A Neuroscientific and Cognitive Examination of Individual Differences in Face Recognition Ability

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DECLARATION

I certify that the work contained in this thesis, or any part of it, has not been accepted in substance for any previous degree awarded to me, and is not concurrently being submitted for any degree other than that of Doctor of Philosophy being studied at the University of Greenwich. I also declare that this work is the result of my own investigations, except where otherwise identified by references and that the contents are not the outcome of any form of research misconduct.

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ABSTRACT

There are large individual differences in face processing ability, with *Super-Recognisers* (SRs) being exceptionally superior to individuals with average face recognition ability. This thesis describes seven experiments examining SRs' cognitive performance as well as neural/electrical activity in order to explore potential *quantitative* and *qualitative* contributions to their face processing superiority. Chapter 4 examined whether SRs rely on holistic and parts-based processing to the same extent as controls, and whether their face recognition superiority can be observed at the face perception stage as well. SRs outperformed controls at face recognition and face matching, inverted face recognition, object recognition and feature matching. SRs also demonstrated normal (*Part-Whole Effect*), greater (*Inversion Effect*), or reduced (*Composite Face Effect)* holistic processing, implying a more effective use of holistic and parts-based processing. Chapter 5 explored whether SRs' face processing superiority transcends to faces they have less experience with (infant faces), and whether this *Other Age Effect* could be observed on a neural/electrical level. SRs outperformed controls on adult and infant faces despite limited experience with the latter. Furthermore, EEG analysis indicated enhanced P1 (pictorial processing) and P600 (explicit recognition) in SRs during face recognition, suggesting they may benefit from a more effective pictorial processing of faces. Chapter 6 employed the *Remember/Know* paradigm with EEG recording to explore SRs' *recollection* and *familiarity* of faces and objects. SRs' recognition was often accompanied by contextual information, suggesting they remembered more than just the stimuli's identity. Furthermore, SRs' visual recognition was reflected in neural/electrical activity in central and right brain sites, while controls only demonstrated central site activation. Applicability of this thesis' findings, as well as the design's limitations and new potential directions for future research are discussed in the final chapter.

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Chapter 1 - Introducing the thesis

Face processing has been a popular topic ever since it has been brought to our attention that there are people who fail to recognise their own reflection in the mirror, let alone their loved ones. These clinical cases (e.g., Bodamer, 1947), where patients suffered some form of brain injury, led scientists to believe that there are brain areas, which specialize specifically in different stages of face processing, i.e., face perception and face recognition.

Our knowledge and understanding of face processing is quite extensive, as psychologists and neuroscientists have made impressive progress in this area of research over the past decades. We can see neonates (minutes after birth) being immediately captivated by faces (actual or schematic) even though they almost certainly have no understanding of what they are looking at (e.g., Fantz, 1963). Such an early interest in faces led psychologists to believe that humans are biologically predisposed to face processing and that faces must be special. Indeed, how can we *not* be experts at face processing when it takes milliseconds to detect a face amongst an array of other objects, while also processing the age, gender, ethnicity, emotional expression and even identity of that face (e.g., Bruce & Young, 1986; Fiske & Neuberg, 1990; Fitousi & Wenger, 2013)? However, research and practice show that unfamiliar face processing is not as effortless and accurate as familiar face processing (e.g., Bruce *et al.*, 1999). In fact, even for individuals who are supposedly trained to discriminate faces, e.g., officers in passport control, errors in unfamiliar face matching are quite common, and are comparable to the general population performance (e.g., White, Kemp, Jenkins, Matheson, & Burton, 2014).

The more face processing is investigated the clearer it becomes that this perceptual function is not absolute and that people in the general population do not have the same proficiency (e.g., Bowles *et al.*, 2009). Most of the population experiences no difficulty in perceiving and recognising faces, yet some are much better than others, resulting in a wide range of normally distributed face recognition ability. One of the recent developments in the face processing research is the observation that there are people whose face recognition is far superior to those in the general population. These *super-recognisers* (SRs) may represent top 2% of the normally distributed face recognition ability, although to date very few studies have investigated their abilities (e.g., Russell, Duchaine, & Nakayama, 2009; Bobak, Dowsett, & Bate, 2016).

The current thesis was designed to explore potential differences in cognitive and neural processing between SRs and individuals with average face recognition ability, in an attempt to detect potential factors contributing to SRs' superiority in face recognition. The thesis begins with an extensive literature review on face processing (see Chapter 2), presenting early and relatively recent ground-breaking findings, and highlighting the most relevant paradigms employed to examine individual differences in face processing. Based on the literature review, the current project has been divided into two components, face perception and face recognition, as SRs may show independent or interactive advantages in either or both of these stages of face processing. Both components are assessed with neuroscientific - *electroencephalography* (EEG), and cognitive tests presented in seven separate experiments (see Chapters 4 – 6).

Chapter 3 describes the methodology selected for defining and investigating super-recognition, while elaborating on the design of the selected tests for examining individual differences in face processing.

Chapter 4 presents the first study recruiting a large number of participants recruited online (n = 820) in Experiment 4.1 and two smaller samples (n = 68 and n = 44) for laboratory testing in Experiments 4.2 and 4.3, respectively. Chapter 4 explores whether SRs' face recognition advantage is face specific or general, by comparing SRs' face and object recognition to that of controls (Experiment 4.1; e.g., Wang, Li, Fang, Tian, & Liu, 2012). Chapter 4 also employs the *Inversion Effect* (Experiment 4.2; e.g., Yin, 1969), the *Composite Face Effect* (Experiment 4.2; e.g., Young, Hellawell, & Hay, 1987) and the *Part-Whole Effect* (Experiment 4.3; e.g., Tanaka & Farah, 1993) to examine whether SRs' face processing superiority could be associated with superior holistic processing or superior parts-based processing (see sections 2.2.2.1 and 2.2.2.2 for a brief review).

The second study, described in Chapter 5, examines the *other age effect (OAE)* – the observation that people are better at processing faces of their own age (see section 2.3.1 for a brief review), and whether SRs' face processing (perception and recognition) is compromised when viewing faces they have little experience with (i.e., infants). As in Chapter 4, this study is divided in three experiments with online participants (n = 820) recruited for Experiment 5.1 and two smaller samples (n = 61 and n = 44) recruited for laboratory testing in Experiments 5.2 and 5.3, respectively. The old/new recognition tests (e.g., Rugg *et al.*, 1998) are employed in order to measure SRs' adult and infant face recognition performance in Experiments 5.1 and 5.2. In addition, Experiment 5.2 employs EEG recording (see sections 2.2.1 and 3.2.3 for a brief review) during adult and infant face recognition in order to explore potential neural markers of SRs' superiority in face recognition and potential neural correlates of the OAE (e.g., Wiese, 2012). Experiment 5.3 employs the adult/infant face matching tests (e.g., Kuefner, Macchi Cassia, Picozzi, & Bricolo, 2008) to explore SRs' potential differences in holistic processing of adult and infant faces.

The final study, presented in Chapter 6, recruited forty-three participants to explore the well-known Remember/Know paradigm (e.g., Burns *et al.*, 2014; see section 2.2.3.3 for a brief review) in order to examine whether SRs rely more on recollection or familiarity during face and object recognition. Experiment 6.1 also employs EEG recording during face and object recognition in order to explore whether either of these memory experiences (recollection and/or familiarity) have a different neural distribution/activity in SRs compared to controls.

The thesis concludes in Chapter 7 with an elaborate discussion of the thesis' results and provides conclusions on potential applications and future directions. Together these chapters are set to explore the potential reasons, behavioural and neural, behind SRs' atypical superiority in face recognition, thereby extending our knowledge about face processing in order to give rise to new clinical and forensic applications.

Chapter 2 – Face processing: Literature Review

2.1 Introduction

Faces are amongst the most important stimuli in social cognition (Adolphs, 2003) and only tenths of a second of face scanning suffice to extract such social information as gender, age, race, attractiveness and even identity (Bruce & Young, 1986; Fitousi & Wenger, 2013; Fiske & Neuberg, 1990). Such a rapid discrimination of identities is an impressive skill considering how similar faces are in their general structure. Accumulating findings from the past decades suggest that our expertise in face processing is facilitated by innate mechanisms that guide face perception development from birth (Fantz, 1963; Gabay, Burlingham, & Behrmann, 2014; Goren, Sarty, & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991; Khalid, Finkbeiner, König, & Ansorge, 2013; for a review see Rivolta, 2014). For instance, one of the most striking observations is neonates' preferential attention towards faces and face-like stimuli (Fantz, 1963; Goren *et al.*, 1975; Johnson *et al.*, 1991). This behaviour demonstrates the presence of rudimentary mechanisms biasing humans' attention to faces and most likely contributing to a prompt development of face processing structures. The contributions of these primitive mechanisms to face perception appear to persist in adulthood (Gabay *et al.*, 2014; Khalid, Finkbeiner *et al.*, 2013).

The uniqueness of faces as stimuli is supported by the reaction they elicit at the level of neural/electrical activity. Electroencephalography (EEG) is one of the current techniques used to record brain activity and when participants are exposed to face stimuli, the neurons fire in a characteristic manner (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer, 2000). More strikingly, schematic faces or any other type of stimuli, which remind participants of a face (e.g., eyes), will elicit a similar neural/electrical response (e.g., Kottlow, Jann, Dierks, & Koenig, 2012; Maratos, Garner, Hogan, & Karl, 2015; Rodriguez *et al.*, 1999).

Our selective attention towards faces may partially explain the dissociation between face and non-face stimuli processing. From a social perspective, faces appear to be more important than any other type of object, and some researchers suggest that faces may be perceived and remembered by a different set of cognitive and neural mechanisms than non-face stimuli (e.g., Carmel & Bentin, 2002; De Haan & Nelson, 1999; Jeffreys, 1996; Sato & Yoshikawa, 2013; Thoma & Lavie, 2013), while others disagree, proposing that faces and objects are processed by the same cognitive and neural entity (e.g., Behrmann & Plaut, 2013; O'Toole, Jiang, Abdi, & Haxby, 2005). However, based on clinical cases, face processing has been shown to be impaired independently from non-face objects and vice versa (e.g., Buxbaum, Glosser, & Coslett, 1998; Duchaine & Nakayama, 2005; Moscovitch, Winocur, & Behrmann, 1997; Sorger, Goebel, Schiltz, & Rossion, 2007; Susilo, Wright, Tree, & Duchaine, 2015), and these dissociations support the notion of faces being 'special'. That said, faces may be merely objects of expertise, as other objects of expertise (e.g., for bird experts or car experts) appear to be processed in a similar manner to faces. For instance, Diamond and Carey (1986) found that objects of expertise, including faces, are difficult to process when inverted, an effect not usually found for general (non-expert) objects (see section 2.2.2.1.1).

Despite the strong biological predisposition to face processing, face perception and face recognition are significantly influenced by experience. For example, while infants appear to process faces of different ethnicities in a similar manner to those of their own ethnicity, this indiscrimination gradually disappears if their environment is dominated by one ethnicity (e.g., Kelly *et al*., 2007; Quinn, Lee, Pascalis, & Tanaka, 2015). This *perceptual narrowing* results in individuals' greater processing abilities with faces of their own ethnicity, commonly referred to as the *own race bias* or the *other race effect* (e.g., Brigham, Bennett, Meissner, & Mitchell, 2007; Malpass & Kravits, 1969; Wu, Laeng, & Magnussen, 2012). Thus, face processing of other ethnicities appears to suffer in comparison to own ethnicity face processing. It is noteworthy that this role of experience with a specific type of faces, which results in greater face processing performance, is also observed for age (e.g., Wiese, 2012) and gender (e.g., Wolff, Kemter, Schweinberger, & Wiese, 2014), whereby faces of own age and gender are processed more efficiently than faces of different age and gender. Again, the extent of these processing differences is modulated by experience. For example, children raised in multicultural families demonstrate a significantly diminished other race effect (Anzures *et al*., 2012; Heron-Delaney *et al*., 2011), as they seem to process faces of (specific) multiple ethnic groups equally well.

The role of experience is further theorized through the concept of *face space coding* (see section 2.2.3.1.1). Valentine (1991) proposes that faces are discriminated in relation to an internally stored average template or prototype that is "assembled" over the years of face exposure. Accordingly, typical faces resembling the average template are harder to recognise, as they are greater in number as opposed to distinctive faces (e.g., Metzger, 2006) that are proposed to be at a greater distance from the average template. Individual encounters and experiences with different faces result in individuals forming their own unique *face space,* thereby contributing to individual differences in face processing. The role of experience and other aspects of face processing will be further explored in the following sections in order to clarify the potential reasons behind individual differences in face recognition.

2.1.1 Individual differences in face processing

Researchers' interest in face processing is boosted by the wide range of individual differences in face processing abilities. *Acquired Prosopagnosia* (AP), or face blindness (Bodamer, 1947), is a neurological condition, usually following a focal brain lesion, compromising the integrity of brain areas associated with face perception and recognition (e.g., Barton, 2008; Barton, Press, Keenan, & O'Connor, 2002; Dalrymple *et al*., 2011; Damasio, Damasio, & Van Hoesen, 1982). As a result, people with AP have severe difficulties in perceiving (*apperceptive prosopagnosics*) and recognising (*associative prosopagnosics*) faces compared to unaffected individuals (De Renzi, Faglioni, Grossi, & Nichelli, 1991; Fox, Iaria, & Barton, 2008). However, while clinical cases spurred the initial excitement over the individual differences encountered in face processing, research from the past decade demonstrates that the typical population without brain damage exhibits significant and informative differences in face processing abilities as well. Importantly, individual differences in face processing appear to be modulated by genetic factors (e.g., Westberg *et al*., 2016; Wilmer *et al*., 2010). For instance, a recent twin study recruiting 2000 participants showed substantial heritability of face recognition ability and that this genetic influence is not shared with other general cognitive abilities (Shakeshaft & Plomin, 2015). Individual differences in face processing have also been attributed to various personality types, moods and levels of arousal (e.g., Bate, Parris, Haslam, & Kay, 2010; Beattie, Walsh, McLaren, Biello, & White, 2016; Cheung, Rutherford, Mayes, & McPartland, 2010; Davis *et al*., 2011; Hills, Werno, & Lewis, 2011; Hills, Marquardt, Young, & Goodenough, 2017; Li *et al*., 2010; Megreya & Bindermann, 2013) and other differential cognitive underpinnings (e.g., attention allocation, Wang, Sun, Ip, Zhao, & Fu, 2015). It is noteworthy, though, that there remains a debate about whether there are gender differences in face processing, as some studies find female advantage (e.g., Cross, Cross, & Daly, 1971; Sun *et al.*, 2016), while others find no significant differences between male and female individuals (e.g., Scherf, Elbich, & Motta-Mena, 2017). Furthermore, face processing does not seem to be significantly attenuated by general intelligence or other cognitive abilities (e.g., Davis *et al.*, 2011; Duchaine & Nakayama, 2006; Palermo, O'Connor, Davis, Irons, & McKone, 2013; Wilmer, Germine, & Nakayama, 2014; although see Gignac, Shankaralingam, Walker, & Kilpatrick, 2016). Importantly, this observation is found for participants across different age groups as well. For instance, Hildebrandt, Wilhelm, Schmiedek, Herzmann, and Sommer, (2011) tested 448 individuals aged 18 – 82-years, and found that their age related decline in face recognition ability was independent from their age related decline in general cognitive ability. Furthermore, individuals with face recognition impairment demonstrate no impairment or deviations in general intelligence or general cognitive ability (e.g., Duchaine, Yovel, Butterworth, & Nakayama, 2006; Duchaine & Nakayama, 2006a).

It has been proposed that the *neuro-typical* population, with no history of brain damage, is normally distributed on a spectrum of face processing skills, resulting in some people being better at discriminating and recognizing faces than others (Bowles *et al.*, 2009; Russell *et al.*, 2009; Russell, Chatterjee, & Nakayama, 2012). Indeed, a simple face matching task (where two stimuli are required to be judged as "same" or "different" without any weight put on memory/recognition) appears to generate a broad spectrum of normally distributed scores (Megreya, Bindemann, & Havard, 2011; Megreya & Bindemann, 2013; Megreya & Bindemann, 2015), while the same observation has been made for face recognition tests (Bobak, Pampoulov, & Bate, 2016; Bowles *et al.*, 2009).

Importantly, this spectrum of individual differences in face processing has been found to reflect quantitative and qualitative differences. For instance, research suggests that face discrimination (i.e., differentiation) is achieved by perceiving the face's surface reflectance (e.g., texture, colour, light reflected off the surface) and the shape of facial features (e.g., Caharel, Jiang, Blanz, & Rossion, 2009; O'Toole, Vetter, & Blanz, 1999). Russell *et al.* (2012) used this paradigm do demonstrate the quantitative nature of individual differences observed in face processing. In their study, participants were asked to match two faces that only differed either in surface reflectance or shape dimension. The results showed that the shape dimension generated better performance (Russell *et al*., 2012). Thus, despite a wide distribution of face processing abilities in their participant samples, the study generated a similar pattern of results - a greater reliance on shape, thereby reflecting *quantitative* differences in individual face recognition ability.

Individuals with AP, on the other hand, are presumably forced to employ *qualitatively* different strategies to viewing faces. For instance, Ramon, Busigny, and Rossion (2010) found that unlike healthy controls, who processed facial features and the spatial relationship between them as a unified whole (see section 2.2.2.1), AP participants relied on individual feature processing (see also Ramon & Rossion, 2010). Thus, while they appear to be at the low end of the spectrum for face processing, their impairment does not stand for a simple quantitative inferiority, but is of a qualitative nature instead (Busigny *et al.*, 2014; Van Belle, De Graef, Verfaillie, Busigny, & Rossion, 2010). Yet one of the crucial developments in the literature highlights the existence of individuals who are atypically poor at face perception and face recognition in the absence of a brain lesion (Behrmann & Avidan, 2005; Duchaine & Nakayama, 2006a). Instead, they appear to have failed to develop the face processing networks

(Behrmann, Avidan, Gao, & Black, 2007; Garrido *et al.*, 2009; Thomas *et al.*, 2009) that reflect the automatic and effortless face discrimination amongst members of the typical population. Accordingly, this condition is commonly referred to as *developmental prosopagnosia* (DP), and it is yet unclear whether DPs' place at the low end of the face processing spectrum reflect a mere quantitative inferiority (e.g., Barton & Corrow, 2016), or if their difficulties reflect potential qualitative causes. Importantly, Russell *et al*. (2012) compared DPs' reliance on surface reflectance and feature shape to that of unaffected individuals from the general population and, despite the difference in accuracy, found both groups to rely equally on both types of information, with an emphasis on feature shape. These particular findings could indicate that DPs' face processing skills are merely quantitatively inferior compared to individuals in the general population. On the other hand, Bobak, Parris, Gregory, Bennetts, and Bate (2017) found that their DPs (n = 10) spent significantly less time fixating the eye region, and more time fixating the mouth region of face stimuli. The authors thus suggested that these results could indicate a qualitative difference in scanning, thereby challenging the quantitative inferiority hypothesis.

Recent observations also bring into focus the opposite end of the face processing spectrum. It appears there are "*super-recognisers*" (SRs) whose face recognition is far superior to that of the typical population; and so far, the few studies exploring this matter have suggested that their superiority is quantitative in nature, as they too rely on feature and surface reflectance to the same extent as the general population (Russell *et al*., 2009; Russell *et al*., 2012). For instance, Bobak *et al*. (2017) showed that both SRs and controls spent more time fixating the nose compared to the eye and mouth regions of the face stimuli, though SRs' dwell time on the nose was significantly greater. The authors also demonstrated that dwell time on the nose region correlated with face recognition ability and they concluded that SRs appear to show a mere quantitative superiority in face processing ability.

It is noteworthy that only ten studies examining SR have been published (see section 2.4), and given the small samples recruited, it is still possible that SRs' superiority in perceiving or recognising faces stems from distinct neural and cognitive processes that are quantitative as well as qualitative in nature. Therefore the present thesis was designed to explore whether SRs' superior face processing skills are associated with behavioural and neural/electrical activity that is distinct from that of the participants within the normal range. Understanding what contributes to their face processing superiority, and whether these factors are quantitative or qualitative, i.e., whether they use differential perceptual strategies, will broaden our knowledge of the subject, which may potentially be applied to clinical and forensic settings. For instance, establishing what distinguishes SRs from individuals with average face recognition could be useful in developing training paradigms to improve police officers' skills in making appropriate identifications (see section 7.3.1).

2.2 Face processing stages

Critically, given that face processing involves two main stages (i.e., face perception and face recognition; e.g., Bowles *et al.,* 2009; Bruce & Young, 1986; Haxby, Petit, Ungerleider, & Courtney, 2000; He, Garrido, Sowman, Brock, & Johnson, 2015), individual differences in face processing ability may stem from either one of the stages. For example, as mentioned before, AP has been subdivided into two types, *apperceptive* and *associative*. Apperceptive AP is manifested through defective face perception and recognition, while perception in associative AP appears to be spared, and they demonstrate only recognition impairment (e.g., De Renzi *et al*., 1991; Fox *et al.,* 2008). The same observations have been made for DPs, as they do not always show impaired perception (e.g., Avidan, Hasson, Malach, & Behrmann, 2005; Dalrymple, Garrido, & Duchaine, 2014; Eimer, Gosling, & Duchaine, 2012).

Face perception and face recognition have been further subdivided into separate sub-stages. Bruce and Young (1986) proposed a cognitive model depicting familiar face recognition. In its simplified version, face perception is discussed in terms of *pictorial* (1) and *structural encoding* (2), whereby image properties and facial structure are processed, respectively. Face recognition is discussed in terms of the *Face Recognition Units (3), Person Identity Nodes (4) and Name Retrieval (5)*. The face in question is compared to previously stored face templates at the level of Face Recognition Units, and upon successful matching, it activates Person Identity Nodes, which allow retrieval of identity-related information; and finally the name associated with this face is retrieved. Face Recognition Units have been associated with implicit recognition of faces, as neurophysiological data reveals familiarity related behaviour in the absence of explicit recognition (e.g., Eimer *et al.,* 2012; Gosling & Eimer, 2011). Person Identity Nodes, on the other hand could be attributed to explicit recognition prior to the person's name recollection. Indeed, the distinction between Person Identity Nodes and name retrieval has been supported by clinical cases where patients could recognise faces but failed to provide their names (Harris & Kay, 1995; Reinkemeier, Markowitsch, Rauch, & Kessler, 1997). In neuro-typical individuals this phenomenon is most commonly known as 'tip of the tongue', when one struggles to remember a name of someone they know.

One of the drawbacks of this model is its serial nature, whereby one perceptual or cognitive stage must complete its processing before the subsequent stage can start processing the visual percept further. Burton, Bruce, and Johnston (1990) proposed a similar model where the same cognitive stages received feedback in a top-down manner, making it an *Interactive Activation and Competition* (IAC) model. For example, familiar and unfamiliar faces are proposed to be processed in a different manner (e.g., Megreya & Burton, 2006; see section 2.3) therefore, counterintuitively, the decision about face familiarity appears to influence face perception, and not the other way around (Buttle & Raymond, 2003; Kloth *et al.*, 2006). Furthermore, Burton *et al.* (1990) added another cognitive component, which stored all the semantic information related to the face, called *Semantic Information Units*. It is noteworthy that Herzmann and Sommer (2010) used EEG recording to demonstrate that when participants remembered the face and the semantic information related to that face, brain activity is attenuated at early stages of face processing – structural encoding. Therefore, semantic information which is activated at a relatively late stage of face processing, activates earlier stages of face processing in a feedforward manner, thereby demonstrating the interactive nature of face processing stages which do not function in a strictly serial manner (see section 2.3).

Yet, since several studies failed to support this model in relation to name retrieval, Brédart, Valentine, Calder, and Gassi (1995) proposed a new model, which matched the IAC model with the exception of name retrieval taking place through a separate lexical route. That way, names were stored separately from Semantic Information Units, which were reserved for all non-lexical information as it could be conceptually represented with less effort than names. This model (still referred to as IAC) partially explains why name retrieval is more difficult than retrieval of other semantic information (e.g., Cohen & Faulkner, 1986).

A large body of research has provided support for IAC models and the dissociation between face perception and face recognition, using different imaging techniques (e.g., George *et al*., 1999; Gorno-Tempini *et al*., 1998; Haxby *et al.*, 2000; Hoffman & Haxby, 2000; Leveroni *et al*., 2000; Minnebusch, Suchan, Köster, & Daum, 2009; Sergent, Ohta, & MacDonald, 1992). Functional Magnetic Resonance Imaging (fMRI) is one of the techniques used to investigate brain activity. It measures Blood Oxygenation Level Dependent (BOLD) contrast to infer what brain areas are activated to initiate a particular function, as a more active area uses up more oxygen. Accordingly, imaging studies focusing on face processing have revealed a set of areas presumed to be involved in face perception and face recognition.

From a neural perspective, face processing has been explained through the core and extended systems. The core system (Figure 2.2.1) comprises *Occipital Face Area*, *Fusiform Face Area* and *Superior Temporal Sulcus*, and is thought to reflect perception and recognition of faces (e.g., Gauthier, Skudlarski, Gore, & Anderson, 2000; Harris, Young, & Andrews, 2014; Minnebusch *et al.*, 2009; Tsao & Livingstone, 2008). Thus researchers tend to associate the core system processing with pictorial processing, structural encoding, Face Recognition Units and Person Identity Nodes. For instance, Harris and Aguirre (2010) demonstrated that *Fusiform Face Area* participates in structural encoding by manipulating perceptual strategies during face processing (see section 2.2.2.2). Furthermore, when Axelrod and Yovel (2015) examined face discriminability (i.e., differentiation between two identities), fMRI data only showed significant activation at the level of Fusiform Face Area, thereby accentuating its role in identity discriminability as well. While generally associated with bilateral activation of face-related brain areas (e.g., Frässle *et al.*, 2015), face processing appears to demonstrate right hemisphere dominance in the Fusiform Face Area (e.g., Frässle *et al.*, 2015; Rossion & Boremanse, 2011). Indeed, it has been argued that the right hemisphere dominance in face processing is potentially the result of the language-related networks predominantly developing and growing stronger in the analytical left hemisphere (e.g., Dundas, Plaut, & Behrmann, 2012; 2014; for a review see Ventura, 2014).

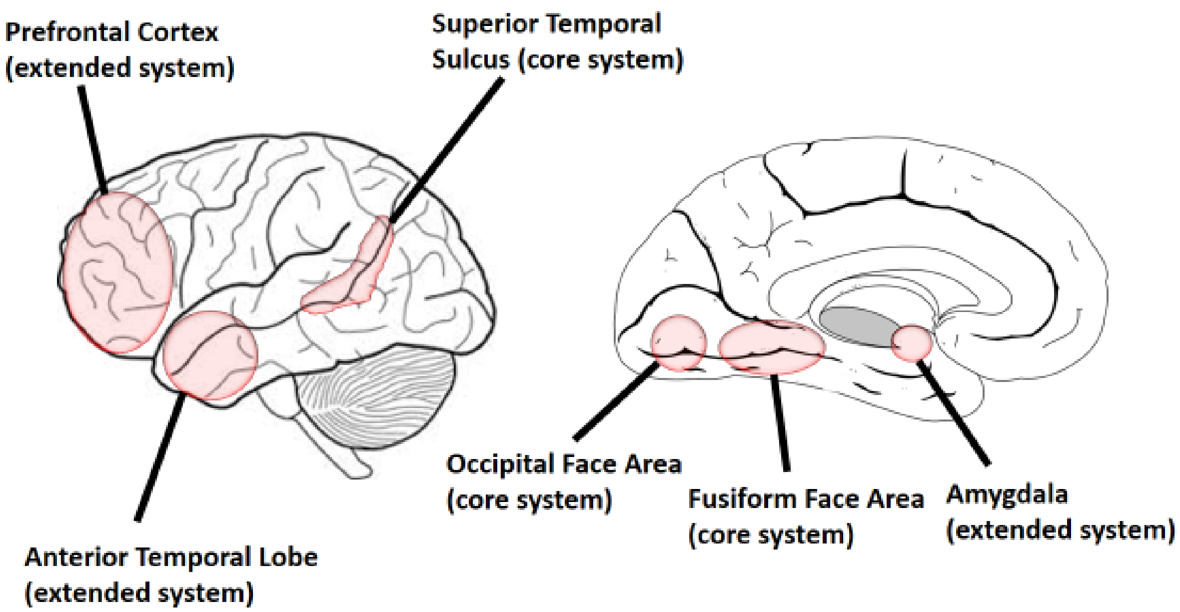

Figure 2.2.1. The core and extended systems comprising brain areas related to face processing. The original (unmarked) images of the brain were acquired from the public domain.

The extended system (Figure 2.2.1), on the other hand, comprises *Anterior Temporal Lobe*, *Amygdala* and several regions of *Prefrontal Cortex*, and appears to reflect the retrieval of semantic information related to faces (e.g., Chan & Downing, 2011; Leveroni *et al.*, 2000; Nielson *et al.*, 2010). Hence the processing taking place at the extended system is thought to reflect Person Identity Nodes, Semantic Information Units and name retrieval of the IAC model described in the previous paragraphs (e.g., Ross, McCoy, Wolk, Coslett, & Olson, 2010). For example, Brambati, Benoit, Monetta, Belleville, and Joubert (2010) used fMRI to distinguish between left and right Anterior Temporal Lobes. They found that the right brain site presumably reflects retrieval of general and specific semantic knowledge about a person, while the left brain site appears to reflect retrieval of only specific semantic knowledge. Thus, in agreement with research studies demonstrating right hemisphere dominance in face processing (e.g., Watanabe, Kakigi, Koyama, & Kirino, 1999; Yovel & Kanwisher, 2004; see also Collins & Olson, 2014) patients with right Anterior Temporal Lobe lesions end up with more pronounced impairments than patients with left Anterior Temporal Lobe lesions. Together, the core and extended systems are two complex networks which play complementary roles in face processing (e.g., Minnebusch, Suchan, Köster, & Daum, 2009; Nasr & Tootell, 2012).

Face perception and face recognition appear to have different developmental trajectories, as the two mature and decline at a different pace (e.g., Bowles *et al*., 2009; Crookes & McKone, 2009; Weigelt *et al*., 2014; Megreya & Bindemann, 2015). However, despite the developmental differences, participants' performances in face perception and face recognition are positively correlated (Veld, Stock, & Gelder, 2012). Indeed, it makes sense for perception and recognition to be co-dependent, as perception occurs at an earlier stage of face processing, inevitably affecting the subsequent stage – recognition (e.g., De Renzi, Scotti, & Spinnler, 1969; De Renzi *et al*., 1991; Duchaine & Nakayama, 2006a). For instance, applying Transcranial Magnetic Stimulation (which momentarily induces a change in neural excitation on the cortical surface) to Occipital Face Area resulted in a temporary recognition impairment (Jonas, Descoins, & Koessler, 2012; Zhao *et al*., 2016). Given that Occipital Face Area is one of the first, serially speaking, regions implicated in perception, these studies demonstrated that disrupting perceptual processing results in disruption of the subsequent stage of processing - recognition.

Note that the face processing model introduced by Bruce and Young (1986) discusses pre-experimentally familiar face recognition; therefore it does not directly apply to processing faces learnt in laboratory experiments. Indeed, there are no existing models explaining face processing in relation to newly (experimentally) learnt faces. However, one important distinction between familiar and unfamiliar face recognition concerns the Face Recognition Unit. It is argued that the Face Recognition Unit can only be activated by an identity which has been encountered on several occasions in different viewing conditions (Bruce & Young, 1986). Thus, an experimentally learnt face, with short and infrequent exposure during encoding/memorising stages, is thought to create a single internal representation of that face. During the recognition stage, this internal representation is either activated or not, resulting in recognition or a miss. Note that most research, as well as the studies reported in this thesis, has employed experimentally learnt (unfamiliar) faces with single exposure during encoding/memorising stages of testing. Indeed, the use of experimentally learnt faces allows the study of identity processing without such confounding/influencing factors as, for example, an uneven amount of semantic information related to specific identities.

2.2.1 Neural/electrical markers of face processing stages

EEG studies have also been used to examine pictorial and structural encoding, Face Recognition Unit, Person Identity Nodes and Semantic Information Units at the level of neural activity. Neuron communication occurs through action potentials which generate electrical impulses - post-synaptic potentials, to propagate other neurons. This post-synaptic activity is what the EEG electrodes pick up on from thousands of neurons firing in synchrony (Cohen, 2014; Dickter & Kieffaber, 2014; Luck 2005) and thus generating a strong enough overall signal for detection and recording by EEG amplification equipment. EEG provides a direct means of measuring the generation of electrical potentials, referred to as 'brain activity', allowing insights into underlying brain function. When EEG is time-locked to a specific event, such as face presentation, *Event Related Potentials* (ERPs) show the change in electrical potential associated with this event. The basic principle underlying ERP extraction is that averaging over a large number of repeated trials will cause random noise to be averaged out, leaving only the stimulus-dependent electrical responses which occurs systematically and at around the same time in each trial. It should be noted that it is notoriously difficult to link any change in ERP activity directly to a specific function. However, studying ERPs in a controlled experimental manner can still provide insights into the way in which individuals differ in their processing of cognitive tasks and this can provide insights into key differences in processing associated with performance differences.

Several ERPs have been linked to face processing. N170, for instance, is a wave of negative electrical activity that peaks over occipito-temporal sites, with right hemisphere dominance, at approximately 170msec after the onset of stimulus presentation (see Figure 2.2.1.1). N170 is significantly larger in amplitude for faces than for other types of stimuli (e.g., Bentin *et al*., 1996, Eimer 2000; Herzmann & Sommer, 2010; Rossion & Jacques, 2008) and has been associated with structural encoding of the face (e.g., Kloth & Schweinberger, 2010; Kloth, Schweinberger, Kovács, 2010). It appears that N170 is modulated by face identity or face familiarity, as the component can be different in amplitude depending on whether the face is recognised or not (e.g., Herzmann & Sommer, 2010; Kloth *et al*., 2006; Shen *et al*., 2016).

