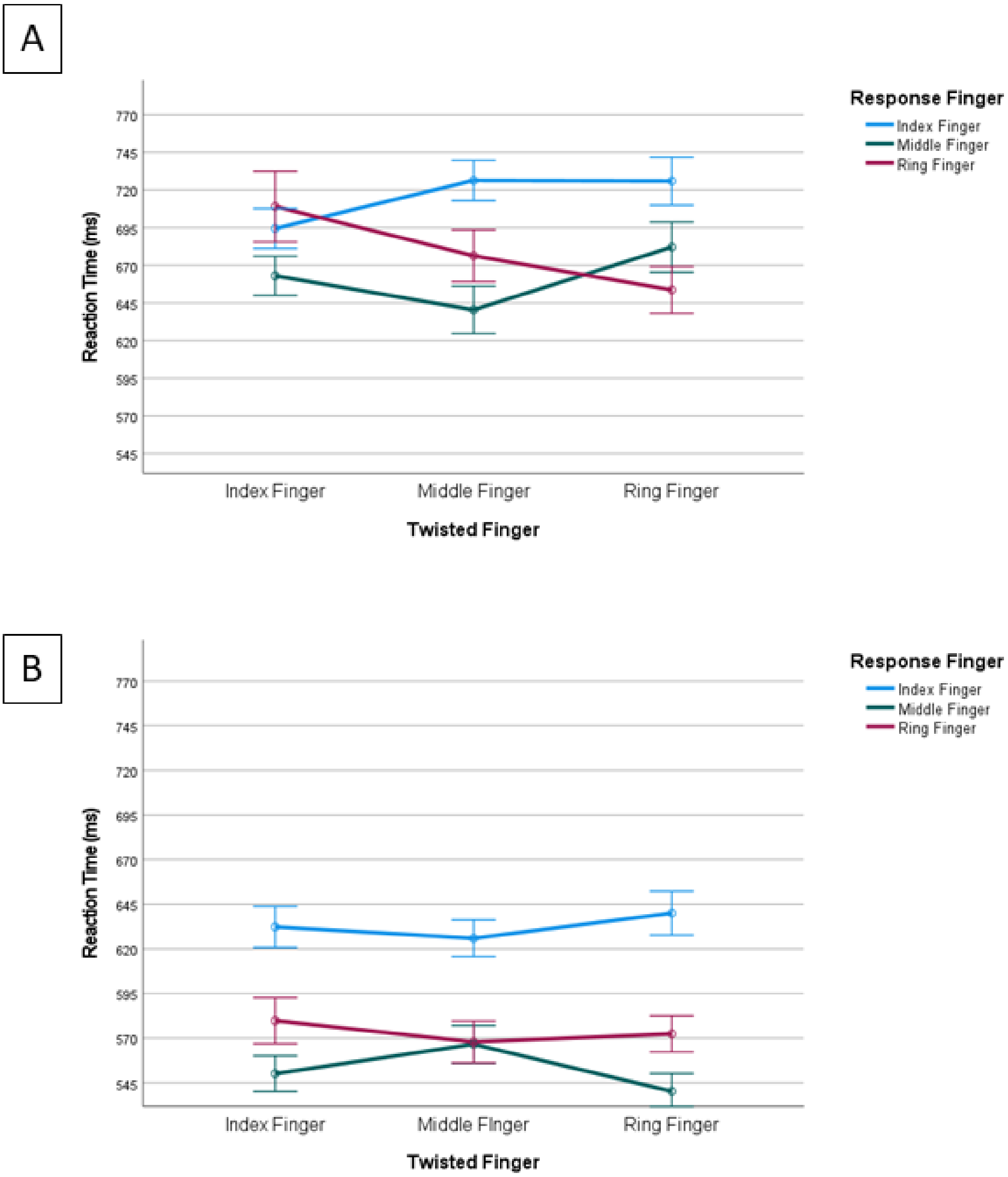


Figure 4-13 Experiment 11 results
(A) RT for response finger as a function for bent finger in distorted condition. (B) RT for response time for twisted finger in unusual condition.

4.6.4 Discussion

As highlighted in Experiment 10, the results indicated that mental simulation occurred consciously with individual fingers. Experiment 11 was therefore designed to investigate the mental simulation of hands without implicit feature stimuli. The task in Experiment 11 was designed to be implicit, focusing on indirect measures of automatic mental simulation. Participants were not instructed to simulate individual fingers, and the task did not require explicit awareness. It was surprising to observe that there was no marginal difference on individual fingers, either index, middle or ring fingers (Figure 4-13). This is not in accord with the earlier observations in Experiment 10, which showed that there was a marginal difference on individual fingers. A possible explanation for this might be that mental simulation does not occur on individual fingers without consciousness. These findings suggest that mental simulation of individual fingers may be facilitated by conscious attention. This aligns with previous research demonstrating that attention plays a crucial role in modulating the vividness and accuracy of mental imagery (Kosslyn, Ganis, & Thompson, 2001).

The inconsistent results between Experiments 10 and 11 may be due to the differing task demands. Experiment 10 required participants to explicitly focus on individual fingers bending, treating each finger as an explicit feature of the task. In contrast, Experiment 11 involved a more holistic hand stimuli where the bending of fingers was an implicit feature, not directly emphasised. The discrepancies observed between Experiments 10 and 11 raise intriguing questions about the interplay between deliberate effort and automatic mental simulation. Whilst Experiment 10 suggests that deliberate effort may facilitate or enhance the automatic mental simulation of individual fingers, the lack of significant differences in Experiment 11 challenges this notion. It is possible that the absence of deliberate effort in Experiment 11 did not eliminate automatic mental simulation but attenuated its effects or shifted the simulation's focus to the whole hand as opposed to individual fingers. This interpretation aligns with the dual-process theory of cognition, which posits that mental processes can be categorised as either automatic or controlled (Baumeister, Vohs, & Funder, 2016). Automatic processes are typically fast, effortless, and unconscious, whilst controlled processes are slower, effortful, and conscious (Valdes-Sosa et al., 2014). Automatic mental simulation likely involves both automatic and controlled components, with the relative contribution depending on task demands (Lieberman, 2007). The findings underscore the need for further research to disentangle the contributions of deliberate effort and automatic processes to mental simulation. Future studies could employ neuroimaging techniques to examine the neural correlates of mental simulation under varying levels of deliberate effort, such as comparing brain activation patterns during active motor imagery tasks versus passive observation of movements.

4.7 General Discussion for Chapter 4

The experiments in this chapter provide valuable insights into the complex interplay between motor and cognitive processes when perceiving hands. Evidence supports the notion that cognitive processes related to hand perception involve automatic mental simulation, potentially engaging the motor system. Additionally, the experiments demonstrate that spatial stimulus-response compatibility affects manual responses to stimuli in the hand category, suggesting that automatic mental simulation modulates these responses. Overall, these findings have important implications for understanding motor-cognitive processes in hand perception and may inform future research in this area. They highlight the significance of spatial stimulus-response compatibility and automatic mental simulation in hand recognition tasks, influencing RT and accuracy. Moreover, understanding the factors involved in hand laterality judgement, including visual cues and motor experiences, has implications for fields such as neural science, rehabilitation and embodied cognition. This research expands our understanding of how to perceive and interact with hands. They also contribute to a growing body of literature on embodied cognition, which suggests that cognitive processes are closely linked to bodily experiences and actions. However, it would be beneficial to explain the connection between these findings and the principles of embodied cognition in more detail. By investigating how motor and cognitive processes interact during hand perception, particularly in the context of a distorted finger, this research aims to provide a deeper understanding of whether and how individuals automatically mentally simulate hand movements whilst perceiving the world around them.

Chapter 5 Electroencephalography Experiment for the Visual Perception of Hands

This chapter describes an EEG experiment on the desynchronisation of mu oscillations in response to distorted finger postures. It links to earlier sections that hands suppress mu rhythm through automatic mental simulation. The following section describes Experiment 12, which addressed whether distorted finger postures suppress mu desynchronisation. The study aimed to investigate the relationship between distorted finger postures and mu desynchronisation. The outcomes of Experiment 12 could provide insights into the neural mechanisms underlying perception of body parts. The outcomes of Experiment 12 could provide insights into the neural mechanisms underlying perception of body parts. It could reveal an automatic mental process that fits well with the neural representation of motor goals and intentions. It is also purportedly relevant in distorted finger configurations that might result in inclination in automatic mental simulation. Mu desynchronisation is a measure of motor cortex activity that reflects the preparation and execution of movement. Investigation of how the mu rhythm desynchronisation, an important marker of motor cortex activity, is affected by distorted finger postures could advance theoretical frameworks of automatic mental simulation. Moreover, findings of this research might contribute to understanding the conceptual processes that underlie brain's simulation of movement in the absence of its actual execution, demonstrating the tight relationship between perception, action, and cognition within the human motor system.

5.1 Experiment 12: Mu Rhythm Modulation by Distorted Finger Postures

5.1.1 Introduction

Hand perception is a sensory process. It plays a crucial role in shaping the mental processes and representations that guide the behaviour. As an intrinsic part of human behaviour, hand perception is associated with cognitive-motor processes (Kang & Tversky, 2016; Schillaci, Hafner, & Lara, 2016). As such, when individuals encounter distorted hand postures, this not only challenges their perceptual systems but also activates a complex interplay between cognitive understanding and motor response, highlighting the intricate connection between hand perception and cognitive-motor processes. Distorted postures represent deviations from expected motor patterns, potentially engaging greater cognitive processing and motor system activity as the brain attempts to interpret these atypical configurations.

The research conducted in Experiment 12, based on secondary analysis of EEG data acquired in the co-authored earlier experiment completed by Hsin-Yuan Chen (the author of this PhD thesis) and Dr Martin Schürmann (the co-supervisor of this PhD project) (Espírito Santo, Chen, et al., 2017), investigated whether mu rhythm responses to distorted finger postures differ from responses to natural finger postures. This characteristic is a parameter for understanding the properties of event-related oscillations. Chairs (in distorted and standard configuration) served as control stimuli, matching the geometric complexity of hands.

In response to salient distorted finger postures (vs natural), an fMRI study found stronger activation in right sensorimotor cortex (Schürmann et al., 2011). Using images of static postures, the fMRI study can be used to predict results of the EEG analysis. Less relevant, but still of interest, is another fMRI study showing sensorimotor activation in response to videos of biologically impossible finger movement (Costantini et al., 2005): activation was found in the parietal lobe, extending into postcentral gyri (right > left). The purpose of the experiment reported here was to assess mu rhythm responses to distorted finger postures compared with responses to natural finger postures. Distorted and standard chairs served as control stimuli. Mu rhythm (8–13 Hz), which is attenuated during action observation and execution, is an oscillation detected across sensorimotor regions, and it is a type of alpha frequency oscillation that occurs in the sensorimotor cortex of the EEG, distinct from the occipital alpha rhythms (Coll, Press, Hobson, Catmur, & Bird, 2017). Of particular interest is the sensorimotor area, where these electrophysiological responses to distorted finger postures appear. This area is involved in the formation of motor programmes, which are necessary for the execution of hand movements. Apart from executing hand movements, mu rhythms are crucial in mental processing. They engage the motor system to tap into stored knowledge, facilitating the planning and execution of the actions. In addition, mu rhythms engage in anticipating, predicting, and interpreting the actions of others.

The EEG activity is categorised into ERPs, which are signals averaged in the time domain, and event-related oscillations analysed through time-frequency methods. The diagram highlights two key phenomena: event-related and desynchronisation (ERD) and synchronisation (ERS). A crucial aspect of the diagram is its detailed exploration of ERD in the mu frequency range, especially how mu suppression serves as an indicator of brain activity during automatic mental simulation. This occurs during action observation, suggesting that simply watching an action triggers neural processes similar to those activated when the observer performs the action themselves. This points to the brain's automatic engagement in mental simulation of observed activities, a fundamental component in understanding mechanisms like empathy and learning by imitation.

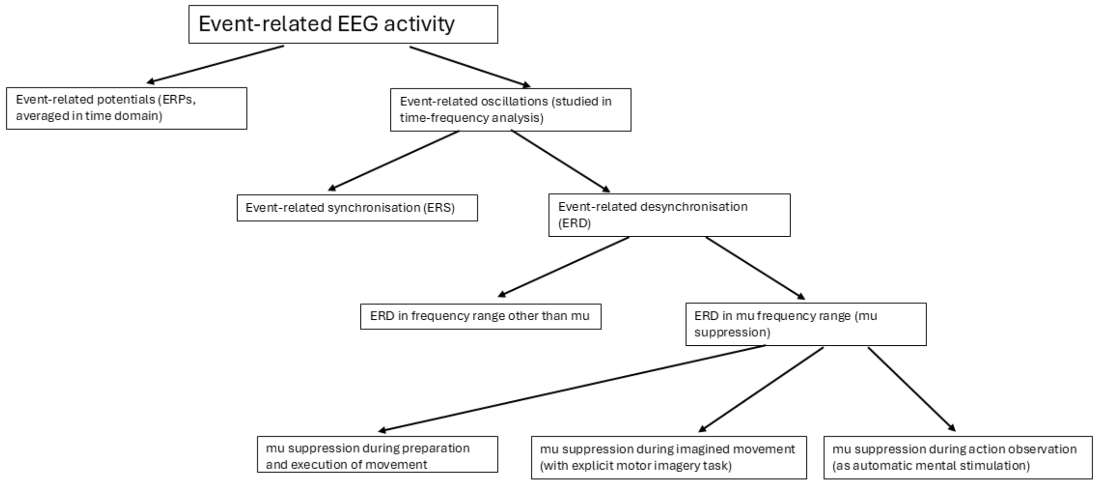


Figure 5-1 Overview of Event-Related EEG Activity
This diagram illustrates the classification and pathways of EEG responses to events, focusing on ERPs and oscillations. It highlights the specific roles of event-related ERD across different scenarios, including the critical process of mu suppression during automatic mental simulation observed during action watching.

Mu rhythm has been used to measure mirror neuron activity based on identical responses during action observation and execution in processes including empathy, theory of mind, and many other socio-cognitive processes (Brunsdon, Bradford, & Ferguson, 2019). For example, differences in mu rhythm responses between clinical and normal samples reveal aberrant mirror neuron responses in autism spectrum disorder and schizophrenia (Hamilton, 2013). Experiment 12 used data from previous research which had collected EEG data and had analysed ERPs using a factorial design (the definition of ERPs can be found in Chapter 1) (Espírito Santo, Chen, et al., 2017). Here, in this experiment, the data were used to analyse event-related brain oscillations rather than ERPs. event-related oscillations are measured in a resting state and become organised, amplified and connected during mental activity triggered by an event or stimulus, leading to evoked or induced oscillatory responses. Because event-related oscillations can indicate whether automatic mental simulation of the hands occurs, if there is a difference in event-related oscillations between observed distorted and natural finger postures, then this may suggest that the differences are consistent with the automatic mental simulation processing of distorted and natural finger postures.