For instance, as previously mentioned, Herzmann and Sommer (2010) manipulated the amount of information available for each test face and demonstrated, that remembering semantic information about a face attenuated N170. Accordingly, this demonstrates the interactive nature of the face processing network depicted in the IAC model, whereby a recognised face (activation of Face Recognition Unit, Person Identity Nodes and Semantic Information Units) influences earlier stages of face processing (pictorial or structural encoding; see also section 2.3). Importantly, studies with combined neural measuring techniques, i.e., EEG and fMRI, found a relationship between N170 and Fusiform Face Area activity (e.g., Horovitz, Rossion, Skudlarski, & Gore, 2004; Sadeh, Podlipsky, Zhdanov, & Yovel, 2010), thus N170 has some connection to identity processing, whether it is direct or not. On the other hand, other studies show that N170 is sensitive to identity only in people with good, but not poor recognition skills (e.g., Turano, Marzi, & Viggiano, 2016), perhaps explaining the fact that not all studies find N170 is modulated by face identity (e.g., Pfütze, Sommer, & Schweinberger, 2002; Tanaka, Curran, Porterfield, & Collins, 2006).

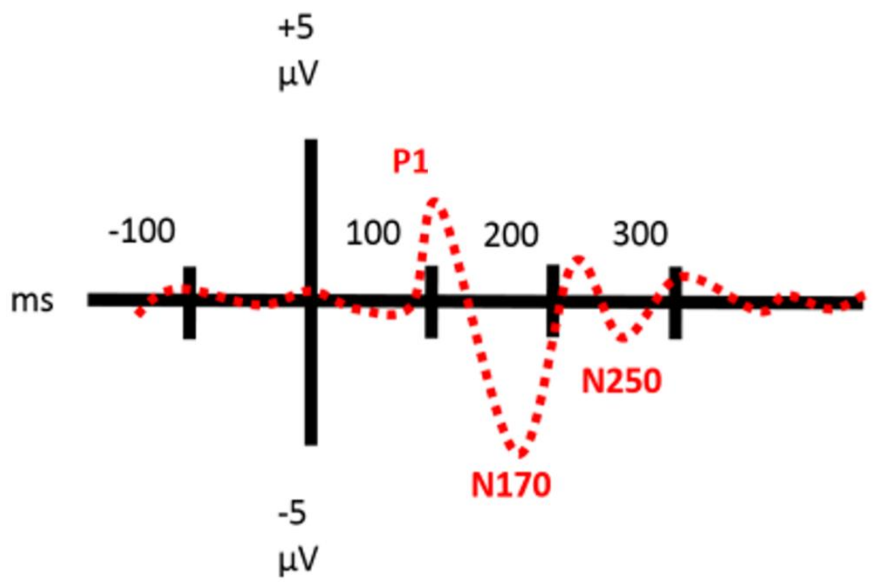

Figure 2.2.1.1. Early Event Related Potentials related to face processing (averaged out across multiple trials).

Importantly, N170 may not be the earliest ERP component related to face processing. P1 is a positive component peaking at approximately 100msec at Occipital sites after the stimulus onset and was originally thought to reflect (attention-dependent) general pictorial encoding during visual processing (e.g., Luck, 2005) and found to be unaffected by individual differences in face processing (e.g., Herzmann, Kunina, Sommer, & Wilhelm, 2010). However recent findings indicate that this component may be face-specific. For instance, Turano *et al.* (2016) showed that P1 is modulated by individual differences in face recognition ability. Specifically the authors found that P1 was enhanced to faces compared to objects in individuals with good face recognition ability (defined as 1 SD above the estimated population mean score on the Cambridge Face Memory Test). Individuals with poor face recognition ability (defined as 1 SD below the mean score), on the other hand, showed similar P1 amplitudes for faces and objects. The authors suggested that this modulation is indicative of good recognisers perhaps showing an early neural tuning to faces, whereby perceptual processing is driven more efficiently

Another important ERP related to face processing is N250 (see Figure 2.2.1.1), which is maximal at approximately 250msec after stimulus onset over tempo-parietal sites and has been linked to identity discrimination/differentiation (Eimer *et al.,* 2012; Kaufmann, Schweinberger, & Burton, 2009; Pfütze *et al*., 2002; Schweinberger, Huddy, & Burton, 2004). This component has been associated with Face Recognition Units (e.g., Herzmann, Schweinberger, Sommer, & Jentzsch, 2004; Sommer, & Jentzsch, 2004), and implicit face recognition (e.g., Eimer *et al.*, 2012). Furthermore Kaufmann *et al.* (2009) demonstrated that N250 becomes more pronounced in reaction to a recognised identity if the latter has been encoded/memorised on several (as opposed to one) occasions. Accordingly, N250 is larger in amplitude for famous than for unknown faces, as well as larger for personally known than for famous faces (Eimer *et al*., 2012; Pfütze *et al*., 2002; Tanaka *et al*., 2006). Note that despite the general right hemisphere dominance observed for face processing (e.g., Bentin *et al.,* 1996; Eimer, 2000; Frässle *et al.*, 2015; Rossion & Boremanse, 2011), N250 often shows greater amplitudes to recognised faces in the left hemisphere (e.g., Pierce *et al.,* 2011; Tanaka *et al.,* 2006). Thus it appears that not all stages of face processing demonstrate right hemisphere dominance. Furthermore, interpretations of the N250 component are not always straightforward. For instance, while some studies suggest that N250 amplitude increases with the ease of processing, as discussed above (Herzmann & Sommer, 2007; Pfütze *et al*., 2002; Tanaka *et al*., 2006), others suggest that the increase in N250 amplitude is indicative of a more effortful processing, as observed for processing faces of other ethnicities (e.g., Herzmann, 2016, see also section 2.2.3.2). Thus ERP findings should always be discussed with caution, especially when exploring individual and group differences.

N250 is usually accompanied by centro-parietal N400, which has been attributed to retrieval of semantic information, thus reflecting Person Identity Nodes and Semantic Information Units, though this component is thought to reflect implicit retrieval of this information (Herzmann & Sommer, 2007). Conscious recollection of identity and related background information has been assigned to *Late Positive Component*, which occurs at parietal sites 500-800msec after stimulus onset (e.g., Rugg & Allan, 2000; Rugg & Curran, 2007). Given its neural characteristics, Late Positive Component is also interchangeably referred to as parietal old/new effect. It is noteworthy that Vilberg, Moosavi, and Rugg (2006) showed that Late Positive Component can be modulated by the amount of background information retrieved, suggesting that it is not a purely face identity component, but a component reflecting person identity along with person-related background information.

Owing to the cognitive and biological distinctions between perception and recognition, individual differences in face processing, i.e., SRs' superiority, may arise from either one of the stages (i.e., perception and recognition). Bobak, Hancock, and Bate (2015), for instance, found that SRs perform better than controls on both perceptual face matching and face recognition tasks. Importantly, not all SR outperform individuals with average recognition ability on perceptual face matching tests (e.g., Bobak, Dowsett *et al*., 2016); thereby further segregating face perception from face recognition. Thus, to understand SRs' outstanding ability, face perception and face recognition should be examined separately as well as interactively, via perceptual matching and recognition tasks. Furthermore, given that DP, a condition reflecting one end of face processing spectrum, has proven to be a heterogeneous condition (e.g., Le Grand *et al*., 2006; Schmalzl, Palermo, & Coltheart, 2008), SRs, a condition reflecting the opposite end of the spectrum, may demonstrate significant heterogeneity as well.

2.2.2 Face perception

The unique nature of faces generates specific and distinct ways of processing them. Beside the face's surface reflectance (pigmentation), researchers have described two aspects of information that can be extracted during face processing: (1) the type of features (e.g., shape, size, colour) and (2) their spatial relations, commonly referred to as *second-order configurations* (e.g., Lobmaier, Bölte, Mast, & Dobel, 2010; Rotshtein, Geng, Driver, & Dolan, 2007). For instance, a number of studies used Jane stimuli to explore the relevance/importance of feature and second-order configuration during face processing (e.g., Freire, Lee, & Symons, 2000; Leder, Candrian, Huber, & Bruce, 2001; Leder & Bruce, 2000; see also Maurer, Le Grand, & Mondloch, 2002). Jane stimuli comprise one identity which is altered across trials either on the feature dimension or the second order configuration (i.e., spatial relations between features) dimension. Thus, in each trial the same identity is either presented with different eyes/mouth/nose, or with different spatial distances between these features (see Figure 2.2.2.1). Studies have demonstrated that noting the differences in second order configuration is significantly more difficult during inverted face presentation, implying that the spatial relations between features play an important role in upright face processing (for a review see Maurer *et al*., 2002). On the other hand, Wang, Quinn *et al*. (2015) found that participants' performances were similar across feature and second order configuration manipulations when they were presented with Jane stimuli of other ethnicities. Therefore other ethnicity faces appear to require less reliance on second order configurations than own ethnicity faces. Furthermore, while some studies show that the extent of second-order configuration processing is positively correlated with face recognition (e.g., Murray, Halberstadt, & Ruffman, 2010; Rotshtein *et al.*, 2007), Siéroff (2001) showed that boosting attention to individual features during face encoding, boosts face recognition performance as well (see also section 2.2.2.2).

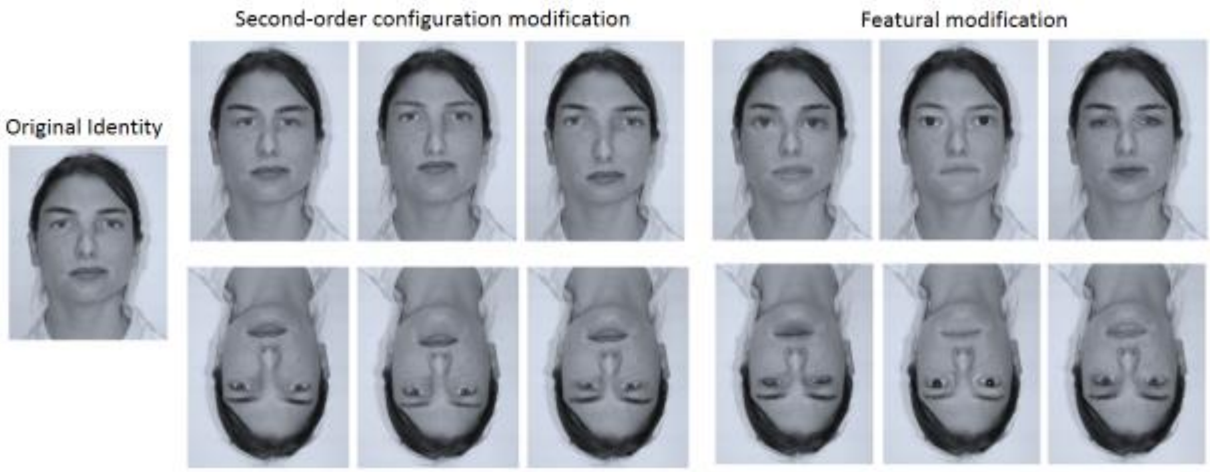

Figure 2.2.2.1. An example of Jane stimuli. The original stimulus is manipulated with the second order modifications and feature modifications. Second-order configuration modifications (left side) are more difficult to spot when faces are inverted. The images were acquired from the database of The Park Aging Mind Laboratory at the University of Texas at Dallas (Minear & Park, 2004). The original facial identity was completely altered in Photoshop.

There have also been debates about whether faces are processed *configurally* or *holistically* even though the two terms are sometimes used interchangeably. However, configural processing stands for the processing of second-order configurations (spatial relations), while holistic processing stands for the processing of both features and second-order configurations (e.g., Yovel & Duchaine, 2006). Importantly, both configural and holistic processing studies suggest that second order configurations play a more important role than individual features in upright face processing. However, holistic processing suggests that all face information (features and second order configurations) is perceived as a unified percept in the neuro-typical population (Yovel & Duchaine, 2006). Configural processing, on the other hand, implies that feature information is processed separately from their spatial relations (Freire *et al*., 2000; Leder *et al*., 2001; Leder & Bruce, 2000; see also Maurer *et al*., 2002). Research findings indicate that features and spatial relations are indeed processed simultaneously (e.g., Boremanse, Norcia & Rossion, 2013; Kimchi, Behrmann, Avidan, & Amishav, 2012), favouring the holistic processing model. Indeed, Kimchi *et al.* (2012) demonstrated that individuals with typical face processing ability are incapable of processing features without being influenced by second order configurations and vice-versa.

As evidence suggests that facial features and second order configurations are processed simultaneously; holistic processing was further explored in this thesis as a potential factor contributing to SRs' exceptional face recognition ability. Importantly, SRs may demonstrate a different reliance on holistic processing compared to individuals with average face recognition ability, reflecting either quantitative or qualitative differences in their perceptual strategies. The next section thus describes the different paradigms designed to measure individual differences in holistic processing, some of which were employed in this thesis.

2.2.2.1 Holistic processing

A large body of research has demonstrated that whole face or holistic processing may dominate the processing of faces in the neuro-typical population (e.g., Abbas & Duchaine, 2008; Avidan, Tanzer, & Behrmann, 2011; Palermo, Willis *et al.*, 2011; Schlitz & Rossion, 2006; Susilo & Duchaine, 2013; Yovel, Levy, & Paller, 2005). Indeed, while upright faces are processed in both an holistic and a parts-based manner (e.g., Flevaris, Robertson, & Bentin, 2008; Miellet, Caldara, & Schyns, 2011; Towler & Eimer, 2016), holistic processing is shown to be more effective than parts-based analysis (i.e., processing one feature at a time), owing to its powerful and automatic nature (e.g., Palermo, Willis *et al*., 2011; Rossion, 2008; Young *et al.*, 1987). More importantly, holistic processing appears to be associated with face recognition as people with impaired holistic processing show deficits in face recognition (Avidan *et al*., 2011; Veld *et al*., 2012; Susilo & Duchaine, 2013). Evidence from three pioneering tasks has supported the important role of holistic processing in face perception.

2.2.2.1.1 Inversion Effect

The first evidence of the importance of holistic processing (Figure 2.2.2.1.1.1) comes from the *Inversion Effect* (Goldstein, 1965; Yin, 1969). Many studies have demonstrated that face processing, including gender, attractiveness, trustworthiness and identity discrimination are significantly impaired if faces are presented upside-down (e.g., Bruce & Langton, 1994; Busigny & Rossion, 2010; Goldstein, 1965; Righart & de Gelder, 2007; Robbins & McKone, 2007; Santos & Young, 2008; Yin, 1969). This effect is observed to a significantly smaller extent for non-face objects, as they are thought to induce parts-based processing (i.e., processing one part at a time) in both orientations. It is noteworthy that testing participants on objects of expertise (car experts or bird experts) shows a similar drop in performance for inverted presentation as it does for faces (Diamond & Carey, 1986), suggesting that holistic processing is employed for processing all objects of expertise, and that faces are merely an example of this expertise. The inversion effect is thought to reflect the disruption of holistic processing (e.g., Mondloch & Maurer, 2006; Rossion, 2009; but see Richler, Mack, Palmeri, & Gauthier, 2011; Susilo, Rezlescu, & Duchaine, 2013), namely due to the disruption of the first order configurations - the general allocation of face features within a face. Thus, individuals are forced to process inverted faces in a parts-based manner, one feature at a time, resulting in reduced accuracy or longer reaction times.

EEG studies have successfully demonstrated that inverted face presentation disrupts holistic processing. For instance, Towler and Eimer (2016) used EEG to demonstrate that inverted faces induce parts-based processing, while upright faces induce both parts-based and holistic processing. In a rapid sequential presentation of two stimuli, ERPs tend to generate lower amplitudes to the second stimulus, as a form of neural adaptation referred to as *repetition effect* or *repetition suppression*. Towler and Eimer (2016) showed that upright sequential matching of faces that were simultaneously manipulated by changes in both internal and external features induced a greater neural repetition effect at N250 than the sum of these manipulations administered separately. Whereas inverted face matching showed no difference in neural repetition effects at N250, when comparing simultaneous manipulation with the sum of these separate manipulations. Thus inverted presentation, unlike upright presentation, generated no additive effects on the neural activity, suggesting that the two types of manipulations could not be perceived simultaneously during inverted presentation.

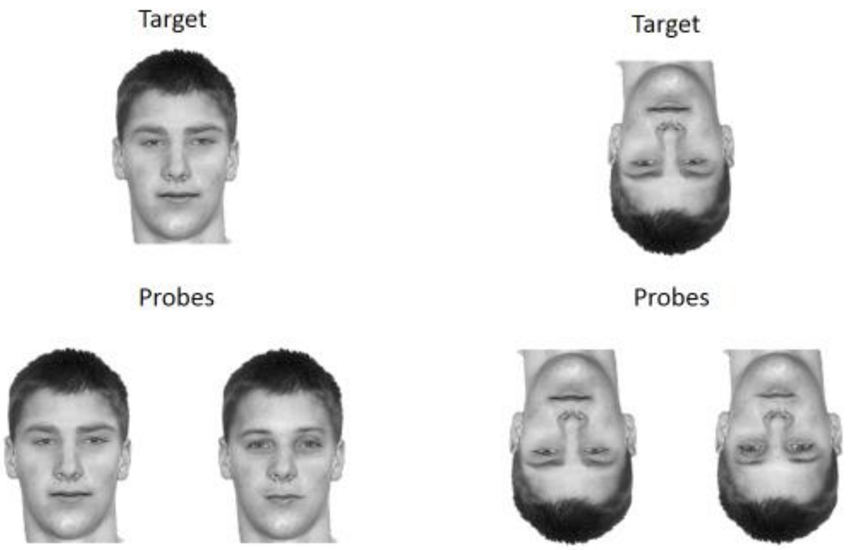

Figure 2.2.2.1.1.1. An example of the Upright and Inverted Face Matching Tests. Participants are required to match probes to target faces in the upright (left) and inverted (right) orientations. The images were acquired from the database of The Park Aging Mind Laboratory at the University of Texas at Dallas (Minear & Park, 2004). The original facial identity was completely altered in Photoshop.

Other EEG studies on face processing show that the N170 component appears to be greater in amplitude and spread in latency when presented with an inverted face, in comparison with upright presentation (e.g., Bentin *et al*., 1996; Eimer *et al*., 2012; for review see Towler & Eimer, 2012). Eimer *et al*. (2012) have suggested that this elevated response is a reflection of more resources being needed for a more demanding analysis, whereas shorter N170 is indicative of more effective face processing, as it presumably allows for a faster activation of configural processing (Kaltwasser, Hildebrandt, Recio, Wilhelm, & Sommer, 2013). However, this ERP effect is not accompanied by a similar Fusiform Face Area reaction. Namely, fMRI findings reveal that a bigger N170 component is accompanied by a reduced activation in the Fusiform Face Area (Kanwisher, Tong, & Nakayama, 1998; Yovel & Kanwisher, 2005). Researchers propose that this discrepancy reflects the notion that participants from the general population process inverted faces in a similar manner as objects, which would result in face related areas being activated to a lesser extent. Striking evidence supporting this view comes from a Transcranial Magnetic Stimulation study, which temporarily disrupted the functioning of the object processing brain area – Lateral Occipital Gyrus (Pitcher, Walsh, & Duchaine, 2011). This selective impairment appeared to have compromised only inverted, not upright, face processing. Thus the increased and prolonged N170 for inverted faces could be the result of object-sensitive areas being activated during inverted face processing. However, while objects and inverted faces appear to involve similar or overlapping processes, given that both tap into parts-based processing, it is possible that the parts-based processing induced by both upright and inverted presentation of faces (see section 2.2.2.2) is distinct from the parts-based processing induced by object presentation. Indeed, given that faces are socially more important than other types of objects (e.g., Adolphs, 2003; see also section 2.1), facial features, even when inverted, are not expected to be processed in the same way as general object parts.

Importantly, AP and DP show no, or significantly reduced inversion effects (e.g., Behrmann & Avidan, 2005; Busigny & Rossion, 2010; Veld *et al*., 2012), meaning their face discrimination performance is equally bad for upright and inverted stimuli. Interestingly, there also exists a *Paradoxical Inversion Effect*, where DPs and APs show better inverted face processing than controls (e.g., de Gelder & Rouw, 2000a; Behrmann, Avidan, Marotta, & Kimchi, 2005). Furthermore, DPs appear to show no characteristic changes in N170 during inverted face perception, suggesting they process faces in both orientations in a similar manner, potentially implying that they process faces in a similar manner to objects (Towler & Eimer, 2012). Researchers suggest that APs (e.g., Ramon & Rossion, 2010) and DPs (e.g., DeGutis, Cohan, Mercado, Wilmer, & Nakayama, 2012) do not process faces holistically because they may have a smaller area of intake, which they can analyse simultaneously. In other words, individuals with prosopagnosia appear to capture only a small portion of a face, where all features and details within that portion can be processed simultaneously. Thus, during face processing, APs and DPs do not benefit from upright face presentation to the same extent as controls, as reflected in their reduced inversion effects. Importantly, Bobak, Bennetts, Parris, Jansari, and Bate (2016) examined holistic processing in SRs by means of inversion effects using two perceptual tests. It is noteworthy that not all SRs (n = 3, 50%) demonstrated a greater inversion effect than controls, and those who did, did not always show it on both tasks, leaving our understanding of their holistic processing inconclusive.

2.2.2.1.2 Composite Face Effect

The second effect (Figure 2.2.2.1.2.1) reflecting the importance of holistic processing in face perception is the *Composite Face Effect (*Young *et al*., 1987). The composite face test takes the top half of a face and compliments it with a bottom half belonging to a different face, creating a new identity. When the original face is presented simultaneously with the artificially created face, participants find it difficult to decide if the top halves of both faces are the same or not (e.g., Young *et al*., 1987; Palermo, Willis *et al*., 2011). Importantly, when the top halves are not aligned with the bottom halves, disrupting the holistic nature of the stimulus, judging whether the top halves are the same or different becomes significantly easier. The Composite Face Effect demonstrates that the holistic nature of faces is both influential and automatic. Even though half of each face is identical across the two stimuli, the presence of different bottom halves makes it difficult to recognise that the top halves are the same.

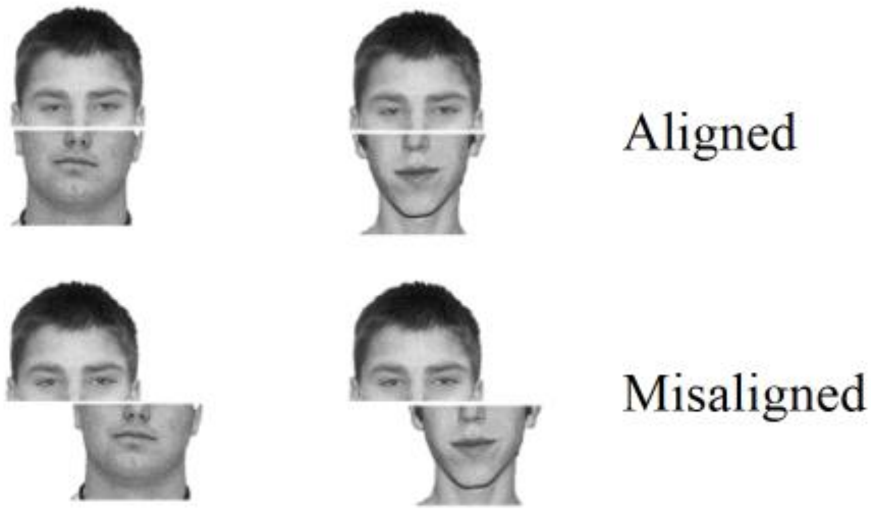

Figure 2.2.2.1.2.1. An example of the Composite Face Test. Participants are required to match top face halves while ignoring the bottom halves in aligned and misaligned conditions. The images were acquired from the database of The Park Aging Mind Laboratory at the University of Texas at Dallas (Minear & Park, 2004). The original facial identity was completely altered in Photoshop.

Researchers have pointed out that the Composite Face Test is not as informative as previously thought, at least when investigating DP, as it generates mixed results across studies (e.g., Avidan *et al*., 2011; Susilo *et al*., 2011). Specifically, DeGutis, Cohan, *et al*. (2012) demonstrated that DPs are able to match healthy controls' performance on this task despite their evident difficulties with face processing. DeGutis, Cohan *et al*. (2012) further demonstrated that DPs do not exhibit a complete lack of holistic processing. Instead, their holistic impairment appears to involve predominantly the eye region, owing to its greater complexity compared to other features. Therefore, given that DPs' impairment of holistic processing may not be absolute, but only partial, it could potentially explain why their performances on the Composite Face Test are similar to that of unaffected individuals. Thus, while DPs generally demonstrate a significantly reduced inversion effect, some may generate a normal composite face effect.

Importantly, a similar observation has been made for SRs, though in the opposite direction. Namely, Bobak, Bennetts, *et al*. (2016) demonstrated that SRs generate a similar composite face effect to that of individuals with typical face processing. Thus, while some SRs show a greater inversion effect (section 2.2.2.1.1), the same SRs displayed a normal composite face effect. The discrepancies in the results observed for DPs and SRs suggest that these tests are not perfect at measuring holistic processing, and if administered one at a time (as opposed to administering both tests to each participant), they may generate inconclusive or even misleading results. Indeed, research shows that different measures of holistic processing do not always correlate with one another, as they demand a different approach from participants, and researchers conclude that these tests may measure different aspects of holistic processing (e.g., DeGutis *et al*., 2013; Wang *et al*., 2012).

2.2.2.1.3 Part-Whole Effect

The *Part-Whole Effect* (Tanaka & Farah, 1993), the third phenomenon of holistic processing (Figure 2.2.2.1.3.1), shows that holistic processing can also facilitate aspects of face discrimination.

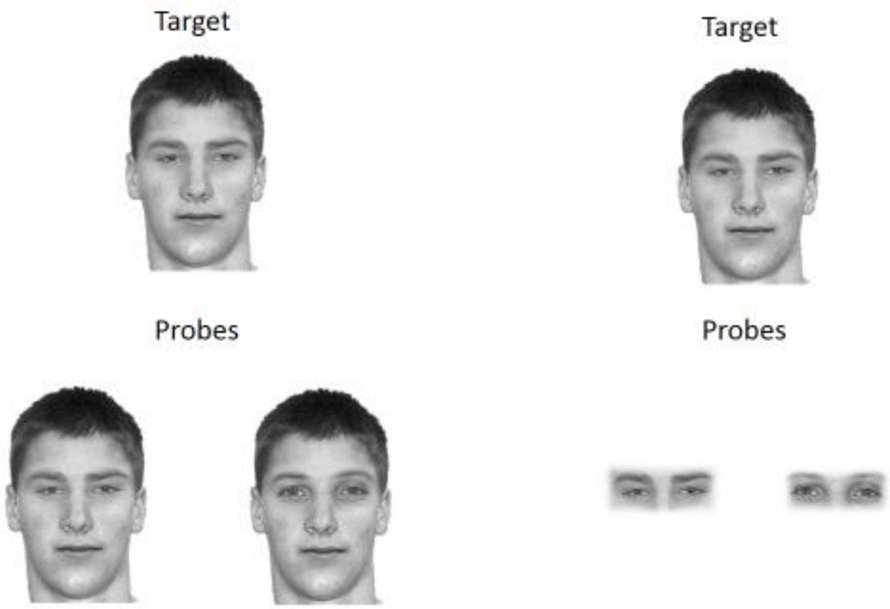

Figure 2.2.2.1.3.1. An example of the Part-Whole Test. Participants are required to match probe faces (left) and probe features (right) to the target face. The images were acquired from the database of The Park Aging Mind Laboratory at the University of Texas at Dallas (Minear & Park, 2004). The original facial identity was completely altered in Photoshop.

In the Part-Whole Test, the participant is asked to discriminate between individual facial features, using an immediate recall paradigm (e.g., DeGutis, Cohan *et al*., 2012; Tanaka & Farah, 1993). In the *whole* condition, participants are presented with a target face, which is immediately followed by two probe faces. The probe images are identical to one another with the exception of one feature (set of eyes, nose or mouth) and only one of the probe images matches the target image. In the *part* condition, the target face is immediately followed by two probe features (set of eyes, nose or mouth), only one of which matches the feature presented in the target face. Studies show that facial feature discrimination is significantly easier when they are presented in the context of the whole face (whole condition), as opposed to in isolation (part condition) (for a review see Tanaka & Simonyi, 2016). Hence, the holistic nature of faces affects individual feature perception as well. The Part-Whole Effect is predominantly observed using upright faces as stimuli, and is often absent for scrambled faces, inverted faces and objects (Tanaka & Farah, 1993; although see McKone *et al*., 2013). The Part-Whole Effect is reduced in DPs (e.g., DeGutis, Cohan *et al.*, 2012) and in participants required to process faces of other ethnicities (e.g., Crookes *et al.*, 2013), indicating a reduced reliance on holistic processing in these groups. There are no documented studies exploring the Part-Whole Effect in SRs.

2.2.2.1.4 Other measures of holistic processing

The general reliance on holistic processing by people within the normal range of face processing has been also supported by a relatively recently developed task - *Gaze Contingent Discrimination Task (GCDT;* Van Belle, De Graef *et al.*, 2010). By employing three conditions of face exposure, participants' performances emphasize individual strengths and weaknesses during faces processing. The three conditions are the 'complete', the 'window' and the 'mask' presentations (Figure 2.2.2.1.4.1). The 'complete' face presentation serves as a control condition, where the participant is exposed to the entire face when matching it to the previously presented target. The 'window' condition requires recognition based on one feature at a time as the software only shows a small window of the image, which is fixated by the participants' eyes. By contrast, in the 'mask' condition the software leaves the entire face image visible with the exception of a little portion fixated by the participants' eyes. Accordingly, the 'window' condition taps into parts-based processing, while the 'mask' condition requires a reliance on holistic processing. The results gathered from this task are quite informative in terms of the qualitative nature of face processing differences. Critically, the 'window' task was significantly more challenging for the general population in comparison with the 'mask' condition (Van

Belle, De Graef *et al.*, 2010). Thus, in line with the majority of studies, the typical population relies on holistic processing to a greater extent than on individual feature analysis.

The same task (GCDT) was employed in investigating one AP (Busigny *et al*., 2014) and six DPs (Verfaillie, Huysegems, De Graef & Van Belle, 2014), in order to compare their perceptual approaches to that of the neuro-typical participants. Importantly, while both types of prosopagnosics demonstrated overall poorer performance than healthy controls, the pattern of results was not identical across AP and DP. While the AP was selectively worse on face discrimination in the 'mask' condition, exhibiting impaired holistic processing, his performance on 'window' trials was comparable to that of healthy controls. Unlike the AP, the six DPs demonstrated a general worsening on all three conditions. These results are in line with some researchers' convictions that while AP is a condition with qualitative impairments in face processing, individuals with DP likely represent the lower end of the face processing spectrum owing to purely quantitative impairments (Eimer *et al*., 2012; Johnson, 2010; Russell *et al.*, 2012).

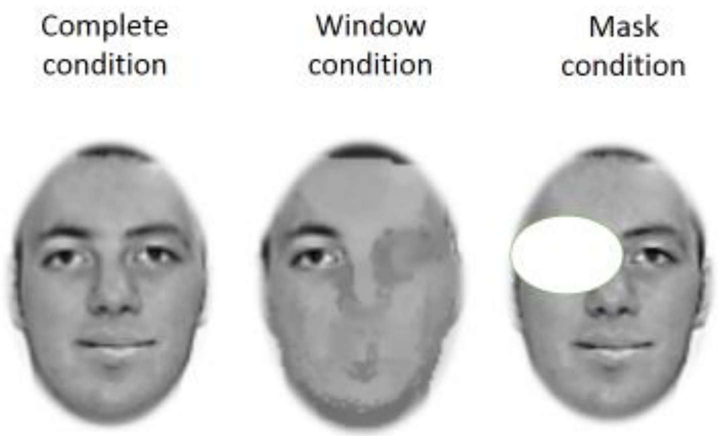

Figure 2.2.2.1.4.1. An example of the Gaze Contingent Discrimination Task. The Window condition induces parts-based processing. The Mask condition induces holistic processing. The images were acquired from the database of The Park Aging Mind Laboratory at the University of Texas at Dallas (Minear & Park, 2004). The original facial identity was completely altered in Photoshop.

Finally, other evidence suggests that, when it comes to the neuro-typical population, faces are indeed processed as a unified whole. Kimchi *et al*. (2012; see also Amishav & Kimchi, 2010) showed that parts-based (feature) analysis is integrated with second-order configuration analysis in healthy controls, which the authors interpret as evidence of holistic processing.

Specifically, participants were asked to judge whether serially presented faces varied in their features or remained the same (*feature relevant condition*), and whether they varied in second-order configurations or not (*configuration relevant condition*). When variations of both types of information occurred simultaneously, healthy controls found it difficult to ignore the irrelevant type of information. Namely, participants took longer to perform on the test when features and second order configurations were manipulated simultaneously, suggesting that the manipulation irrelevant to the set condition was difficult to ignore. This effect is known as *Garner's interference* (Garner, 1974). Importantly, DPs were also investigated in this study and their results suggest that they process both types of information separately because they showed no Garner's interference in either condition (Kimchi *et al*., 2012). In other words, they took the same time to perform in both conditions regardless of whether the manipulations were employed individually or simultaneously. This suggests that DPs are able to ignore irrelevant facial information (features or second order configuration), indicative of impaired holistic processing.