The study of event-related oscillations caused by distorted finger postures, particularly the mu rhythm, is crucial for understanding how the brain adapts to unusual sensory input from the hands. This research could elucidate the mechanisms underlying automatic mental simulation, shedding light on how the brain processes and integrates unexpected sensory information. Many previous studies show that mu rhythm desynchronisation reveals the interaction of motor skills between hand action and object recognition (Babiloni et al., 2003; Drew, Quandt, & Marshall, 2015; Kumar et al., 2013; Kumar, Yoon, & Humphreys, 2012; Setti, Borghi, & Tessari, 2009). In addition, some studies show that the desynchronisation of mu oscillations reveals the underlying mechanism of automatic mental simulation for static hands (Barhoun et al., 2019; Hyde et al., 2017). The term 'mu rhythm desynchronisation' is used here in its broadest sense to refer to the ERD of the mu rhythm. ERD designates a short-lasting and localised power attenuation of rhythms, whereas event-related synchronisation describes a short-lasting and localised enhancement of rhythms (Pfurtscheller, 1991; Pfurtscheller & Klimesch, 1992).

It was predicted that there would be reduced mu band power for distorted finger postures compared to natural postures. This reduction would suggest increased sensorimotor processing to adapt to the unusual sensory input caused by the distorted postures. Time-frequency analysis of EEG signals was used in this experiment as it provides the correct visualisation of those signals to extract the various rhythms of frequencies such as alpha, beta, and gamma waves (Bhardwaj et al., 2015; Newson & Thiagarajan, 2018). The prediction was that distorted finger postures would suppress mu rhythm more strongly than would natural finger postures. The mu suppression in the hand region is a well-documented phenomenon. This suppression is thought to be due to a process called ‘cortical inhibition’, which helps to focus attention and to filter out irrelevant information. If event-related oscillations are also suppressed by difference between distorted and natural finger postures, then this could serve as a new explanation for the emergence of automatic mental simulation. To measure the suppression of mu rhythm, the time-frequency analysis for mu desynchronisation and mu synchronisation was used. The measurements of event-related oscillations of mu rhythms were performed using time-frequency analysis because it is a powerful tool for identifying changes in neural oscillations that occur over time and across different frequency bands. This method helped researchers pinpoint which brain wave patterns changed when people performed certain actions or had specific thoughts. Specifically, it allowed them to identify the particular changes in mu rhythms, a type of brain activity often linked to movement and observation.

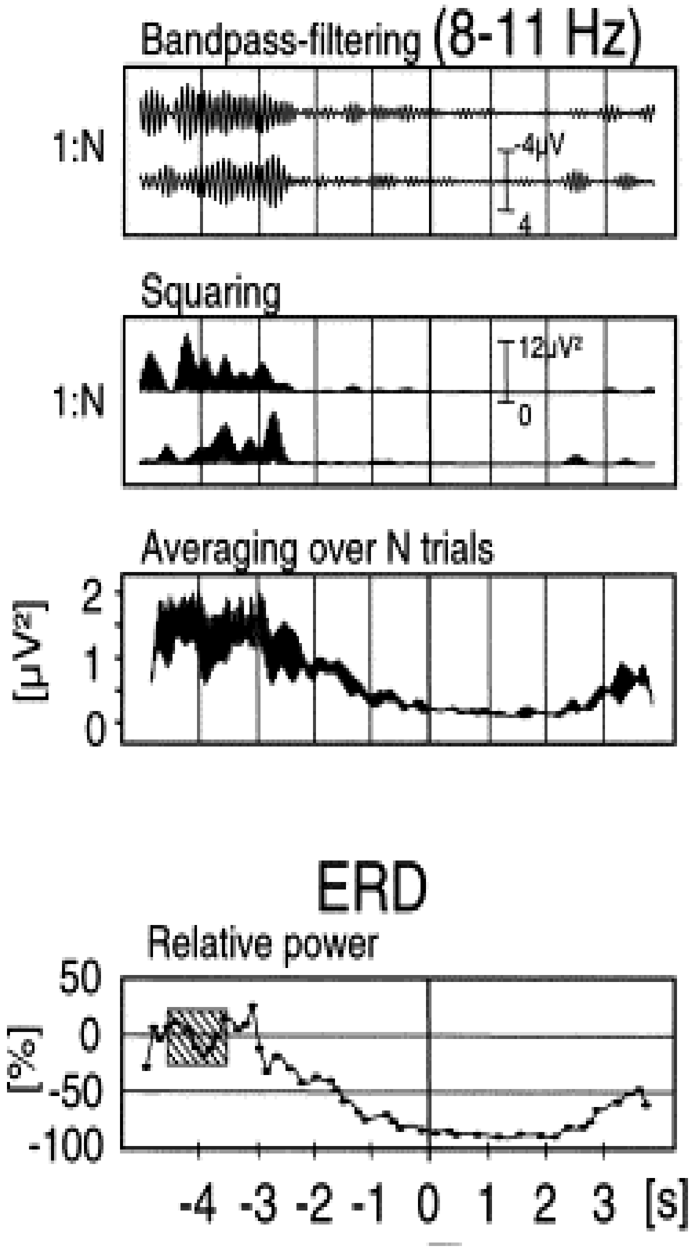


Figure 5-2 Calculated event synchronisation mu suppression in shown in the time windows
Adapted from Pfurtscheller and Lopes da Silva (1999). Notice timescale (bottom of diagram), -5 to 4 seconds relative to movement onset (different from timescale in Experiment 12 of this thesis). (1) Top row: After artefact removal, raw EEG has been bandpass filtered, here 8-11 Hz. Notice reduction of amplitude (suppression) approximately 2.5 seconds before movement onset. ‘1:N’ indicates multiple trials. Preprocessing isolates signal but does not confirm source or role. (2) Second row from top: Signal from top row has been squared (all amplitude values > 0), in preparation for averaging. (3) Third row from top: Squared signal from all trials (1:N) has been averaged. (4) Bottom row: Averaged squared signal has been smoothed and rescaled (relative to baseline amplitude from -4.5 to -3.5 seconds which equals 100%).

5.1.2 Method

5.1.2.1 Participants

Fifteen right-handed participants, 11 females and 4 males (18-45 years, M = 24.80, SD = 3.62) with no history of neurological or psychiatric disorders or drug abuse by self-report, participated in an earlier experiment during the author's master's degree (Espírito Santo, Chen, et al., 2017). All participants gave written, informed consent and had normal or corrected to normal visual acuity by self-reported, and all received either course credits or inconvenience allowances. The current study included a larger sample size than the previous study (Thierry et al., 2006). Data from one participant was omitted due to excessively noisy signals during the experiment, a potential issue that could stem from technical problems or participant movement, which could not be conclusively resolved. Written informed consent was obtained from all participants. The experiment was approved by the Ethics Committee of the School of Psychology (University of Nottingham, ethics code 300) and carried out following the Helsinki Declaration.

5.1.2.2 Materials and apparatus

Two types of stimuli were used in the Masters experiment. (1) Images of hands, computer-generated from 3D models based on photographs of real hands that were processed according to an in-house protocol (Espírito Santo, Chen, et al., 2017) using Blender software (https://www.blender.org). Altogether 48 hand images were generated (24 distorted, 24 natural). (2) Images of chairs, computer-generated from 3D models using Blender software. To complement the hand images, 48 chair images were generated (24 distorted, 24 standard) (Figure 5-3).

Participants were asked to sit in a Faraday cage (2.5 × 2.3 × 2.3 m) in a quiet room at room temperature. EEG signals were recorded using the 64-channel Active-Two acquisition system (BioSemi) (BioSemi, Amsterdam, Netherlands). 64 active electrodes were placed using a BioSemi cap, maintaining impedances below 20 kΩ. An additional 6 Ag / AgCl electrodes were mounted at mastoid, frontal and temporal positions (M1, M2, F9, F10, T9, T10). Triggers were sent and acquired by Cedrus Stimtracker. EEG signals were sampled at 1024 Hz, digitised at 24 bit depth and collected using BioSemi ActiView 7.0 software. EEG data were analysed using MATLAB version R2020a (MathWorks, 2020) and FieldTrip toolboxes (Oostenveld, Fries, Maris, & Schoffelen, 2011). A band-pass filter (1–100 Hz) was applied to remove the noise. Data were subsequently segmented into epochs with a length of −200 ms to 800 ms. Each trial was baseline-corrected (-200 to 0 ms). Filtering, segmentation, and baseline correction were applied to remove noise, isolate relevant epochs, and normalise the signal for each trial, facilitating event-related analysis.

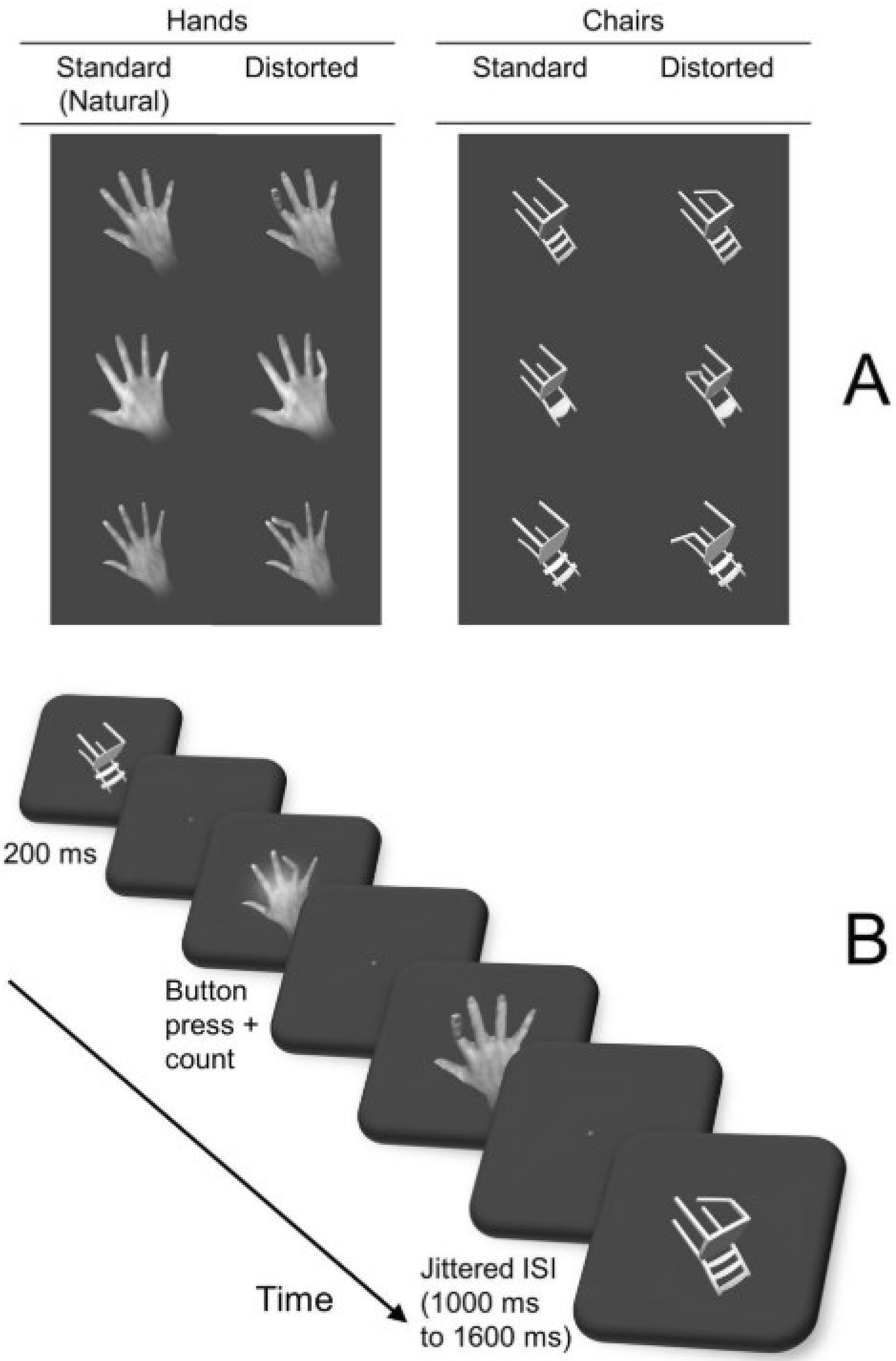


Figure 5-3 Stimulus setup in Experiment 12
(A) Stimulus categories, 3 (out of 6) exemplars per category, each in natural and distorted configurations. Stimuli are computer-generated using an in-house protocol. (B) Stimulus timeline. Stimulus timeline includes one distorted finger posture image with superimposed shadow and one without shadow. Stimuli not shown to size (actual size 4° of visual field). This figure is taken from a previous study (Espírito Santo, Chen, et al., 2017).

5.1.2.3 Design and procedure

Stimuli were presented on a computer screen (ViewPixx3D, 1920 × 1080 pixels, 23.6 inches, 120 Hz refresh rate, 1 ms pixel response time) from a distance of approximately 60 cm. The stimuli were presented as 250 × 250-pixel images, corresponding to a size of 4 degrees visual angle on a grey background. The images were presented for 200 ms, with an interstimulus interval of 1000, 1200 or 1600 ms randomly (Figure 5-3). In order to maintain participants' attention, a semitransparent white overlay, termed as 'white shadow', was applied to some images. This white shadow, sized 100 × 100 pixels, was used as a visual effect to influence viewer attention. The number of shadows that appeared was randomly assigned between 8 and 16 per block of hand stimuli. Participants were informed of the minimum and maximum numbers at the beginning. They responded with their right hand. This was the same hand as the viewed hand images, which could be an advantage because it minimises the cognitive load required for motor preparation and response execution. In addition, participants were instructed to mentally keep track of the number of shadows they detected. At the conclusion of the experiment, they reported their total shadow count. Before they began, they were shown example images to practise for about two minutes. Each of the stimuli was presented twice during a 192-image block of stimuli in pseudorandom order, using PsychoPy. Each block took about five min, and each participant completed five blocks.