Other studies also demonstrate an interesting dissociation in holistic processing. For instance, studies show that gender discrimination is attainted via holistic processing (e.g., Yokoyama, Noguchi, Tachibana, Mukaida, & Kita, 2014), yet many DPs with impaired holistic processing perform comparably to controls on gender discrimination tasks (Chatterjee & Nakayama, 2012; DeGutis, Chatterjee, Mercado, & Nakayama, 2012). The authors point out that holistic processing appears to be spared for gender and sometimes age discrimination (demonstrated via Inversion Effect) but is not strong enough to discriminate between identities. This dissociable nature of holistic processing is at least partially explained by experience. Namely, people in general have a more successful experience in discriminating gender (only two options) than discriminating between identities. Perhaps this segregation within holistic processing consists of more branches, which are pronounced in some individuals to a greater extent than in others. This dissociation may also play a role in individual differences in face recognition.

The studies described above suggest that holistic processing is the hallmark of face processing. Given that effective holistic processing significantly contributes to effective face processing, this perceptual strategy is an important factor to investigate when comparing SRs to individuals with average recognition ability. As previous research recruited small samples of SRs and generated mixed results (e.g., Bobak, Bennetts, *et al.*, 2016; Russell *et al.*, 2009), holistic processing was further investigated in this thesis in more depth (see Chapter 4).

2.2.2.2. Parts-based processing

As discussed above, the ability to process faces holistically significantly contributes to people's general expertise with face processing. However, Miellet *et al.* (2011) showed that during effective face processing, individuals employ both holistic and parts-based scanning. Namely, their participants used central fixations (for global/holistic information intake) as well as individual feature fixations (see also Bagepally, 2015) when identifying faces.

Figure 2.2.2.2.1. Spatial filter manipulations of face stimuli. Low spatial filter is favourable for global/holistic processing and High spatial filter encourages parts-based processing. The images were acquired from the database of The Park Aging Mind Laboratory at the University of Texas at Dallas (Minear & Park, 2004). The original facial identity was completely altered in Photoshop.

Research shows that parts-based processing, whereby individual features are processed one at a time, makes important contributions to individual differences in face processing (e.g., Chan, Chan, Lee, & Hsiao, 2015; Chuk, Chan, & Hsiao, 2014; Civile, McLaren, & McLaren, 2014; Sæther, Belle, Laeng, Brennen, & Øvervoll, 2009; Van Belle, Ramon, Lefèvre, & Rossion, 2010). For instance, the inversion effect – though initially argued to reflect the disruption of holistic processing during inverted presentation of faces – appears to be partially explained by the parts-based processing disruption as well, in that inverted face processing is hindered because the inverted features are more difficult to process during upside-down presentation (e.g., Civile *et al*., 2014; Barton, Keenan, & Bass, 2001; see for review Maurer *et al*., 2002). Flevaris *et al.* (2008) also demonstrated that holistic and parts-based processing are both important for face discrimination. They used high and low frequency filter presentation (Figure 2.2.2.2.1), which benefit parts-based and holistic processing, respectively, to show that both types of analysis are used during face processing, as both presentations significantly contributed to the generation of N170, the most prominent neural marker of face processing. Thus, again, parts-based processing significantly contributes to effective face processing.

Critically, some studies suggest that N170 is a component that is sensitive specifically to the presence of eyes, as opposed to the entire face (e.g., Bentin, Golland, Flevaris, Robertson, & Moscovitch, 2006; Itier, Alain, Sedore, & McIntosh, 2007; Zheng, Mondloch, Nishimura, Vida, & Segalowitz, 2011), whereas Hills, Ross, and Lewis (2011) suggest that the N170 attenuation (e.g., a wider EEG waveform, indicative of a more demanding processing) during inverted face processing, is the result of participants not looking at the eye region as much when faces are upside down. In addition, Bentin *et al.* (2006) showed that faces with objects in place of eyes elicited N170 that resembled the object ERP, not the face-like ERP, showing that faces without typical eyes do not even elicit a face-like neural response. Therefore, if faces are no longer perceived as faces when certain features are misplaced – without changing the overall configuration of the face – it further points out that parts-based processing is crucial in face processing. In fact studies show that the eyes and mouth are the most important features for identity discrimination, demonstrating the undoubted importance of parts-based processing in effective face discrimination and recognition (e.g., Sæther *et al.*, 2009; Van Belle, Ramon *et al.*, 2010). Other neuroimaging studies have also looked at different patterns of activity generated by parts-based and holistic processing. For instance, Harris and Aguirre (2010) showed that Fusiform Face Area, the one brain area persistently linked to identity discrimination, appears to perform parts-based and holistic processing. Indeed their fMRI study used a composite face test to show that there are neuron populations in the right Fusiform Face Area which are tuned to individual parts, independently from the whole face representations, highlighting the importance of both types of processing in face discrimination. Furthermore, Flack *et al.* (2015) linked Superior Temporal Sulcus activity to parts-based processing. Importantly, Nguyen and Cunnington (2014) found a positive relationship between N170 component and Superior Temporal Sulcus activation, suggesting that this area plays an important role in generating the N170 component. In line with both of these studies, Harris and Nakayama (2008) found that M170 (ERP equivalent for *Magnetoencephalography (MEG)*, another device measuring electrical activity) was more sensitive to facial features than to global properties of a face (although see Mercure, Dick, & Johnson, 2008), thereby solidifying a relationship between N170, Superior Temporal Sulcus and parts-based analysis. That said, several studies using different paradigms (e.g., Mercure *et al.*, 2008; Wang, Sun, *et al.*, 2015) showed no significant modulation differences in N170 using feature and configuration manipulations, while fMRI findings (e.g., Golarai, Chahremani, Eberhardt, & Gabrieli, 2015) also disagree on what face related brain areas can be attributed to parts-based and holistic processing.

Therefore it appears that despite the superior influence of holistic processing on effective face processing (as discussed in section 2.2.2.1), parts-based processing also contributes significantly to individual differences observed in face processing ability as well. For instance, it appears that the more faces are similar to one another the more individuals must rely on parts-based processing as opposed to holistic processing (e.g., Ramon & Van Belle, 2016; see also Barton, Radcliffe, Cherkasova, Edelman, & Intriligator, 2006), thus parts-based processing is crucial for difficult face discrimination. In addition, Chan, Wong, Chan, Lee, and Hsiao (2016) in their eye-tracking study found that individuals with analytical patterns of fixations, indicative of parts-based processing, demonstrated better recognition performance, a finding in line with their previous results (Chan *et al*., 2015; Chuk *et al*., 2014). In addition, some of the most persuasive evidence highlighting the importance of parts-based analysis is the existence of DPs whose face processing deficits cannot be explained by either impaired holistic processing or defective face space coding (see sections 2.1 and 2.2.3.1.1), as both appear to function properly. Susilo *et al*. (2011) report on a case where face space coding and holistic processing were within the normal range, and yet were not sufficient for normal face processing (in this case, both perception and memory). The authors thus suggest that this DP's difficulties may arise from defective parts-based processing or may be a result of a weaker view/image generalization. Furthermore, another case study involving a six-year-old child with DP showed that training him to pay more attention to internal facial features improved his face recognition (Pizzamiglio *et al*., 2015). In addition, Lobmaier *et al.* (2010) used a scrambled/blurred face paradigm to demonstrate that when using unfamiliar faces as stimuli, scrambled faces were easier to process, demonstrating a parts-based advantage, while Lobmaier and Mast (2007) found that familiar face processing demonstrated a more holistic advantage as they are better recognised in blurred as opposed to scrambled conditions (Lobmaier & Mast, 2007). This difference in type of processing was also demonstrated using participants and stimuli of different ethnicity. Tanaka, Kiefer, and Bukach (2004) used the part-whole paradigm to demonstrate that Caucasians view faces of their own ethnicity more holistically, and faces of other ethnicities – in a more parts-based manner. Together these findings indicate that parts-based processing may be crucial for effective face processing, especially under more demanding conditions (unfamiliar faces or faces of other ethnicities).

As discussed previously (section 2.2.2.1), holistic processing appears to be a more effective way of processing faces. Accordingly, if parts-based analysis is not as effective as holistic processing in the general population, then it may be one of the primary candidates for mechanisms reflecting individual differences in face recognition ability, potentially contributing to SRs' superiority. Research involving clinical participant groups shows that those individuals who outperform healthy controls on face recognition tests, appear to achieve this because of the greater attention they pay to individual features. For instance, individuals with *Autism Spectrum Disorder* (ASD) are generally worse at face recognition (e.g., Wallace, Coleman, & Bailey, 2008; for a review see Weigelt, Koldewyn, & Kanwisher, 2012) owing to their apparent indifference towards faces as part of their social impairment (e.g., Baron-Cohen *et al*., 1996; Kanner, 1943; Wing, 1997; Riby & Hancock, 2008). However, depending on the task requirements, some ASD participants will engage in a detailed face scanning, and owing to their heightened attention to detail and features, referred to as *local bias* (e.g., Caron, Mottron, Berthiaume, & Dawson, 2006; for a review see Happé & Frith, 2006) will sometimes outperform healthy controls (Deruelle, Rondon, Gepner, & Tardiff, 2004; Hobson, Ouston, & Lee, 1988). Interestingly a similar observation was made in a study involving a different clinical group, *Body Dysmorphic Disorder*. Since the key feature of this condition is sufferers' preoccupation with their appearance (Phillips, 1996), people diagnosed with BDD pay more attention to individual face features. Critically, Jefferies, Laws, and Fineberg (2012) found that people with BDD perform better on face recognition tests than healthy controls. Thus superior parts-based processing seems to improve typical face processing skills, serving as a plausible underlying cause for SRs' advantage. For example, Royer, Blais, Gosselin, Duncan, and Fiset (2015) showed that people with higher recognition performance relied on minimal information available to them in order to perform a recognition task. Namely, participants performed a recognition task which employed bubblised face images (another form of visual noise which serves to conceal a significant portion of the face). The visual noise level was increased for participants with higher recognition accuracy. The results suggested that people with good recognition ability required less visual information for them to recognise the target face or at least to activate an internal representation of that face (Royer *et al*., 2015). Whether SRs demonstrate a superior parts-based processing to that of the general population was investigated in this thesis (see Chapter 4).

2.2.3 Face recognition

As has been previously mentioned, performance in face perception is positively correlated with performance in face recognition (e.g., Veld *et al.*, 2012). In part, this co-dependence is likely to be explained by the stage-like organisation of face processing. With perceptual processes preceding face recognition, it makes sense that inadequate perceptual strategies are likely to compromise face recognition (e.g., De Renzi *et al*., 1969; De Renzi *et al*., 1991; Duchaine & Nakayama, 2006a). However, it is still possible for SRs to show higher recognition rates to those of controls, despite similar perceptual strategies. Indeed, some SRs show similar matching performance to that of controls (e.g., Davis, Lander, Evans, & Jansari, 2016).

2.2.3.1 Factors predicting individual face recognition

As noted previously, correlational studies have found that individual face recognition abilities can be linked to individual reliance on holistic processing, as demonstrated by the Composite Face Test and Part-Whole Test (DeGutis, Wilmer, Mercado, & Cohan, 2013; Richler, Cheung, & Gauthier, 2011; Wang *et al.*, 2012). However, the same studies suggest not underestimating the role of other perceptual strategies in relation to face recognition (DeGutis *et al*., 2013). In fact, Dennett, McKone, Edwards, and Susilo (2012) showed that perceptual strategies that do not include holistic processing play an important role in face recognition as well. Specifically their regression analysis demonstrated that general visual memory and face space coding are also independent predictors of face recognition.

2.2.3.1.1 Face space coding and face recognition

Valentine (1991), in his face space model, proposes that exposure to faces generates a stored representation of a template that represents the average of all previously encountered faces (Figure 2.2.3.1.1.1). Consequently, the average template changes according to the types of faces that the individual continues to be exposed to. Furthermore, when a new face is perceived it occupies a specific place in the face space in relation to the average template. For instance, the further a face is from the centred average (i.e., the more distinct the face is) the easier it is to recognise at the subsequent exposure. For example, caricatured faces with enhanced distinctiveness and idiosyncrasies are situated away from the typical prototype and given their relatively fewer numbers, are easier to recognise than veridical faces. The typical looking veridical faces, on the other hand, are thought to be closely grouped together near the typical prototype which makes them more difficult to recognise than atypical or caricatured faces (e.g., Itz, Schweinberger, & Kaufmann, 2016; Rhodes, Byatt, Tremewan, & Kennedy, 1996). Furthermore, when faces are of a different ethnicity, they are thought to be situated away from the average prototype, where they are closely grouped together (Valentine *et al.*, 2015), which makes them distinct from own ethnicity faces, but difficult to discriminate amongst one another (Figure 2.2.3.1.1.1).

More importantly, face space coding is assumed to be at least partially reflected by face *After-Effects* (Rhodes & Leopold, 2011; Robbins, McKone, & Edwards, 2007; Valentine *et al*., 2015), which are measured in the following way. When a participant views one identity for a specific amount of time, he or she becomes more sensitive to an identity with opposite characteristics (Jeffery & Rhodes, 2011). A typical example involves two identities taken together to create several morphs, each resembling the two identities to a different degree. One of the identities (identity A) is nominated as adaptor, and the participant is asked to view it for a predetermined duration. Next, when viewing morphs resembling the two identities to a varying percentage (90% identity A + 10% identity B, 80% identity A + 20% identity B, 70% identity A + 30% identity B, etc.), adaptation to identity A makes the participant more sensitive to identity B (Laurence & Hole, 2012). Participants with lower after-effects need a higher B to A identity percentage ratio to discriminate identity B than participants with higher after-effects.

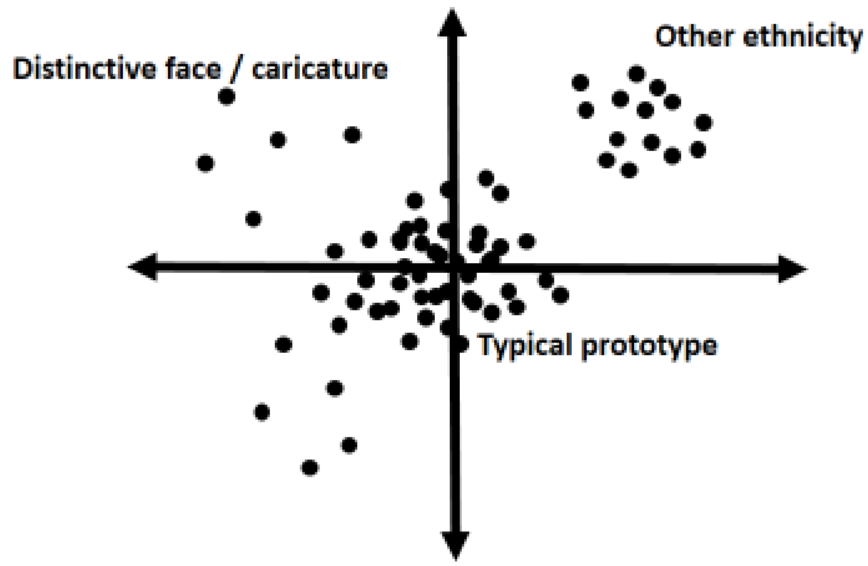

Figure 2.2.3.1.1.1. Multidimensional face space. Typical faces are clustered at the 'average' centre, and the more distinctive faces are situated away from the centre.

Importantly, recent studies have demonstrated that face after-effects linked to identity are positively correlated with face recognition ability (Rhodes, Jeffery, Taylor, Hayward & Ewing, 2014; Dennett *et al*., 2012). In other words, greater after-effects (which in turn are associated with a "larger" face space) are associated with greater face recognition performance (Rhodes *et al*., 2014; Dennett *et al*., 2012). Studies comparing DPs to participants with average face recognition ability show that DP is partially explained by lower face after-effects (e.g., Palermo, Rivolta, Wilson, & Jeffery, 2011). Importantly, the studies investigating participants whose performance on face recognition is within the normal range appear to also show a significant correlation between face space coding and face recognition (e.g., Rhodes *et al*., 2014). Thus, face space coding is a good demonstration of how individual experience with different face exposure modulates face perception and face recognition. In fact, one study demonstrated that hometown population is positively correlated with participants' performance on face recognition, whereby individuals who grew up in small towns showed lower face recognition performance than individuals who grew up in large cities (Balas & Saville, 2015). Thus it would appear that greater exposure to faces at an early age facilitates face recognition performance.

2.2.3.1.2 Age and face recognition

Another factor influencing face recognition performance is age. While face perception appears to mature quite early (e.g., Carey & Diamond, 1994; Mondloch, Pathman, Maurer, Le Grand, & de Schonen, 2007), the development of face recognition appears to be less prompt, reaching maturity relatively late, and continually improving with age, as is demonstrated by a positive correlation between age and face recognition (Susilo, Germine, & Duchaine, 2013; Weigelt *et al*., 2014). Importantly, while other cognitive abilities improve gradually with age, undoubtedly contributing to face recognition improvement, studies show that memory for faces undergoes a domain specific development as well, independently from general development (Susilo *et al*., 2013; Weigelt *et al*., 2014). Importantly, there is an approximate age range (30-35 years-of-age) when face recognition reaches its peak, though it is thought to begin to decline at the age of 50 (Bowles *et al*., 2009; Crook & Larrabee, 1992). Thus elderly participants show lower performance on face processing tests (e.g., Adams-Price, 1992; Hicks, Alexander, & Bahr, 2017), which is complemented by electrophysiological data that is different from young adults' results, whereby elderly participants showed delayed latency for N170 (e.g., Deiber *et al*., 2010).

The current thesis's participants are likely to demonstrate inter-individual differences in face recognition based on the aforementioned factors that appear to at least partially predict face recognition performance. However, face recognition could be further explored independently from these factors, as differences in face recognition, observed at the level of behavioural and neural/electrical activity can be found despite similar face space and similar age.

2.2.3.2 Implicit recognition of faces

One of the most striking observations in face processing research, which will also be explored in this thesis, involves covert (unconscious) recognition. Typically, covert processing can be measured using *Skin Conductance Response*, applying electrodes on participants' fingers, measuring the difference in perspiration patterns in response to specific stimuli, including faces (e.g., Bauer, 1984; Jones & Tranel, 2001).

EEG studies have also demonstrated evidence of covert face recognition. When participants are presented with faces that they have seen before but fail to recognize overtly, their brain responses are different from those that are elicited by faces they have never seen before (Eimer *et al.*, 2012; Gosling & Eimer, 2011; Herzmann *et al.,* 2004). EEG studies demonstrate that previously shown faces may elicit a pronounced N250 component, regardless of the participants' old/new responses (Eimer *et al*., 2012). Accordingly, this pattern of brain activity can be associated with covert recognition. It is likely that some face stimuli do not reach the threshold for conscious perception owing to a decreased attention and resource allocation during the encoding phase, which results in weaker neural propagation to memory related brain areas. On the other hand, if the participant does acknowledge the face as familiar, then the N250 response is accompanied by a later ERP component, P600 elicited at more central regions for recognised famous faces (Eimer *et al*., 2012). It is noteworthy, that N250 can be falsely activated in participants who think they recognise a face (Wirth, Fisher, Towler, & Eimer, 2015). It could be a result of one or more features within the test face erroneously activating internally stored face templates with similar features, resulting in a false alarm match. While there is no direct evidence to account for this potential explanation, this observation, nevertheless, suggests that neural communication is not without fault, and that internal face representations can be erroneously activated even if they do not correspond to the actual target face being tested.

It is noteworthy, that implicit recognition in the form of an attenuated N250 is found in both the general population and DPs (Eimer *et al*., 2012). Critically, 6 out of 12 DPs failed to encode the structural information of the face and thus showed no N250 component in reaction to a repeated identity (Eimer *et al*., 2012). On the other hand, the remaining 6 DPs, whose perception performance was not as impaired as in the other DPs, replicate the results generated by control participants who do not explicitly recognize a repeated face (Eimer *et al*., 2012). Thus, once again, the face recognition difficulties experienced by some DPs can be partially explained by compromised communication between perceptual and memory related areas, necessary for overt recognition. Indeed, a more recent study showed that those DPs who did demonstrate typical memory related ERPs, had a significant delay (in N250 and P600) and a decreased amplitude (in P600) (Parketny, Towler, & Eimer, 2015).

As mentioned previously, the amplitude changes in recognition related ERP components are sometimes tricky to interpret. Looking at different encoding/memorising strategies prior to recognition can potentially clarify neural reactions to recognised faces (e.g., Bernstein, Beig, Siegenthaler, & Grady, 2002; Marzi & Viggiano, 2010). For instance, Marzi and Viggiano (2010) demonstrated that previously unfamiliar faces are better remembered if the initial encoding was deep (judging whether the target face could belong to an actor or politician) as opposed to shallow encoding (whether the target face was in the upright or inverted presentation). Overall the results indicated that the brain activity associated with both explicit and implicit recognition, were modulated by the encoding strategy and by the stimulus orientation. Specifically, the N170 component was of shorter latency for 'old' faces (stimuli presented in the encoding stage) compared to 'new' faces, though this happened for both, shallow and deep encoding stimuli. It is noteworthy though, that regardless of recognition, deep performance encoding resulted in N170 of smaller amplitude, possibly reflecting repetition suppression of faces that were better memorised; this repetition suppression was not observed for faces encoded in the shallow condition. Put in another way, shallowly encoded faces may have induced a greater activity to match the increased cognitive load of processing a face that was weakly processed the first time of exposure. Furthermore, faces encoded in a shallow manner appeared to elicit greater amplitude of the N250 component, again, regardless of whether they were recognised or not. Greater amplitude at early stages of processing appears to reflect a more effortful and a more cognitively loaded processing, as found by other studies as well (e.g., Herzmann, 2016). The ERP component associated with conscious recognition (P600), on the other hand, showed greater amplitude for recognised faces in the deep encoding condition only, potentially reflecting a greater activation of identity related representations.

Given that SRs are expected to generate a higher hit rate on recognition tasks, they may also be expected to generate a more pronounced P600 component associated with explicit recognition, potentially reflecting a more efficient propagation from neural populations at an earlier stage of face processing associated with implicit recognition – N250 component. Indeed, Kaltwasser *et al.* (2013) suggest that when one ERP component is short in latency, it can activate the following ERPs (stages of processing) faster. Thus SRs are expected to have smaller/shorter N250 potentially demonstrating their relative ease of processing. This would fall in line with the quantitative hypothesis, whereby SRs neural patterns are similar to those of controls, differing only in efficiency of communication/processing. It is also possible, however, that their face recognition is qualitatively different as well, which could be explored through the recollection/familiarity paradigm described next.

2.2.3.3 Familiarity versus Recollection in face recognition

Another research area that stems from face recognition is the quantitatively and qualitatively different states experienced by individuals during face recognition. Recent research has highlighted the difference between face familiarity and face recollection (e.g., Aggleton & Brown, 2006; Burns, Tree & Weidemann, 2014; Yonelinas, 2001). Familiarity is associated with a sense of knowing that the face has been previously encountered without remembering where and when this took place. Recollection, on the other hand, is associated with face recognition which is accompanied by contextual information (e.g., who the person is or where they were first encountered).

EEG studies demonstrate distinct neural/electrical activity according to how concretely participants remember faces (e.g., Aggleton & Brown, 2006; Burns *et al*., 2014). The feeling of familiarity in response to a face appears to elicit activity in posterior sites of the brain (e.g., MacKenziet & Donaldson, 2007; Yovel & Paller, 2004) while the concrete recollection of the presented face generates anterior as well as posterior activity (e.g., Burns *et al*., 2014; MacKenziet & Donaldson, 2007; Yovel & Paller, 2004). This observation implies that recollection induces a stronger propagation across the face-related brain units. However, research suggests that the difference between familiarity and recollection is not quantitative, thus it does not necessarily reflect the level of confidence, i.e., recollection responses are not associated with higher confidence in recognition compared to familiarity responses (Düzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; MacKenzie & Donaldson, 2007; Selmeczy & Dobbins, 2014).

Burns *et al*. (2014) explored the distinction between these two aspects of face recognition across the general population and DPs in order to determine whether DPs' face processing impairments are quantitative or qualitative in nature. Upon memorizing a set of faces that were repeated several times, the participants were subjected to recognition trials when they were meant to respond "remember", to faces they remembered seeing (with additional contextual information), "know", to the faces they thought they saw previously (without being able to justify it), or "new", to faces they did not see in the learning trials. The researchers found that controls generated enhanced positive activity over the left posterior and anterior region for familiar faces ("know" responses) between 300-500msec and 500-700msec, whereas 'remembered' faces elicited positive activity in anterior and posterior regions of both hemispheres at the same time intervals, with a bigger emphasis on the right hemisphere. As for DPs, their familiarity response displayed far weaker activation that covered less of the scalp and effects were brief. Importantly, small patches of positivity were observed in extremely anterior regions in DPs, which were not found in controls, resembling the pattern of activity generated during object recognition. When the authors replicated the study using objects and words, they found that DPs appeared to generate a similar neural response to familiar objects as they did to familiar faces, unlike controls. These findings are in line with previous research demonstrating that DPs process faces in both orientations (upright and inverted) in the same manner, possibly implying that they process faces as they would process objects. Meanwhile control participants appear to process faces as they would process objects only when faces are inverted.

Interestingly, the DPs' "remember" responses, while substantially fewer in number, appeared to generate a similar pattern of activity as that generated by controls, minus the anterior positivity found in control participants. Another difference pointed out by the authors is the delay at which the recollection response was elicited in DPs. The authors also point out that the similar neural delay in recollection is observed during object recognition.

One aim of this thesis is to explore the distinction between familiarity and recollection in SR (see Chapter 6). It is not yet clear whether SRs' face recognition superiority is reflected in greater familiarity or greater recollection, and whether these recognition experiences have the same neural patterns as individuals from the general population.

2.3 The interactive nature of face processing stages

While face perception and face recognition appear to contribute to face processing performance independently, it is also worth considering the interactive nature of these processing stages, and how this interaction contributes to individual differences in face processing.

The feed-forward nature of perception and recognition is best demonstrated through the idea that face recognition influences face perception (e.g., Bate, Haslam, Tree, & Hodgson, 2008). For example, face familiarity appears to influence face perception (e.g., Dwyer, Mundy, Vladeanu, & Honey, 2009; Hungr & Hunt, 2012; Mundy, Honey, & Dwyer, 2007; Tomita, Yamamoto, Matsushita, & Morikawa, 2014; Visconti di Oleggio & Gobbini, 2015), in that perception of known and unknown faces is not the same (e.g., Gobbini & Haxby, 2007; Johnston & Edmonds, 2009; Osborne & Stevenage, 2008). For example, Bate *et al*. (2008) showed that prosopagnosic participants scanned familiar faces differently in comparison to unfamiliar faces, proposing that familiar faces induce a different processing strategy than unfamiliar faces, regardless of participants' awareness. Furthermore, Faerber, Kaufmann, Leder, Martin, and Schweinberger (2016) showed that familiarity influences where a face is represented in face space, whereby familiar faces are generally perceived as more distinct than unfamiliar faces, again reflecting how recognition influences perception. Neuroimaging studies have also demonstrated that this stage-like communication between face perception and face recognition is not necessarily unidirectional. Studies involving human and non-human primates demonstrate that perceptual encoding receives feedback from more anterior regions involved in face recognition (Tsao, Freiwald, Tootell, & Livingstone, 2006; Busigny *et al*., 2014). Another piece of evidence supporting the feedback communication proposal is the finding that Anterior Temporal Lobe, a brain area related to face recognition (e.g., Li, Dong *et al*., 2016; for a review see Collins & Olson, 2014), affects perception. For example, Busigny *et al*. (2014) found that the faulty networking between anterior and posterior perception-related areas in AP individuals (due to a focal lesion to right Anterior Temporal Lobe), resulted in impaired holistic processing. Therefore, while activity in the Anterior Temporal Lobe (extended system) is associated with face recognition, it appears to have an indirect yet a significant influence on holistic processing – a perceptual strategy, induced by areas in the core system. Given its contribution to individual differences in face processing, the interactive nature of face perception and face recognition was explored in this thesis via the *Other Age Effect* further elaborated on in the next section.

2.3.1 Categorisation of faces influences face perception and recognition

Whether a face is familiar/known or not is a decision that requires a certain level of categorisation. Importantly, face familiarity is not the only type of categorisation that takes place after face detection. Cognitive findings have suggested that before individuals even begin analysing a face, that face is implicitly categorized as either socially relevant or irrelevant, i.e., in-group (e.g., similar ethnicity, age, social status) versus out-group (e.g., different ethnicity, age, social status) (e.g., Adams, Pauker, & Weisbuch, 2010; Deaner, Shepherd, & Platt, 2007; Young, Hugenberg, Bernstein, & Sacco, 2012). While familiarity is one of the factors determining a face's relevance, other factors include gaze direction, ethnicity, social class, age and so on. These factors can modulate face processing on a behavioural and neural level (e.g., Baus, Bas, Calabria, & Costa, 2017; Brown, Uncapher, Chow, Eberhardt, & Wagner, 2017; Sessa & Dalmaso, 2015; Young, Slepian, Wilson, & Hugenberg, 2014).

Importantly, socially relevant faces appear to be processed more holistically than irrelevant faces (e.g., Young *et al.*, 2014). This observation was made for familiar faces (e.g., Osborne & Stevenage, 2008), for own race faces (e.g., Michel, Caldara, & Rossion, 2005; Michel, Rossion, Han, Chung, & Caldara, 2006; Rhodes, Brake, Taylor, & Tan, 1989; Tanaka *et al.*, 2004) though not all studies support this finding (e.g., Horry, Cheong, & Brewer, 2014), and for faces of own age (e.g., Kuefner *et al.*, 2008).

The more effective processing of own age faces is known as the other age effect (Anastasi & Rhodes, 2005). Some studies show that while children are better at child face recognition, adults are better at adult face recognition (Anastasi & Rhodes, 2005; Kuefner *et al.*, 2008; Lamont, Stewart-Williams, & Podd, 2005). However, other studies demonstrated that most people from all age groups are better with face discrimination and recognition when viewing young adult face stimuli (for a review see Macchi Cassia, 2011). Specifically, they have found children appeared to be better at processing young adult faces compared to child or elderly faces, possibly owing to their behavioural preference of observing their adult care-givers. Meanwhile older adults do not demonstrate a typical other age effect because of their prolonged exposure to relatively younger faces. Therefore, since all age groups are surrounded by adult faces to a significantly greater extent than by children or elderly, studies tend to show that faces of children and older people generate lower hit rates during recognition tasks (e.g., Havard & Memon, 2009; Kuefner *et al*., 2008; Macchi Cassia, Kuefner, Picozzi, & Vescovo, 2009). Interestingly, the level of difficulty increases when new-borns' faces are used as stimuli (e.g., Kuefner *et al*., 2008), as they exhibit even fewer inter-individual differences in features and configuration. However, people who are exposed to children and new-borns on a daily basis generate higher performances on these tasks (Macchi Cassia, Picozzi, Kuefner, & Casati, 2009). Therefore the new-borns' lowered physical distinctiveness cannot solely account for discrimination difficulties observed in members of the general population. Instead this evidence further supports the role of experience/exposure in face perception and recognition. Indeed, the general consensus on the other age effect is that recognition of faces will significantly drop for age groups that participants have relatively little exposure to.

Consequently, such findings as these raise the question of how much does individual experience contribute to SRs' recognition performance. For instance, not all SR may demonstrate the other race effect, yet this lack of race effect could be attributed to both: superior perceptual skills and to a greater exposure to other races depending on their life experiences (e.g., occupation). A further aim of the current study is to see how SRs perform relative to typical controls when viewing faces that both groups are likely to have less experience with, such as infant faces. If SRs outperform the general population then it would be a stronger indication of perceptual superiority that is not confounded by individual experience. On the other hand, if SRs show either a similar pattern of results as controls, or their performance is significantly different across types of stimuli (infant versus adult faces), then individual experience is likely to significantly contribute to neural functioning exhibited by SRs.

2.4 The summary of super-recognition (SR) literature to date and the present thesis

The aim of this thesis is to explore potential *recognition-based* and *perceptual* reasons behind SRs' exceptional face recognition ability. Based on the current literature review, there are two main stages constituting face processing which may independently or interactivity contribute to individual differences in face recognition ability.

First of all, face recognition abilities may vary due to individual differences at the first stage of face processing: face perception. Indeed Russell *et al*. (2009) were the first researchers to empirically test individuals with exceptionally good ability in face recognition. Their study described four individuals who significantly outperformed participants with average face recognition skills on two recognition tests, *Cambridge Face Memory Test (CFMT+)* and *Before They Were Famous Test*, and one perception test, *Cambridge Face Perception Test*. This study demonstrated that SRs' superiority is found for both recognition and perception.

Other studies have also demonstrated that SRs' superiority is generally found for both face recognition and face perception/matching. Bobak, Hancock *et al*. (2016) and Bobak, Dowsett *et al.* (2016) found a group advantage for face matching. However, not all SRs demonstrate a perceptual/matching advantage, as was demonstrated by Bobak, Bennetts *et al*. (2016), and Davis *et al.* (2016). This suggests that SR is a heterogeneous concept, and that while it is possible that some SRs' exceptional recognition ability is aided by their superior perceptual skills, there are also those SRs whose superior face recognition cannot be attributed to a perceptual advantage. Indeed, it is possible that for some SRs, this extraordinary face recognition ability is merely a result of a more effective storage of facial percepts or a stronger activation of recognition related storage units. Therefore, face perception and face recognition can display simultaneous variability across individuals, multiplying the dimensions of individual differences.

Next, Russell *et al.* (2012) demonstrated that DP and SR occupy the opposite ends of the face recognition spectrum while demonstrating only quantitative differences in performance. They found no differences in perceptual viewing strategies between SRs, DPs and controls during face processing. Indeed, when asked to match two faces that only differed either in pigmentation (surface reflectance) or feature shape dimension, all three participant groups demonstrated a greater reliance on feature cues during face matching, thereby reflecting qualitatively similar perceptual strategies employed during face processing (Russell *et al*., 2012).

SRs' quantitative superiority was also argued in an eye-tracking study by Bobak *et al*. (2017) who found that SRs, as controls, spent more time looking at the nose in comparison to other face regions, though this effect was significantly greater in SRs. The lack of qualitative differences in face processing between SRs and typical individuals has been also demonstrated when investigating their holistic processing, the hallmark of face processing expertise. Indeed, the Composite Face Test showed no difference in holistic processing between SRs and controls (Bobak, Bennetts *et al*., 2016). On the other hand, the Inversion Effect (as measured by upright and inverted versions of the Cambridge Face Perception Test) appears to be greater in some SRs (Bobak, Bennetts *et al*., 2016; Russell *et al*., 2009). Importantly, a greater Inversion Effect cannot be viewed as a direct measure of qualitative difference in face processing (Noyes *et al*., 2017). When SRs and controls demonstrate an Inversion Effect, it implies that their upright face processing benefits from an effective integration of features/parts and their spatial configurations, whereas a difference in magnitude of the Inversion Effect may indicate quantitative or qualitative differences in face processing. For instance, Russell *et al.* (2009) propose that since the magnitude of Inversion Effect is correlated with face recognition ability across the entire range of this ability (see also de Gelder & Rouw, 2000b; Duchaine *et al*., 2006), the continuous distribution of Inversion Effects from low to top end may suggest that SRs' superiority is quantitative in nature. On the other hand, APs show reduced Inversion Effects while reflecting a qualitative inferiority in face processing (e.g., Busigny & Rossion, 2010). Therefore studies on Inversion Effects do not clarify whether specific individual differences are of quantitative or qualitative nature.

While SRs generally show enhanced recognition and perception for faces, it has not been extensively investigated whether their advantage is face-specific or general. Bobak, Bennetts *et al.* (2016) tested six SRs and found only two of them to exceed controls on object processing. Similarly, Davis *et al*. (2016) found two out of ten SRs to exceed controls on object recognition. These and aforementioned observations about SR heterogeneity have been further investigated in this thesis.

A final remark on SRs' visual processing was pointed out by Noyes *et al*. (2017), who stress in their review that SRs do not exceed controls on all the measures. Thus, not only are SRs almost never 100% accurate in their visual processing decisions, whether it is recognition or perception of faces or objects, they sometimes demonstrate an average level of performance.

Accordingly, when considering the superiority of face recognition displayed by SRs, it is worth exploring individual differences manifested at the level of perception and recognition.

It might be hypothesised that they will demonstrate a distinct pattern of results at more than one level in comparison to controls. Furthermore, whether SRs’ recognition superiority is face-specific or general is further explored in this thesis, as previous research findings were inconclusive. Finally, while SR literature indicates a general trend of quantitative superiority, the small sample size recruited in previous studies as well as the lack of any neurocognitive data (e.g., EEG data) potentially limits the conclusion that SRs’ superiority is strictly quantitative. The next chapter focuses on the methodological approach adopted to investigate SRs’ face processing ability.

Chapter 3 – Methodology

3.0 Introduction

Chapter 2 described decades of research exploring different face processing paradigms. This literature review demonstrated how individual differences in face processing can be teased out at different stages of processing (e.g., perception versus recognition). Furthermore, individual differences in face processing can be modulated/confounded by a number of factors, such as participant characteristics (e.g., demographics, personality, motivation); types of tests employed (e.g., test instructions), types of face stimuli used (e.g., cropped versus uncropped, upright versus inverted), types of data recording (e.g., behavioural versus neural recordings). Identifying these different stages and uncovering the influence of confounds/moderators is critically dependent upon the selection and correct implementation of an appropriate methodology. Therefore this chapter will focus on the methodology selected for this thesis in its investigation of super-recognition (SR).

3.1 Participant recruitment

3.1.1 Defining super-recognisers (SRs)

This next section will describe the three-step strategy used to define SRs and controls for this thesis. All participants were administered the 102-trial short-term Cambridge Face Memory Test: Extended (CFMT+) (Russell *et al*., 2009) which has been employed in most previous SR research (Bobak, Bennetts *et al*., 2016; Bobak, Dowsett *et al*., 2016; Bobak, Hancock *et al*., 2016; Bobak *et al*., 2017; Davis *et al*., 2016; Russell *et al*., 2009; Russell *et al*., 2012) to verify ability and is the extended version of the original 3-block 72-trial CFMT (Duchaine & Nakayama, 2006a), comprising a final fourth additional block of 30 trials.

In the first block, participants are presented with three different viewpoints (3 seconds each) of one identity during the learning stage (Figure 3.1.1.1 A). Their recognition is immediately tested in three recognition trials where the target image is accompanied by 2 distractor faces, i.e., three-alternative forced choice (Figure 3.1.1.1.B). This procedure is repeated for five other targets, thereby forming the first 18 trials of the test (6 target faces tested in 3 viewpoints). The recognition stage has no time limit. Note that the first block tends to generate almost perfect performance in the general population (i.e., individuals without face processing deficits), given its immediate recognition paradigm. Thus the primary goal of this block is for participants to familiarise themselves with the target faces, which are tested under more demanding conditions in the following blocks.

The second block presents participants with the same six identities simultaneously for 20 seconds, and this learning phase is followed by 30 recognition trials (five trials per identity) during which the same six identities are presented in different images (Figure 3.1.1.1 B). Note, that while giving the opportunity to review the target faces at the beginning (20 seconds), the second block tests participants' recognition throughout 30 trials without any additional reviewing of the target faces in-between, thereby introducing a gradual delay between memorising and recognising.

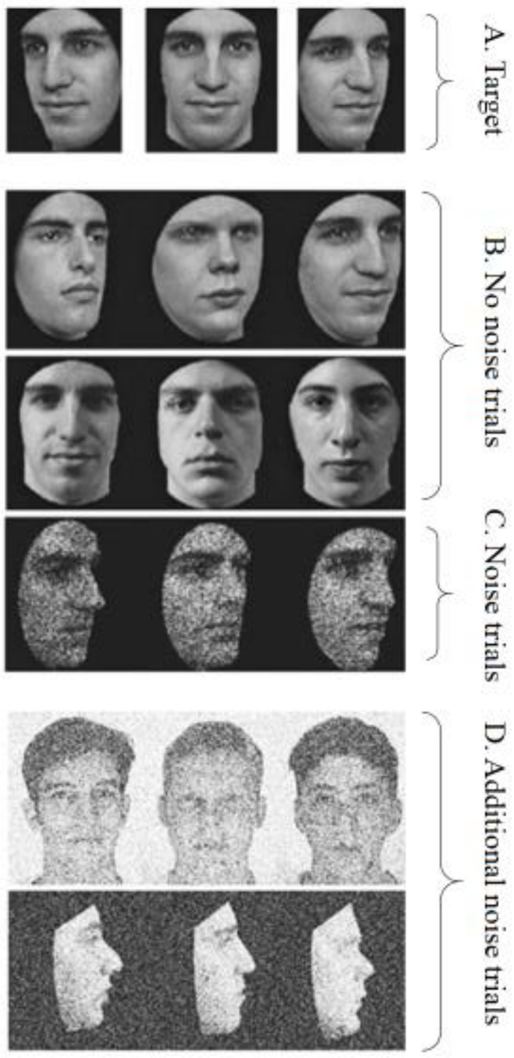

Figure 3.1.1.1 Cambridge Face Memory Test +. The upright and inverted versions are identical, comprising 4 blocks of 102 trials. The image was acquired from Russell et al. (2009), © 2009 The Psychonomic Society, Inc., with permission of Springer.

The third block has the same learning phase as the second block - reviewing of six identities for 20 seconds – which is followed by 24 recognition trials (4 trials per each identity). The key feature of the third block is the use of visual noise, which presents the same identities in confounding conditions (Figure. 3.1.1.1 C). The final block (30 trials) is identical to the previous block though the same identities are confounded by changes in facial expressions and profile presentations (Figure 3.1.1.1 D). Note that unlike blocks 2 and 3, the final block provides no opportunity to review the target faces before testing face recognition, adding further delay between memorising and recognising. Finally, the distractor images repeat more often in the final blocks of the test. This is intended to ensure that participants focus on identifying the memorised target faces rather than basing their responses on feelings of familiarity.

This test is probably the most valid measure of face recognition ability created to date, as it demonstrates a number of good qualities. First, given the test's relatively delayed recognition paradigm, it indirectly demonstrates whether participants have had the chance to create an internal visual representation of the faces presented to them during the first block. Employing a relatively delayed recognition paradigm in blocks 2, 3 and 4 indirectly reflects the participants' capacity to store visual representations of faces for a relatively long period of time. Furthermore, the use of different viewpoints and different images of the same identities enforces identity discrimination rather than image matching or image recognition, thus again testing whether participants have created and stored an internal representation of the faces. In addition, the use of repeated distractor faces across trials ensures that the target faces are selected in recognition trials based on recognition rather than a feeling of familiarity, as participants become familiar with targets and with repeated distractor faces.

Second, the use of the 'noise' paradigm (images with visual artefacts) is argued to induce a greater reliance on holistic processing (Duchaine & Nakayama, 2006b; see also McKone, Martini, & Nakayama, 2001). Since holistic processing is thought to be the hallmark of face processing (e.g., Avidan, *et al*., 2011; Busigny *et al.*, 2010; Wang *et al.*, 2012), high performance on the 'noise' trials is thought to reflect face-specific recognition ability. The face specificity of the test images is also strengthened by removing external features/cues (e.g., hair) in the learning phase to discourage general parts-based processing during memorising and recognizing. Furthermore, Duchaine and Nakayama (2006b) justified the face specificity of the CFMT (original version) by demonstrating significant inversion effects across participants for each test block (even the first block). Furthermore, with each block, performance on the upright version decreased while inversion effects increased, suggesting that upright face specificity of the test increases with each testing block. Importantly, while several studies (Duchaine & Nakayama, 2006b; Richler *et al.*, 2011; DeGutis *et al.*, 2013) demonstrate a relationship between CFMT and holistic processing, CFMT performance is significantly dependent on parts-based processing as well. DeGutis *et al.* (2013) demonstrated that while holistic processing has a unique contribution to CFMT performance variance (21%), parts-based processing related to faces (i.e., features) explained a significant amount of CFMT variance above and beyond holistic processing (38%). Thus, as discussed in Chapter 2 (sections 2.2.2.1 and 2.2.2.2), holistic and parts-based processing are important factors contributing to individual differences in face recognition ability.

Finally, another factor demonstrating the effectiveness of CFMT+ as an appropriate classification tool, is that most of the reported SRs who have contacted research labs claiming to have an exceptionally good face recognition ability have shown appropriately high scores on the CFMT+ (minimum score of 92/102). Indeed, only a small number (*n* = 5) of participants who contacted our research lab claiming to be SR generated average scores on CMFT+. Furthermore, there were no SRs with high CFMT+ scores (>92/102) who were not already aware of their superior face recognition ability.

Thus, the CFMT+ attributes can be summarised as follows:

1) Storage of internal face representations is tested via the delayed recognition paradigm and via different view/image presentation
2) Face specificity of individual recognition ability is tested via the visual noise paradigm and removal of external features
3) CFMT+ performance closely matches self-reports of SRs

Table 3.1.1.1 SRs' mean CFMT+ scores in previous research

	Number of SRs	Lowest score	M	(SD)	Cut-off[1]
Russell *et al*. (2012)	6	-	95.00	(1.90)	93.10
Davis *et al.* (2016)	10	94	94.96	(1.90)	93.06
Bobak, Hancock *et al*. (2016)	7	92	95.71	(1.53)	94.18
Bobak, Dowsett *et al*. (2016)	7	94	97.70	(3.20)	94.50
Bobak *et al.* (2017)	8	94	95.62	(2.44)	93.18

[1] The potential cut-off points of the CFMT+ score were calculated by subtracting 1 SD from the mean scores generated by SRs in each reported study

All published work on SR to date has employed inclusion criteria of self-reports of extraordinary ability, and a CFMT+ cut-off point of 90/102 (Bobak Dowsett, *et al.*, 2016; Bobak, Hancock, *et al*., 2016; Bobak *et al.*, 2017; Russell, *et al*., 2009; Russell *et al*., 2012), as this score was at least 1 standard deviation above the sample mean score recorded by previous research. Table 3.1.1.1 summaries the mean scores (out of 102) and standard deviations generated by SRs on the CMFT+ in each reported study.

With these mean scores in mind, it appears the initial cut-off point of 90/102 may be too low for SR classification. Thus, to make the inclusion criteria less lenient, participants recruited for this research were classified as SRs if their score fell within 1 standard deviation of the mean scores reported for SRs in previous studies (Table 3.1.1.1). Therefore the cut-off point of 93/102 was selected for SR investigation in this thesis. It is noteworthy, that towards the end of data collection for the current thesis, Bobak, Pampoulov *et al*. (2016) published a study recruiting 254 student age participants (Mean CFMT+ = 70.7 (out of 102), SD = 12.3) and suggested a stricter cut-off point of 95/102 for SR, indicative of 2 standard deviations above the sample mean – as this value was indicative of the estimated population mean. However, it is possible that face processing studies tend to attract people who are interested in faces and who believe they are good at face recognition, thereby introducing a bias in recruitment. Assuming that people who are bad and/or who are not interested in face recognition avoid participating in such research, it is probable that CFMT+ scores reported to date have been inflated, making the cut-off point for SR potentially too strict. Indeed, as will be reported in detail later, the online study reported in this thesis (Chapter 4 Experiment 4.1, and Chapter 5 Experiment 5.1) administered the CFMT+ to 820 participants and showed a clearly inflated sample mean (M = 84.3, SD = 10.7), almost a standard deviation above that reported in previous research. With that in mind, SRs recruited for the current research provided self-reports of excellent ability and achieved a CFMT+ score of at least 93/102 (note: only two of the 46 SRs recruited achieved a score of 93/102. The remainder scored above this).

Importantly, due to the high-ability recruitment bias to the projects in this thesis, in order to make a clear distinction between SRs and controls, the current project aimed to recruit control participants with “average” ability for between-group comparisons. Participants whose scores were within 1 SD of the CFMT+ mean reported by Bobak, Pampoulov *et al.* (2016) were classified as controls, making up the range of 59 – 83 (of 102). Those participants (mainly achieving scores between 84 and 92) who did not meet the SR and control criteria were included in correlational analyses only.

Note that despite the undoubted attributes of the CFMT+ as a diagnostic/classifying tool, it may not be a perfect measure of face recognition ability. Indeed, research shows that in rare cases, some DPs are capable of achieving an artificially high score on the CFMT (e.g., Esins *et al.*, 2016). Similarly, some individuals who generate an exceptionally high score on the CFMT+ may show only average ability on other face recognition tests (e.g., Davis *et al.*, 2016). Thus, CFMT and CFMT+ have been shown to induce artificially higher scores in the past, erroneously classifying participants as DPs and SRs, respectively. It is possible that the reason some participants are able to generate artificially higher scores on CFMT and CFMT+ is the fact that the target identity is presented on each trial, allowing participants to guess the correct response. Indeed, all multiple choice tests share the same weakness in design – the possibility to guess the correct response. Furthermore, given that the initial SR classification relies solely on participants' scores in relation to a specific threshold (i.e., 93/102), factors unrelated to face recognition ability (e.g., concentration, luck) may sway individual scores in either direction.

For these reasons, SRs recruited for this project were tested on the CFMT+ as well as an additional short term test of face recognition (see section 3.2.2), in order to verify that their CFMT+ score was not artificially induced. As such, for the second face recognition test (to verify SR ability), low scorers (2 SD below the SR mean) were excluded from the SR group. The same test was used to confirm that the controls' face processing ability was typical (2 SD within the control mean).

Finally, it should also be noted that semantic information and name retrieval, while being important aspects of familiar face recognition (Bruce & Young, 1986; Burton *et al*., 1990) are not discussed in the context of experimentally learnt face processing, and therefore are not included in the process of SR classification.

In summary a three step process was used to define SR ability here:

1. Self-belief in exceptional ability
2. Scores of 93 or above on the CFMT+
3. Scores within 2 SD of the SR group mean on the additional short-term face recognition test

3.1.2 Online and lab participation

3.1.2.1 Online pilot studies.

An online study was conducted as a pilot, in order to recruit a large participant sample (*n* = 820) to test whether the individuals recruited for the lab testing were representative of the SR population and of the general population for controls. Participant recruitment was facilitated and encouraged by the media attention to the topic of SR. The CFMT+ was used with the same criteria to classify participants into SR (n = 199) and control (n = 279) groups. Note that the high proportion of SRs in this sample (24.27%) is indicative of a recruitment bias, which is discussed in Chapter 7. All participants were included in the correlational analysis. The online tests included the *face and object old/new recognition tests* (Chapter 4, Experiment 4.1), as well as the *adult and infant face recognition (old/new) tests* (Chapter 5, Experiment 5.1). See section 3.2.2 for a complete description of the tests.

3.1.2.2 Laboratory studies.

Following media articles and programmes (radio and television) on SR, as well as online tests examining face recognition (Davis *et al*., 2016), encouraging people to contact our lab, 114 participants (including controls) were recruited to participate in the lab studies. Note that of those participants who have completed the online studies (Experiments 4.1 and 5.1) only two (controls) participated in the laboratory testing. These studies were divided into two components. The first component made up the tests described in Chapter 4 (Experiment 4.2), Chapter 5 (Experiment 5.2) and Chapter 6 (Experiment 6.1) and recruited 68 participants. The second component made up the tests described in Chapter 4 (Experiment 4.3), Chapter 5 (Experiment 5.3) and Chapter 6 (Experiment 6.1) and recruited 46 participants. Approximately half of the participants completed the CFMT+ (test used to allocate participants into SR or control group, see section 3.1.1) online, whereas the rest completed it in our lab. The recognition tests in Chapter 5 (Experiment 5.2) and Chapter 6 (Experiment 6.1) were administered during EEG recording (see sections 3.2.3 and 3.3.2).

3.2 Measurements employed

3.2.1 Autism (AQ) and Empathy Quotients (EQ) and additional information

Given that face processing appears to have a positive relationship with empathy (e.g., Bate *et al*., 2010) and tends to be modulated by autistic traits (e.g., Baron-Cohen *et al*., 1996; Deruelle *et al*., 2004), laboratory participants were administered the Empathy Quotient (EQ) (Baron-Cohen & Wheelwright, 2004) and Autism Quotient (AQ) (Baron-Cohen & Wheelwright, 2001) in order to test whether SRs and controls matched on these characteristics.

The EQ is a self-report measure of empathy which consists of 60 items/statements. Participants are required to respond how strongly they agree/disagree with each statement. The test-retest reliability for the EQ was found to be $r = .97$, and Cronbach's $\alpha = .92$ (Baron-Cohen & Wheelwright, 2004), suggesting it is a reliable and valid measure of empathy.

The AQ is a self-report measure of the level of autistic traits which consists of 50 items/statements. Participants are required to respond how strongly they agree/disagree with each statement. The test-retest reliability for the AQ was found to be $r = .70$ (Baron-Cohen & Wheelwright, 2001), and Cronbach's $\alpha = .82$ (Austin, 2005), suggesting it is a reliable and valid measure of autistic traits.

Other additional information was recorded in order to control for handedness, vision, age, gender, and neurological/psychological disorders. Note that the additional information sheet (see Appendix for Figure A3.2.1.1) also asked participants to report on their occupation and daily exposure to infants/children, as this criterion was used for participant recruitment in Chapter 5 (Experiments 5.2 and 5.3).

3.2.2 Face processing tests

All the tests used for this thesis were adaptations of well-known tasks, with the exception of the CFMT+ (upright and inverted). All the tests were designed using existing templates that have been tested and proven to be informative in studies discussed in Chapter 2.

Cambridge Face Memory Test+ (CFMT+ $_{Upright}$ and $_{Inverted}$: The first tests measuring holistic processing in Chapter 4 (Experiment 4.2) are the *upright* and *inverted* versions of the *Cambridge Face Memory Test+* (see section 3.1.1 for a detailed description). The design of the inverted test is identical to the upright version, comprising 4 blocks of 102 trials. The *inversion effect* – an indication of disrupted holistic processing (e.g., Bruce & Langton, 1994; Busigny & Rossion, 2010; Goldstein, 1965; Righart & de Gelder, 2007; Robbins & McKone, 2007; Santos & Young, 2008; Yin, 1969) – was calculated by subtracting the inverted scores from the upright scores, and by measuring effect sizes of the differences.

Composite Face Test (CFT): The second test measuring holistic processing in Chapter 4 (Experiment 4.2) is the *CFT* replicating the test employed in DeGutis *et al.* (2013), Richler, Cheung *et al.* (2011) and Wang *et al*. (2012). The *composite face effect* is reflected by the lower accuracy and retarded RT in aligned versus misaligned conditions. This test was chosen for the current thesis for several reasons. Studies have used the CFT in conjunction with the Navon letter task (1977) – a big letter made up of small letters, and found that the composite face effect is related to global bias (seeing the big letter faster than the little letters it is made up of). For instance, Avidan *et al.* (2011) administered both tasks (CFT and Navon letter task) to people diagnosed with prosopagnosia and found that the latter showed no composite face effect, which correlated with their local bias exhibited in the Navon task. Furthermore, Weston and Perfect (2005) showed that the composite face effect can be attenuated if participants are administered the Navon task first, with an emphasis on local processing. In other words, the group that was preconditioned to process stimuli with a local bias showed a significantly reduced composite face effect. Note however, that this effect was not long lasting, demonstrating the persistent and involuntary nature of holistic processing and more importantly, demonstrating that the CFT is sensitive enough to tease it out.

Another reason for choosing this test is the relationship it has with face recognition ability, as the composite face effect has been found to positively correlate with face recognition, whether it is a raw score on a face recognition test (DeGutis *et al.*, 2013; Richler, Cheung *et al*., 2011), or a face-specific recognition score derived from subtracting object recognition scores from face recognition scores (Wang *et al.*, 2012). However, not all studies have demonstrated this association (e.g., Konar, Bennett, & Sekuler, 2010; Horry *et al*., 2014). The reason behind the contrasting findings regarding CFT may be due to the different designs of the task employed by different studies. The original version of CFT includes two types of trials, same and different top halves, while the bottom halves are always different for each type of trial. Richler, Cheung *et al*. (2011) point out that this design introduces a response bias, because the participants are more likely to respond 'different' (see also DeGutis *et al*., 2013; Horry *et al*., 2014). Instead, it is recommended researchers employ four types of trials whereby different and same bottom half conditions can have either same or different top halves, eliminating response bias. Consequently, the original version of the task has become known as the partial design (2 types of trial), and the extended version, as the complete design (4 types of trials). Importantly, statistical analysis demonstrates that the complete design has more validity than the partial design (Richler, Cheung *et al*., 2011). Furthermore, it appears that the studies employing the complete design are more likely to find the expected correlation between the composite face effect and face recognition accuracy (e.g., DeGutis *et al*., 2013, Richler, Cheung *et al*., 2011). Richer *et al*. (2011), for instance, found that both CFMT and a basic old/new recognition task correlated with the composite face effect. The same authors found no relationship between holistic processing and face recognition scores using only the partial design of the CFT. DeGutis *et al*. (2013) similarly demonstrated a relationship between face composite face effect and face recognition using the complete design of CFT. Note, however, that there are some limitations to using the CFT as certain authors question its validity. For instance, Richler *et al*. (2015) found no relationship between face recognition (CFMT+) and holistic processing while employing the CFT, thereby questioning whether the composite face effect actually reflects holistic processing (see also 4.4 General Discussion in Chapter 4).

Part-Whole Test: The third of the perception tests designed to measure holistic processing in Chapter 4 (Experiment 4.3) included *the Part-Whole Test* (e.g., Crookes, Favelle, & Hayward, 2013; McKone *et al.*, 2013). This test has proven to be a reliable measure of holistic processing given that it is administered in both upright and inverted orientations (e.g., McKone *et al*., 2013), as the more reliable measure of holistic processing would derive from the difference (subtraction) between the two conditions. Note that this test was administered to a different sample of SRs and controls than the first two holistic tests.

Face and object recognition tests (old/new): Chapter 4 (Experiments 4.1 and 4.2) also employed the paradigm measuring face and object recognition, the old/new test. The old/new test has been used across many recognition studies and has proved to be a reliable measure of recognition (e.g., Baus *et al.*, 2017; Bernstein, Young, & Hugenberg, 2007; Rugg *et al.*, 1998). The primary goal of the face recognition old/new test was to verify SRs' ability and control's 'averageness' (see section 3.1.1), while the object recognition old/new test was used to explore whether SRs' face recognition superiority transcends to other visual stimuli. The two tests were also used to measure face-specific recognition (Wang *et al*., 2012) by subtracting object recognition accuracy from face recognition accuracy, in an attempt to link it to holistic processing (reflected in the inversion effect and composite face effect). Chapter 5 (Experiments 5.1 and 5.2) also employed an old/new recognition test using adult and infant faces as stimuli. The design of the test was identical to the old/new test using faces and objects in Chapter 4 (Experiments 4.1 and 4.2). The difference in accuracy between adult and infant stimuli was used to measure the *Other Age Effect (OAE)*, as well as effect sizes of the differences.

Adult and infant face matching tests: Chapter 5 (Experiment 5.3) included a matching test measuring holistic processing in the context of the other age effect. This was designed using Macchi Cassia, Picozzi *et al.* (2009) and Kuefner *et al*.'s (2008) versions as templates. It included upright and inverted matching of adult and infant faces in separate blocks, where participants saw the target image immediately followed by a test image. Participants responded 'same' or 'different' when comparing the test image to the target image. The difference in accuracy between upright adult and infant matching was used to measure the OAE, while the difference between upright and inverted conditions was used to measure holistic processing employed by both adult and infant faces.

The Remember/Know test: Chapter 6 (Experiment 6.1) employed the commonly used paradigm to test visual recognition, the Remember/Know test. This test distinguishes between *familiarity* and *recollection* in healthy (Koen & Yonelinas, 2014 Yovel, & Paller, 2004) and clinical populations (Burns *et al.*, 2014; Lombardi *et al*., 2016; Martin *et al*., 2011a). It is a modified version of the typical old/new test, in that it requires participants to memorise a set of images in the encoding stage in order to recognise them in the recognition stage. The important feature of the test is the response options participants can choose from in the recognition stage. The ‘remember’ response is selected for faces that participants remember seeing while being able to justify their recollection (typically remembering something specific about the image in question). The ‘know’ response is selected for faces the participants acknowledges having seen in the encoding stage, without being able to justify it. Thus ‘remember’ responses are thought to reflect recollection, while ‘know’ responses are thought to reflect familiarity (e.g., Gardiner, 1988; Tulving, 1985). As with a classic old/new test, participants are required to respond ‘new’ to faces they do not recognise. This test has a number of variations, specifically concerning the response options provided to participants. For instance, some studies use a *one-step* response, where participants choose between the ‘remember’, ‘know’, and ‘new’ options immediately after seeing a face. Other studies may choose to have a *two-step* recognition response, where participants first chose whether they recognise the face or not, by responding ‘old’ or ‘new’, and if they respond ‘old’, they are further asked to elaborate on their recognition by responding ‘remember’ or ‘know’. Bruno and Rutherford (2010) compared the influence of these response options and found that it made no significant difference across methodological approaches, namely there was no difference between one-step and two-step paradigms. On the other hand, Selmeczy and Dobbins (2014) suggest that the two-step paradigm introduces a delay which may compromise the participants’ subjective experience following the moment they classified the stimulus as ‘old’.

Another potentially important methodological difference is the number of response options introduced by different studies. Indeed, some researchers think that having only three response options (‘remember’, ‘know’ and ‘new’) makes for less reliable and less pure ‘know’ responses (e.g., Bruno & Rutherford, 2010; Tousignant, Bodner, & Arnold, 2015). Since recollection (‘remember’ response) is a more explicit and concrete type of recognition, the ‘know’ responses are sometimes perceived as too ambiguous by participants, who may choose this response option by default for all the faces they do not concretely recognise. As a result, it is argued that many false alarms (falsely ‘recognised’ distractor face) that participants make during the recognition stage end up being classified as ‘know’ responses. To avoid the Remember/know test turning into a remember/false alarm test, the ‘guess’ response option was introduced to force participants to respond ‘know’ only when they were sure of seeing the stimuli before, rather than choosing it by default (Eldridge, Sarfatti, & Knowlton, 2002). Importantly some researchers do not perceive the ‘guess’ option as helpful, as research showed that instead of eliminating noise from ‘know’ responses, it potentially compromises both ‘remember’ and ‘know’ responses instead, by making participants more liberal to making ‘guess’ responses (e.g., Migo, Mayes, & Montaldi, 2012; Tousignant *et al.*, 2015).

Based on these findings, the remember/know paradigm employed in this study was the one-step design with only three response options (‘remember’, ‘know’ and ‘new’) as other methodological moderations were judged to be optional rather than useful (Bruno & Rutherford, 2010; Selmeczy & Dobbins, 2014).

3.2.3 Electroencephalography (EEG) recordings

As well as measuring behavioural aspects of super-recognition, the current thesis was also designed to explore potential cognitive and neural factors reflecting or contributing to SRs’ significant superiority in face recognition. It employed electroencephalography (EEG) to explore the differences in neural/electrical activity that may complement SRs’ behavioural pattern of results in Chapter 5 (Experiment 5.2) and Chapter 6 (Experiment 6.1). EEG is one of the most commonly used brain recording techniques, known for its non-invasiveness and its ability to capture neural processes that occur quickly over a short time period such as that which occurs in face processing (Bentin *et al*., 1996; Eimer, 2000; Eimer & Gosling, 2012; Kaufmann *et al.*, 2009; Pfutze *et al*., 2002; Schweinberger *et al.*, 2004; Turano *et al.*, 2016). It has been used to demonstrate neural activity is sensitive to different types of stimuli (e.g., Bentin *et al*., 1996; Eimer, 2000), for different clinical and neuro-typical populations (e.g., Burns *et al*., 2014; Towler, Gosling, Duchaine, & Eimer, 2012) while teasing out different perceptual stages (e.g., Eimer & Gosling, 2012; Pfutze *et al.*, 2002) and strategies (e.g., Wang, Guo, & Fu, 2016; Wang, Sun *et al*., 2015).

Most published EEG studies present data from as few as 10 - 30 participants (e.g., Barragan-Jason, Cauchoix, & Barbeau, 2015; Eimer, Gosling, Nicholas, & Kiss, 2011; Miyakoshi, Kanayama, Nomura, Iidaka, & Ohira, 2008; Towler & Eimer, 2016; Zhao *et al.*, 2017), owing to general discomfort, long recording sessions and noisy data collection. Furthermore, most studies investigating such atypical participant groups as *developmental prosopagnosics (DPs)* present EEG findings with significant effects from as few as 8 - 12 participants (e.g., Burns *et al*., 2014; Eimer *et al*., 2012). Accordingly, the present project aimed to recruit at least 15 participants in each group (SR and control) in order to attain reasonable statistical power.

3.2.3.1 EEG recording and the 10 - 20 montage

EEG used in this project involved 19 active electrodes imbedded in an ECI electro-cap (Electro-cap International, Inc.) attached to the surface of the scalp in order to measure the electrical activity generated by neural communications (Figure 3.2.3.1.1). In the 10-20 montage, the distance between *nasion* (just above the bridge of the nose) and *inion* (bump at the back of the head) is used to derive the relative position of all the electrodes, as they are situated 10% of the nasion-inion distance away from each other. The earlobes (marked as A1 and A2 in Figure 3.2.3.1.1) were selected as reference electrodes, and activity recorded from these electrodes was subtracted from the activity recorded by the 19 active electrodes. FPz, situated between FP1, FP2 and FZ (not shown in Figure 3.2.3.1.1) was selected as the ground electrode, which records all the irrelevant electrical activity generated by the surrounding environment, in order to be subtracted from all the active and the reference channels:

Relevant brain-related activity = (Active Electrodes – Ground Electrode) – (Reference Electrodes – Ground Electrode)

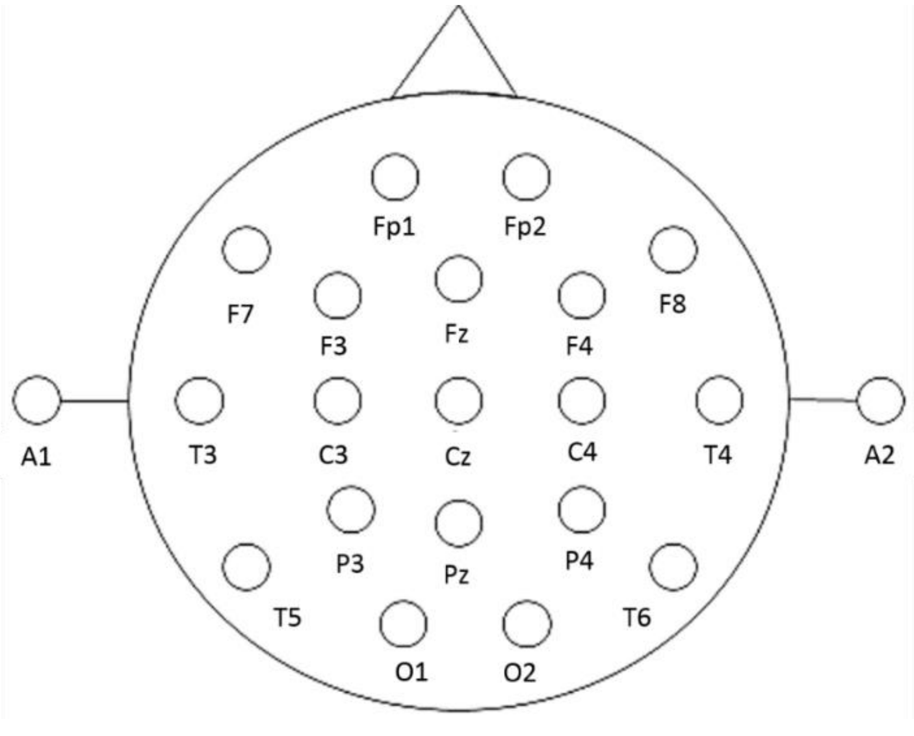

Figure 3.2.3.1.1 EEG electrode montage for 19 active and 2 reference electrodes.