5.1.2.4 Data preprocessing

Segmented trials were put through an independent component analysis to remove blink, eye movement, and electromyogram activity related to artefacts. EEG in the 8-13 Hz frequency band was examined, and activity in this band found in central scalp electrodes C3 and C4, directly over the motor and premotor cortices, was identified as mu rhythm. Time-frequency analysis for event-related oscillations involves decomposition of the EEG signals into magnitude and phase information for each frequency present in the EEG and characterises their changes over time concerning task events (Natraj et al., 2013; Roach & Mathalon, 2008). Time-frequency analysis comprises methods and measures that capture different aspects of EEG magnitude and phase relationships (Keren, Yuval-Greenberg, & Deouell, 2010; Yuval-Greenberg, Tomer, Keren, Nelken, & Deouell, 2008). Compared to ERPs which are calculated by averaging the EEG signal from all trials, EEG signal from all trials in the time domain, event-related oscillation were studied by time-frequency analysis of single trials and subsequent averaging in the time-frequency domain. Averaged time-frequency representations show event-related oscillations in different frequency bands (Bossi et al., 2020; Oostenveld et al., 2011).

To estimate event-related desynchronisation and event-related synchronisation, the EEG power spectrum was cut into 1000-ms time windows, each beginning at the onset of the stimulus in each trial. This method accounts for variations in response time and jitter between trials. Starting at the onset of each trial, the EEG power ratio of each successive 1000-ms epoch relative to baseline was calculated (Humphreys et al., 2013; Kumar et al., 2013). Ratios were transformed to account for individual variability and nonnormality of the distribution. An enhanced EEG power indicates event-related synchronisation, whilst a diminished EEG power indicates event-related desynchronisation (Bernier, Dawson, Webb, & Murias, 2007; Raymaekers, Wiersema, & Roeyers, 2009).

5.1.3 Results

Event-related oscillations were measured from C3 and C4, which are standard electrode positions located on the sensorimotor cortex (Figure 5-4). The results for the time-frequency representation are presented (Figure 5-5, Figure 5-6, Figure 5-7). The results of event-related oscillations power for averaging four frequency bands (9, 10, 11 and 12 Hz) are presented (Figure 5-8). The EEG powers were analysed using a three-way repeated measures ANOVA over configuration (distorted and natural/standard), stimulus type (hand and chair) and hemisphere (left and right). The main effect of configuration showed no significance [F(1, 12) = 3.644, p = 0.080, η_p^2 = 0.233]. In addition, there was no significant interaction between configuration, stimulus type and hemisphere [F(1, 12) = 0.486, p = 0.499, η_p^2 = 0.039].

The results of event-related oscillations for each frequency band (9, 10, 11 and 12 Hz) are presented. The EEG powers analysed using a three-way repeated measures ANOVA over configuration (distorted and natural), stimulus type (hand and chair) and hemisphere (left and right). There was no main effect of configuration with p below 0.1 for the 11 Hz frequency band [F(1, 12) = 3.785, p = 0.075, η_p^2 = 0.240]; for the 10 Hz frequency band [F(1, 12) = 3.680, p = 0.079, η_p^2 = 0.235]; for the 9 Hz frequency band [F(1, 12) = 3.565, p = 0.083, η_p^2 = 0.229]. In addition, there was no significant interaction between configuration, stimulus type and hemisphere for the 12 Hz frequency band [F(1, 12) = 0.716, p = 0.414, η_p^2 = 0.056]; for the 11 Hz frequency band [F(1, 12) = 0.591, p = 0.457, η_p^2 = 0.047]; for 10 Hz [F(1, 12) = 0.445, p = 0.517, η_p^2 = 0.036] and 9 Hz [F(1, 12) = 0.287, p = 0.602, η_p^2 = 0.023].

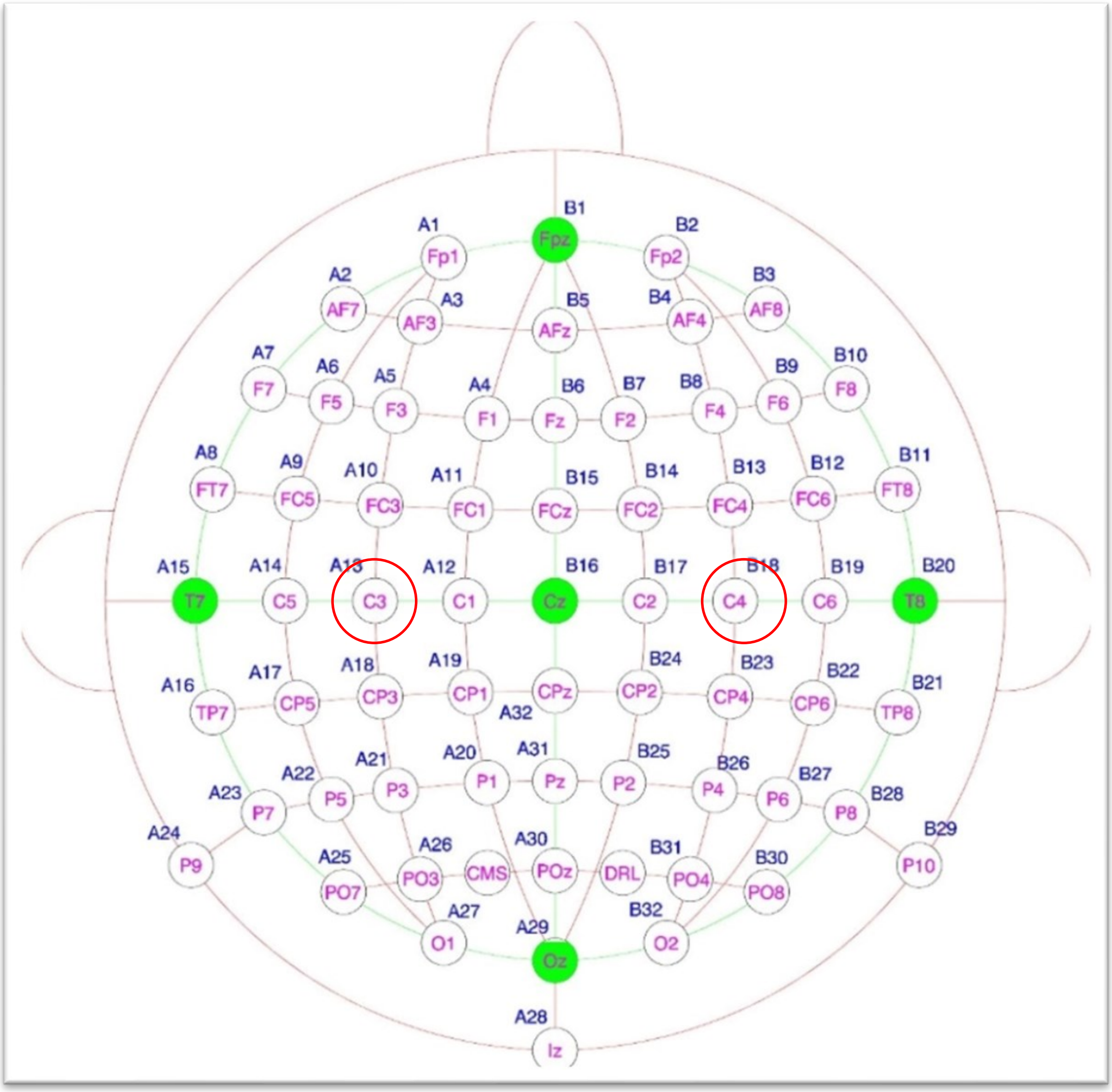


Figure 5-4 Electrode placement for Experiment 12.
Adapted from BioSemi , Electrodes C3 and C4 measured mu oscillations which were analysed to understand brain activity related to automatic mental simulation.

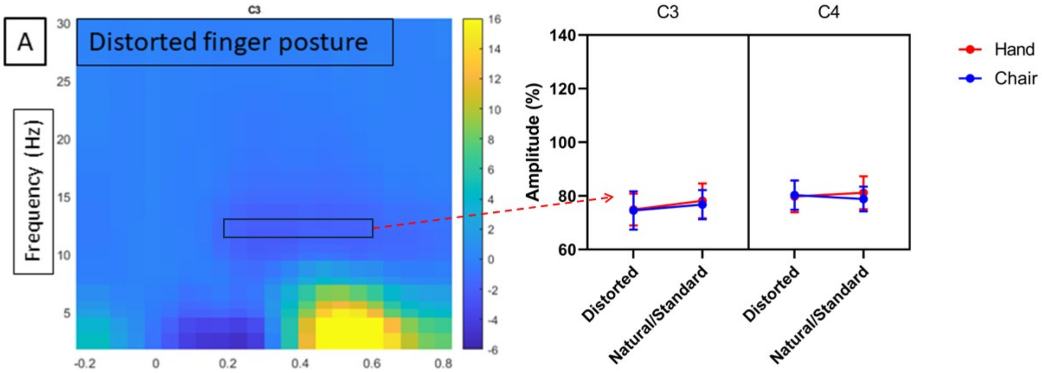


Figure 5-5 Line chart illustrates the results of a time-frequency analysis performed on EEG data.

In left time-frequency analysis diagram, the x-axis represents time, whilst the y-axis represents frequency and right colour bar represents power (i.e., amplitude). In right line chart, the lines demonstrate the amplitude in a certain the time (200-600 ms) and frequency (12 Hz in for this line chart) for distorted finger postures.

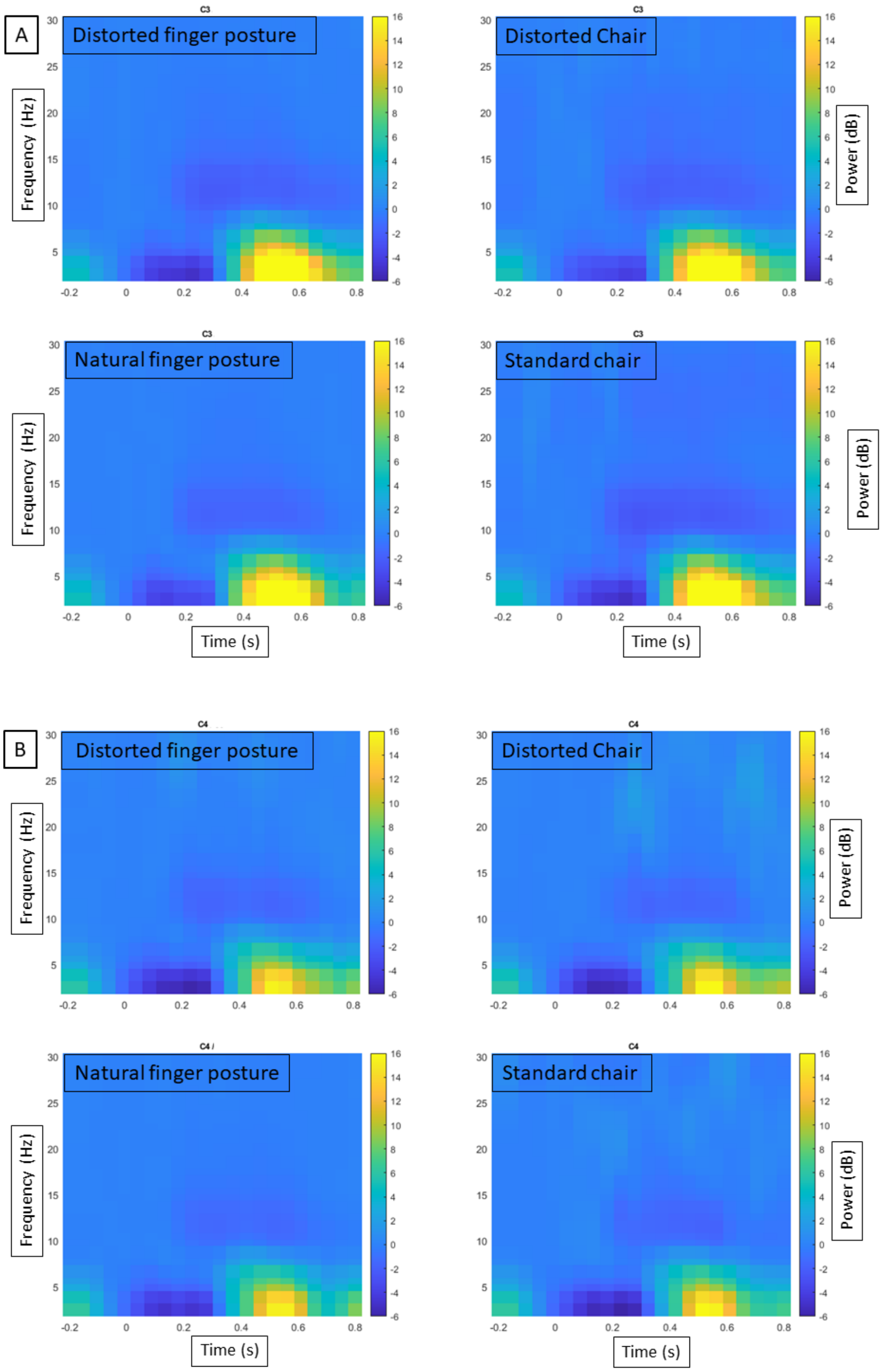


Figure 5-6 Experiment 12 results (Part A)
Time-frequency representation of the EEG activity for different stimulus types. (A) C3 electrode results (B) C4 electrode results. Time-frequency show ERD from multiple frequency bands. Therefore, power is colour coded.

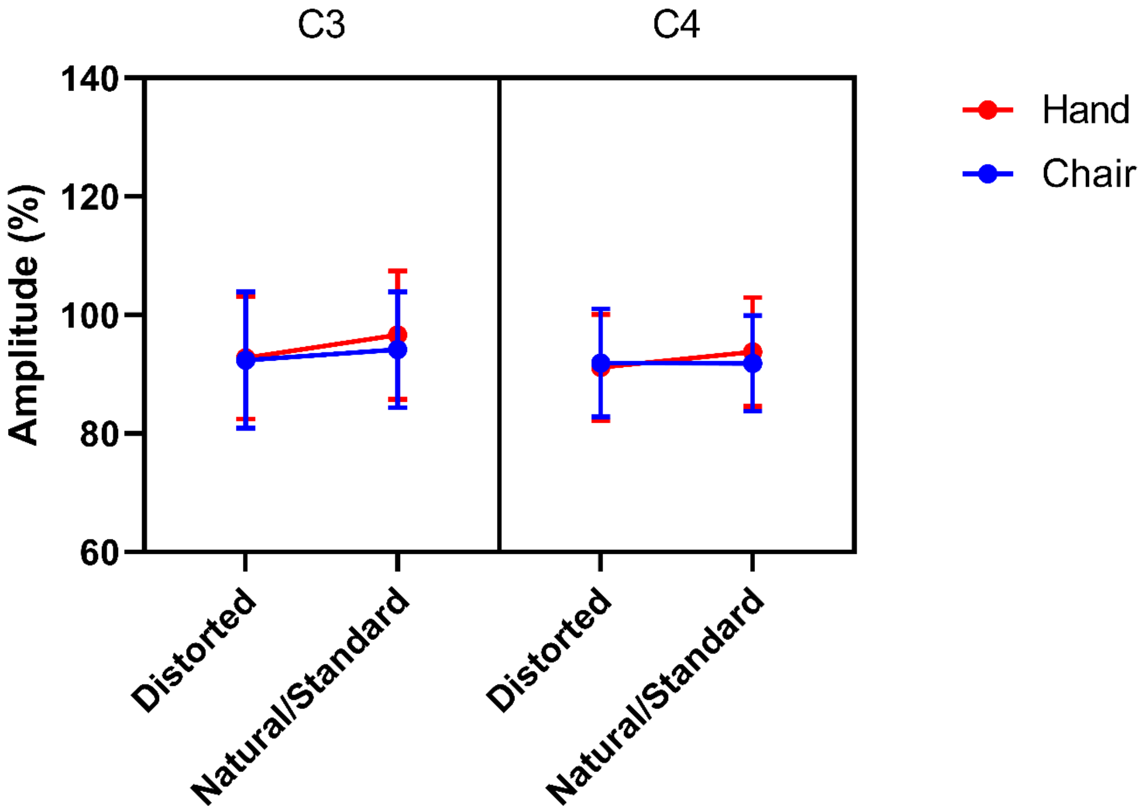


Figure 5-7 Experiment 12 results (Part B)
EEG power of event-related oscillations averaged over four frequency bands (9, 10, 11 and 12 Hz).

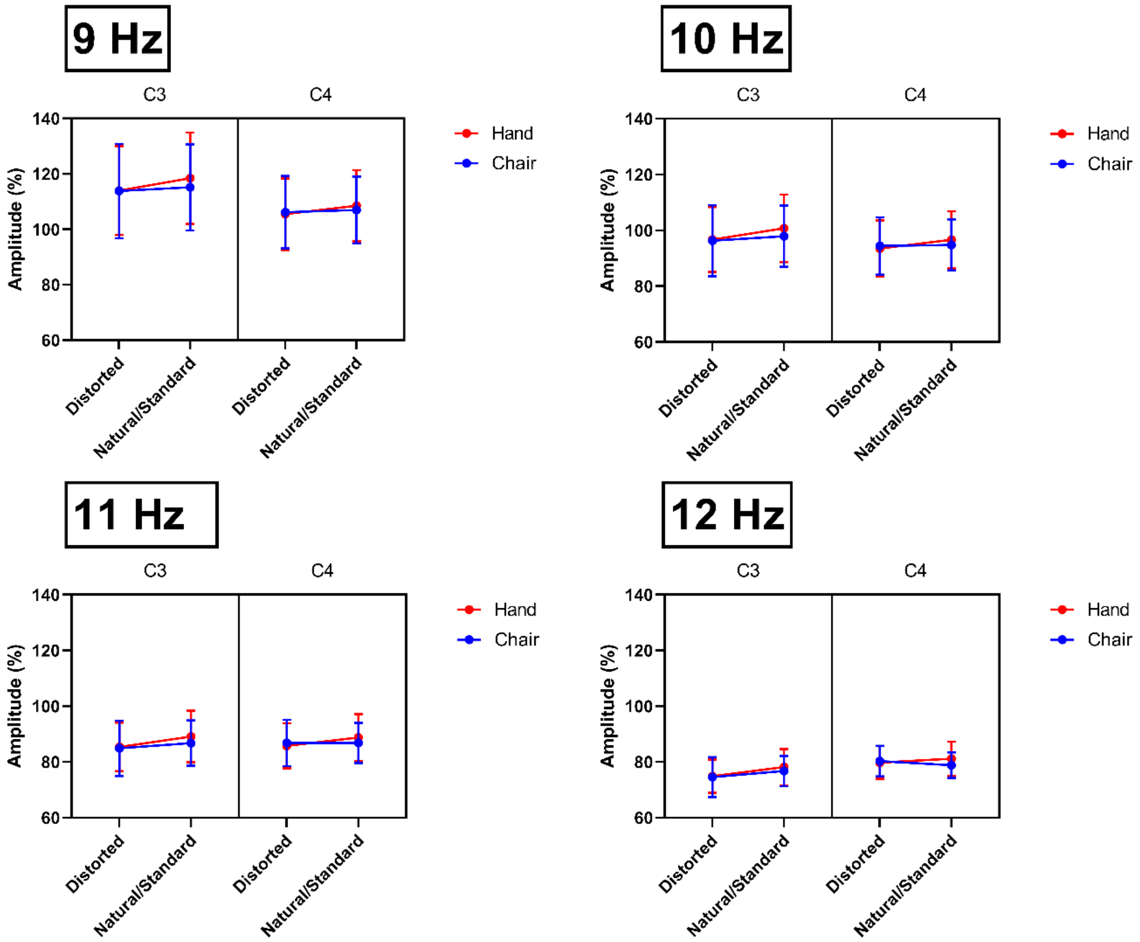


Figure 5-8 Experiment 12 results (Part C)
EEG power of event-related oscillations of each frequency band.

5.1.4 Discussion

There was no interaction between the configuration (distorted and natural/standard objects) and stimulus type (hand or chairs). Moreover, it is unlikely that mu rhythm desynchronisation occurred with the hands or the chairs, which were used as control stimuli because of the shape resemblance to hands. If the brain had used the same neural structures to process hands and chairs in the primary sensorimotor cortex, it would have suppressed mu rhythms differently (Fox, Bakermans-Kranenburg, Yoo, Bowman, Cannon, Vanderwert, Ferrari, & van Ijzendoorn, 2016; Hobson & Bishop, 2017). Another possible explanation for no interaction may be that mirror neurons in the motor cortex were not activated by the differences of configuration and stimulus type. Greater mu suppression for distorted and natural stimuli may reflect increased mirror neuron activity for salience, biologically plausible stimulus type and configurations. Mu rhythm desynchronisation is a widely used measure of motor cortex activation and has been identified as a possible measure of the MNS (Fox, Bakermans-Kranenburg, Yoo, Bowman, Cannon, Vanderwert, Ferrari, & van Ijzendoorn, 2016; Hobson & Bishop, 2017). It has been experimentally demonstrated that the mu rhythm desynchronisation in the primary sensorimotor area is activated by automatic mental simulation. This suggests that the mu rhythm desynchronisation in the primary sensorimotor area reflects mirror neuron activation by movement observation (Marshall & Meltzoff, 2011; Sakihara & Inagaki, 2015). This phenomenon is strongly related to automatic mental simulation. Thus, it is likely that mu rhythm desynchronisation is caused by the different responses of the MNS for automatic mental simulation.

There was no significant main effect of the stimulus type. One explanation for the lack of main effect for stimulus type (hands and chairs) in mu desynchronisation could be that the two stimulus categories may not differentially engage the MNS and the sensorimotor cortex to the extent of producing distinct mu rhythm responses. Possible reasons for this lack of main effect in mu desynchronisation are: (1) Irrelevant stimulus category: Although from the previous research, chairs are good control stimuli for hands (Espírito Santo, Chen, et al., 2017; Schürmann et al., 2011), they as objects without direct relevance to the human motor system or social cognition, may not activate the MNS as strongly as stimuli related to biological motion (e.g., hands or other body parts). The differences in mu desynchronisation between hands and chairs may not be large enough to produce a main effect. (2) Insufficient contrast between stimulus types: the stimuli depicting hands and chairs might not differ enough in terms of their engagement with the MNS, especially if the images or videos of hands are not involved in actions that strongly evoke motor simulation (e.g. if they are static or display simple movements). This is because mirror neurons are more likely to be activated by dynamic, goal-directed actions rather than passive or non-goal-oriented stimuli, as evidenced by studies showing that mirror neurons respond more robustly to actions with clear goals and intentions (Rajmohan & Mohandas, 2007).

There was no significant interaction between the stimulus type and configuration in terms of power suppression across all mu rhythm bands. A possible explanation for the lack of interaction between stimulus type (hands and chairs) and configuration (distorted and natural) in an experimental study could indeed be that the similarities in the geometry of hands and chairs led the brain to respond to them without engaging different mechanisms. In other words, the brain may not have discriminated between the stimuli based on their type or configuration due to their geometric similarities. The brain may perceptually group hands and chairs together based on their geometric properties, making it difficult to differentiate between the stimulus types and configurations running with perceptual grouping. The suggestion that the brain may perceptually group hands and chairs together based on geometric properties is supported by research in visual perception and object recognition (Palmer & Rock, 1994). Whilst it may seem counterintuitive, this phenomenon is not necessarily at odds with our understanding of hands and objects, but rather highlights the complexities of perceptual processing. This grouping is not at odds with the understanding because it reflects the brain's efficient pattern recognition mechanisms, which can identify shared geometric properties across diverse objects to streamline visual processing. Further exploration of this concept can provide valuable insights into the workings of the human brain.

If the finding showed a significant interaction, this could suggest that the stimulus type and configuration might have an interactive effect on the neural response. Mu rhythm bands, which are typically associated with the sensorimotor cortex, can be influenced by automatic mental simulation. When a person observes another individual performing a specific action, the mu rhythm in their brain becomes suppressed, also called desynchronised. This desynchronisation is thought to reflect the activation of the underlying MNS, letting the observer automatically mentally simulate the action seen without actually executing it. This automatic mental simulation may be crucial in many parts of social cognition, such as empathy, imitation, and understanding the intentions and emotions of others.

Understanding this interaction may provide insight into how the brain integrates information from various sources to guide behaviour. By examining these interactions, the underlying neural mechanisms of automatic mental simulation can be better understood. The result could be interesting because it may highlight a complex relationship between stimulus type and configuration, and it is related to the research question as it contributes to a deeper understanding of neural processing and the factors that influence it. However, the findings indicate that there is no clear evidence to support the idea that the type and configuration of the stimulus have a combined effect on neural processing related to automatic mental simulation.

Distorted finger postures play a crucial role in understanding others' actions, imitating them and learning from them (Gallese, Eagle, & Migone, 2007). Mu oscillations, linked to mirror neuron activity, are commonly seen over the sensorimotor cortex and associated with automatic mental simulation. When people performing actions involving hands with specific finger postures are observed, the mu rhythm in the observers changes (Cross, Mackie, Wolford, & de C. Hamilton, 2009; Molenberghs, Brander, Mattingley, & Cunnington, 2010). Distorted finger postures trigger a stronger activation of the motor cortex by definition. Presumably, the unique position of distorted postures presents a novel challenge for the brain, and as such, the motor cortex registers a strong response. As implied by the functional interpretation of the motor cortex, it can be surmised that this strong response occurs due to a higher interpretation load (Schürmann et al., 2011). Notably, the visual angle from which the posture is observed and the emotional response are also likely to factor into the increased response. The distorted postures are also likely to prompt stronger cognitive processing, adding to the higher interpretation load in the motor cortex activation (Schürmann et al., 2011).

This can lead to differences in mu oscillation suppression, which can be attributed to the mirroring neuron system being more sensitive to salient objects. Distorted finger postures may not align well with the internal models the brain has built for standard movements, leading to a weaker activation of mirror neurons and a subsequent change in mu oscillation patterns. As there was no evidence to support the prediction that mu oscillation suppression would occur between distorted and natural finger postures, this suggests that the experimental design may require improvement or refinement to better address the research question. It is pertinent to highlight that the use of static images and neutral poses served as necessary controls, though they might have been inadequate in terms of sufficiently stimulating the MNS; hence, a limitation was placed on this part of the study design. But future studies investigating mirroring in neural responses may need to use a more dynamic stimulus or imply motion some other way if they want a stronger activation signal for the mirror system.

Several factors could contribute to the lack of significant differences in mu oscillation between distorted and natural finger postures in the experiment. (1) Insufficient sample size: A small sample size might not provide enough statistical power to detect significant differences, even if they exist. Increasing the number of participants could help improve the reliability of the findings. After measuring, the sample size should be more than 24. The results of this experiment should be interpreted cautiously. The number of participants in this study is smaller than what would typically be recommended for an experiment with this design and expected effect size. This smaller sample size may affect the reliability of the findings. Therefore, increasing the number of participants for this experiment should be considered. (2) Learning effects: Participants may have adapted to the distorted finger postures over time, reducing the differences between natural and distorted postures. Counterbalancing the order of presentation or introducing breaks between tasks could reduce these learning effects (Blasche, Szabo, Wagner-Menghin, Ekmekcioglu, & Gollner, 2018).

In addition to the above factors, some research has shown that the duration of presentation of the stimuli may be crucial for evoking mu oscillation (Jones et al., 2009). If the duration of the presentation of the finger postures was not long enough to evoke mu oscillation suppression, this could be a contributing factor to the lack of significant differences in mu oscillation found between distorted and natural finger postures. Firstly, if the duration of the presentation of each finger posture was too short, participants' brains may not have had enough time to process the action and exhibit mu oscillation suppression. Secondly, the short presentation duration of 200 ms might have made it challenging for participants to give sufficient attentional resources to the stimuli, particularly for the distorted finger postures, which may have required more cognitive processing. Extending the presentation duration to at least 800 ms would provide more time for participants to process the action and engage their MNS (Bonini, Rotunno, Arcuri, & Gallese, 2022).

Thirdly, building on the previous point, the results of this experiment should be interpreted cautiously due to the brief presentation duration of only 200 ms. The short presentation duration probably did not cause mu rhythm desynchronisation because mu rhythm desynchronisation, which is a feature of event-related oscillations, typically needs more time to be activated compared to ERPs (Barlaam, 2011). For example, in a study involving a visual perception task, mu rhythm desynchronisation was only observed after 400 ms of stimulus presentation, whilst ERPs components were already present at 100 ms. The different time courses likely reflect the distinct neurocognitive processes indexed by desynchronisation of the sensorimotor mu rhythm in line with models of hierarchical information flow in the brain during perception and cognition. This suggests that different neural mechanisms are involved in these two types of brain activity and that their time courses differ significantly. Therefore, increasing the duration of the presentation in this experiment should be considered but was not possible in this PhD project.