In the 10-20 montage, the 19-channel set-up includes Frontal (F), Central (C), Parietal (P), Temporal (T), and Occipital (O) electrodes. The odd numbering of the electrodes indicates that they cover the left hemisphere of the scalp, while the even numbers indicate the right hemisphere portion of the electrodes. Finally, while electrodes marked as ‘z’ are situated at the centre of the scalp, the numbering system is used to indicate how far from the centre the electrodes are situated, with greater numbers – further from the centre.

3.2.3.2 EEG and Event Related Potentials (ERPs)

When one neuron has a message to transmit to another neuron, this exchange of information takes place in a synapse between the first neuron’s axon terminals and the second neuron’s dendrites. This information then travels along the dendrite toward the soma (or cell body). If the summation of post-synaptic potentials is strong enough, it sends a new action potential along the axon in order to propagate other neurons. This post-synaptic activity in the dendrites is what the EEG electrodes pick up on from thousands of neurons firing in synchrony (Cohen, 2014; Dickter & Kieffaber, 2014; Luck 2005) and thus generating a strong enough signal to be detected and recorded by EEG amplification equipment. For instance, when each trial constitutes a presentation of an image (i.e., event) averaging trials of the same condition results in a small EEG extract classified as an Event Related Potential (ERP), which can then be linked to a specific function. Averaging over a large number of repeated trials causes random noise to be averaged out, leaving only the stimulus-dependent electrical responses which occur systematically and at around the same time in each trial.

Table 3.2.3.2.1 Summary of Event Related Potentials in face recognition literature

ERP	Latency (msec)	Electrode site	Association
P1	80-120	O1 and O2	Pictorial encoding and attention allocation
N170	150-200	T5 and T6	Structural encoding
N250	200-300	T5 and T6	Implicit identity recognition Face Recognition Units
N400	300-500	F 3,4,Z	Identity familiarity Person Identity Nodes
P600	500-800	P/C 3,4,Z	Identity explicit recognition Person Identity Nodes and Semantics

As demonstrated in Chapter 2, studies in face processing have focused specifically on P1 (pictorial encoding and attention allocation), N170 (structural encoding), N250 (implicit identity discrimination), N400 (identity familiarity), P600 (identity explicit recollection) (e.g., Bentin, *et al*., 1996; Curran & Hancock, 2007; Eimer, 2000; Eimer & Gosling, 2012; Kaufmann *et al*., 2009; Pfutze *et al*., 2002; Schweinberger *et al.*, 2004; Turano *et al.*, 2016; Yovel & Paller, 2004). Table 3.2.3.2.1 summarises the proposed cognitive and functional associations for each ERP. Given that previous studies used EEG caps with different configurations and a different number of electrodes, the electrode locations selected for analysis in this thesis are not identical but closely matched to locations showing maximal neural response in previous studies. Therefore, P1 was analysed at channels O1 and O2 (e.g., Tanaka *et al*., 2006; Turano *et al*., 2016), and N170 and N250 were both analysed at channels T5 and T6 (e.g., Rossion & Caharel, 2011; Tanaka *et al*., 2006; Turano *et al*., 2016; Yang *et al*., 2014), as these are the closest channels to reflect occipito-temporal sites. Furthermore, given that explicit recognition and recollection are interchangeably referred to as the *late old/new parietal effect*, P600 was analysed at channels P3, P4 and Pz (e.g., Smith, 1993; Düzel *et al*., 1997) in Chapter 5. Chapter 6, on the other hand, only looked at neural responses associated with familiarity and recollection, using similar electrode sites as Burns *et al.* (2014) study: P, C, F (3,4,Z), as these channels have been shown to generate maximal neural responses associated with the two recognition constructs during face processing (e.g., MacKenziet & Donaldson, 2007; Yovel & Paller). See section 3.3.2 for a full description of EEG recording and analysis.

3.3 Analyses

3.3.1 Behavioural analyses

For behavioural analysis in Chapters 4 – 6, all the data were visually inspected to check for normal distributions. The variables violating the assumption of normal distribution are reported in each experiment if appropriate.

Analyses were conducted for correct ‘old’ responses (hits), correct ‘new’ responses (correct rejections: CRs), and signal detection theory sensitivity ($d^{/}$) and response bias (criterion: C) statistics (e.g., Green & Swets, 1966), as well as response times (RTs). Mixed ANOVAs were employed for group analysis in all studies, regardless of data normality. For non-normally distributed variables, non-parametric Mann-Whitney U test and Wilcoxon matched-pair signed-rank test were used for independent samples and paired samples comparisons, respectively. The results were considered significant if they fell below the traditional $p < .05$ threshold. Bonferroni corrections were applied to multiple correlations and to post hoc multiple comparisons (Perneger, 1998), whereby the corrected *p* value was calculated by dividing 0.05 by the number of comparisons.

Note that studies investigating atypical populations, such as DPs (e.g., Le Grand *et al.*, 2006) and SRs (e.g., Bobak, Bennetts *et al*., 2016) generally perform analyses at the individual level, especially when examining small samples, to account for potential heterogeneity of the group. Individual analyses were also performed for SRs' performance reported in this thesis. Thus Chapters 4 (Experiments 4.2 and 4.3) and 5 (Experiments 5.2 and 5.3) employed modified t-tests for single cases (e.g., Crawford, Garthwaite, & Porter, 2010) as well as group analyses. The individual analyses compared the performance of each SR on all tests against the controls, thereby measuring test performance consistency and generating an estimate of the proportion of the general population each SR would be expected to exceed.

3.3.2 EEG recording and analyses

Chapters 5 (Experiment 5.2) and 6 (Experiment 6.1) used EEG recording to complement behavioural data and to explore individual differences in neural/electrical activity between SRs and controls. In both experiments the EEG was recorded using Mitsar WinEEG and a 10-20 system cap comprising 19 silver electrodes. FPz was used as the ground electrode and the reference electrodes were placed on both earlobes as they provide a neutral site for both hemispheres. The average of linked earlobes was used as the reference to subtract from all the active channels. No additional electrodes were used for eye movement as participants were instructed to keep their eyes on the fixation cross and Dickter and Kieffaber (2014) point out that Independent Component Analysis does not require input from additional eye-movement electrodes (EOG) for correcting blink artefacts. Impedance was kept under 5kΩ to ensure a clearer reading of the signal. The data was recorded with a sampling rate of 512Hz (the maximum sampling rate provided by Mitsar), as a higher sampling rate allows to record neuron activity of higher frequency, thereby allowing a wider range of EEG analysis. The data was filtered at 150Hz to avoid missing potentially useful data of high frequency, however only the 0-45Hz range was used for the final analysis (Cohen 2014; Dickter & Kieffaber, 2014; Luck, 2005).

Mitsar WinEEG was used to analyse the data. Independent Component Analysis was used to remove eye blinks/movements from the data. Visual inspection of the waveform and location of the activity was used to remove two components generating eye blinks and eye movements for each participant. Extracts recording anything above 100μV were removed from the analyses as waves of such high amplitude were most likely artefacts/noise (e.g., muscle tension or excess movement).

In Experiment 5.2 the recorded data was divided into 120 epochs of 1000msec each (-300msec – 700msec) for each trial type, using 300msec for baseline correction (Mitsar WinEEG requirement). Grand-averages were computed for all the encoding and recognition trials. Note that participants' responses on recognition trials were classified as either *Hits* or *Correct Rejections* (e.g., Wiese, Komes, & Schweinberger, 2012). Grand-averages of amplitudes and latencies were calculated for P1 and N170 for encoding trials (40 trials per stimulus), as well as for P1, N170, N250 and P600 for hits and correct rejections during recognition trials. Amplitude and latency for all ERPs were analysed at channels as reported in Table 3.2.3.2.1. The time ranges selected for each ERP component are reported in Experiment 5.2 (see section 5.2.1.6).

In Experiment 6.1 the recorded data was divided into 480 epochs of 1000msec each (-300msec – 700msec) for each trial type, using the same baseline correction. Grand-averages were computed for hits and correct rejections. Hits were classified as either correct 'remember' or 'know' responses, and correct rejections were selected from correct 'new' responses. Amplitudes and latencies of ERPs for 'remember', 'know', and 'correct rejections' responses were extracted from channels P (3/z/4), C (3/z/4) and F (3/z/4) during two time intervals, 300-500msec and 500-700msec after the stimulus onset, as previous studies have demonstrated these regions to be associated with familiarity and recollection during these time windows (e.g., Burns *et al*., 2014; MacKenzie & Donaldson, 2007; Yovel & Paller, 2004).

As in previous research (e.g., Burns *et al*., 2014; MacKenzie & Donaldson, 2007), participants with a minimum of 15-20 trials were retained for final analyses to ensure a reasonable signal-to-noise ratio (though see Experiments 5.2 and 6.1 for further details). The descriptive tables of artefact-free trials for each participant can be found in Appendices (see Tables A5.2.2.3 and A6.1.2.2), whereby participants with less than 15 artefact-free trials are marked as '**' and are thus excluded from analyses. *Local peak amplitude measure* was the method selected for measuring ERP amplitudes, which is one of the most common methods described by Luck (2005). The maximum peak amplitude is selected in the predetermined time window while being greater than the average of 3 – 5 surrounding peaks on each side. To obtain latency measures, the latency of selected local amplitude peak within a time window of interest was measured (Luck, 2005).

Mixed ANOVAs were employed for group analysis, regardless of data normality. For non-normally distributed variables, non-parametric Mann-Whitney U test and Wilcoxon matched-pair signed-rank test were used for independent samples and paired samples comparisons, respectively. The results were considered significant if they fell below the traditional $p < .05$ threshold. Note that EEG analyses employed a different method of p value corrections to account for multiple comparisons. Given that any two neighbouring electrodes will record electrical activity generated by two neuronal populations that significantly overlap with one another, the data recorded at these channels is strongly correlated. For this reason, the EEG data analyses reported in Experiments 5.2 and 6.1 used the Dubey/Armitage-Parmar (D/AP) method of correcting the p value, whereby the average correlation between the variables involved in the comparisons is taken into account, thereby attenuating the corrected p value (Sankoh, Huque, & Dubey, 1997).

Chapter 4 – Super Recognisers' (SRs) face processing abilities and holistic/parts-based processing.

4.0 Introduction

Chapter 2 discussed the large individual differences in face recognition ability in the population. The spectrum varies from those diagnosed with developmental prosopagnosia (DP) (e.g., Duchaine & Nakayama, 2006b), to super-recognisers (SRs; Russell *et al*., 2009). Both groups are normally defined as being more than two standard deviations below (DP) or above (SR) 'average' ability, with their deficit/advantage mainly being face-specific. It is noteworthy, that the broad distribution of face recognition ability is also found for face perception/matching (e.g., Megreya *et al.*, 2011; Megreya & Bindemann, 2013, Megreya & Bindemann, 2015), where sequential or simultaneous presentation of stimuli requires identifying a target face without relying on recognition. While most DPs show a significant impairment in face matching (e.g., Chatterjee & Nakayama, 2012; Eimer *et al*., 2012), SR literature shows mixed results (Bobak, Bennetts, *et al*., 2016; Bobak, Dowsett, *et al.*, 2016; Bobak, Hancock, *et al*., 2016; Davis *et al.*, 2016). These individual differences in face processing have been attributed to genetics (e.g., Shakeshaft & Plomin, 2015) and traits such as autism and empathy (e.g., Bate *et al.*, 2010; Weigelt *et al.*, 2012). However, one of the most robust explanations of individual differences in face processing derive from differences in processing styles, that is holistic and parts-based processing (e.g., DeGutis *et al.*, 2013; Maurer *et al*., 2002; Richler, Cheung *et al*., 2011; Wang *et al.*, 2012).

4.0.1 The measures of holistic processing

Holistic processing, the notion of facial features and their spatial relations being processed as a unified construct (Rossion, 2008; Tanaka & Farah, 1993), partly explains individual differences in upright face recognition (e.g., DeGutis *et al*., 2013; Richler, Cheung *et al*., 2011; Wang *et al*., 2012). Inverted faces are more difficult to process than inverted objects, suggesting that holistic processing is disrupted when faces are inverted, and that upright object processing relies less on holistic processing (Behrmann & Avidan, 2005; Valentine, 1988; Yin, 1969). While significantly reduced, or absent altogether in DPs (e.g., Behrmann & Avidan, 2005), this Inversion Effect (IE), is greater in SRs (Bobak, Bennetts, *et al*., 2016; Russell *et al*., 2009), implying that SRs' superior recognition of faces is strongly advantaged by the effective integration of upright facial features and configurations. However, SR numbers in these studies were small limiting generalisation, and not all displayed a strong IE, suggesting that as with DP (e.g., Bate & Bennetts, 2014; Susilo & Duchaine, 2013), SR may not be a homogeneous construct.

A second measure of holistic processing is derived from the Composite Face Test (Young *et al*., 1987). This test requires participants to judge whether the top halves of two face composites (faces split into two halves horizontally and intermixed with different top and bottom halves) are the 'same' or 'different'. When aligned, it is difficult to ignore the bottom face half, as holistic processing binds the configurations into a unified whole. These configurations are disrupted with misaligned images, so that parts-based processing makes face half discrimination easier. For instance, Taubert and Alais (2009) showed that even a small shift in alignment is disruptive to holistic perception, and makes the task easier. DP is associated with a reduced Composite Face Effect (CFE), indicative of disrupted holistic processing and greater reliance on parts-based processing mechanisms (e.g., Palermo, Willis *et al.*, 2011; although see Le Grand *et al*., 2006; Susilo *et al*., 2011). Bobak, Bennetts *et al*. (2016) used the composite face test (using faces and objects in upright and inverted orientations) to examine holistic processing in SRs. When analysing accuracy, none of the six SRs tested displayed a larger CFE than controls. With RTs, the CFE was greater for one SR only. This might suggest that whereas in most of the population, superior face recognition ability is associated with a greater reliance on holistic processing, there may be an upper limit. Indeed, it might suggest that enhanced parts-based perceptual processing additionally drives SR's skills.

A third commonly-used measure of holistic processing is the Part-Whole Effect (PWE) (Tanaka & Farah, 1993) which shows that individual features are more easily recognised in the context of the entire face than individually (DeGutis *et al*., 2013; Wang *et al*., 2012). PWE appears to be significant only in upright faces, and is absent for scrambled faces, inverted faces and objects (Tanaka & Farah, 1993), though McKone *et al*. (2013) showed that inverted faces can also sometimes induce the PWE, and suggested that both inverted and upright versions should be included in tests. The scores from the inverted condition should then be extracted from the upright condition in order to calculate a measure of holistic processing. PWE has been shown to be reduced in Caucasian participants when processing other ethnicities in comparison to processing faces of their own ethnicity (Crookes *et al.*, 2013). That said, PWE findings show that processing own ethnicity faces benefits from both enhanced holistic processing and more effective parts-based processing (Hayward, Crookes, & Rhodes, 2013). There are no documented studies exploring PWE in SRs.

4.0.2 Composite face effect (CFE), Part-whole effect (PWE) and face recognition

The CFE and PWE have been often used to test holistic processing as a potential predictor of face recognition. Several studies found a positive relationship between the CFE and face recognition ability (e.g., Richler, Cheung *et al*., 2011), and CFE/PWE and face recognition ability (e.g., DeGutis *et al*., 2013; Wang *et al*., 2012). It is noteworthy that Wang *et al*. (2012) only found a significant relationship between CFE/PWE and face recognition, when subtracting object recognition scores from face recognition scores, to produce a measure of face-specific recognition. Indeed, Wang *et al.* (2012) propose that face recognition studies should not put so much emphasis on the raw scores of face recognition tests, as other general factors always contribute to an overall performance. It is noteworthy, that while finding a significant independent correlation between CFE and PWE and face recognition in their participants (n = 337), Wang *et al*. (2012) pointed out that the two measures of holistic processing did not correlate with one another. That said, when DeGutis *et al*. (2013) calculated CFE and PWE by regressing control conditions (misaligned and part trials, respectively) from the relevant holistic conditions (aligned and whole trials, respectively), they found the two tasks to be significantly correlated ($r = .44$, $p < .005$). Furthermore DeGutis *et al.* (2013) showed that the holistic properties derived from the Composite Face Test explained 13% of variance in face recognition performance (as measured by the Cambridge Face Memory Test), while holistic processing derived from the Part-Whole Test explained 21% of variance. The authors suggested that PWE may capture aspects of holistic processing that CFE does not. Furthermore, both Wang *et al*. (2012), and DeGutis *et al*. (2013) suggest that the two tasks demand a different approach from participants and induce a different processing style, as CFE is intervening in nature (bottom half interferes with processing), and PWE is facilitating (whole face facilitation of feature recognition), but that both tap into holistic processing.

Importantly, there are studies finding no relationship between holistic processing and face recognition (e.g., Horry *et al*., 2014; Konar *et al*., 2010). For example, Horry *et al*. (2014) failed to find a relationship between *Cambridge Face Memory Test (CFMT)* and CFE, and the authors suggest that the CFMT could be dependent on parts-based processing as well as holistic processing. Indeed DeGutis *et al*. (2013) demonstrated that holistic processing (adjusted R^2 = .21) is not the only predictor of face recognition performance. In fact, they showed that together with holistic processing, parts-based processing derived from the non-holistic trials of the Composite Face Test (adjusted R^2 = .25) and Part-Whole Test (adjusted R^2 = .38) appeared to predict a greater portion of CFMT performance variance than holistic processing on its own. Note that only parts-based processing related to facial features predicted the CFMT variance, but not general parts-based processing (DeGutis *et al.*, 2013). Furthermore, research exploring children's face processing suggests that holistic processing (measured by the CFE as well as the PWE) develops at a young age and that holistic processing in children is comparable to that of adults (e.g., Carey & Diamond, 1994; Mondloch *et al.*, 2007), implying that holistic processing may not necessarily improve with later age, whereas face recognition appears to develop with age (Bowles *et al.*, 2009; Susilo *et al.*, 2013; Weigelt *et al.*, 2014). Therefore, it is possible that the improvement of face recognition with age is owing to face-specific and general visual improvements that include factors other than holistic processing (e.g., parts-based processing).

Individual differences in face processing exhibited by typical and atypical populations appear to be at least partially explained by individual differences in holistic processing as well as individual differences in general visual processing (i.e., parts-based processing). The present study first aimed to explore whether SRs demonstrate recognition superiority that is specific to faces (Experiments 4.1 and 4.2) and whether their superiority in face recognition could be observed in face perception/matching as well (Experiment 4.3). The second aim of the study was to explore whether SR is associated with a specific reliance on holistic processing as measured by the Inversion Effect (IE), Composite Face Effect (CFE) (Experiment 4.2) and Part-Whole Effect (PWE) (Experiment 4.3), and/or a specific reliance on parts-based processing (Experiment 4.3).

4.1 Experiment 1

Experiment 4.1 recruited a large sample of participants in order to explore the face-specificity of SRs' recognition superiority using face and object recognition tests. Based on previous research recruiting small samples, finding an almost exclusive advantage for faces compared to objects (Bobak, Bennetts *et al.*, 2016), SRs were expected to demonstrate a greater face-specific recognition to that of controls. In which case SRs were expected to show an enhancement only for face recognition. On the other hand, their superiority in face recognition could be aided by a general visual recognition superiority. In which case, their face-specific recognition could be coupled with enhanced object recognition, and if so, no group differences in face-specific recognition would be predicted.

4.1.1 Methods

4.1.1.1 Design

An independent-measures component, drawing on the inclusion criteria discussed in Chapter 3 (section 3.1.1) to allocate participants to groups, compared the performance of SRs and controls on the *Cambridge Face Memory Test: Extended (CFMT+)* and *face and object recognition tests (old/new),* with scores extracted to compute *face-specific recognition*. A correlational component examined the relationships between performances on all measures.

4.1.1.2 Participants

Following media articles and programmes (radio and television) on SR, an online study loaded on the Qualtrics platform collected data from 820 participants (CFMT+: 41 - 102; *M* = 84.33, *SD* = 10.71; males = 107 (of 241 reported), mean age = 31.24, *SD* =9.41)[2]. Using the inclusion criteria discussed in Chapter 3, 199 SRs (CFMT+: 93 - 102; *M* = 95.54, *SD* = 2.1, 33 males, mean age = 32.19, *SD* = 9.31); and 279 controls (CFMT+: 59 - 83; *M* = 75.21, *SD* = 6.19, 34 males and mean age = 30.21, *SD* = 10.16) were retained for group analyses. Note that age and gender was only reported for 75 participants in each group. Furthermore, 4 SRs defined using the CFMT+ and 7 controls were excluded based on their low/high sores respectively on the second recognition test (see Chapter 3, section 3.1.1). SRs and controls were matched on age, $t(148) = 1.24$, $p = .217$, and gender proportions, $\chi^2(1, n = 150) < 1$, $p = .870$.

4.1.1.3 Materials

Cambridge Face Memory Tests (extended): Upright (CFMT+): The short-term CFMT+ (Russell *et al*., 2009) has been employed in most previous SR research to verify SR ability and is the extended 102-trial version of the original 72-trial CFMT (Duchaine & Nakayama, 2005). See Chapter 3 (section 3.1.1) for a more detailed description.

Face Recognition Test (Old/New): The male and female adult white face stimuli were acquired from the database of The Park Aging Mind Laboratory at The University of Texas at

[2] Note: a great number of demographic information was not recorded either due to technical error or participant deliberate omission

Dallas (Minear & Park, 2004). Adobe Photoshop was used to remove external features (e.g., hair) and distinguishing marks (e.g., freckles). The face images uploaded online were approximately 6.5cm x 9cm.

The test was arranged in two phases (learning and recognition), and to avoid potential floor effects by asking participants to memorise 40 faces in one phase, it consisted of two learning blocks (20 trials per block) and two recognition blocks (40 trials per block). In the first learning phase the image appeared for 2 seconds on the screen followed by the two response options. Participants were required to respond whether the faces appeared 'older' or 'younger' than 30-years. The recognition phase followed immediately after the leaning phase, though it did not begin until participants clicked on the 'Continue' button, indicating they were ready to proceed. In the recognition phase half the trials depicted faces seen in the learning phase, and participants were instructed to respond 'old' or 'new' for faces they recognised and did not recognise, respectively (Figure 4.1.1.3.1). The second learning and recognition block started shortly after completion of the first block.

Object Recognition Test (old/new): The motorbike stimuli for the object recognition test were from the California Institute of Technology database (Fergus, Perona, & Zisserman, 2003). The images were approximately 14cm x 8cm. The design was virtually identical to the face recognition test as it had the same stimuli numbers, blocks and procedure, except that participants reported whether motorbikes were 'modern' or 'not' ('M' or 'N') in the learning phase (Figure 4.1.1.3.1). This test was employed to calculate the participants' face-specific recognition.

Analyses were conducted in both tests of correct 'old' responses (hits), correct 'new' responses (correct rejections: CRs), and signal detection theory sensitivity ($d^{/}$) and response bias (criterion: C) statistics (e.g., Green & Swets, 1966). High positive values of $d^{/}$ indicate good discrimination of 'old' and 'new' stimuli. Negative values of C are indicative of conservative response biases or a tendency to respond 'new' under conditions of uncertainty; positive values indicate liberal response biases or a tendency to respond 'old'. Note that no response times (RTs) were recorded in this online study.

To calculate Face-specific recognition, sensitivity scores ($d^{/}$) on the object recognition test (old/new) were subtracted from those on the face recognition test (old/new). The face and object (old/new) recognition tests were not matched on the level of difficulty, thus the difference between the two tests was only compared between, but not within, participant groups.

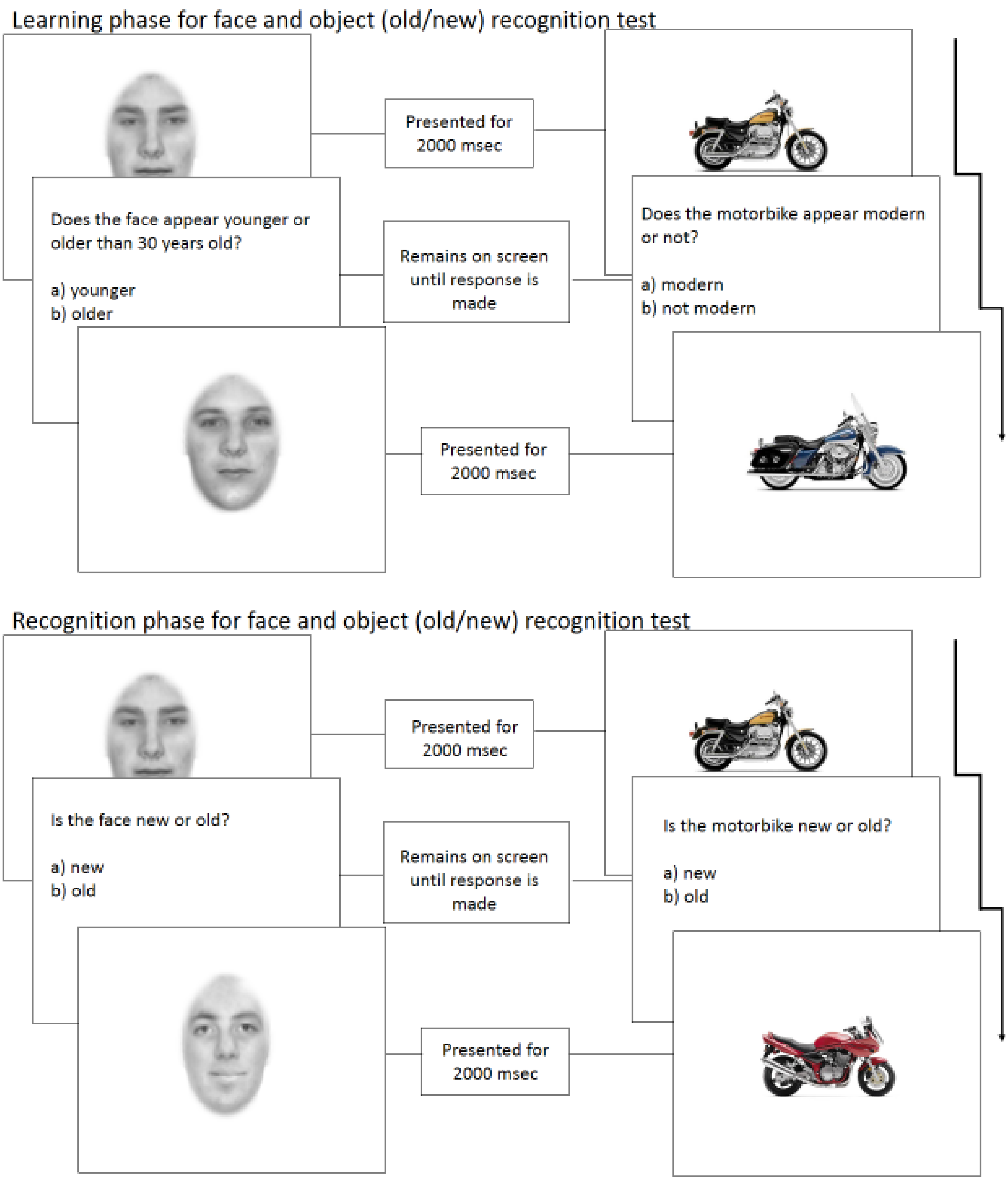

Figure 4.1.1.3.1. An example of the face and object (old/new) recognition tests. The original facial identities were completely altered in Photoshop.

4.1.1.4 Procedure

After providing informed consent, online participants first completed the online version of the CFMT+. They then proceeded to complete the old/new face recognition test and old/new object recognition test in a counterbalanced order. The entire testing session took approximately 90[3] minutes, and all participants were fully debriefed at the end.

4.1.2 Results

Note that in order to rule out the possibility of a response bias introduced by the response options (‘*older’* and ‘*younger*’ responses in the learning phase, and ‘*old’* and ‘*new*’ responses in the recognition phase) in the face recognition test (old/new), a second version of the same test was introduced online with different instructions in the learning phase, where participants were asked to judge the faces’ gender (‘male’ or ‘female’). The two versions showed no differences in performance, as four independent-measures t-tests found no encoding instructions influence on hits, $t(818) = -0.42$, $p = .673$; CRs, $t(818) = 0.28$, $p = .777$; sensitivity (d'), $t(818) = 0.02$, $p = .987$; or criterion (C), $t(818) = 0.35$, $p = .728$. Data from the two versions were pooled for subsequent analyses.

Table 4.1.2.1. Mean online performance on face and object recognition tests (old/new)

	SRs (n = 199)			Controls (n = 279)		
	M	(SD)	95% CI	M	(SD)	95% CI
CFMT+	95.54	(2.10)	95.24, 95.83	75.21	(6.19)	74.48, 75.94
Face Recognition Test (old/new)						
Hits	0.88	(0.08)	0.87, 0.89	0.77	(0.11)	0.76, 0.79
CR	0.90	(0.08)	0.88, 0.91	0.82	(0.11)	0.80, 0.83
d'	2.60	(0.55)	2.52, 2.67	1.78	(0.52)	1.71, 1.84
C	0.05	(0.31)	0.01, 0.09	0.09	(0.31)	0.05, 0.12
Object Recognition Test (old/new)						
Hits	0.77	(0.11)	0.75, 0.78	0.73	(0.12)	0.72, 0.75
CR	0.70	(0.13)	0.68, 0.71	0.68	(0.13)	0.67, 0.70
d'	1.34	(0.59)	1.26, 1.42	1.17	(0.56)	1.10, 1.24
C	-0.12	(0.28)	-0.16, -0.08	-0.08	(0.26)	-0.11, -0.05
Face-specific Recognition						
d'	1.26	(0.65)	1.17, 1.35	0.61	(0.65)	0.53, 0.68

[3] Note: the online study took approximately 90 minutes to complete as it included other tasks reported in Chapter 5 (Experiment 5.1). Excluding additional tasks would amount to approximately 60 minutes of online testing.

Table 4.1.2.1 depicts the mean performance of SRs and controls on each test. Four 2 (stimulus-type: face, object) x 2 (group: SR, control) ANOVAs examined these outcomes (hits, CRs, d/, C).

Hits: The stimuli-type main effect was significant, $F(1, 476) = 191.00$, $p < .001$, $\eta^2 = .29$. Hit rates for faces were higher than objects. The group main effect was significant, $F(1, 476) = 68.78$, $p < .001$, $\eta^2 = .13$, whereby SRs outperformed controls. There was a significant interaction, $F(1, 476) = 38.07$, $p < .001$, $\eta^2 = .07$, whereby SRs' recognition superiority over controls was more pronounced for faces, $F(1, 476) = 124.29$, $p < .001$, $\eta^2 = .21$, than for objects, $F(1, 476) = 10.62$, $p = .001$, $\eta^2 = .02$, though both effects were significant.

CRs: The stimuli-type main effect was significant, $F(1, 476) = 766.51$, $p < .001$, $\eta^2 = .62$. CRs for faces were higher than for objects. The group main effect was significant, $F(1, 476) = 28.52$, $p < .001$, $\eta^2 = .06$, whereby SRs outperformed controls. There was a significant interaction, $F(1, 476) = 30.20$, $p < .001$, $\eta^2 = .06$ whereby SRs outperformed controls on faces, $F(1, 476) = 79.76$, $p < .001$, $\eta^2 = .14$, but not on objects, $F(1, 476) = 1.34$, $p = .248$, $\eta^2 = .003$.

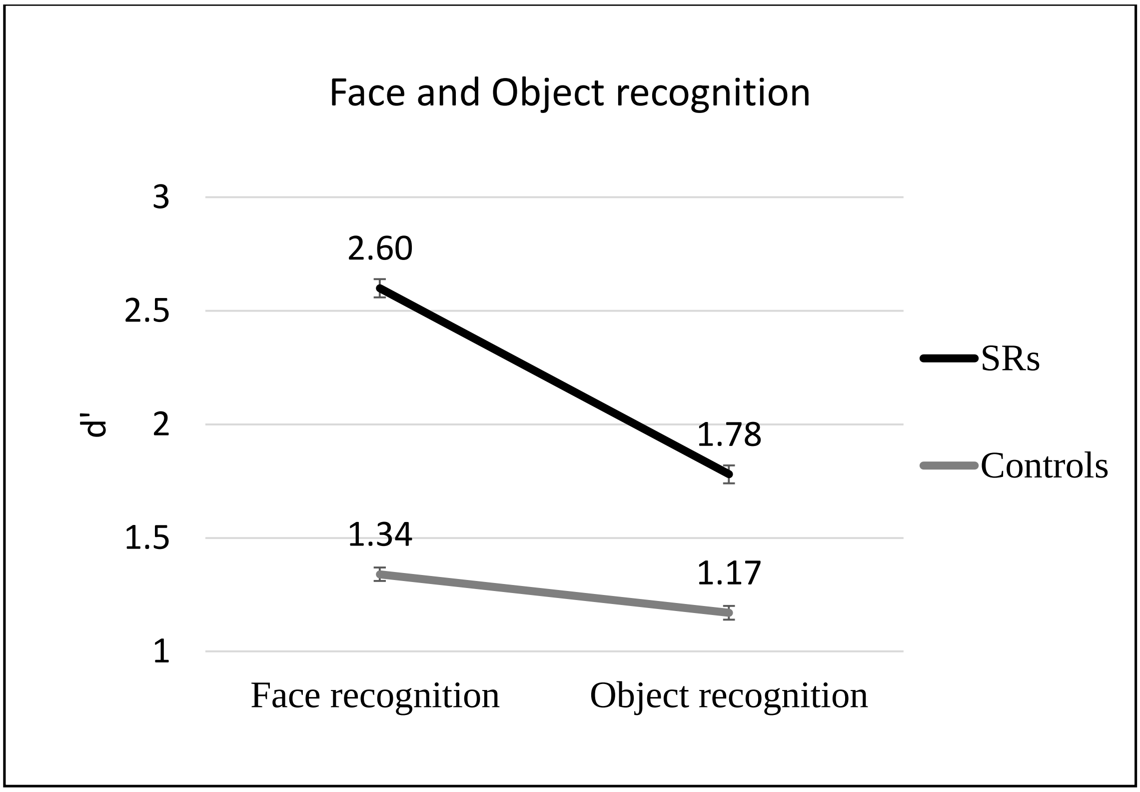

Figure 4.1.2.1. Mean scores generated by SRs and controls on face and object (old/new) recognition tests. Error bars = standard error of the mean

Sensitivity (d′): The stimulus-type main effect was significant, $F(1, 476) = 962.37$, $p < .001$, $\eta^2 = .67$. Sensitivity for faces was higher than objects. The group main effect was significant, $F(1, 476) = 138.95$, $p < .001$, $\eta^2 = .23$, whereby SRs outperformed controls. The interaction was significant, $F(1, 476) = 116.90$, $p < .001$, $\eta^2 = .20$, whereby SRs' recognition superiority over controls was more pronounced for faces, $F(1, 476) = 272.76$, $p < .001$, $\eta^2 = .36$, than for objects, $F(1, 476) = 9.62$, $p = .002$, $\eta^2 = .02$, though both effects were significant.