The findings indicate no interaction between configuration and stimulus type on mu rhythm desynchronisation; distorted and natural stimuli, whether finger postures or chairs, elicited similar responses. Geometric complexity similarities between hands and chairs did not significantly influence the results. This suggests that neural processing related to automatic mental simulation may not significantly depend on object configuration or stimulus type. However, the rapid presentation duration of the stimuli may have limited the experiment's ability to detect differences in mu rhythm patterns. For greater effect sizes and more reliable, generalisable results, future studies could use longer presentation durations, larger sample sizes, control for individual differences, increase task difficulty, reduce learning effects, and refine the experimental design.

5.2 General Discussion for Chapter 5

This chapter presents an EEG experiment on the visual perception of hands and the relationship between distorted finger postures and mu desynchronisation. The study aimed to investigate the neural mechanisms underlying perception of body parts and provide insights into potential interventions for individuals with motor impairments. Experiment 12, which was based on secondary analysis of EEG data acquired in a co-authored earlier experiment, investigated whether mu rhythm responses to distorted finger postures differ from responses to natural finger postures. There is no evidence to support the idea that the type or configuration of the stimulus have any effect on neural processing related to automatic mental simulation. However, the results could be interesting because they may highlight a complex relationship between stimulus type and configuration. Mu desynchronisation is a measure of motor cortex activity that reflects the preparation and execution of movement. The study found that distorted finger postures suppress mu desynchronisation, indicating that they may interfere with motor control processes. This characteristic is a parameter for understanding the properties of event-related oscillations. The outcomes of Experiment 12 could provide valuable insights into potential interventions for individuals with motor impairments. By understanding how distorted finger postures affect mu desynchronisation, researchers may be able to develop targeted interventions to improve motor control in individuals with impairments such as stroke or cerebral palsy. In conclusion, this chapter provides valuable information on an EEG experiment investigating the visual perception of hands and its relationship with mu desynchronisation. The findings suggest that distorted finger postures may interfere with motor control processes, highlighting potential implications for individuals with motor impairments. Further research in this area could lead to targeted interventions to improve motor control and quality of life for those affected by these conditions.

Chapter 6 General Discussion

6.1 Overview

The aim of the thesis was to examine whether hands (in particular hands with distorted finger postures) are salient and to study the mechanisms underlying the visual processing of hands with distorted finger postures, with a focus on automatic mental simulation. To achieve this aim, four methods were used: (1) visual search tasks, (2) eye tracking and pupillometry, (3) motor-cognitive tasks and (4) EEG. SEREC approved all methods, ensuring ethical compliance and participant protection. The visual search task was used to examine whether hands with distorted finger postures are salient in active and passive vision; eye tracking and pupillometry were used to examine whether hands with distorted finger postures are salient in active vision; motor-cognitive tasks were used to examine whether automatic mental simulation occurs during the visual processing of hands with distorted finger postures; EEG was used to search for brain activity related to the visual processing of hands with distorted finger postures and was also used to examine whether hands with distorted finger postures evoke different brain activity to hands with natural finger postures.

6.2 Main Findings

Using the first method, visual search experiments, it was found in Experiments 1 and 2 that the hand was more salient than the whole body and that distorted finger postures were more salient than natural finger postures. In Experiments 3 and 4, it was found that visual mechanisms involved passive vision when observing hands with distorted finger postures in visual search. Control Experiment 1 identified that inanimate object control stimuli (grenades and balls) had similar affective reaction and arousal to the distorted and natural finger postures, respectively. These inanimate objects were used in Control Experiment 2, in which it was found that the salience in visual search was caused by human body salience rather than inanimate object salience. Contrary to expectations, Control Experiment 3 revealed an intriguing finding: the distorted finger postures were not more salient than the distorted toe postures, despite fingers typically being considered more prominent in daily interactions. The toe postures, which served as control stimuli with similar anatomical structures, unexpectedly matched the salience of finger postures. From the eye movement experiments, including pupillometry, the findings were the following. The evidence in Experiments 5 and 6 supported the results of Experiments 1 to 4 listed in Chapter 1. Experiments 5 and 6 also clarified the issue, raised in the preceding visual search experiments in Chapter 1, of whether the salience involved active or passive vision or both. The results in Experiments 5 and 6 showed that the mechanism of processing hands with distorted finger postures involved both active and passive vision. These findings clarify previous research on the salience of visual stimuli and contribute to one's understanding of the mechanisms involved in visual processing.

Motor-cognitive tasks (i.e., tasks investigating motor cognition) were used in Experiments 7 to 11. In Experiments 7 and 8, using the Simon task, it was found that automatic mental simulation occurred for natural finger postures. In Experiment 9, the observations confirmed the results reported by previous studies that automatic mental simulation (in sensorimotor structures) supports the visual processing of hands. Additionally, Experiment 9 showed that when hands were presented on the screen, automatic mental simulation occurred not only with a single hand but also with both hands shown together.

In contrast to previous experiments, Experiment 10 tasked participants explicitly to distinguish between distorted and natural finger postures. Conversely, Experiment 11 was designed to investigate to examine whether automatic mental simulation was specific to individual fingers. In this experiment, participants were instructed to respond using either their index, middle, or ring finger under conditions anticipated to induce automatic mental simulation. Findings from Experiment 10 revealed that RTs were quicker when individual fingers corresponded to the task explicitly, compared to the conditions in Experiment 11, which were designed to elicit automatic mental simulations.

Finally, in Experiment 12, the EEG results from the mu rhythm provided evidence that, in brain processing, the mu desynchronisation tended to occur for the difference between the configuration (distorted and natural/standard) rather than for the difference between stimulus type (hands and chairs). Furthermore, there was no interaction for mu desynchronisation between configuration and stimulus type.

6.3 Interpretation of Results

6.3.1 Visual search for hands with distorted finger postures

From the experiments in Chapter 1, (1) hands were shown to be more salient than whole bodies and (2) distorted finger postures were more salient than natural finger postures. This salience occurred with feet with toes, which have similar structures to hands with fingers; however, it did not occur when using neutral objects with the same affective reaction and arousal. The absence of a salience difference between grenades and balls (the control stimuli) contrasts with the observed salience difference between distorted and natural finger postures. This finding suggests that the heightened salience of distorted hands is specific to hand stimuli, rather than being part of a general tendency to perceive emotionally charged stimuli as more salient. The control stimuli (grenades and balls) were matched in affective reaction and arousal to the distorted and natural finger postures yet did not elicit the same salience effect. This result indicates that the increased salience of distorted hands likely stems from factors unique to the perception and processing of hand-related stimuli, rather than from general emotional or arousal-based mechanisms. This specificity to hand stimuli supports the prediction that hands, like faces, have a special status in visual perception. The results suggest a unique perceptual sensitivity to hand configurations, possibly involving specialised neural mechanisms for hand perception.

Applying feature integration theory to visual search tasks involving hands and whole bodies, the differences in the processing of these stimuli can be attributed to the complexity and distinctive features of the objects. According to feature integration theory, there are two stages in visual search tasks: the preattentive stage and the focused attention stage. In the preattentive stage, basic features such as colour, size and orientation are rapidly processed in parallel across the visual field. If target objects have a distinctive feature, they can be detected quickly during this stage (Müller &

Krummenacher, 2006; Theeuwes, 1991). For hands and whole bodies, the hands may have more distinguishable features, such as specific finger configurations or orientations, which can be easily identified during the preattentive stage. Whole bodies are more complex as many parts of the human body need to be considered. This complexity may make it more difficult to identify unique features during the preattentive stage. If target objects, such as hands, do not have a unique feature distinguishing them from the other stimuli, the visual search proceeds to the focused attention stage (Wolfe & Bennett, 1997; Zhang & Onyper, 2020). During this stage, the observer must examine each item in series by directing their attention to it and integrating the individual features to identify the target. The relative complexity of hands versus whole bodies in visual search tasks is not as straightforward as it might initially appear. Whilst whole bodies may seem simpler (essentially a rectangle with four appendages), hands actually present a more compact and potentially more complex arrangement (a smaller shape with five protruding digits). This unexpected complexity of hands might contribute to their distinctive processing in visual attention.

The preattentive processing of hands likely involves mechanisms beyond the traditional visual system. Rather than relying solely on basic visual features like colour, edges, and orientation, it is possible that specialised neural structures, such as the amygdala, play a crucial role. These structures may process hands preattentively due to their biological and social relevance, similar to how eyes and emotional faces are rapidly detected. This specialised processing could explain the efficiency of hand detection in the focused attention stage, despite their structural complexity. Whilst feature integration theory provides a general framework for understanding visual perception, it is important to note that it can be expanded to incorporate both low-level visual features and higher-order, stimulus-specific processes. In the case of hands, this expanded view allows us to consider both general visual processing mechanisms and specialised neural pathways that may be uniquely attuned to hand stimuli. A study has shown that certain areas of the brain are more responsive to the sight of hands compared to other body parts, suggesting a specialised pathway for processing hand-related stimuli (Bracci et al., 2010; Brand, Piccirelli, Hepp-Reymond, Eng, & Michels, 2020). This specialisation is likely due to the biological significance of hands in human interactions and communication. The observed differences in visual search processes for hands and whole bodies can be explained by these distinct neural pathways. Unlike general body stimuli, which are processed through more common visual processing routes, hands engage additional, specialised neural circuits optimised for recognising and interpreting biologically significant stimuli. This perspective aligns with an expanded understanding of feature integration theory, which incorporates both low-level visual features and higher-order perceptual and cognitive processes. By including both general and specialised pathways, researchers can better understand the complexities of how hands are perceived differently from whole bodies.

Applying the feature integration theory to visual search tasks with distorted finger postures and natural finger postures, the differences in the processing of these stimuli can be attributed to the complexity and distinctive features of the respective stimuli as well. Distorted finger postures may have unique and unusual features that are not common in everyday life. These features could be easily identified during the preattentive stage, leading to faster detection of distorted finger postures (Wolfe & Bennett, 1997; Zhang & Onyper, 2020). However, natural finger postures are less salient, so it is more difficult to distinguish them from other neutral objects (e.g., necklace or bread roll) in the preattentive stage. The visual search for natural finger postures may take more time and rely on the focused attention stage, in which the observer must examine each object in series by directing their attention to it and integrating the individual features to identify the target. Distorted finger postures may be detected more quickly due to their unique features. Experimental data reveal accelerated detection specifically for distorted finger postures, not for chairs. Results show comparable detection speeds for distorted fingers and toes, suggesting body part specificity rather than a universal distortion effect. These findings highlight the complexity of visual processing mechanisms, warranting further investigation. As for hands and whole bodies, the differences in the visual search processes for distorted and natural finger postures, as explained by the feature integration theory, can be attributed to the varying levels of distinctiveness of the features and the salience of these stimuli.

The active and passive vision visual search experiments in Chapter 1 showed that humans are sensitive to human body images, as they are important social cues for survival, communication, and interaction (Hershler & Hochstein, 2005, 2006; Itier & Batty, 2009). The visual search experiments involved comparing the salience of distorted finger postures with natural finger postures and grenades with balls, which serve as control stimuli. The control stimuli (grenades and balls) had similar affective reaction and arousal values to the distorted and natural finger postures, ensuring that any differences in attention or response were not due to emotional factors. The observation that salience occurred between distorted and natural finger postures but not between grenades and balls suggested that the participants' attention was specifically drawn to human body images. This finding aligns with earlier research indicating that the human visual system is sensitive to human body-related stimuli (Peelen, Atkinson, Andersson, & Vuilleumier, 2007; Peelen & Downing, 2007). One possible explanation for this phenomenon is that human body images, including hands, provide important social cues that carry survival values. The ability to quickly identify and react to these cues could have offered evolutionary advantages, such as interpreting gestures or recognising threats. Whilst potentially dangerous or significant in some contexts, grenades and balls do not carry the same inherent social information and may not capture attention as effectively (Barrett, Adolphs, Marsella, Martinez, & Pollak, 2019; Schmidt & Cohn, 2001).

One possible explanation for this phenomenon is that human body images, including hands, provide important social cues that carry survival values. This prediction is supported by neuroimaging studies showing selective brain activation for body parts (Nummenmaa, Glerean, Hari, & Hietanen, 2013) and developmental research indicating infants' early preference for human forms (Simion, Regolin, & Bulf, 2008). Potential mechanisms underlying this phenomenon include threat detection, social cognition, action understanding, and empathy. For instance, quickly identifying human hands could help recognise potential threats, whilst observing hand movements facilitates learning and imitation of complex behaviours (Melloni, Lopez, & Ibanez, 2013). Additionally, hands play a crucial role in nonverbal communication, allowing individuals to infer others' intentions and emotional states (Goldin-Meadow & Alibali, 2013). These mechanisms likely evolved due to their significant adaptive advantages in human social environments, enhancing our ability to navigate complex social interactions and cooperate effectively. The ability to quickly identify and react to these cues could have offered evolutionary advantages, such as interpreting gestures or recognising threats. Whilst grenades and balls may be potentially dangerous or significant in certain contexts, they lack the inherent social information and evolutionary relevance that hands possess. Unlike hands, which have been integral to human social interaction and survival throughout our evolutionary history, grenades and balls are evolutionarily novel stimuli. As such, humans have not evolved specific perceptual mechanisms to detect and process these objects rapidly. This evolutionary mismatch may explain why grenades and balls do not capture attention as effectively as hands, despite their potential significance in modern contexts (Barrett et al., 2019; Schmidt & Cohn, 2001). This perspective underscores the importance of considering both the evolutionary history of human perception and the relative novelty of stimuli when studying attentional processes.

The difference in salience between distorted and natural finger postures compared to distorted and natural toe postures could be attributed to the following factors: (1) Evolutionary importance: humans have evolved to use their hands for various tasks, including tool use, communication and manipulation of the environment. As a result, the visual system has developed a greater sensitivity to hand postures with the fingers, compared to that of feet with toes (Hashimoto et al., 2013). Whilst the visual system has generally developed a greater sensitivity to hand postures with fingers compared to that of feet with toes, the research in this thesis on visual search tasks have shown no significant difference between hands and feet. This suggests that the heightened sensitivity to hands may be context-dependent or task-specific and may not manifest in all types of visual processing. (2) Functional significance: The fingers play a crucial role in tasks that require fine motor skills, such as writing or picking up small objects. In contrast, the toes are primarily involved in tasks that require gross motor skills, such as walking or maintaining balance. This functional difference could contribute to the increased salience of distorted and natural finger postures compared to that of toe postures (Fischer, Suggate, & Stoeger, 2020). (3) Context: The context in which the visual stimuli are presented could also influence salience. If the images are presented in a context where hand postures are more relevant (e.g., in a study involving manual tasks), then the salience of the finger postures might be more pronounced. All three factors contribute to the difference in salience. Their relative importance may vary depending on the specific situation or experimental design. Further research is needed to determine which factor strongly influences different scenarios. This difference in salience can affect active vision in visual search and may influence how quickly and accurately people can identify and process relevant information in a given scene (Cho & Proctor, 2003).

There are similar results for active vision and passive vision in visual search for the hands and the whole bodies in this thesis, with the hands being more salient than the whole bodies, primarily because of the inherent features of the hands which make them stand out, regardless of the vision approach employed. These features include: (1) Unique Features: Hands have distinctive features, such as fingers, which make them easily recognisable. These features are apparent in both active and passive vision scenarios, allowing observers to identify hands more quickly than whole bodies, which may not have equally striking features (Conson et al., 2020b; Tsao & Livingstone, 2008a). (2) Movement: Hands are often more mobile and expressive than whole bodies and play a vital role in various tasks and gestures. Their dynamic nature makes them stand out and attracts attention in both active and passive vision, whereas whole bodies may show more limited or subtle movements (Johnson-Glenberg & Megowan-Romanowicz, 2017). (3) Functional significance: hands are essential for interaction and manipulation in daily activities. This functional importance may cause observers to be more attuned to detecting hands in both active and passive vision. Whole bodies, whilst also important, may not receive the same level of attention because of their broader functional context (Fischer et al., 2020). (4) Interaction: Hands often interact with objects and other parts of the human body, which can increase saliency in both active and passive vision. Whole bodies may not be involved in as many direct interactions, thus reducing saliency (Cho & Proctor, 2003). These factors, which remain consistent in both active and passive vision, contribute to the consistent results seen in both active and passive vision, whereby hands are more salient than whole bodies. The inherent features of hands make them more noticeable and easily identifiable, even if the observer is actively exploring the environment or passively processing the visual input.

6.3.2 Eye movement including Pupillometry for hands with distorted finger postures

Eye movement in active vision is the mechanism by which human eyes gather information from their environment by moving them. The visual system actively seeks salient or important information in a scene and attention is drawn to areas of interest (Findlay & Gilchrist, 2003). Hands can attract more attention than whole bodies for several reasons. (1) Expressiveness of hands: Hands are an essential part of nonverbal communication and are often used to convey emotions and intentions or to supplement verbal communication. Neural circuits are configured to process these social signals, which can facilitate the interpretation of and appropriate responses to interpersonal interactions (Krauss et al., 1996). (2) Fine motor skills: hands are responsible for intricate and precise movements enabling humans to perform various tasks, such as writing, typing and manipulating objects. Observing hand movements can provide information about a person's actions or intentions, which can be important in certain contexts (Becchio, Manera, Sartori, Cavallo, & Castiello, 2012). (3) Interaction with objects: Hands are the main way by which humans interact with the environment. They are used to manipulate objects. So, observing hands can help understand how someone uses or interacts with objects, which could be relevant in some situations (Carfì et al., 2021). (4) Biological importance: From an evolutionary perspective, quick identification and interpretation of hand movements is essential for survival. Hands can signal a potential threat (e.g., holding a weapon) or an opportunity for collaboration (e.g., offering help). Thus, the visual system has evolved to pay attention to hand movements (Caspar, Pallasdies, Mader, Sartorelli, & Begall, 2022). (5) Perceptual salience: Hands are often more visually distinctive from the background than the rest of the body. They can form unique and contrasting shapes with their surroundings, making them more conspicuous and attracting more attention. The attention drawn to the hands rather than the whole bodies can be attributed to the combination of their communicative, functional and evolutionary importance and their perceptual salience (Davoli & Tseng, 2015).

From the results in Chapter 3 addressing the attentional differences between distorted and natural finger postures, it was found that the distortion of the finger posture caused the subjects to be more likely to shift and focus their attention on the distorted finger postures, indicating that visual attention is affected by changes in the physical characteristics of the hands. Specifically, the subjects demonstrated a bias towards attending to the distorted finger postures, suggesting that these postures may be perceived as more salient or attention-grabbing than natural finger postures. Some reasons can be inferred based on general principles of visual perception and attention. (1) Novelty: Human brains are wired to pay more attention to novel or unexpected stimuli. Distorted finger postures are less common and more unusual compared to natural ones, so they are likely to stand out and capture people's attention (Modirshanechi, Becker, Brea, & Gerstner, 2023). (2) Visual saliency: Distorted finger postures may create more complex and irregular shapes, which can lead to higher visual saliency. Visual saliency refers to the distinctiveness of an object in its environment, which can cause it to stand out from the surroundings and attract attention (Schürmann et al., 2011). (3) Perceived anomaly or deviation from norm: Human brains are attuned to detecting patterns and deviations from what is considered ‘normal’. Distorted finger postures may draw attention because they deviate from the typical hand configurations encountered daily. This heightened attention to unusual stimuli could be a byproduct of a general cognitive tendency to notice and process novel or unexpected information in the environment. It is part of the broader cognitive apparatus for processing and understanding surroundings, which includes identifying and examining unusual or less common phenomena (Fernandes et al., 2013; van Wingen, Geuze, Vermetten, & Fernández, 2011). (4) Emotional response: Distorted finger postures can evoke emotions like curiosity, surprise, or even disgust, leading to increased attention. Emotional stimuli attract attention more effectively than neutral stimuli (Schürmann et al., 2011). (5) Cognitive processing: The brain may require more cognitive resources to process distorted finger postures compared to natural ones due to their unusual appearance. This increased cognitive demand can lead to increased attention (Schürmann et al., 2011). These explanations are based on general principles of visual perception and attention, and the specific reasons for increased attention to distorted finger postures may vary depending on the context and individual differences. Further research would be needed to understand the phenomenon. For example, to quantify visual saliency, the exploration of distorted finger postures can be done using computational models. This can involve the use of existing saliency models, or the development of new ones specifically designed for hand postures. By analysing and comparing the generated saliency maps for distorted and natural finger postures, it becomes possible to identify the distinct visual features that contribute to the differential levels of saliency between the two.

6.3.3 Automatic mental simulation for hands with distorted finger postures

Automatic mental simulation occurs more readily with hands than chairs in the Simon task because hands are a part of the human body and are intimately connected to our sense of self and motor actions. Automatic mental simulation is the process by which our brain imagines and represents actions or scenarios, often without actually executing them. Since hands are directly involved in most of our daily activities and are essential for performing various motor tasks, they are more likely to be involved in mental simulations. Human brains have a natural tendency to focus on information and actions related to our own bodies (Willems, 2009). Chairs are inanimate objects without connections to a motor system or a sense of self. Therefore it is predicted that they do not trigger the same automatic mental responses as hands do (Schürmann et al., 2011).

The thesis results confirm this theoretical understanding, demonstrating that automatic mental simulation indeed occurred more readily with hands compared to chairs in the Simon task. This finding provides empirical support for the prediction that body-related stimuli (hands) elicit stronger automatic mental simulations than non-body-related objects (chairs). This difference in automatic mental simulation between hands and chairs based on the Simon task highlights the significance of embodiment in cognitive processes. The observed results underscore how our perception, cognition, and action are deeply intertwined with our bodily experiences, which influences how humans mentally simulate and interact with the world. These findings contribute to our understanding of embodied cognition, suggesting that our cognitive processes are fundamentally shaped by our physical experiences and body awareness.

Hand laterality tasks, as discussed in this thesis, involve presenting images of hands in different orientations and positions, including both single-handed and both-hand images. Participants are asked to identify whether the displayed hand is left or right. Studies have shown that automatic mental simulations occur in response to these images during the task, suggesting that people mentally manipulate the hand representations to determine laterality (Parsons, 1987, 1994). Research in this thesis has provided information on how our brains process and simulate motor actions. Research has shown that participants who are shown images of hands automatically perform mental simulations to determine their laterality (i.e., left or right) (Liepelt, 2014). These automatic mental simulations occur even when the image displays a single hand or both hands together. In both-hand images, participants can automatically mentally simulate both hands simultaneously or focus on one hand and then the other. In both cases, the mental simulations of both hands are activated so that participants can determine the lateral position of the hands in the image (Liepelt, 2014). These findings have broad implications for understanding human motor cognition and how our brains process and simulate actions. They also highlight the remarkable capacity of our brain to generate automatic mental simulations in response to one handed and both handed images.

6.3.4 Event-related oscillations for hands with distorted finger postures

The EEG experiment analysed in this thesis explored in this thesis investigated how the brain reacts to distorted versus natural finger postures by analysing mu desynchronisation, linked to mirror neuron activity. These neurons, located primarily in the premotor cortex, facilitate both action execution and observation, contributing to empathy and imitation. Because some evidence from motor-cognitive tasks was identified, it was suggested to reanalyse existing EEG data, which originally measured ERP, to assess MNS responses as participants observed or mimicked these postures (Ellinghaus et al., 2017; Liepelt, 2014; Scerrati et al., 2017). This approach intended to further explore the neural mechanisms underlying these tasks. However, the findings showed no significant differences in mu desynchronisation between the two types of postures. This lack of significant difference suggests that the brain research did not provide clear evidence to support the idea that these two postures are processed differently by the MNS. The analysis in Chapter 5, which involved an experiment not conducted during the timeframe of this thesis, did not yield strong evidence. However, this does not necessarily mean there is no difference in processing. The experimental design, sample size, or other factors may not have been sensitive enough to detect subtle differences, or other neural mechanisms not captured by mu desynchronisation may be involved. Further research is needed to explore these possibilities and provide a more comprehensive understanding of how the brain, particularly the MNS, processes and simulates different finger postures.

6.4 Research Implications

These findings for parts of the human body and hands with distorted finger postures have significant implications for policy making for the use of uncommon human body images, psychological treatments for schizophrenia and autism and computer vision for hands with distorted finger postures.

6.4.1 Policy making

The results can be used to create policies when using unusual human body images. For example, some governments post pictures of accidents showing unusual human body images as a warning in places where traffic accidents are common, such as road junctions, in the hope that people will be discouraged from breaking traffic rules (Figure 6-1). Although governments may not employ unusual human body images in traffic safety campaigns, impactful visuals are essential in strategies to enhance road safety and influence behaviour, aligning with the World Health Organisation's emphasis on effective communication in injury prevention (Peden et al., 2004). However, these images are likely to attract attention and cause accidents. Extensive studies on roadside advertising has shown that attention-grabbing visuals can distract drivers (Decker et al., 2014; Wang, Clifford, Markham, & Deegan, 2021). Studies have demonstrated that billboards and other roadside displays, particularly those with provocative or graphic content, can divert drivers' attention from the road, potentially increasing the risk of accidents. Using accident scene images as deterrents may have unintended consequences, potentially compromising road safety rather than enhancing it. A further example is that of discordant artworks, such as statues with broken arms (intentional or otherwise), placed along main traffic arteries. Whilst these are intended to beautify cities, they can also be dangerous because they distract road users (Lakhan, Pal, Baluja, Moscote-Salazar, & Agrawal, 2020; Nordfjærn, Jørgensen, & Rundmo, 2012).

Figure 6-1 An example of a picture for warning pictures about traffic accidents.
Some governments post pictures of accidents showing unusual human body images as a warning in places where traffic accidents occur. In this picture, a person is lying on the ground, retrieved from https://www.gettyimages.co.uk/detail/photo/accident-car-crash-with-male-delivery-guy-bicycle-royalty-free-image/1364213224. (Images).

Figure 6-2 An example of a picture for discordant artworks.
In this picture, a statue of parts of a human body (arm) were placed on the street, retrieve from https://ga.de/freizeit/reise/neue-arm-statue-in-new-york-sorgt-fuer-aerger_aid-47177749 (Bonn, 2019).

6.4.2 Psychological treatment

Although the underlying nature of the relationship between individual schizophrenia patients and their social perception is still unclear, it has been experimentally demonstrated that patients with schizophrenia have difficulty recognising body language in social situations (Wible, 2012; Wible, Preus, & Hashimoto, 2009). Reactions to distorted finger postures are viewed as informative because they can provide insight into the cognitive processes of patients who have inaccurate or altered perceptions of their own body (Navas-León et al., 2023; Nikolov, Zalisna, Novikova, Makeyev, & Duchenko, 2022; Velikanov, Levashkevich, Stoljarova, & Demchenko, 2022). Exploring the results of this research could potentially contribute to our comprehension of how to psychologically assist patients with schizophrenia. Studies have demonstrated that individuals with schizophrenia exhibit significant challenges in perceiving both distorted and natural finger postures, which may be linked to deficits in body schema and proprioceptive processing (Gallese & Ferri, 2014; Postmes et al., 2014). Furthermore, identifying the specific cognitive processes involved in the perception of distorted finger postures could also lead to the development of more targeted and effective interventions for patients with schizophrenia. Distorted finger postures, in particular, require more complex visual and cognitive processing due to their unnatural configurations, potentially exacerbating perceptual difficulties in these patients (Butler & Roediger, 2008). By pinpointing the exact cognitive mechanisms that are impaired, such as visual processing, attention, or working memory, researchers and clinicians can design interventions that directly address these specific deficits. For instance, deficits in visual processing have been linked to abnormalities in the dorsal visual stream among individuals with schizophrenia (Doniger, Foxe, Murray, Higgins, & Javitt, 2002). For example, if visual processing is found to be the primary issue, interventions might focus on enhancing visual discrimination skills. Alternatively, if attention is the main problem, cognitive remediation therapies could be tailored to improve attentional control (Wykes, Huddy, Cellard, McGurk, & Czobor, 2011). Cognitive remediation has been shown to improve not only cognitive deficits but also functional outcomes in patients with schizophrenia (McGurk, Twamley, Sitzer, McHugo, & Mueser, 2007). This targeted approach could potentially result in more efficient treatment strategies, faster recovery times, and improved overall outcomes for patients with schizophrenia (Longo, 2022; Luvsannyam et al., 2022; Perez et al., 2023).