Response bias (criterion C): The stimulus-type main effect was significant, $F(1, 476) = 133.48$, $p < .001$, $\eta^2 = .22$, showing that responses for objects were more liberal than for faces. The group main effect was not significant, $F(1, 476) = 2.47$, $p = .117$, $\eta^2 = .005$. There was no interaction, $F(1, 476) < 1$.

Correlational analyses

Correlation coefficients between all measures for all participants ($n = 820$) are presented in Table 4.1.2.2.

Table 4.1.2.2 Correlational analyses for all online measures (n = 820)

	Face old/new test				Object old/new test				Face-specific recognition
	Hits	CR	d′	C	hits	CR	d′	C	d′
CFMT+	0.33*	0.34*	0.49*	0.01	0.15*	0.07	0.15*	-0.06	0.32*
Face Recognition Test (old/new)									
Hits		0.04	0.69*	-0.67*	0.42*	-0.01	0.27*	-0.30*	0.41*
CR			0.70*	0.67*	-0.03	0.33*	0.21*	0.26*	0.47*
d′				0.01	0.26*	0.21*	0.32*	-0.03	0.66*
C					-0.33*	0.25*	-0.05	0.42*	0.05
Object Recognition Test (old/new)									
Hits						0.04	0.70*	-0.66*	-0.32*
CR							0.72*	0.70*	-0.38*
d′								0.03	-0.50*
C									-0.05

* Correlation is significant at the 0.001 level (2-tailed)

Correlations were considered significant ($p = .001$) only after applying Bonferroni corrections to account for multiple comparisons ($n = 45$). As predicted, performances on the CFMT+ were more strongly related to face recognition (old/new) test scores compared to object recognition, as indicated by hits, correct rejections and sensitivity index. Accordingly, CFMT+

scores were also positively and significantly related to face-specific recognition ability. Additional regression analyses were performed to show that performance on the object recognition test (d') explained only 2% of the CFMT+ scores variance, $R^2 = .02$, $F(1, 818) = 18.94$, $p < .001$. More importantly, while together face and object recognition scores significantly predicted CFMT+ scores, explaining a significant portion of variance in CFMT+ performance, $R^2 = .23$, $F(2, 817) = 126.00$, $p < .001$, performance on the object recognition test, $b = -.004$, $t(817) = 0.12$, $p = .902$, made no additional significant contribution to CFMT+ performance beyond that of face recognition performance, $b = .49$, $t(817) = 15.09$, $p < .001$.

Finally, analyses of face and object recognition tests generated no correlations between hits and correct rejections, thus individuals who generate high hit rates do not necessarily generate high rates of correct rejections. In line with previous research (e.g., Wiese *et al.*, 2012) these results demonstrate that the two responses reflect two distinct processes (see General Discussion).

4.1.3 Discussion

Experiment 4.1 recruited a substantial sample of participants to demonstrate that SRs have a generally superior visual recognition, as they outperformed controls on both face and object recognition tests. Importantly, SRs' recognition for faces was far better than their recognition for objects, as reflected in hits, correct rejections and sensitivity index. Though the face and object (old/new) recognition tests were not matched on the level of difficulty, SRs demonstrated a larger difference in performance between the two tests compared to controls. Therefore, while SRs demonstrate a general visual recognition superiority, this advantage is more pronounced for faces. These results thus contradict the recent study by Bobak, Bennetts *et al*. (2016), whose findings suggested a general trend of face-specific superiority, possibly due to the far higher numbers of participants recruited here. Finally, while SRs appear to demonstrate a superior general parts-based processing (indirectly demonstrated by their enhanced object recognition), regression analysis suggests that this type of processing does not predict or explain SRs' face recognition ability (measured by CFMT+).

4.2 Experiment 2

Building on the findings from Experiment 4.1, Experiment 4.2 measured the relationship between face recognition, object recognition, and holistic processing derived from the composite face effect (CFE) and inversion effect (IE) measures. Based on previous research testing ‘normal’ range participants, a positive relationship was expected between face recognition ability and the propensity to process faces holistically, as operationalised by stronger IE and CFE. On the other hand, based on the results from Experiment 4.1, it is possible that the face processing superiority of SRs may also be driven by more effective parts-based processing mechanisms. In which case, enhanced parts-based processing could attenuate IE and CFE in the opposite direction, resulting in potentially weaker IE and CFE in SRs.

4.2.1 Methods

4.2.1.1 Design

An independent-measures component compared the performance of SRs and controls on the *Cambridge Face Memory Test: Extended (CFMT+), and the Cambridge Face Memory Test: Inverted (CFMT-I)* (Russell *et al*., 2009), with scores from both used to compute the Inversion Effect (IE); two-phase *face and object recognition tests (old/new)*, with scores extracted to compute face-specific recognition; and the *Composite Face Test*, for calculation of the composite face effect (CFE) on accuracy and RTs. A correlational component examined the relationships between performances on all measures. Additional individual level analyses examined the homogeneity of SR responses.

4.2.1.2 Participants

Following media articles and programmes (radio and television) on SR, volunteer members of the public claiming they possessed SR ability were invited to attend the university. University e-mail adverts requested participation by staff or students in order to encourage recruitment of roughly demographically matched controls. In total, 68 participants contributed (32 males, mean age = 38.9 years, *SD* = 12.5). Using the inclusion criteria discussed in Chapter 3 (section 3.1.1), 20 SRs (CFMT+ raw score: 93 - 100; *M* = 95.15, *SD* = 1.60; 9 males, age = 39.2, *SD* = 11.6) and 33 controls (CFMT+: 61 - 82; *M* = 72.48, *SD* = 6.72; 14 males, mean age = 37.8, *SD* = 14.6) were retained for group analysis. Note that while one CFMT-defined SR was excluded based on their low score on the second recognition test (see Chapter 3, section 3.1.1), all the CFMT-defined controls were retained as they showed the expected average ability on the second recognition test.

SRs and controls were matched on age, $t(51) < 1$, $p = .959$, gender proportions, $\chi^2(1, n = 53) < 1$, $p = .699$, on autistic traits $t(49) < 1$, $p = .686$, but not on empathy, $t(49) = 3.09$, $p =$

.003, Cohen's d = .92. In line with previous research showing a positive relationship between face recognition and empathy (Bate *et al*., 2010), SRs demonstrated higher empathy scores[4]. The data of the remaining 15 participants (CFMT+: 84 - 94; M = 88.58, SD = 3.06) not included in the SR or control groups were analysed in the correlational component only.

4.2.1.3 Materials

Cambridge Face Memory Tests (extended): Upright (CFMT+) and Inverted (CFMT-I): The upright version of CFMT+ used in this experiment was the same as that used in Experiment 4.1 (see also Chapter 3, section 3.1.1 for a full description).

The inverted version of CFMT+ (CFMT-I) has a similar 102-trial design to the CFMT+ except that faces are inverted. CFMT-I was used to measure inverted face processing and to calculate the inversion effect (IE) by subtracting CFMT-I from CFMT+[5]. Note that previous research (Bobak, Bennetts *et al.*, 2016; Russell *et al.*, 2009) used *Cambridge Face Perception Test* (upright and inverted) to calculate the *perceptual* IE in SRs and found mixed results, while the *recognition-based* IE has not yet been examined.

Face and Object Recognition (Motorbike) Tests (Old/New): The same face and object recognition tests (old/new) were used as in Experiment 4.1. These tests were administered using the MATLAB 2014a (MathWorks, USA) extension Psychtoolbox (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007). The visual angle of the image presentation was 4.90° by 5.72° for faces and 5.72° by 4.09° for motorbikes.

As in Experiment 4.1, the test had 2 learning blocks (20 trials each) and 2 recognition blocks (40 trials each). Each trial began with a 500msec central fixation cross, followed by a 2000msec stimulus presentation. To ensure attention was paid to stimuli during the learning phase, participants pressed 'O' if faces appeared older than 30-years; 'Y' if younger (Note: Experiment 4.1 found no response bias when using these response options). Following a brief break[6], in the recognition phase half the trials depicted faces seen in Phase 1, and participants were instructed to respond 'O' for old and 'N' for new faces. The second learning and recognition block started shortly after completion of the first block.

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[4] Note: Autism and Empathy scores were not recorded for 2 control participants.

[5] Note: when calculating the Inversion Effect by standardising the difference between CFMT+ and CFMT-I to upright performance, i.e., [(CFMT+) – (CFMT-I)] / CFMT+, both group and individual analyses generate similar results (see Appendix for Tables A4.2.2.5- A4.2.2.6)

[6] Note: the recognition block did not begin until participants pressed the 'Enter' key to indicate they were ready to proceed to the recognition stage

The object recognition test had the same design as the face recognition test, except in the learning phase participants were required to respond if the motorbikes appeared modern or not modern (‘M’ or ‘N’).

Analyses were conducted of correct ‘old’ responses (hits), correct ‘new’ responses (correct rejections: CRs), and signal detection theory sensitivity ($d^{/}$) response bias (criterion: C) statistics (e.g., Green & Swets, 1966), and response times (RTs).

To calculate Face-specific recognition, sensitivity scores ($d^{/}$) on the object recognition test (old/new) were subtracted from those on the face recognition test (old/new).

Composite Face Test: This test was designed in Adobe Photoshop and presented in PsychoPy2 (Peirce, 2007), using the *complete* version as a template (Richler, Cheung *et al.*, 2011). The 20 male faces were from the Max Planck Institute database (Troje & Bulthoff, 1996), split horizontally in half to create randomly mixed face composites (Figure 4.2.1.3.1). The visual angle of stimuli presentation was approximately 2.8° by 3.8°.

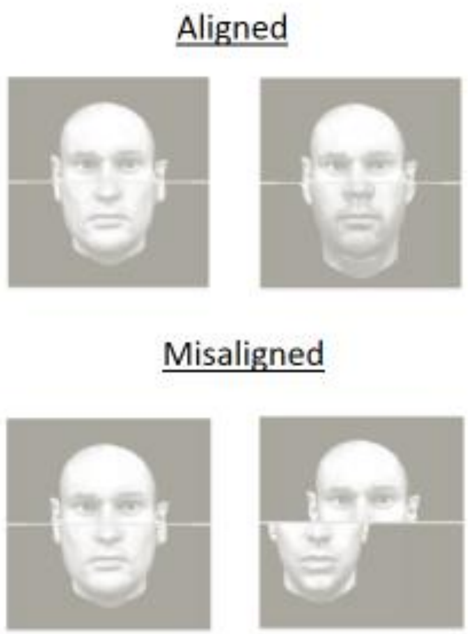


Figure 4.2.1.3.1. An example of the Composite Face Test trials in aligned and misaligned conditions.

Consisting of 160 trials and presented in aligned and misaligned blocks, participants completed 40 trials in four conditions: 1) *same-congruent* (the two composites had same top and same bottom halves), 2) *same-incongruent* (the two composites had same top halves but different bottom halves), 3) *different-congruent* (the two composites had different top and different bottom halves) and 4) *different-incongruent* (the two composites had different top halves but same bottom halves). The aligned trials were presented separately from misaligned trials and the order of presentation was counterbalanced. Note that the partial design of the Composite Face Test includes only two types of the aforementioned trials: same-incongruent and different-congruent trials.

Participants completed four practice trials to ensure familiarity with instructions (to respond 'same' or 'different' ('S' or 'D') as quickly as possible). Each trial began with a fixation cross (200msec) followed by a blank screen (150msec) and a rapid sequential presentation of two composite faces (200msec) with an inter-stimulus interval (400msec). The next trial began immediately after a response. Compared to when misaligned, participants were expected to be less accurate, with longer RTs on same-incongruent and different-incongruent trials with aligned composites. The CFE for accuracy and RT were calculated using standard formulae:

$$CFE_{complete} = (\text{Aligned congruent trial}_{Accuracy/RT} - \text{Aligned incongruent trial}_{Accuracy/RT}) - (\text{Misaligned congruent trial}_{Accuracy/RT} - \text{Misaligned incongruent trial}_{Accuracy/RT})$$

Thus, as the equation suggests, the performance on the misaligned (control) condition was subtracted from the performance on the aligned (i.e., holistic) condition. Furthermore, within each alignment condition (i.e., aligned and misaligned), the performance on incongruent trials (whereby participants were expected to make errors owing to holistic manipulations involved) was subtracted from the accuracy on congruent trials (whereby participants were expected to make no errors, as these served as control trials).

To compare the outcomes to previous research the $CFE_{Partial}$ was also calculated for the laboratory participants. To obtain $CFE_{Partial,}$ only data from two (of four) types of trials was selected for analyses: 1) same or 2) different top halves, always accompanied by different bottom halves. Given that the partial design does not take the congruency/incongruency of face halves into account, the $CFE_{Partial}$ was calculated using the equation:

$$CFE_{Partial} = \text{Misaligned trial}_{Accuracy/RT} - \text{Aligned trial}_{Accuracy/RT}$$

4.2.1.4 Procedure

After providing informed consent, laboratory participants completed the tests in the following order on a computer: CFMT+, CFMT-I. The Face Recognition Test (old/new) and the Object Recognition Test (old/new) were administered in a counterbalanced order. The last test administered was the Composite Face Test. The entire experiment took approximately 90 minutes[7], and all participants were fully debriefed at the end.

4.2.2 Results

The mean scores generated by SRs and controls on all measures are presented in Table 4.2.2.1

Table 4.2.2.1. Mean performances of SRs and controls on each test outcome.

	SRs (n = 20)				Controls (n = 33[8])			
	M	(SD)	95% CI		M	(SD)	95% CI	
CFMT+	95.15	(1.60)	94.40,	95.90	72.90	(6.64)	70.47,	75.34
CFMT-I	61.25	(10.42)	56.37,	66.13	54.16	(6.59)	51.74,	56.58
Inversion Effect (IE)								
IE	33.90	(10.03)	29.21,	38.59	18.72	(6.91)	16.23,	21.21
Face recognition test (old/new)								
Hits	0.82	(0.11)	0.77,	0.87	0.75	(0.14)	0.70,	0.80
CR	0.90	(0.09)	0.86,	0.94	0.75	(0.11)	0.71,	0.79
d/	2.43	(0.55)	2.17,	2.68	1.48	(0.57)	1.28,	1.69
C	0.20	(0.42)	0.01,	0.40	-0.01	(0.35)	-0.13,	0.12
Object recognition test (old/new)								
Hits	0.71	(0.08)	0.68,	0.75	0.69	(0.12)	0.65,	0.74
CR	0.69	(0.16)	0.61,	0.77	0.53	(0.17)	0.47,	0.59
d/	1.11	(0.49)	0.88,	1.34	0.61	(0.39)	0.47,	0.76
C	-0.03	(0.30)	-0.17,	0.12	-0.24	(0.38)	-0.38,	-0.11
Face-specific recognition								
d/	1.31	(0.66)	1.01,	0.62	0.91	(0.64)	0.68,	1.15
Composite Face Effect (CFE)								
Accuracy	17.63	(17.46)	9.45,	25.80	30.00	(17.78)	23.48,	36.52
RT	0.11	(0.21)	0.01,	0.21	0.02	(0.19)	-0.04,	0.09

Inversion effect (IE): CFMT+ and CFMT-I: A 2 (orientation: upright, inverted) x 2 (group: SR, control) ANOVA revealed a main effect of orientation, $F(1, 50) = 502.65$, $p < .001$, $\eta^2 = .91$; as expected upright scores were higher than inverted. A group main effect demonstrated the expected superiority of SRs over controls, $F(1, 50) = 87.58$, $p < .001$, $\eta^2 = .64$. There was also a significant orientation x group interaction, $F(1, 50) = 41.84$, $p < .001$, $\eta^2 = .46$.

[7] Note that the testing session included other tests reported in Chapter 5 (Experiment 5.2) thereby attenuating the duration of the session. Excluding additional tests would amount to 75 minutes of testing.
[8] Data was not recorded for object recognition test for one control, and for CFMT-I for another control.

Simple effects comparing upright and inverted faces within each group, revealed that as expected SRs displayed a stronger IE, $F(1, 19) = 339.02$, $p < .001$, $\eta^2 = .87$, than controls $F(1, 31) = 165.40$, $p < .001$, $\eta^2 = .77$

Face-specific recognition: Face and object recognition tests (old-new): Four 2 (stimulus-type: face, object) x 2 (group: SR, control) ANOVAs examined mean outcomes.

Hits: The stimulus-type main effect was significant, $F(1, 50) = 20.19$, $p < .001$, $\eta^2 = .29$. Hit rates for faces were higher than objects. There was no significant group main effect, $F(1, 50) = 2.12$, $p = .152$, $\eta^2 = .04$, or interaction, $F(1, 50) = 1.76$, $p = .191$, $\eta^2 = .03$.

CRs: The stimulus-type effect was significant, $F(1, 50) = 106.09$, $p < .001$, $\eta^2 = .68$. CR rates for faces were higher than objects. There was also a significant group effect, $F(1, 50) = 21.85$, $p = .001$, $\eta^2 = .30$. SRs made more CRs than controls. There was no significant interaction, $F(1, 50) < 1$.

Sensitivity (d'): The stimulus-type effect was significant, $F(1, 50) = 128.26$, $p < .001$, $\eta^2 = .72$. Sensitivity to faces was higher than to objects. There was also a significant group effect, $F(1, 50) = 46.96$, $p < .001$, $\eta^2 = .48$. SRs had better discriminability than controls. A significant interaction was found, $F(1, 50) = 5.38$, $p = .024$, $\eta^2 = .10$, whereby SRs' recognition superiority over controls was more pronounced for faces, $F(1, 50) = 35.05$, $p < .001$, $\eta^2 = .41$, than for objects, $F(1, 50) = 16.29$, $p = .001$, $\eta^2 = .25$, though both effects were significant.

Response bias (criterion C): The stimulus-type, $F(1, 50) = 23.40$, $p < .001$, $\eta^2 = .32$, and group main effects, $F(1, 50) = 5.33$, $p = .025$, $\eta^2 = .10$ were significant. Responses to faces were more conservative than to objects; and in contrast to controls who tended to display a liberal response bias, SRs displayed a more conservative response. In other words, SRs were more likely to respond 'new' during recognition trials. There was no significant interaction, $F(1, 50) < 1$.

RTs: The main effects were not significant for either stimulus-type, $F(1, 50) < 1$, or group, $F(1, 50) = 1.90$, $p = .175$, $\eta^2 = .04$. The interaction was not significant, $F(1, 50) = 3.58$, $p = .065$, $\eta^2 = .07$

In summary, SRs were superior to controls at both face and object recognition, although effect sizes for faces were stronger. Although SR's sensitivity for faces was significantly higher than controls, these results were not driven by better recognition of previously viewed faces per se (hit rates), but by SR's higher CR rates of previously unseen faces, driven by a conservative response bias.

Composite face effect (CFE)

Analyses on the complete version of the Composite Face Test showed that CFE $_{Accuracy}$, $t(51) = -2.51$, $p = .015$, Cohen's $d = .71$, but not CFE $_{RT}$, $t(51) = 1.51$, $p = .115$, significantly differed between groups. In stark contrast to previous research and expectations, SRs displayed a significantly lower CFE than controls.

Replicating the complete design conclusions, the partial design of the Composite Face Test also showed a group difference in CFE $_{Accuracy}$, $t(51) = -3.17$, $p = .003$, Cohen's $d = .87$, with SRs ($M = 9.75$, $SD = 11.26$, 95% $CI = [4.48, 15.02]$) showing a lower CFE than controls ($M = 19.84$, $SD = 11.81$, 95% $CI = [15.59, 24.10]$), but no CFE $_{RT}$ effect, $t(50) = 1.50$, $p = .139$.

Composite Face Test stimuli repetition and the Composite Face Effect

In order to rule out the possibility of SRs' reduced CFE being modulated by the repetition of the face-half stimuli (20 bottom and top halves repeating throughout 80 trials in each alignment condition), a correlation was run between trial order and the Composite Face Test accuracy and found no relationship between the two constructs in the aligned, $r(80) = .16$, $p = .152$, nor misaligned condition, $r(80) = -.02$, $p = .836$.

Correlational analyses

Given that Experiment 4.1 reported correlational analyses across all the face and object recognition tests measures, analyses reported in this experiment focus on holistic processing measures and their relationship to face/object recognition (d') only (Table 4.2.2.2). Correlations were considered significant ($p = .001$) only after applying Bonferroni corrections to account for multiple comparisons ($n = 45$).

There was a positive correlation between scores on the two face recognition tests (CFMT+ and face (old/new) test), and the predicted Inversion Effect (IE), demonstrating that participants with greater face recognition showed greater IE. Thus, in line with research, there was a positive relationship between face recognition and holistic processing as measured by the IE. Note that there was no significant correlation between CFMT+ scores and the Composite Face Effect (CFE) derived from the complete version of the Composite Face Test. Indeed, when evaluating CFE $_{Accuracy}$, the effect was in the negative direction. However, there was a significant negative correlation between CFMT+ scores and the CFE derived from the partial design of the Composite Face Test. In line with the group analyses reported above, participants with higher CFMT+ scores tended to show lower CFE. The two holistic processing measures showed only a small relationship, whereby the CFE derived from the partial design was negatively correlated with the IE (r = -0.27, p = .035), though potentially owing to low power, this correlation did not reach statistical significance (Bonferroni corrected p = .001).

Note that face-specific recognition appears to correlate with CFMT+ (Experiment 4.1, n = 820) but not CFMT-I (inverted version). Therefore, in line with research, inverted face recognition benefits less from the perceptual processes (holistic and facial parts-based processing) involved in upright face recognition. While facial parts-based processing was not examined in this Experiment, holistic processing as measured by IE and CFE $_{RT}$ showed a positive correlation with face-specific recognition, though the correlations did not reach statistical significance (p > .001).

Table 4.2.2.2. Correlation coefficients across holistic and recognition scores (n = 68).

	CFMT-I	Inversion Effect	Composite Face Effect				Face (Old/New) test	Object (Old/new) test	Face-Specific Recognition
			Complete		Partial				
			Accuracy	RT	Accuracy	RT			
	%	%	%	Sec	%	Sec	d'	d'	d'
CFMT+	0.43*	0.71*	-0.23	0.18	-0.39*	0.17	0.61*	0.42*	0.34
CFMT-I		-0.33	-0.18	0.18	-0.20	0.10	0.29	0.31	0.08
Inversion Effect			-0.13	0.10	-0.27	0.14	0.39*	0.21	0.24
Composite Face effect									
Accuracy				0.01	0.65*	0.03	0.04	-0.13	0.12
RT					0.05	0.78*	0.30	0.12	0.22
Partial Composite Face effect									
Accuracy						0.13	-0.10	-0.21	0.04
RT							0.26	0.11	0.19
Face (Old/New) test									
d/								0.27	0.80*
Object (Old/New) test									
d/									-0.36

* Correlation is significant at the 0.001 level (2-tail)

Reliability and generalisability of the laboratory results: Comparing data from Experiment 4.1 and Experiment 4.2

In order to ensure that recruitment methods did not introduce bias and did not affect generalisability, the data from Experiments 4.1 and 4.2 were compared on the (old/new) face/object recognition tests using a 2 (group: SR, control) x 2 (condition: online, laboratory) x 2 (stimulus type: face, object) ANOVA for analysis.

CFMT+ comparisons: A 2 (group: SR, control) x 2 (condition: online, laboratory) ANOVA on CFMT+ scores found only a significant main effect of condition, that online participants (M = 83.67, SD = 11.17) scored higher than laboratory participants (M = 81.04, SD = 12.32), $F(1, 527) = 4.42$, $p = .036$, $\eta^2 = .01$.

Face-specific recognition: Face and object recognition tests (old-new) comparisons: Hits: The stimulus-type main effect was significant, $F(1, 526) = 77.81$, $p < .001$, $\eta^2 = .13$. Hit rates for faces were higher than objects. The group main effect was significant, $F(1, 526) = 16.37$, $p < .001$, $\eta^2 = .03$. SRs outperformed controls. The condition main effect was significant, $F(1, 526) = 10.15$, $p = .002$, $\eta^2 = .02$; online participants outperformed lab participants. A significant stimulus-type x group interaction, $F(1, 526) = 10.54$, $p = .001$, $\eta^2 = .02$, and simple effects found that SRs demonstrated a larger face-specific recognition, $F(1, 526) = 59.45$, $p < .001$, $\eta^2 = .10$, than controls, $F(1, 526) = 20.04$, $p < .001$, $\eta^2 = .04$.

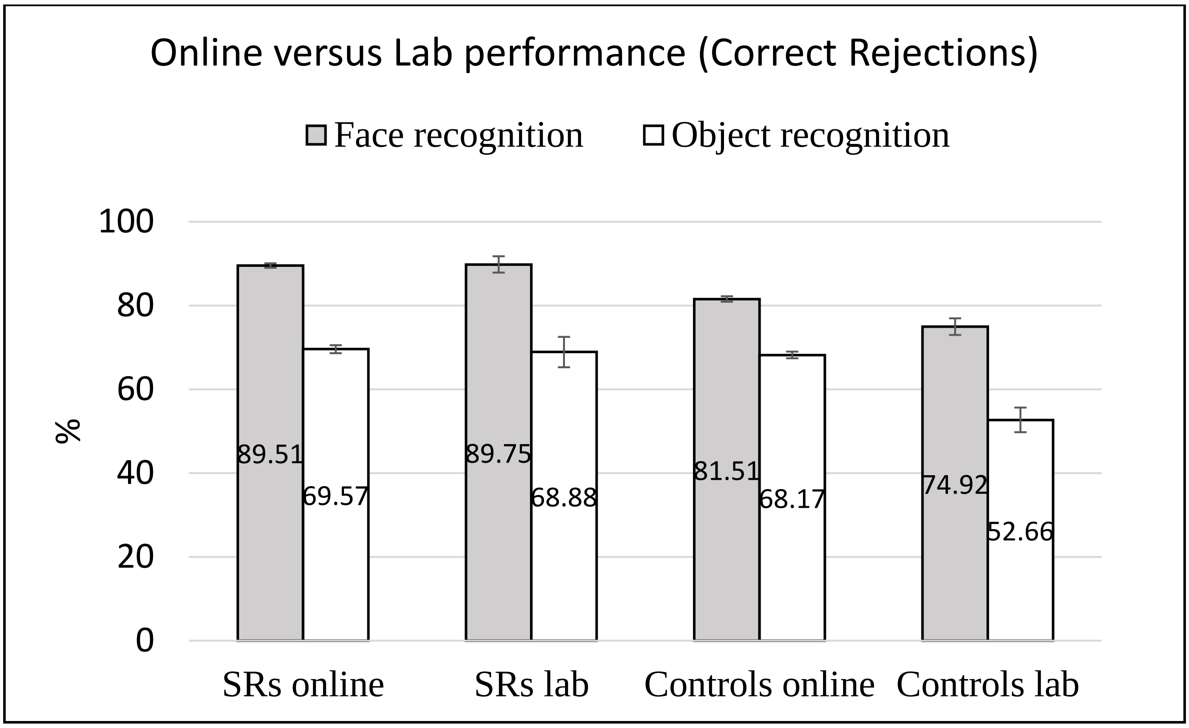


Figure 4.2.2.1. SRs' and controls' performance (correct rejections) on face and object recognition in online and lab conditions. Error bars = standard error of the mean.

CRs: The stimulus-type effect was significant, $F(1, 526) = 377.07$, $p < .001$, $\eta^2 = .42$. CRs for faces were higher than objects. The group effect was significant, $F(1, 526) = 48.22$, $p < .001$, $\eta^2 = .08$. SRs outperformed controls. The condition effect was significant, $F(1, 526) = 14.99$, $p = .001$, $\eta^2 = .03$; online participants outperformed lab participants. A significant stimulus-type x condition interaction, $F(1, 526) = 6.29$, $p = .012$, $\eta^2 = .01$, and simple effects found that the difference in object performance between lab participants and online participants, $F(1, 526) = 16.22$, $p < .001$, $\eta^2 = .30$, was greater than their face performance difference, $F(1, 526) = 4.73$, $p = .030$, $\eta^2 = .01$. There was also a significant group x condition interaction, $F(1, 526) = 13.80$, $p < .001$, $\eta^2 = .03$. SRs performed similarly across conditions, $F(1, 526) < 1$, while online controls outperformed laboratory controls, $F(1, 526) = 37.12$, $p < .001$, $\eta^2 = .07$. The three-way interaction was significant, $F(1, 526) = 4.13$, $p = .043$, $\eta^2 = .01$. Laboratory participants showed a main effect of stimulus-type, $F(1, 50) = 106.09$, $p < .001$, $\eta^2 = .68$, with faces generating a better performance. They also showed a main effect of group, $F(1, 50) = 21.85$, $p < .001$, $\eta^2 = .30$, with SRs outperforming controls. There was no interaction, $F(1, 50) < 1$, as SRs and controls showed a similar decline between faces and objects. Online participants, on the other hand, showed a main effect of stimulus-type, $F(1, 476) = 766.51$, $p < .001$, $\eta^2 = .62$, and a main effect of group, $F(1, 476) = 28.52$, $p < .001$, $\eta^2 = .06$, with higher performance for faces and higher performance in SRs, while also showing a stimulus-type x group interaction, $F(1, 476) = 30.20$, $p < .001$, $\eta^2 = .06$. Faces generated a significant group difference between SRs and controls, $F(1, 476) = 79.76$, $p < .001$, $\eta^2 = .14$, while objects did not, $F(1, 476) = 1.34$, $p = .248$, $\eta^2 = .003$. Overall, the interaction effects demonstrate (as depicted in Figure 4.2.2.1) that SRs recruited online show a face-specific superiority when it comes to correctly identifying stimuli as new, as their object recognition performance was similar to that of controls. The laboratory SRs, on the other hand, while showing similar results to online SRs, demonstrated a general visual superiority, because laboratory controls showed a significantly lower performance on object recognition compared to online controls.

Sensitivity (d'): The stimulus-type effect was significant, $F(1, 526) = 430.28$, $p < .001$, $\eta^2 = .45$. Sensitivity for faces was higher than objects. The group effect was significant, $F(1, 526) = 83.26$, $p < .001$, $\eta^2 = .14$; SRs outperformed controls. The condition effect was significant, $F(1, 526) = 22.21$, $p < .001$, $\eta^2 = .04$; online participants outperformed lab participants. A significant stimulus-type x group interaction, $F(1, 526) = 31.66$, $p < .001$, $\eta^2 = .06$, and simple effects found that SRs ($d'_{\text{Faces}} - d'_{\text{Objects}} = d'_{\text{Difference}} = 1.26$) possessed larger face-specific recognition, $F(1, 526) = 283.89$, $p < .001$, $\eta^2 = .35$, than controls ($d'_{\text{Difference}} = 0.63$), $F(1, 526) = 147.37$, $p < .001$, $\eta^2 = .22$.

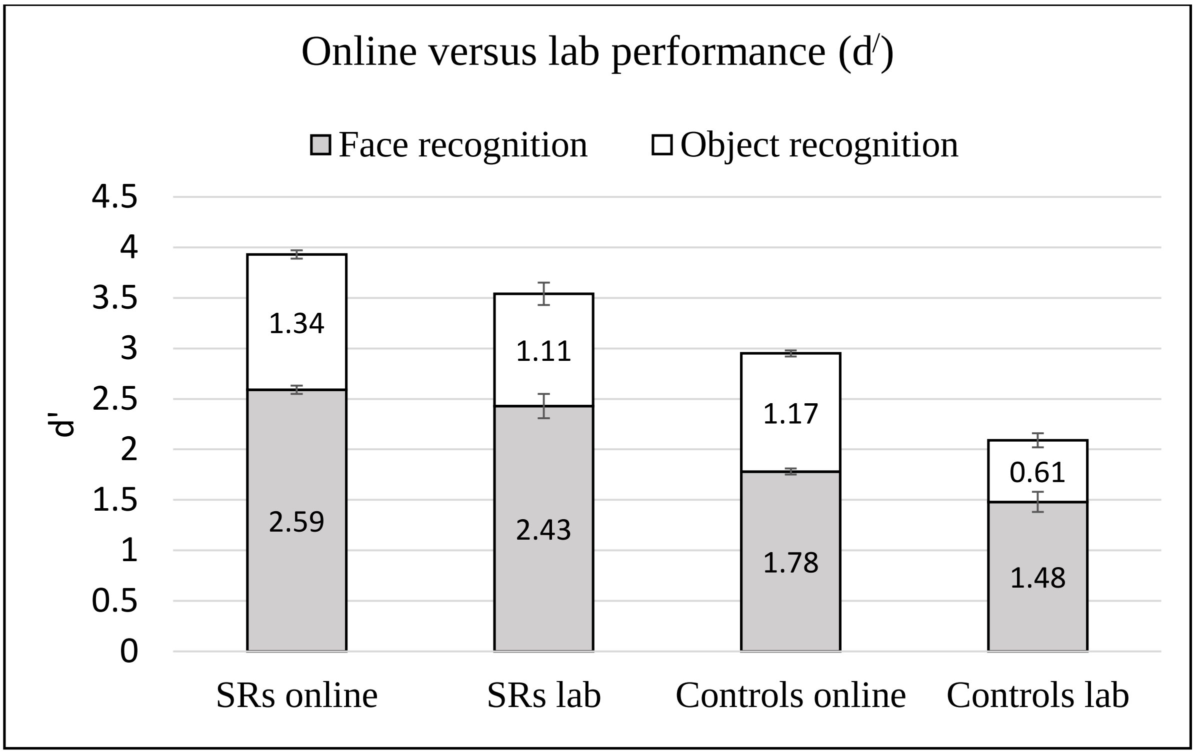


Figure 4.2.2.2. SRs' and controls' performance (d/) on face and object recognition in online and lab conditions. Error bars = standard error of the mean.