In addition, research has shown that face recognition is impaired in autism (O'Hearn et al., 2016; Ozonoff, 2012). Therefore, examining the results of this research could help to understand how distortions in body images affect autistic individuals. The findings of this study may offer insights into developing treatments that enhance body image recognition for individuals with autism. Additionally, these insights could extend to the therapeutic approaches for various psychological conditions. For example, anxiety disorders have been linked to altered face recognition (Leuchter, Cook, Hunter, Cai, & Horvath, 2012; O'Hearn et al., 2016), and this research could be used to study how perceptions of one's body that are altered or inaccurate affect people with anxiety disorders. This could potentially lead to the development of better therapies and treatments for anxiety disorders. Overall, the results of this research have the potential to shed light on how distorted finger postures can affect cognitive processes in various mental illnesses. This may contribute to a better understanding and development of treatments for schizophrenia, autism and other forms of mental illness. This research could potentially provide insights that might assist in the creation of more nuanced treatment strategies for these conditions

6.4.3 Computer vision

The results for hands and distorted finger postures offers crucial insights for developing computer vision algorithms and mapping artificial neural networks, with a particular focus on hands and distorted finger postures. The algorithms being developed can identify hands, allowing a deeper understanding of visual mechanisms underlying hand processing and distorted finger posture selectivity (Cheok, Omar, & Jaward, 2017). This understanding facilitates the creation of a hierarchical neural network model of the ventral visual stream, instrumental in machine learning contexts (Pisharady & Saerbeck, 2015; Schütz et al., 2011).

The potential applications of such methods are diverse and multifaceted. They range from gesture and sign language recognition, facilitating more natural interaction with devices and aiding the deaf community, to augmenting virtual reality experiences through accurate hand tracking (Li, Huang, Tian, Wang, & Dai, 2019). Modelling distorted postures enhances recognition accuracy by accounting for individual variations and imperfect gestures, whilst improving hand tracking in challenging virtual reality scenarios. Further applications can be seen in robotics, where understanding human hand movements improves cooperation and task execution (Abdlkarim et al., 2023; Qi, Ma, Cui, & Yu, 2023). Incorporating distorted posture models allows robots to better interpret and respond to a wider range of human hand movements, enhancing human-robot interaction. Other domains include healthcare, biometrics and human behaviour analysis (Costa et al., 2022; Perez et al., 2023). In healthcare, it aids in diagnosing hand conditions and designing rehabilitation programmes. For gaming, it improves hand-based controls' responsiveness. In biometrics, it enhances identification accuracy. In behaviour analysis, it provides deeper insights into nonverbal communication. These areas could significantly benefit from a more salient recognition of the hand compared to other body parts (Bujak et al., 2013; Cihan Camgoz, Koller, Hadfield, & Bowden, 2020; Kato, Billinghurst, Poupyrev, Imamoto, & Tachibana, 2000; Kelly, Manning, & Rodak, 2008; Masurovsky et al., 2020; Nooruddin, Dembani, & Maitlo, 2020; Tsarouchi, Matthaiakis, Makris, & Chryssolouris, 2016; Zhou, Jiang, & Lin, 2016).

Models of the ventral visual stream for face recognition are already well-developed in deep learning, whilst those for hand recognition are yet to be fully explored (Baek, Song, Jang, Kim, & Paik, 2021; Rodriguez, Nayak, Chen, Krishnan, & Huang, 2022). This research bridges this gap and offers a substantial contribution to machine learning, particularly in the field of computer vision and deep learning. The insights gained are also invaluable for robotics, enhancing a robot's ability to understand and respond to human hand gestures (Ritter & Haschke, 2015). Consequently, the presented findings provide a new perspective on the visual mechanisms underlying hand and distorted finger posture processing, with implications spanning machine learning, computer vision, deep learning, and robotics.

6.5 Work Reflections on Gaps and Future Directions

Although this PhD project has (1) successfully demonstrated the salience of hands and distorted finger postures and (2) found more evidence and thus led to a better understanding of the automatic mental simulation of hand and distorted finger postures, some limitations regarding the experimental design should be noted.

6.5.1 Limitations and future work

6.5.1.1 Limitations indicating areas of future work on hands and whole bodies

Issues associated with studying the different parts of the human body include their different visual properties. There are three different visual properties regarding hands, faces and whole bodies: stimulus shape, real-world image ratio and communication function. Firstly, it remains unclear so far whether the results in this thesis concerning hands and whole bodies were specific to the use of images of real hands and real whole bodies or whether the same results would have been generated using images of shapes of hands and whole bodies. Further studies could compare results using silhouettes and stick figures instead of images of real hands and whole bodies. Secondly, the size ratio between the images of hands and whole bodies in the experiments did not reflect real-world size ratio. Therefore, further research could examine the consequences of presenting the hand and whole body images in a real-world ratio (i.e., hand and whole body images reduced and increased proportionally, respectively). Thirdly, Given the complexity of the communication function of hands, which involves numerous variables, and considering the current lack of identified control stimuli specific to hand communication, this aspect falls outside the scope of the present discussion. It is important to recognise that whilst this topic is pertinent, it requires a distinct line of investigation due to its multifaceted nature.

6.5.1.2 Limitations indicating areas of future work on distorted and natural finger postures

Experiment 12 was set up to study the difference in automatic mental simulation with ERD between distorted and natural finger postures. However, due to COVID-19 related alterations, previous EEG data generated for an ERPs experimental designed to investigate distorted finger postures had to be used with the corresponding presentation duration of stimuli being 200 ms. The results in Experiment 12 showed a trend for differences in mu desynchronisation for different shape (i.e., distorted and natural). This suggested that the 200 ms duration for the ERPs experiments would probably have been insufficiently long to evoke brain oscillations in ERD experiments. This is confirmed by previous studies which have shown that the typical duration of presentation is more than 800 ms to evoke brain oscillations in ERD experiments (Başar, Schmiedt-Fehr, Oniz, & Başar-Eroğlu, 2008). In the future, an experiment for measuring automatic mental simulation with a presentation duration of 800 ms could be run to confirm whether the strength of the different brain oscillations evoked between distorted and natural finger postures is significantly different.

6.5.2 Further research leads

In addition to future work based on the improvement of experimental design, the findings in this thesis provide insights for future research into distorted finger postures. Building on a previous ERPs experiment comparing the interaction of stimulus type (hand and chair) and configuration (distorted and natural/standard, respectively) (Espírito Santo, Chen, et al., 2017), a further ERPs experiment comparing the interaction of a new stimulus type (hand) and new configuration (distorted, unusual and natural) could be conducted. The unusual configuration refers to the fact that the fingers bend voluntarily instead of being bent by external force. This experiment was planned but could not be conducted due to the COVID-19 restrictions. Previous studies of brain activity for non-neutral hand postures (including distorted and natural finger postures), however, are limited to distorted finger postures (Avikainen et al., 2003; Espírito Santo, Chen, et al., 2017; Schürmann et al., 2011), but no known empirical research has focused on exploring unusual finger postures, which refer to fingers bent naturally. Distorted and unusual finger postures are similar in geometric complexity, and even though both distorted and unusual finger postures are bent, they have different biological constraints. That is, a human can demonstrate unusual finger postures but not distorted finger postures. Moreover, in automatic mental simulation, the visual processing is different. Experiments 10 and 11 used motor cognition tasks to explore this topic (i.e., explicit feature as cues with distorted and natural finger postures and automatic mental simulation for distorted and unusual finger postures), and some interesting results were found. However, it remains unclear how individual variations in mental simulation might impact the interpretation of these tasks. Do these variations influence the perceived distortion of finger postures? Furthermore, how do these mental simulations correlate with the actual motor ability or disability of individuals? Finally, a central question pertains to the neurophysiological evidence: are there detectable differences in ERPs) when individuals mentally simulate distorted versus unusual finger postures? Thus, it is of interest to know whether there are differences in ERPs between distorted finger postures and unusual finger postures.

6.6 Final Conclusions

Hands, like faces, convey social information, instructions, and intentions to the observer. This PhD project investigated how hands, particularly those with distorted finger postures, attract more attention than whole bodies through visual search and eye movements. The study aimed to determine if the exceptional salience of distorted hand postures reflects specific cognitive processing patterns in human behaviour. Results showed that distorted finger postures were indeed more noticeable than natural ones, implicating both active and passive modes of observation in their perception. Further investigations within the project through motor cognition experiments revealed that the mental simulation of hands is activated not just for individual hands but also when both hands are viewed together. This suggests a broader engagement of cognitive resources when processing hand gestures. However, a subsequent experiment using an explicit feature task to probe the mental simulation of individual fingers brought mixed results. Participants responded quickly to unusual or distorted configurations of the index, middle, or ring fingers, prompting further inquiry in Experiment 11. Unfortunately, this experiment did not corroborate the presence of automatic mental simulation at the level of individual fingers, presenting a need for additional research and leaving questions open for future exploration. Despite the lack of anticipated EEG evidence to support the mental model, the project still offered significant insights. It highlighted the complexity of hand perception and the potential for alternative investigative approaches. Overall, the findings suggest that hands play a significant role in visual processing, not only in motor cognition but also in the perception of static images.

Chapter 7 Appendix

7.1.1 Appendix 1: Online experiment setting and participants recruitment for online experiments

7.1.1.1 Online behavioural experiment setting

Due to COVID-19, laboratories were closed, and laboratory experiments were transformed into nonlaboratory experiments. The face-to-face laboratory environment and the nonlaboratory environment, for online experiments, in particular, are different. For example, the researcher cannot stand next to the participants, supervise them, and immediately give the required assistance in nonlaboratory environments. Online behavioural experiments had not received any attention before the outbreak of COVID-19 and were thus underdeveloped. However, during the pandemic, online behavioural experiments became widely used and were one of the few experiments that could be conducted and used to investigate the issues of interest to me during that period. Additional settings, which were not used in the face-to-face experiments, had to be added to the online experiments to ensure consistent conditions, irrespective of the location. Therefore, the following additional settings were added to the online behavioural experiments.

7.1.1.2 Detecting operating systems and browsers.

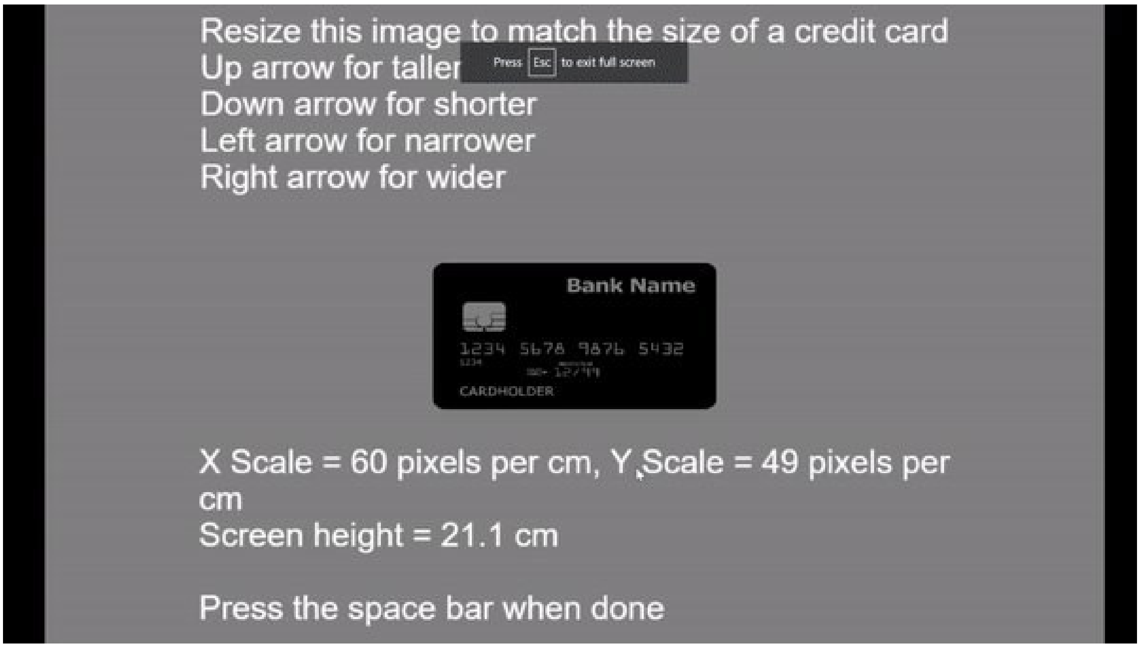
In the laboratory, the offline behavioural experiments were conducted on a laptop, a 14-inch HP EliteBook 840, using PsychoPy written in Python programming language. For online data collection, PsychoJS, written in JavaScript programming language, was used to conduct the studies online. The literature suggests that Google Chrome and Firefox are the most suitable browsers for Pavlovia PsychoPy. In addition, the literature also suggests that Windows and Macintosh are the most compatible operating systems for Pavlovia PsychoPy. To avoid the disruption of unusual browsers or operating systems, participants were instructed to use Google Chrome and Firefox, Windows and Macintosh. Pavlovia PsychoPy was set to recognise these browsers and the operating system. If participants did use other browsers or operating systems, the data were removed from the database.

7.1.1.3 Forced stop experiments

In offline behavioural experiments, participants complete experiments with a short pause in between each block (Di Luca & Pesenti, 2010; Rand & Heuer, 2020). In addition, the experiments are completed within 30 minutes (Rauchbauer, Pfabigan, & Lamm, 2018). Therefore, the online behavioural experiments were designed to mimic offline experiments by having a forced stop setting. The online behavioural experiments were set so that if participants did not finish within 30 minutes, the experiment would end immediately, and the data were excluded from the database. This setting prevented the participants from pausing the experiments for too long, which could have invalidated the experiment.

In the offline behavioural experiments (Experiments 1 and 2), participants rarely responded randomly after on-site observation. However, it is difficult to ensure that participants do not respond randomly in online behavioural experiments. Moreover, in offline behavioural experiments (Experiments 1 and 2), participants could ask any experiment-related questions following the practice trials. However, in online behavioural experiments, they could not ask any experiment-related questions even after the practice trials. To prevent participants from responding randomly or without understanding the experiment instructions, the online behavioural experiments were set to stop immediately if participants answered incorrectly five times in a row.