Response bias (criterion C): The stimulus-type effect was significant, $F(1, 526) = 71.49$, $p < .001$, $\eta^2 = .12$. The group effect was significant, $F(1, 526) = 5.35$, $p = .021$, $\eta^2 = .010$, whereby SRs were more conservative than controls. There was no effect of condition, $F(1, 526) < 1$. A significant group x condition interaction, $F(1, 526) = 10.58$, $p = .001$, $\eta^2 = .02$, and simple effects found that in the lab, SRs tended to display a conservative response bias, and a slight liberal bias online, $F(1, 526) = 4.15$, $p = .042$, $\eta^2 = .008$, whereas controls displayed a neutral response bias online and a liberal response bias in the lab, $F(1, 526) = 7.10$, $p = .008$, $\eta^2 = .01$.

In summary, on the combined face and object recognition test results, hit rates, CR rates and d/ were all higher for online participants than laboratory participants, although CR effects were stronger for controls. Online participants also outperformed the laboratory participants at the CFMT+. Unlike with the laboratory data, in which SRs' CRs and d/ but not hits were superior to controls, when combined with the online data, SR hit rates were also significantly higher than controls – a probable consequence of greater statistical power. These effects were partly driven by a tendency for SRs in the lab to display a conservative response bias, whereas those online displayed a slightly liberal response bias. Opposite effects were found with controls as they tended to display a neutral response bias online and a liberal response bias in the lab. It is possible that the reason behind the slight superiority demonstrated by online participants is the difference in the image size, in that face and bike images uploaded online were bigger in size than the images presented on the laboratory computer screen.

Individual level analyses: The full individual level analyses (described in Chapter 3, section 3.3.1) employing modified t-tests for single cases (e.g., Crawford, Garthwaite, & Porter, 2010), compared the face-specific recognition, IE, CFE $_{Accuracy}$ and CFE $_{RT}$ scores of each SR against the control mean (Figures 4.2.2.3 – 4.2.2.6). All individual scores and analyses are reported in Tables A4.2.2.1 – A4.2.2.4 (See Appendices).

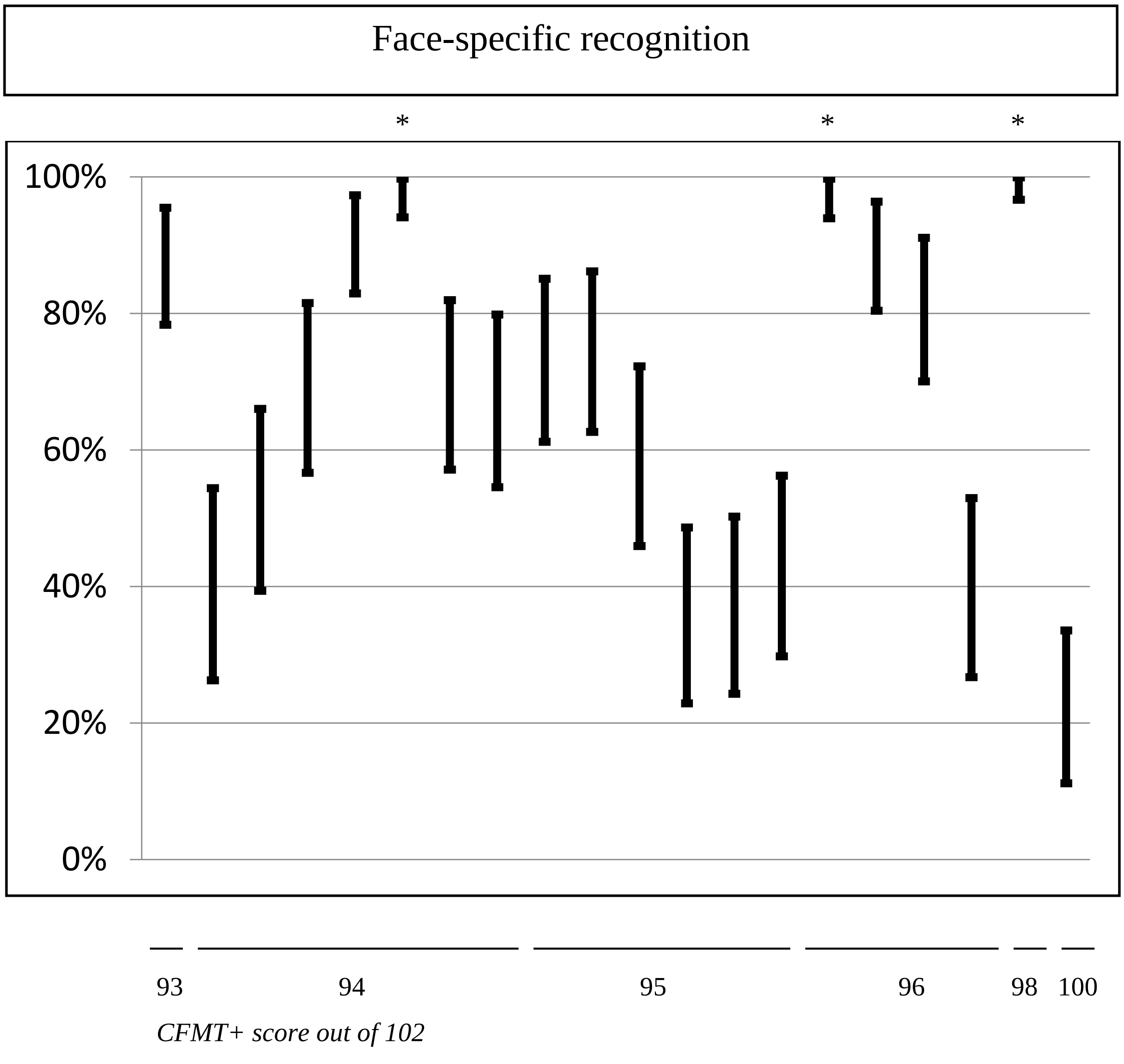


Figure 4.2.2.3. Upper and lower bound confidence intervals (95%) of the estimated proportion of the general population expected to fall below each super-recogniser (SR, n = 20) based on the face-specific recognition. To enhance interpretability, the SRs are ordered based on their CFMT+ scores, with lower SR scorers to the left – higher to the right.

The figures display the 95% confidence intervals (CI) of the proportion of the general population each SR would be expected to exceed on these measures. In ascending order from left to right, the display reflects the SR's CFMT+ scores. The lower bound confidence intervals (95%) from Figure 4.2.2.3 demonstrate that 14 SRs were likely to possess superior face-specific recognition compared to controls (given that 14 SRs scored higher than 50% of controls), although based on single-case t-tests, only three were significantly higher (marked *). Thus, while SRs as a group demonstrate a general superiority in visual recognition, the majority of SRs shows a more pronounced advantage for face recognition.

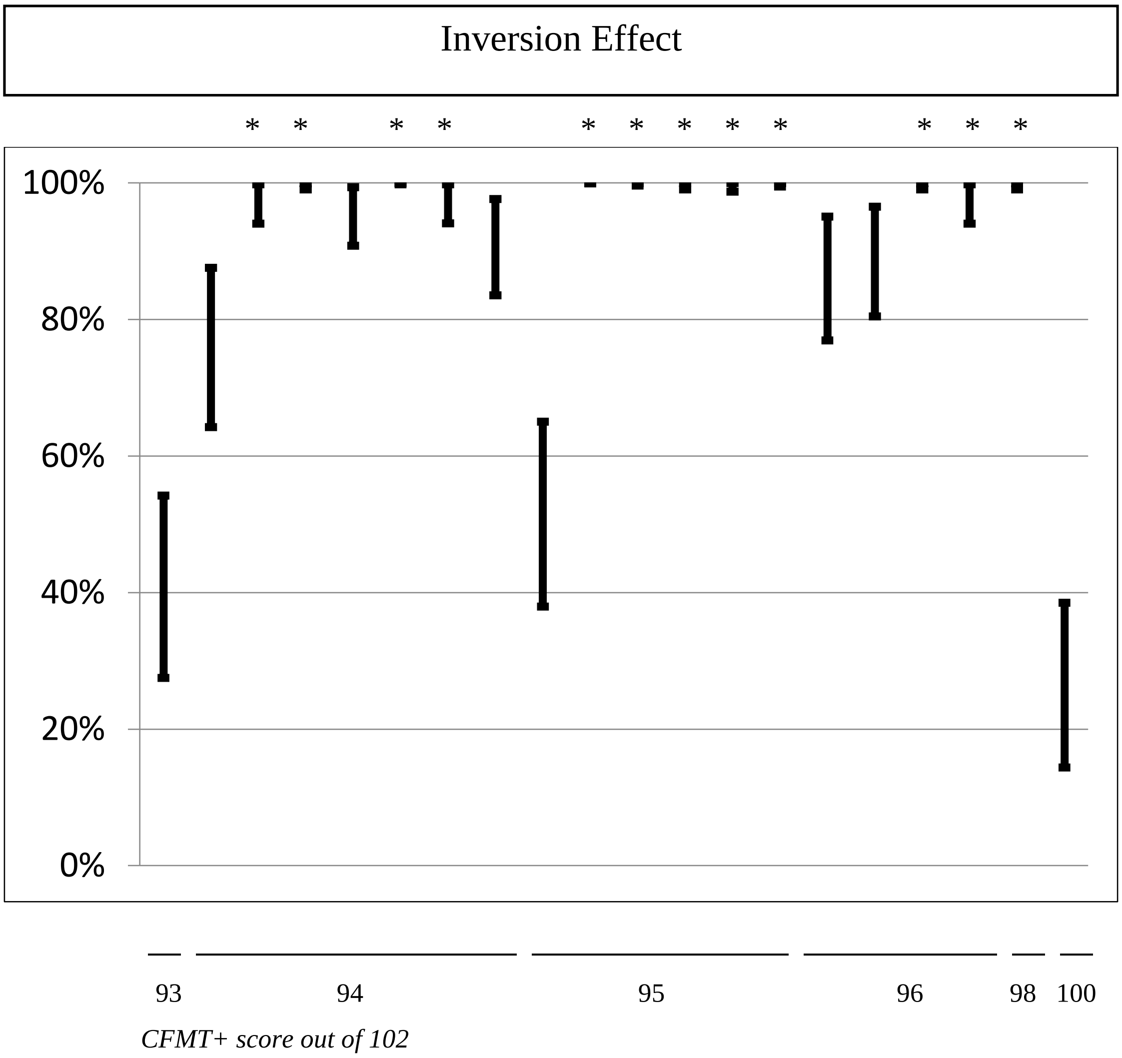


Figure 4.2.2.4. Upper and lower bound confidence intervals (95%) of the estimated proportion of the general population expected to fall below each super-recogniser (SR, n = 20) based on the Inversion Effect (IE). To enhance interpretability, the SRs are ordered based on their CFMT+ scores, with lower SR scorers to the left – higher to the right.

Next, from Figure 4.2.2.4 the vast majority of SRs (n = 18/20) showed a pattern of higher IE scores than controls, and for 12 out of 20 SRs this was significantly higher. A stark contrast can be found when viewing CFE $_{\text{Accuracy}}$ in Figure 4.2.2.5, as most SRs tended to display a lower CFE than the control mean, although only two SRs displayed a significantly different effect, one greater, and one lower than controls. Finally, from Figure 4.2.2.6, only two SRs showed a significantly greater CFE $_{\text{RT}}$ ($p < .05$), while the rest of the SRs showed similar results to controls.

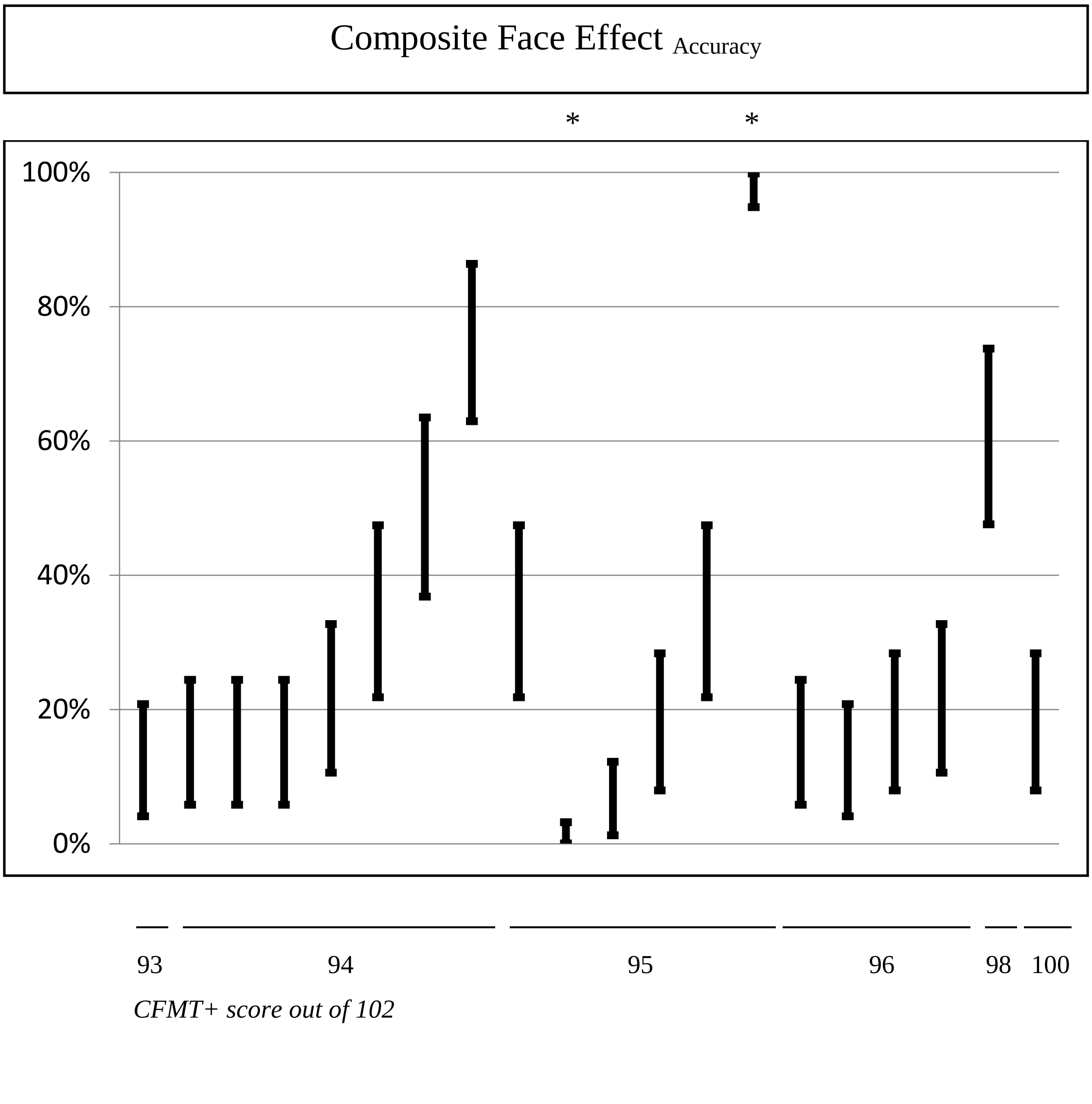


Figure 4.2.2.5. Upper and lower bound confidence intervals (95%) of the estimated proportion of the general population expected to fall below each super-recogniser (SR, n = 20) based on the Composite face effect: CFE $_{Accuracy}$ ($d^{/}$). To enhance interpretability, the SRs are ordered based on their CFMT+ scores, with lower SR scorers to the left – higher to the right.

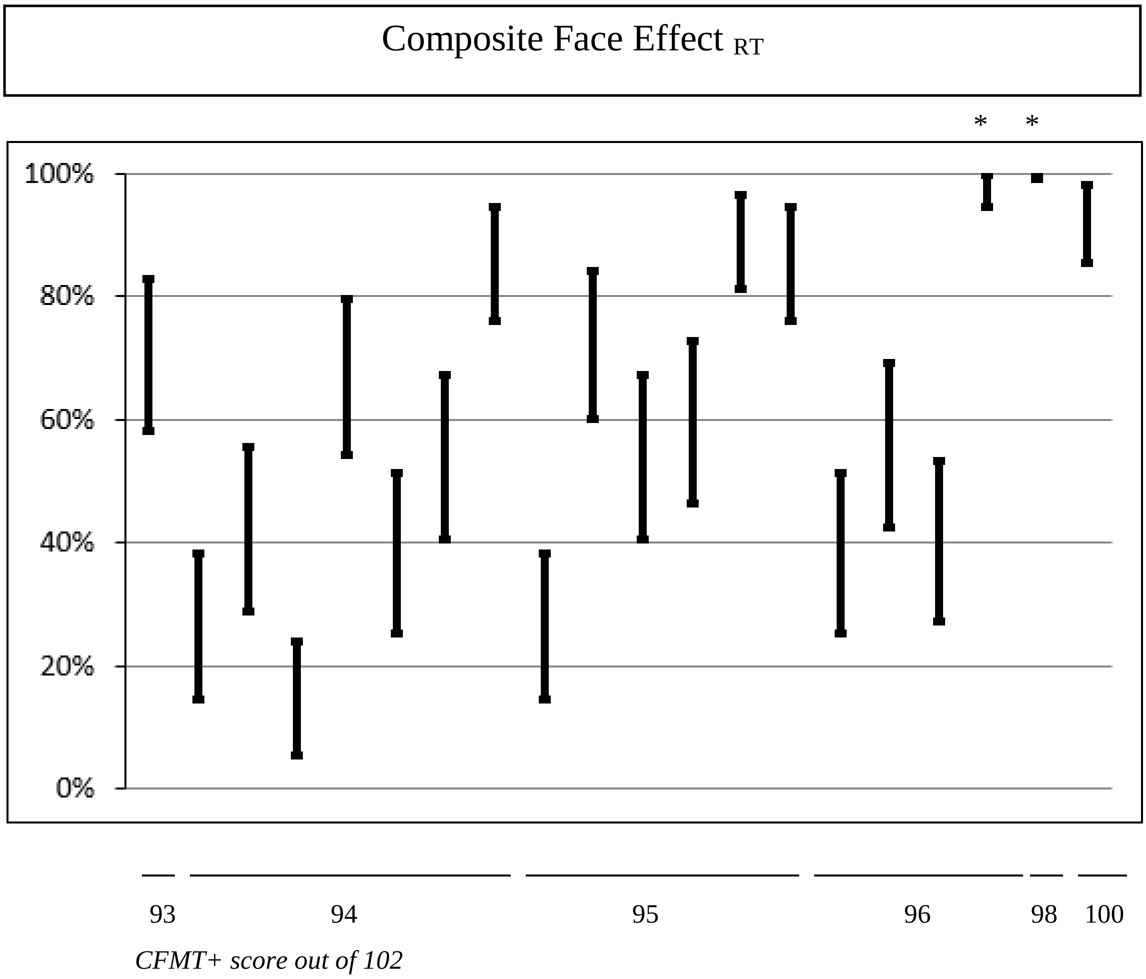


Figure 4.2.2.6. Upper and lower bound confidence intervals (95%) of the estimated proportion of the general population expected to fall below each super-recogniser (SR, n = 20) based on the CFE $_{RT}$ scores. To enhance interpretability, the SRs are ordered based on their CFMT+ scores, with lower SR scorers to the left – higher to the right.

4.2.3 Discussion

This study demonstrated significant group differences on the two holistic processing tests measuring the Inversion Effect (IE) and the Composite Face Effect (CFE). First, in line with previous findings on the *perceptual* IE (e.g., Russell *et al*., 2009), SRs displayed a larger *recognition-based* IE. Thus while both SRs' and controls' face processing was significantly advantaged by upright presentation, it remains to be seen what drives SRs' relatively greater advantage. First, the magnitude of IE is thought to reflect the reliance on holistic processing (e.g., Rossion, 2009), therefore SRs appear to benefit from the upright presentation of features and their second-order configurations to a greater extent than controls. However, inverted presentation hinders the effectiveness of parts-based processing as well (e.g., Civile *et al*., 2014). Therefore, SRs' greater IE could be a result of a greater reliance on holistic processing, as well as more effective parts-based processing. Note, however, that if SRs' upright and inverted face processing indeed benefits from more effective parts-based processing, the latter is likely to involve face related, rather than general parts-based processing. Indeed, the findings from Experiment 4.1 suggest that the general parts-based processing derived from object processing did not contribute to the participants' CFMT+ performance.

Surprisingly, SRs as a group demonstrated a significantly *smaller* CFE $_{\text{Accuracy}}$ and although effect sizes were smaller than those for the IE, this suggests they may be less susceptible to the holistic *perceptual* interference mechanisms of the Composite Face Test. Indeed, given that previous research (e.g., Bobak, Dowsett *et al*., 2016) suggests that most SRs demonstrate superior matching skills as well, their potentially superior perceptual processing could attenuate their performance on the Composite Face Test, whereby they may match sequentially presented stimuli more effectively (indicative of less errors induced by the holistic manipulations of the test).

Furthermore, as in Experiment 4.1, the current sample of SRs (n = 20) demonstrated a general superiority in visual recognition, as they significantly outperformed controls on inverted face recognition and on object recognition as well. However, their superiority was particularly pronounced for upright faces, as they demonstrated a relatively greater face-specific recognition (the difference between face recognition performance and object recognition performance), which was observed in both group and individual analyses. Overall, it appears that counter to previous findings (Bobak, Bennetts *et al.*, 2016; Davis *et al.*, 2016; see also Noyes *et al*., 2017), SRs' recognition superiority transcends to visual stimuli other than upright faces.

It is noteworthy, that laboratory SRs may have been slightly inferior at both face and object recognition to SRs in the wider population, as demonstrated by Experiment 4.1. Therefore, the significant differences found between controls and SRs in this experiment may have been greater if superior SRs matching the ability of the online participants had been recruited. All online SRs were invited to attend the laboratory studies, although as many were from outside the UK this was not practical in most cases.

Experiment 4.3 was set to clarify the SRs' reliance on holistic processing and parts-based processing by the means of the *Part-Whole Test.*

4.3 Experiment 3

In Experiment 4.3 a different sample of participants was tested to explore SRs' holistic processing by means of another holistic processing measure, the *Part-Whole Test (PWE).* The same test was used to measure SRs' upright face matching in order to explore whether their face recognition superiority is evident at the face perception stage as well. Based on previous research (Bobak, Bennetts *et al*., 2016) and the Experiment 4.2 findings, it was hypothesized that SRs would demonstrate either similar or an enhanced holistic processing (measured by the whole over part advantage in the Part-Whole Test), *and* an enhanced parts-based processing (measured by the part condition of the Part-Whole Test), compared to controls. Furthermore, based on previous findings (e.g., Bobak, Dowsett *et al*., 2016) SRs' were hypothesised to demonstrate superior face matching compared to controls (measured by the whole condition of the Part-Whole Test).

4.3.1 Methods

4.3.1.1 Design

An independent-measures design was employed, allocating participants to SR and control groups using the inclusion criteria discussed in Chapter 3, to measure the participants' PWE, whole face matching and parts-based processing performance, using Accuracy and RTs. Additional individual level analyses examined the homogeneity of SR responses.

4.3.1.2 Participants

Forty-four participants with normal or corrected vision were recruited for Experiment 4.3 (18 males, mean age = 34.22 years, SD = 10.15). Based on the inclusion criteria discussed in Chapter 3, 24 SRs (CFMT+: 94 - 101; *M* = 96.78, *SD* = 2.31; 12 males, mean age = 37.42, *SD* = 8.38) and 20 controls (65 - 81; *M* = 72.69, *SD* = 4.68; 6 males, mean age = 29.35, SD = 10.29) were included in the final between-group analyses.

The groups were matched on gender, $\chi^2(1, n = 44) = 1.81$, $p = .179$, Empathy $t(24) < 1$, $p = .503$, and Autism Quotients, $t(24) < 1$, $p = .911$. Note that unlike in Experiment 4.2, SRs showed similar levels of empathy to controls. Furthermore, SRs in this experiment were older than controls, $t(42) = 2.87$, $p = .006$, $d = .86$, which is discussed later.

4.3.1.3 Materials

The Part-Whole Test: The stimuli comprising Caucasian young adult faces used for this test were obtained from the database of The Park Aging Mind Laboratory at The University of Texas at Dallas (Minear & Park, 2004). Adobe Photoshop was used to create new identities by substituting internal features (eyes, nose, mouth) with features from different faces, in order to create 24 target faces (50% male). The visual angle of the face presentation was approximately 3.8° x 6.7°.

The test required participants to match the target face to two probe images, only one of which matched the target image. Importantly, the test comprised two matching conditions, *whole* and *part*. In the whole condition (72 trials), the target image - the whole face, is followed by two probe images – two whole faces. Importantly, the probe images were identical to one another, with the exception of one feature (eyes, nose, or mouth). In the part condition (72 trials), the target image – the whole face, is followed by two probe images – two sets of a particular feature (e.g., two noses, two mouths, or two sets of eyes), with only one of the feature set belonging to the target face.

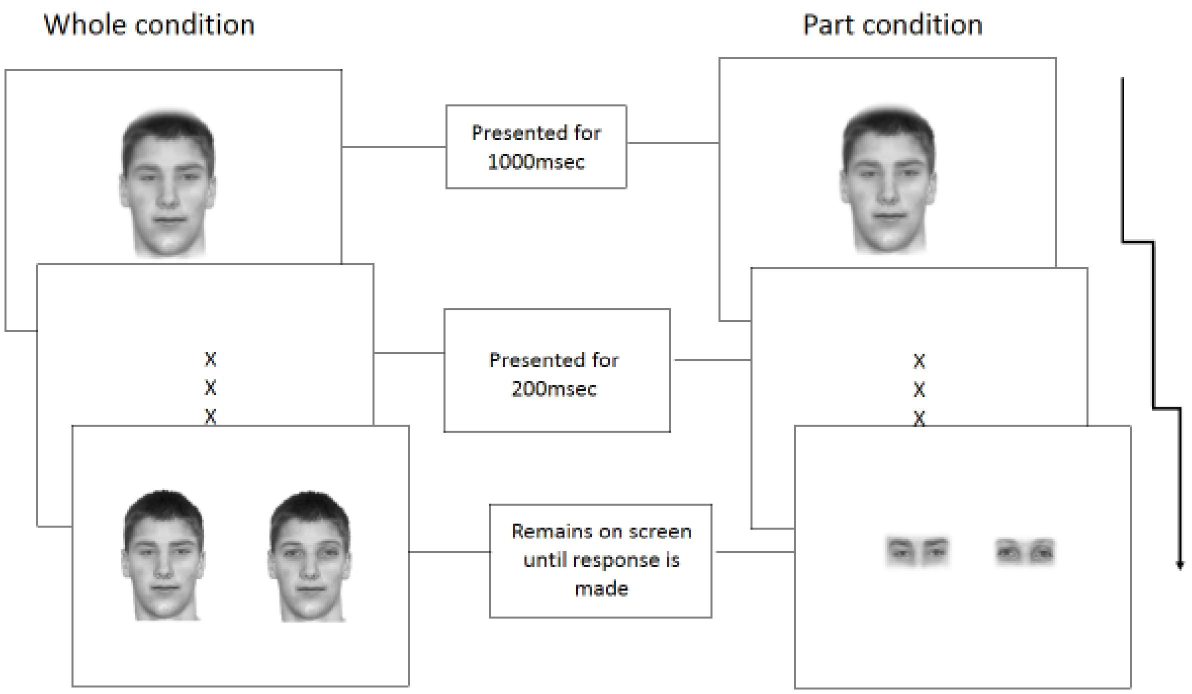


Figure 4.3.1.3.1. An example of the Part-Whole Test: whole and part conditions. The original facial identities were completely altered in Photoshop.

Thus the test comprised 144 matching trials. Each trial began with a target image (1000 msec) in the centre of the screen, followed by three Xs situated vertically (one underneath the other) at the centre of the screen (200 msec), and followed by two images (two faces or two sets of one feature), with only one image matching to the target image. The participant was required to select which image matched the target image. The two images remained on the screen until the participant made a response ('1' for the image on the left, and '0' for the image on the right). Figure 4.3.1.3.1 provides an example of the whole and part trials.

The same test was administered in the *inverted* presentation, where stimuli were rotated by 180°. The design of the inverted version was identical to the upright version.

To calculate the Part-Whole Effect (PWE) for the individual analyses, the following formulae were used:

1) *Upright accuracy (Whole condition – Part condition) – Inverted accuracy (Whole condition – Part condition)*
2) *Inverted RT (Part condition – Whole condition) – Upright RT (Part condition – Whole condition)*

To compare SRs' performance on upright face matching and feature matching to that of controls, participants' performance on the whole and part conditions (upright) were examined without taking the inverted conditions into account.

4.3.1.4 Procedure

After providing informed consent, participants familiarised themselves with the test's instructions, and began the Part-Whole Test in the upright and inverted orientations. The order of the two orientation blocks was counterbalanced. The entire experiment took approximately 30 minutes, and all participants were fully debriefed at the end

4.3.2 Results

In Experiment 4.3, SRs' holistic processing was investigated by the means of the part-whole effect (PWE). The mean performance SRs and controls expressed in accuracy and RTs is shown in Figures 4.3.2.1 and 4.3.2.2. Mixed ANOVAs 2 (condition: whole, part) x 2 (orientation: upright, inverted) x 2 (group: SR, control), were performed for Accuracy and RT.

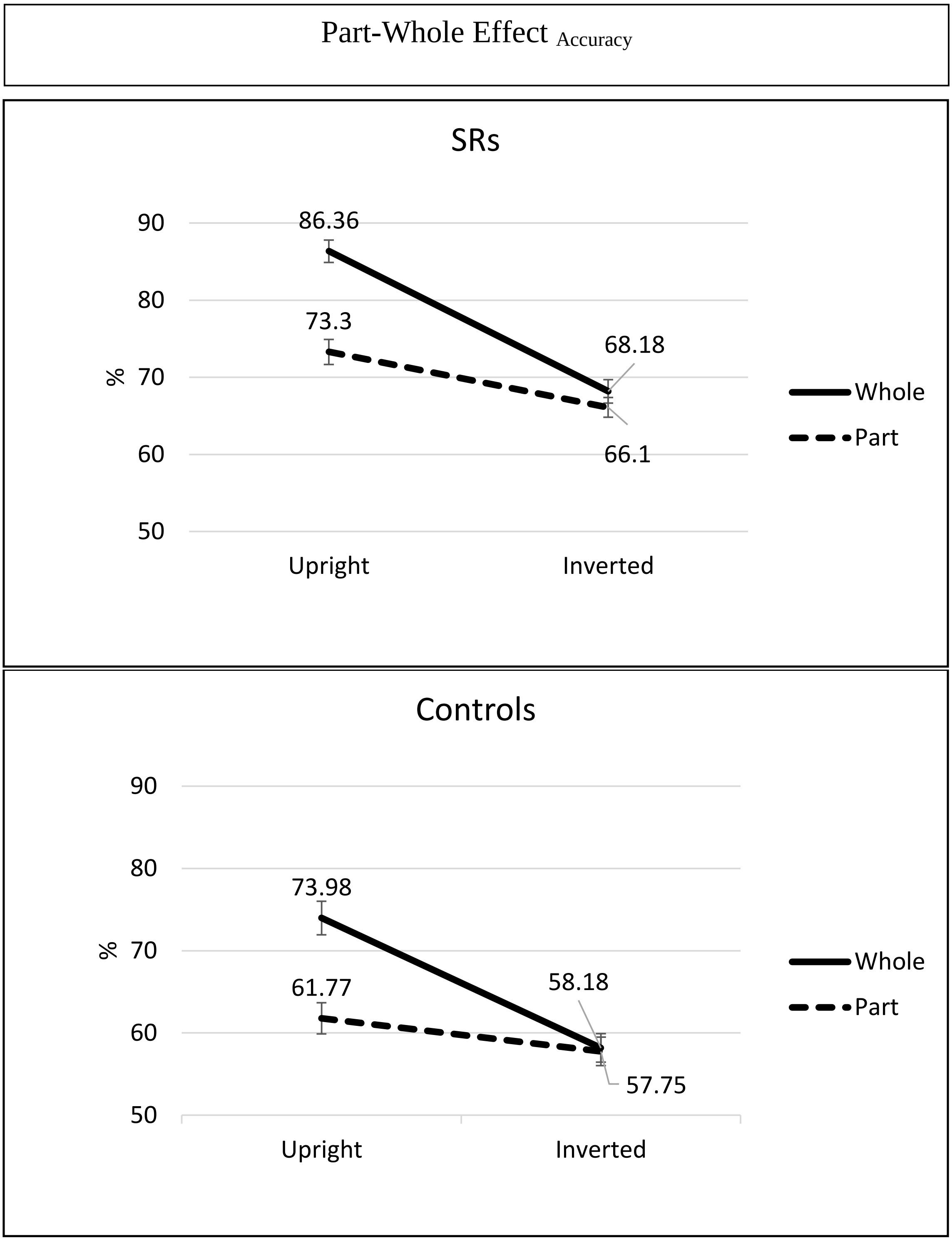


Figure 4.3.2.1. The mean performances of SRs and controls on the part-whole test (Accuracy). Error bars = standard error of the mean.