7.1.1.4 Screen scale settings



Resize this image to match the size of a credit card
Up arrow for taller
Down arrow for shorter
Left arrow for narrower
Right arrow for wider

X Scale = 60 pixels per cm, Y Scale = 49 pixels per cm
Screen height = 21.1 cm

Press the space bar when done

Figure 7-1 Card task instructions used to adjust the visual stimuli size on the screen

In the offline behavioural experiments, the visual stimuli size was scaled with centimetres as parameters and presented on a laptop, a 14-inch HP EliteBook 840. The visual stimuli size was identical for the different participants. However, this measurement was not applicable in online behavioural experiments because the visual stimuli size was affected by the model of the laptop, the model of the monitor, the resolution settings, the browsers and even the operating systems (Lago, 2021; Li, Joo, Yeatman, & Reinecke, 2020; Reinecke, Rinck, & Becker, 2008). To solve the problem, a tool available in PsychoJS was used. Participants were shown a credit card on the screen and were asked to place a physical credit card over the image (Figure 7-1). They then had to adjust the screen image size to match the size of the physical credit card. In doing so, the size of the visual stimuli in the subsequent experiments would be the same in each participant’s online context.

7.1.1.5 Participant recruitment for online behavioural experiments

Participant recruitment differed between offline and online behavioural experiments. The latter necessitated additional considerations, for example, issues regarding cyber security (the platforms used in these experiments claimed to be cyber security safe).

The flowchart of participant recruitment for online behavioural experiments is presented in the figure below (Figure 7-2). The three platforms used in this thesis were: SONA system, Qualtrics and Pavlovia PsychoPy. The SONA system was used for recruiting psychology students as it could record their academic credits. Qualtrics was used to collect and manage participant information. Pavlovia PsychoPy was used to conduct online behavioural experiments (Peirce et al., 2019).

The procedure of participant recruitment was as follows. Psychology students accessed and registered for these experiments using the SONA system, which then redirected them to Qualtrics. The researcher received a study ID from SONA and basic information about the participant. Non-psychology students accessed and registered for these experiments directly through Qualtrics. All participants received a random ID generated by Qualtrics, which they had to note down. This was required by the researcher to confirm participant identity. At no point did participants record their name in the system; however, ages and genders were collected on the Qualtrics survey platform.

Psychology students who had registered for academic credits received them automatically from the SONA system having completed the experiments. All other participants who had not registered for academic credits, had to send the Qualtrics random ID to the researcher who then transferred the inconvenience allowance.

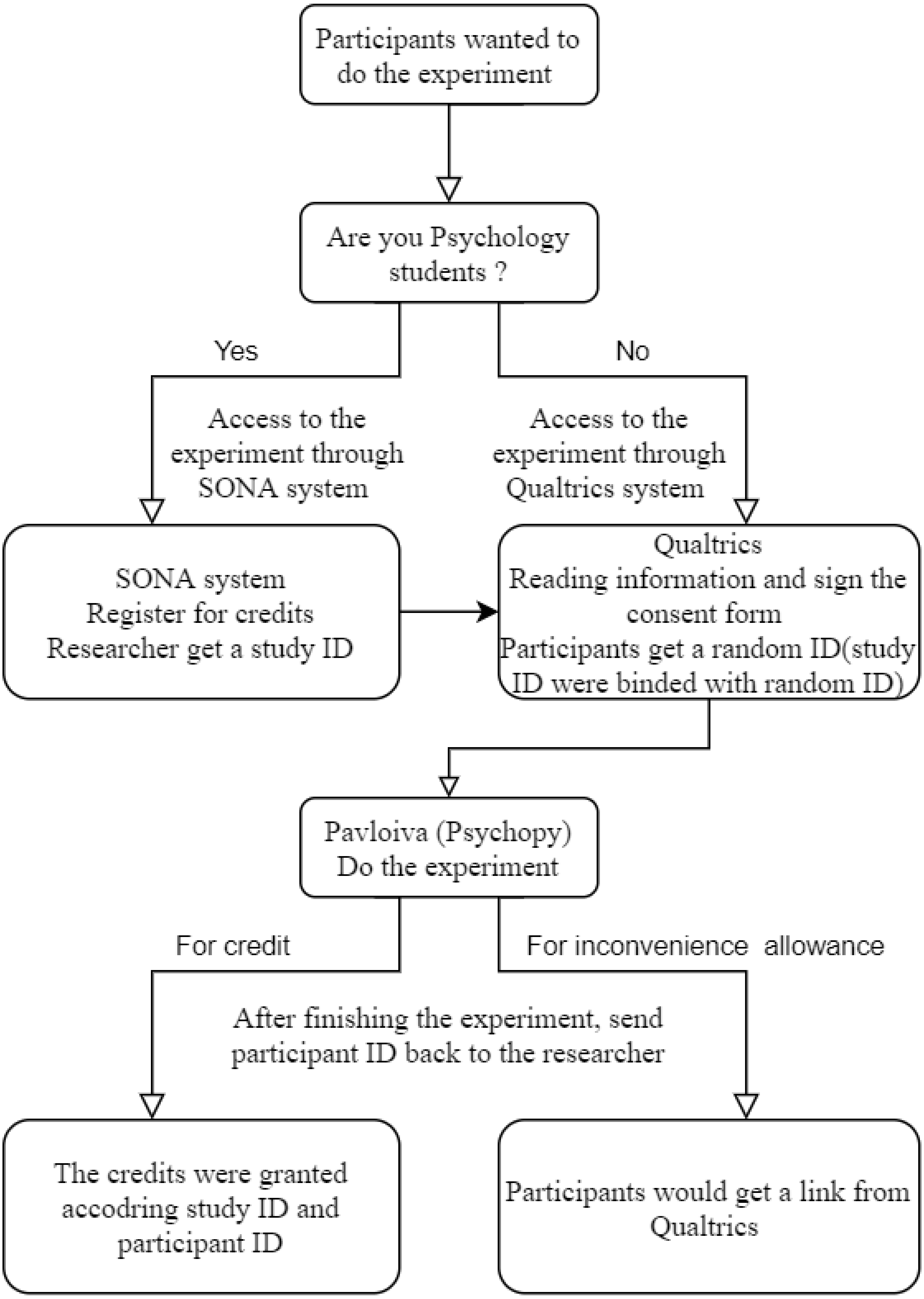


Figure 7-2 The flowchart of participant recruitment for online behavioural experiments

The chart depicts the procedure for psychology and non-psychology students, the collection of basic information, and the procedure for assigning academic credits or inconvenience allowances.

7.1.2 Appendix 2: Stimuli creation for hand model in motor-cognitive task

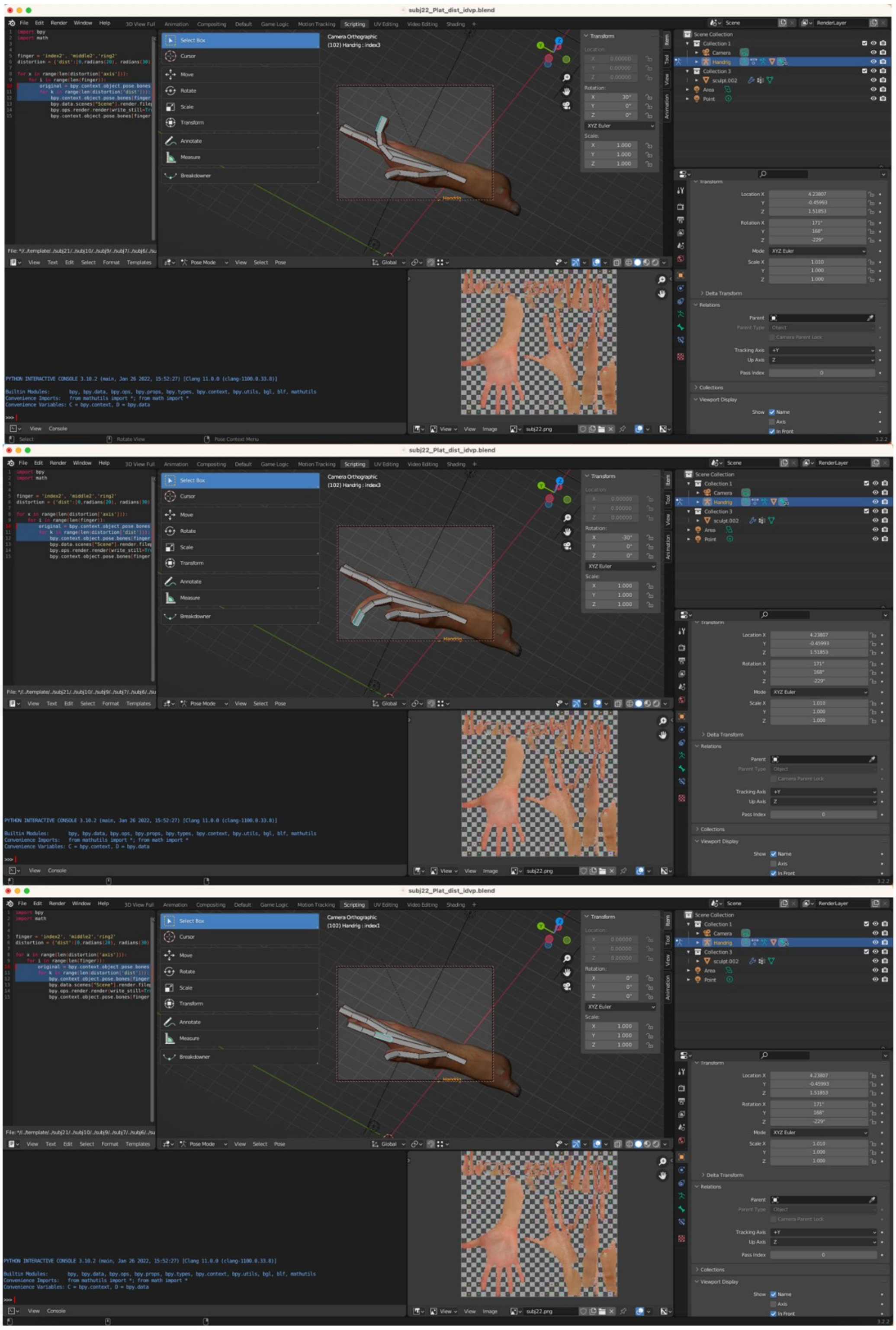
In motor-cognitive task, hands with distorted and unusual finger postures (with three different views, invisible dorsal and visible palm view; visible dorsal and invisible palm view; invisible dorsal and invisible palm) were needed. Using computer-generated images in motor-cognitive tasks offers advantages like control over variables, standardisation, flexibility, replicability, and ethical considerations. It allows researchers to manipulate and customise stimuli whilst ensuring consistent and reliable results. However, generating a 3D model from images is a complex process that involves steps like feature extraction, depth estimation, point cloud generation, surface reconstruction, and refinement. Each step presents its own challenges, and researchers are constantly working on improving these techniques. Fortunately, Miguel Santo have generated templates for hands with Blender and published in Espírito Santo, Chen, et al. (2017). Blender, a free 3D modelling software which contains an API that allows easy access to conduct any type of operations on interfaced data.

Although the templates available in Blender make the process of creating materials easier, it is still a challenging task to generate appropriate and suitable materials. The preprocessing step refers to Miguel Thesis. In Blender, the process of generating materials involves several steps. After importing the acquired meshes, operations such as alignment, vertices stitching, decimation, and remeshing are performed to merge the palmar and dorsal models whilst maintaining relative positioning. Redundant vertices are removed, resulting in a smoothed mesh. UV mapping was used to unwrap the model, converting 3D coordinates to 2D. The UV map is then applied to the image texture, allowing for the application of texture and finalising the modelling process. Additionally, the Blender API enables the manipulation of bone structures, offering precise control over finger distortions by controlling the relative positions of the bones. To resolve issues with overlapping and cutoff appearances, cuboid-shaped bone tessellation is increased, and smoothing modifiers are applied to create a gradual falloff effect. These manipulations are linked to the bones controlling the mesh.

Although Miguel has completed the aforementioned process and created a template, each time you want to generate the material, it is necessary to repeat the steps described above to a certain extent. The need to repeat the process for generating materials arises because each material requires specific operations and adjustments to be performed. Even with a template as a starting point, customisations and adjustments are necessary for each material, leading to the need to run the process again.

It is important to consider the bending angles of the fingers at their respective joints whilst creating the bending finger effect. The upward bending angles of the fingers at their respective joints are as follows. The metacarpophalangeal joint is located at the base of each finger and has a upward bending angle of approximately 60 degrees. Moving further along the finger, one find the proximal interphalangeal joint, which is the middle joint. The proximal interphalangeal joint also has an upward bending angle of around 30 degrees. Finally, the distal interphalangeal joint is the joint closest to the fingertip, and it typically allows bending at an angle of about 10 degrees (Figure 7-3). In contrast, the downward bending angles of the fingers at their respective joints are as follows. The metacarpophalangeal joint, located at the base of each finger, allows a downward bending angle of approximately 60 degrees. Moving along the finger, the proximal interphalangeal joint, the middle joint, typically permits a downward bending angle of around 30 degrees. Lastly, the distal interphalangeal joint, closest to the fingertip, has a downward bending angle of approximately 10 degrees (Figure 7-3).

To render images in Blender without different luminance, it is important to establish consistent lighting conditions and use global illumination techniques. Set up controlled and uniform lighting using diffused sources or strategic placement of multiple lights. Global illumination features such as ambient occlusion and indirect lighting should be enabled to achieve an even distribution of light. Additionally, calibrate the exposure settings in Blender to ensure proper exposure, avoiding overexposure or underexposure. By following these steps, images can be rendered with consistent luminance, resulting in a visually cohesive and balanced outcome (Figure 7-4).



```
import bpy
import math


finger = 'index2', 'middle2','ring2'
distortion = {'dist':[0,radians(20), radians(30)
    
for x in range(len(distortion['axis'])):
    for i in range(len(finger)):
        original = bpy.context.object.pose.bones
        for k in range(len(distortion['dist'])):
            bpy.context.object.pose.bones[finger
            bpy.data.scenes["Scene"].render.filep
            bpy.ops.render.render(write_still=Tr
            bpy.context.object.pose.bones[finger
```

```
PYTHON INTERACTIVE CONSOLE 3.10.2 (main, Jan 26 2022, 15:52:27) [Clang 11.0.0 (clang-1100.0.33.8)]

Builtin Modules:       bpy, bpy.data, bpy.ops, bpy.props, bpy.types, bpy.context, bpy.utils, bgl, blf, mathutils
Convenience Imports:   from mathutils import *; from math import *
Convenience Variables: C = bpy.context, D = bpy.data

>>>
```

Figure 7-3 Examples of stimuli in Blender for motor-cognitive tasks.
From top to bottom is distorted finger postures, unusual finger postures and natural finger postures.

Figure 7-4 Examples of stimuli generated through Blender software for motor-cognitive tasks
From top to bottom is distorted finger postures, unusual finger postures and natural finger postures.

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