Part-Whole Effect $_{RT}$

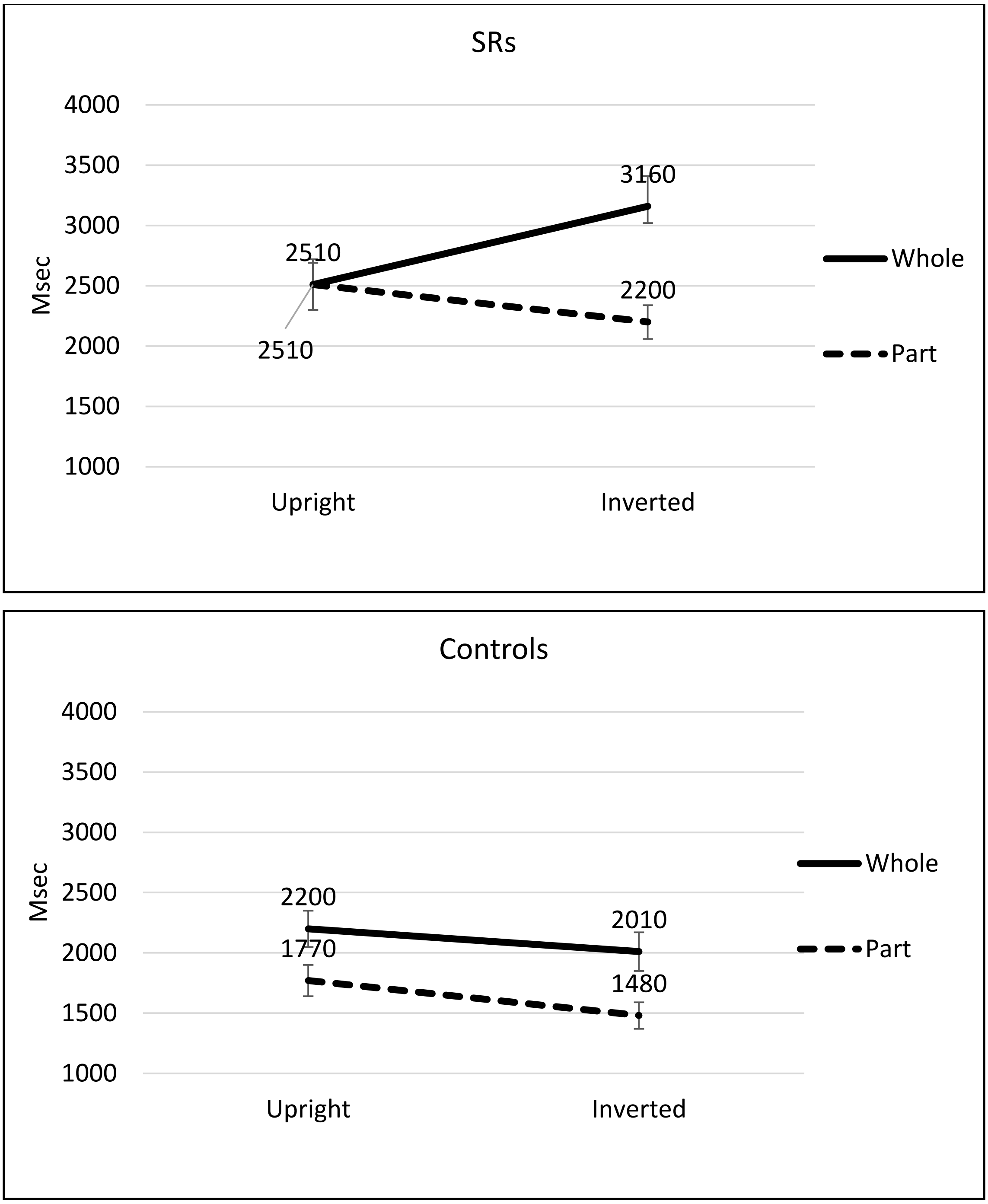


Figure 4.3.2.2. Mean performances of SRs and controls on the part-whole test (RT). Error bars = standard error of the mean.

Part-whole test $_{Accuracy}$: This ANOVA found a main effect of condition, $F(1, 42) = 64.02$, $p < .001$, $\eta^2 = .60$, showing better performance for the whole condition over part condition. There was also a main effect of orientation, $F(1, 42) = 141.43$, $p < .001$, $\eta^2 = .77$, whereby performance was better in the upright orientation. A main effect of group was found, $F(1, 42) = 38.18$, $p < .001$, $\eta^2 = .48$, whereby SRs outperformed controls. There was a significant condition x orientation interaction, $F(1, 42) = 52.71$, $p < .001$, $\eta^2 = .56$, whereby upright orientation showed a whole over part advantage, $F(1, 42) = 103.57$, $p < .001$, $\eta^2 = .71$, while the inverted orientation did not, $F(1, 42) = 2.29$, $p = .138$, $\eta^2 = .05$, demonstrating the part-whole effect for the upright orientation only. There were no condition x group, $F(1, 42) < 1$, nor orientation x group, $F(1, 42) = 1.28$, $p = .264$, $\eta^2 = .03$, interactions. The three-way (condition x orientation x group) interaction was not significant, $F(1, 42) < 1$. The lack of a significant three-way interaction suggests that SRs and controls showed no difference in the $\text{PWE}_{\text{Accuracy}}$.

Part-whole test $_{RT}$: This ANOVA shows a main effect of condition, $F(1, 39) = 24.74$, $p < .001$, $\eta^2 = .39$, whereby participants showed longer RTs for faces compared to parts. There was a main effect of group, $F(1, 39) = 13.72$, $p = .001$, $\eta^2 = .26$, whereby SRs showed longer RTs than controls. There was no effect of orientation, $F(1, 39) < 1$. There was no condition x group interaction $F(1, 39) < 1$. There was a condition x orientation interaction, $F(1, 39) = 17.89$, $p < .001$, $\eta^2 = .31$, whereby, the whole condition took longer than the part condition in the inverted orientation, $F(1, 39) = 56.30$, $p < .001$, $\eta^2 = .59$, but not in the upright orientation, $F(1, 39) = 2.62$, $p = .114$, $\eta^2 = .06$ There was a group x orientation interaction, $F(1, 39) = 6.25$, $p = .017$, $\eta^2 = .14$, whereby controls showed marginally shorter RTs for inverted processing, $F(1, 39) = 3.97$ $p = .053$, $\eta^2 = .09$, SRs' longer RTs for inverted processing was not significant, $F(1, 39) = 2.33$, $p = .135$, $\eta^2 = .06$. The three-way (condition x orientation x group) interaction was also significant, $F(1, 39) = 12.07$, $p = .001$, $\eta^2 = .24$. SRs showed a main effect of condition, $F(1, 21) = 9.73$, $p = .005$, $\eta^2 = .32$, whereby their RTs were longer in the whole than part condition. SRs showed no main effect of orientation, $F(1, 21) = 1.71$, $p = .205$, $\eta^2 = .08$, but they did show a condition x orientation interaction, $F(1, 21) = 19.63$, $p < .001$, $\eta^2 = .48$, whereby they spent more time on the whole condition in the inverted orientation, $t(21) = 6.22$, $p < .001$, Cohen's $d = .72$, while showing no difference between whole and part conditions in the upright orientation, $t(21) < 1$[9], which is indicative of an inverse part-whole effect in the inverted orientation, and of no part-whole effect in the upright orientation. Controls showed a main effect of condition, $F(1, 18) = 22.77$, $p = .001$, $\eta^2 = .56$, whereby RTs were longer for the whole condition. Controls also showed a main effect of orientation, $F(1, 18) = 6.92$, $p = .017$, $\eta^2 = .28$, whereby upright orientation generated longer RTs. The condition x orientation interaction was not significant, $F(1, 18) = 1.01$, $p = .329$, $\eta^2 = .05$.

[9] Note that for SRs the RT variable of the 'part' condition in the upright orientation is not normally distributed, thus nonparametric post hoc test was run (Wilcoxon matched-pair signed-rank).

The RT component demonstrates that controls show no part-whole-effect $_{RT}$. Indeed both orientations induced longer RTs for the whole condition. In line with predictions, controls generated a whole over part *accuracy* advantage only in the upright orientation, which was not attenuated by RT, as the RT pattern was similar across both orientations.

SRs, on the other hand, demonstrated an inverse part-whole effect $_{RT.}$ They spent more time on the whole versus part condition in the inverted orientation, which, as with controls, did not result in the whole over part advantage in inverted accuracy. More importantly they showed virtually identical RTs in the upright orientation, while showing a whole over part advantage in the upright accuracy. Thus, while controls' whole over part advantage in accuracy was coupled with longer RTs for the whole condition, SRs' whole over part advantage in accuracy was accompanied by the same RTs for the whole and part conditions. This could be owing to SRs being more motivated than controls to perform well, as indicated by equally long RTs in both whole and part conditions.

Face and Feature matching: In order to compare participant groups on their upright face matching and on parts-based processing, the 'whole' and 'part' conditions of the Part-Whole Test were analysed separately. A 2 (condition: whole, part) x 2 (group: SR, control) ANOVA showed that SRs generated a higher performance on face matching, $F(1, 42) = 26.56$, $p < .001$, $\eta^2 = .38$, and on feature matching, $F(1, 42) = 21.66$, $p < .001$, $\eta^2 = .34$, than controls. Therefore, SRs' face processing superiority is observed at the level of perception as well as recognition. Furthermore, SRs' superiority of upright face processing transcends to individual features/parts as well. Note that similar results were observed for the inverted orientation, whereby SRs generated a higher performance on face matching, $F(1, 42) = 20.53$, $p < .001$, $\eta^2 = .33$, and on feature matching, $F(1, 42) = 17.01$, $p < .001$, $\eta^2 = .29$, than controls.

Individual analyses: Modified t-tests for single cases (e.g., Crawford *et al.*, 2010), compared the Part-Whole Effect scores (Accuracy and RT) of SRs against the control mean. In order to explore SRs' superiority in face matching and feature matching, individual analysis was also performed on the *upright whole* and *part* conditions.

Figures 4.3.2.3 and 4.3.2.4 displays the 95% confidence intervals (CI) of the proportion of the general population each SR would be expected to exceed on these measures. In ascending order from left to right, the display reflects the SR's CFMT+ scores. (For all individuals scores and analyses see Appendices for Tables A4.3.2.1 – A4.3.2.4).

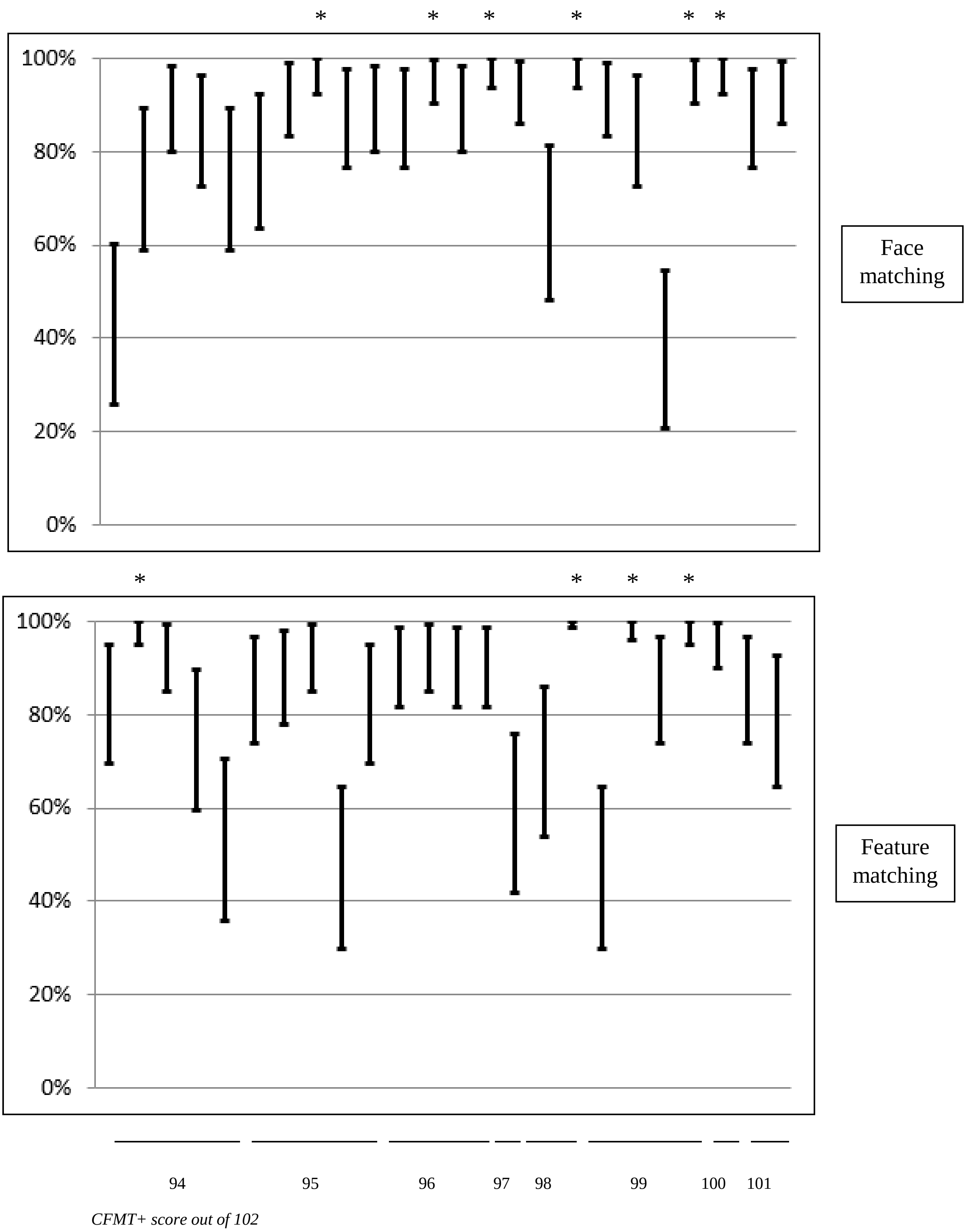
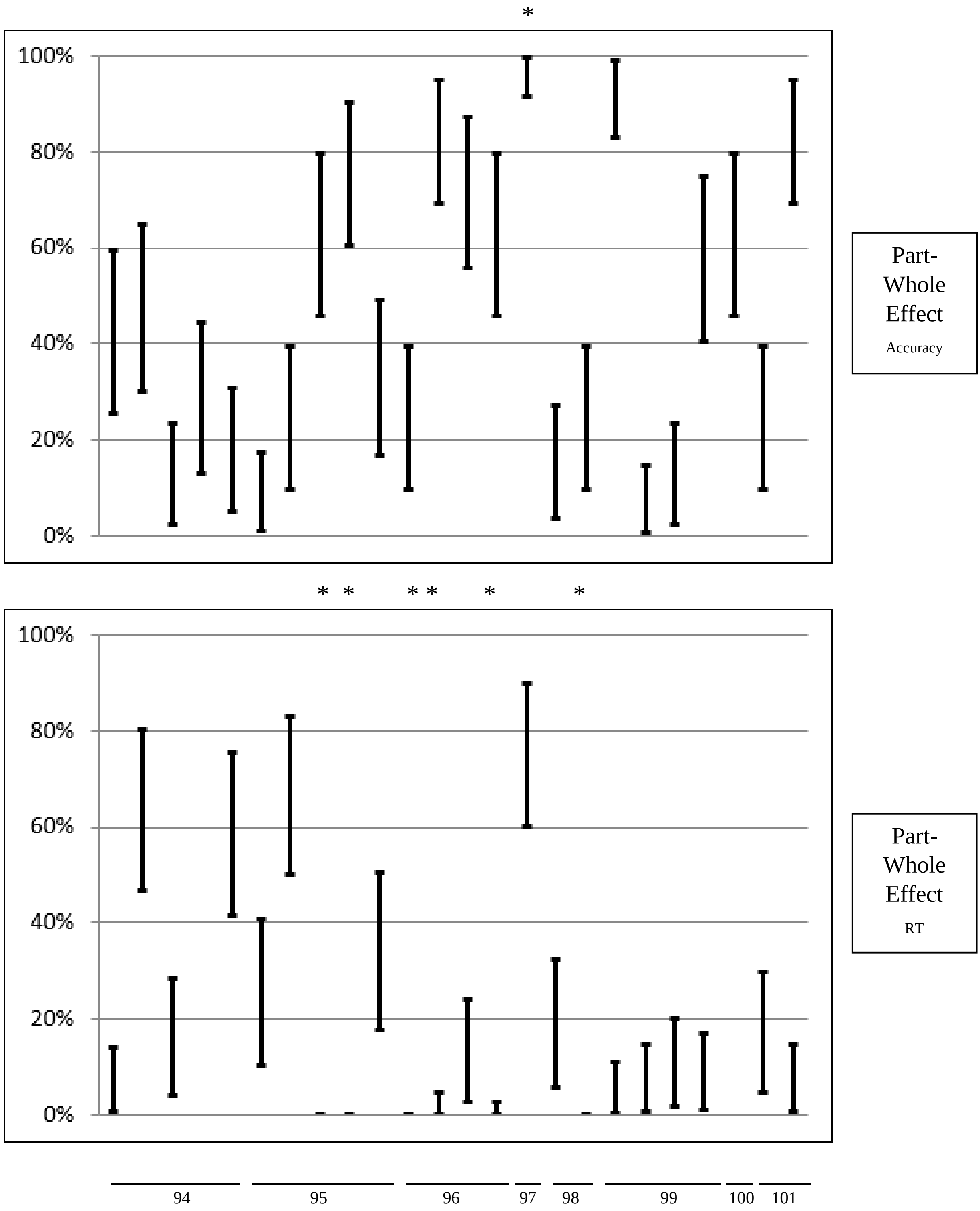


Figure 4.3.2.3. Upper and lower bound confidence intervals (95%) of the estimated proportion of the general population expected to fall below each super-recogniser (SR, n = 24) based on their Face matching and Feature matching. To enhance interpretability, the SRs are ordered based on their CFMT+ scores (out of 102), with low SR scorers at the left – high at the right.



CFMT+ scores out of 102

Figure 4.3.2.4. Upper and lower bound confidence intervals (95%) of the estimated proportion of the general population expected to fall below each super-recogniser (SR, n = 24) based on their Part-Whole Effect (PWE) $_{Accuracy}$ and $_{RT}$. To enhance interpretability, the SRs are ordered based on their CFMT+ scores (out of 102), with low SR scorers at the left – high at the right.

For face matching and feature matching the vast majority of SRs individually exceeded the control mean, but only six (25 %) and four (16.67%), respectively, were significantly better. For the Part-Whole Effect $_{\text{Accuracy}}$, only one SR (4.17%) showed a significantly enhanced holistic processing compared to controls. For the Part-Whole Effect $_{\text{RT}}$ component, six SRs (25%) showed a significantly more negative part-whole effect.

4.3.3 Discussion

Experiment 4.3 found that SRs exceeded controls on face matching as indicated by their performance on the 'whole' condition of the Part-Whole Test. Both group and individual analyses demonstrated that for the vast majority of SRs, their superiority in face processing is not limited to recognition. However, as found in previous studies (Bobak, Bennetts, *et al*., 2016; Bobak, Dowsett, *et al.*, 2016; Bobak, Hancock, *et al*., 2016; Davis *et al*., 2016), not all SRs outperformed controls, suggesting they are not a homogenous group. That said, such factors as tiredness and motivation potentially contribute to individual results displayed by both groups as well, which is further discussed in the General Discussion (see section 4.4) and Chapter 7.

Experiment 4.3 also explored SRs' holistic processing using the Part-Whole Effect (PWE). While SRs demonstrated overall a greater accuracy on Part-Whole Test, the accuracy component showed no group differences in the PWE, thereby demonstrating no between-group differences in holistic processing. However, while both SRs and controls demonstrated a significant PWE $_{\text{Accuracy,}}$ controls demonstrated an RT - Accuracy trade-off where their whole face advantage in accuracy was accompanied by longer RT for the whole face condition. Importantly, SRs showed the same whole face advantage in accuracy but no RT difference between whole and part conditions. However, since SRs spent overall more time on both 'whole' and 'part' conditions, this lack of RT - Accuracy trade off cannot be interpreted as a more automatic/influential holistic effect demonstrated in the accuracy component. It is possible that the group difference in RTs could be owing to a different level of motivation displayed by SRs and controls. Indeed, Noyes *et al*. (2017) suggest that SRs are likely to be more motivated than individuals with a normal-range ability in face processing (although see section 4.4 and Chapter 7).

The final important finding of this experiment is SRs' superiority in feature matching, as indicated by their performance on the 'part' condition of the Part-Whole Test. Both group and individual analyses show that the vast majority of SRs show an enhanced facial parts-based processing, supporting the findings from Experiment 4.2 whereby SRs exceeded controls on inverted face recognition (which is suggested to rely on parts-based processing). This advantage in facial parts-based processing could also potentially explain SRs' reduced composite face effect (CFE), as it may have facilitated them to overcome the holistic illusion created by intervening incongruent trials. Finally, while the enhanced general parts-based processing appears to have no significant effect on CFMT+ performance (Experiment 4.1), the enhanced facial parts-based processing could potentially have a more substantial contribution to SRs' superior ability in recognising faces.

4.4 General Discussion

This study set out to clarify whether SRs' enhanced recognition skills are face-specific and whether their superiority is limited to face recognition or if it is accompanied by superior perception/matching skills as well. Secondly, the study used three holistic processing measures to test whether SRs' recognition superiority could be associated with an enhanced holistic processing and/or enhanced parts-based processing.

Experiments 4.1 and 4.2 found that SRs' recognition was significantly superior for both faces and objects (motorbikes). Previous research found only 2 out of 6 (Bobak, Bennetts *et al.*, 2016) and 2 out of 10 SRs (Davis *et al.*, 2016) to significantly exceed controls on object processing. Therefore, counter to previous research findings, this study demonstrates that SRs' visual recognition superiority is not face-specific, but general. Importantly, SRs' recognition superiority was relatively larger for faces, as they demonstrated a greater difference in performance between the two tests (face recognition score – object recognition score) compared to controls. Furthermore, the positive relationship found between the scores on the CFMT+ and face-specific recognition in Experiment 4.1 was not as substantial ($r = .32$, $p < .001$). Together these findings suggest that SR may reflect a general visual recognition superiority with a more pronounced advantage for face processing.

In regards to holistic processing, Experiment 4.2 found that, in line with previous research (Bobak, Bennetts *et al.*, 2016; Russell *et al.*, 2009), SRs demonstrate a greater Inversion Effect (IE) than controls. As a group, SRs were significantly more accurate at upright and inverted face recognition, *and* they displayed a larger IE, as the difference between their upright and inverted scores on the *Cambridge Face Memory Test* (CFMT+) and CFMT-I (inverted) (Russell *et al.*, 2009) was greater. A few SRs displayed a different pattern of results on the individual analyses, although for the vast majority (18 out of 20), the pattern of results was in the consistent direction supporting proposals that SRs' superior recognition of faces is strongly advantaged by a more effective integration of upright facial features and configurations (Bobak, Bennetts *et al.*, 2016; Russell *et al.*, 2009). Indeed, across all participants there was a significant positive correlation between the IE and face recognition ability as measured by the extended (CFMT+) (Russell *et al*., 2009), suggesting that this aspect of holistic processing reflects differences in face recognition ability at all levels of the population – even Developmental Prosopagnosics (DPs) (e.g., Behrmann & Avidan, 2005).

Importantly, while SRs demonstrated a greater IE in the *recognition* component, the *perceptual* measures of holistic processing showed a different pattern of results. First, contrary to greater IE, SRs as a group demonstrated a significantly *smaller Composite Face Effect* (CFE) than controls when analysing accuracy, and although effect sizes were smaller than those for the IE, with only one SR significantly different than controls on the individual analyses, this suggests they may be less susceptible to the holistic perceptual mechanisms of the CFE. These results run counter to most previous research that has found significant correlations between CFE and face recognition performance (DeGutis *et al*., 2013; Richler, Cheung *et al*., 2011; Wang *et al*., 2012). It is noteworthy that Richler *et al*. (2015) argued that participants taking the Composite Face Test are likely to familiarise themselves with the face halves (top and bottom halves derived from only 20 faces repeat across 160 trials) which would make them less susceptible to CFE. However, such an explanation of the reduced SR CFE found in this study is unlikely, as there was no correlation found between trial order and SR accuracy on the composite face test. Therefore, while the Composite Face Test is thought to demonstrate the intervening nature of holistic processing by interfering with participants 'same/different' decisions, SRs do not seem to be affected by this interference to the same extent as individuals with typical face processing. It is possible, that this diminished interference is partly driven by enhanced parts-based processing, as was demonstrated by SRs' enhanced inverted face recognition and object recognition in the same experiment. Furthermore, SRs may be less susceptible to the holistic illusions created by the composite face test as a result of their superior face matching skills (e.g., Bobak, Dowsett *et al.*, 2016).

Second, contrary to a greater IE and reduced CFE, SRs demonstrated a significant part-whole effect (PWE) $_{\text{Accuracy}}$, indicative of their effective holistic processing, which, importantly, was similar to that of controls. Given the facilitating nature of the 'whole' condition in the Part-Whole Test (in that the whole face facilitates feature matching), SRs in Experiment 4.3 were expected to demonstrate at least normal PWE despite the SRs' reduced CFE in Experiment 4.2. While SRs' potentially enhanced parts-based processing may facilitate overcoming the interfering nature of incongruent trials in the Composite Face Test, there is no reason to expect SRs' enhanced parts-based processing to affect the facilitating nature of the 'whole' condition in the Part-Whole Test.

Furthermore, the greater IE was not accompanied by greater PWE. On the one hand, it could be the result of a difference in sampling, as Experiments 4.2 and 4.3 used two different samples of SRs and controls. In that case, there is a possibility that if SRs from Experiment 4.2 were administered the Part-Whole Test, they would show a greater PWE to match their greater IE. On the other hand, it is possible that SRs from the two experiments showed a greater IE and normal PWE because one is a recognition component and the other is a perceptual component of holistic processing. The scope of the current studies was unable to clarify this matter.

Importantly, while SRs' enhanced object (Experiment 4.1) and inverted face (Experiment 4.2) processing indirectly demonstrated superior parts-based processing, results from Experiment 4.3 confirmed SRs' superior parts-based facial processing (measured by the 'part' condition of the Part-Whole Test). The observation of SRs' enhanced inverted face recognition, object recognition and individual feature matching runs counter to previous SR research proposing that their upright face recognition superiority does not transcend to other stimuli (for a review see Noyes *et al*., 2017). It is possible that the discrepancy between previous research and the current findings is the difference in sample size, as even disregarding the online study recruiting 199 SRs, Experiments 4.2 and 4.3 still recruited significantly larger numbers of SRs compared to previous studies which were limited by their small SR sample sizes.

Note that the *general* parts-based processing, which is thought to drive object processing, appeared to have no significant relationship with CFMT+ performance (the test used to define SR) in Experiment 4.1. However, it is possible that SRs' enhanced *facial* parts-based processing may have a more substantial contribution to their face recognition superiority, though this was not directly tested. Nevertheless, together these findings suggest that SRs' enhanced face recognition ability may be associated with enhanced parts-based processing. Indeed, it appears that people with good recognition skills require very little facial information for recognition. A recent study used bubblised images to explore individual differences in face processing (Royer *et al*., 2015). The degraded images of faces were adjusted based on the participants' performance: the better they were at face processing, the more degraded the images would get. The authors suggested that based on the results, individuals with good recognition skills (though they did not specifically test SRs) require far less facial information in order to activate an internal face representation. Thus it is possible that SRs manage to activate their internal representations of recently learnt faces more effectively, relying on both individual features and the holistic aspects of faces.

SRs also demonstrated enhanced face matching, which was indicated by both group and individual analyses. However, some SRs performed similarly to controls, thereby supporting previous findings (Bobak, Bennetts, *et al*., 2016; Bobak, Dowsett, *et al.,* 2016; Bobak, Hancock, *et al*., 2016; Davis *et al*., 2016) and once again pointing out the heterogeneous nature of SR. It is noteworthy, that matching of faces that are very similar to one another, as is the case with the Part-Whole Test, is thought to be specifically aided by parts-based processing (Ramon & Van Belle, 2016). Given that SRs demonstrated similar holistic processing (PWE) to that of controls, their face matching superiority could potentially be attributed to enhanced parts-based processing, or a combination of greater holistic processing (greater IE) and greater parts-based processing.

A final remark on the findings reported in Chapter 4 concerns the distinction between hits (recognising a previously seen face) and correct rejections (correctly identifying that a particular face has not been shown previously). Indeed, Experiment 4.1 demonstrated no correlation between the two response types, indicating that those participants who generate a high hit rate do not necessarily generate a high rate of correct rejections. Thus the (lack of) relationship between the two response types appears to be mediated by participants' response bias. Namely, if participants with high hit rates display a conservative response bias, they will generate high rates of correct rejections. If they display a liberal response bias, they would generate low rates of correct rejections. Furthermore, the lack of correlation between hits and correct rejections further demonstrates that recognising a face as previously seen reflects processing that is distinct from recognising that a face has not been previously shown. It is noteworthy that SRs exceeded controls on both hits and correct rejections (Experiment 4.1), suggesting that SRs' exceptional ability transcends to correctly identifying stimuli they have not been previously exposed to. Thus, at a group level, super-recognisers appear to be super-rejecters as well (see Chapter 7, section 7.2.3).

There are some limitations to this research. Firstly, the numbers of recruited SRs were low meaning that statistical power was potentially too low to detect important group differences. Nevertheless, to date, these are the largest groups of SRs to be included in a research study, and several important group effects as well as individual differences were detected. These findings support the notion that SRs are not a homogenous group, and that some may be superior on face recognition ability only, whereas others may possess enhanced perceptual processes as well. Furthermore, recent research (Bobak, Pampoulov *et al*., 2016) has suggested that a higher minimum performance threshold on the CFMT+ (95/102) than used here (93/102), and by all previous published research on SR (90/102) should be employed. While the 95/102 cut-off is suggested to better represent the scores of 2 standard deviations above the estimated population mean, it should be noted that based on the individual performance observed in Figures 4.2.2.3 and 4.3.2.3, the 93/94 (of 102) SRs in this study performed similarly to >94 SRs (see also section 7.2.1 and appendix for Table A7.2.1.1).

Furthermore, unlike previous studies on SR, the current experiments used a second face recognition test to verify SR ability, thereby strengthening the validity of the current SR samples.

It should also be noted that laboratory SRs (Experiments 4.2 and 4.3) may be slightly inferior at both face and object recognition to SRs in the wider population (Experiment 4.1). Therefore, the significant differences found between controls and SRs in the laboratory tests may have been greater if superior SRs had been recruited. Alternatively, the online participants could have performed slightly better than the laboratory participants given that the images uploaded online were greater in size compared to those displayed on the laboratory computer.

Another limitation to this study is the age difference observed between groups in Experiment 4.3, where SRs were significantly older than controls. Given that age has been found to positively correlate with face recognition, at least up to mid-30's (e.g., Susilo *et al*., 2013), this could potentially suggest that the group differences found between SRs and controls were at least partly owing to SRs' greater age. If this were the case, SRs' superiority in face processing could be deemed a natural consequence of their recognition improving with age, thereby implying that if they were tested at a younger age, they would show similar performance to that of controls. However, while age undoubtedly attenuated some of the participants' performance in Experiment 4.3, it is unlikely that age contributes significantly to SRs' extraordinary face processing ability. Indeed, 13 out of 24 SRs were within 1 SD of the control mean age in Experiment 4.3, while young SRs are also prevalent in Experiments 4.1 and 4.2, as well as published research.

Furthermore, another limitation of the study is the potential difference in participants' motivation, which was not controlled for in the experiments described above. It is arguable that SRs as a group are more motivated than controls to perform better on the tests which are explicitly designed to investigate their extraordinary skills in face processing (Noyes *et al*., 2017). Thus the interpretation of SRs' enhanced performance on face processing tests is always partly confounded by the fact that their motivation-driven attention to tests potentially helps them outperform controls. On the other hand, Bobak, Dowsett *et al*. (2016) tried to experimentally control for motivation by means of monetary incentive, and found that 'motivated' controls performed similarly to 'non-motivated' controls. However, this lack of motivation-driven difference in performance cannot transcend to all studies using SRs and controls, thus while motivation is a factor that cannot be properly controlled for in an experimental setting, as it does not match a natural sense of motivation, it is a factor that potentially attenuated individual scores on experimental tests and thus cannot be ignored.

Finally, it should be pointed out that the demanding nature of some of the tests described in this study (e.g., Part-Whole Test) may have attenuated individual performance generated by SRs and controls

In conclusion, SRs' visual recognition superiority appears to be general, rather than *only* face-specific, while their face processing superiority is found for both recognition and perception. Furthermore, most of the current SRs demonstrate either normal or enhanced holistic processing, indicated by a normal PWE and a stronger IE, respectively. However, it appears that SRs' superiority in face recognition benefits potentially from enhanced holistic processing *and* enhanced parts-based processing, as indicated by their superior inverted face recognition, superior feature matching, and their reduced CFE.

Chapter 5 – Super-Recognisers (SRs) and the Other Age Effect (OAE)

5.0 Introduction

Chapter 2 discussed the special nature of faces as visual stimuli. Neurocognitive findings suggest that face processing is a domain-specific skill, as a collection of brain areas is thought to be specifically related to processing faces (e.g., Haxby *et al*., 2000). However, researchers suggest that our adult face processing expertise is not necessarily neurologically hardwired, but is, instead, a result of our extensive experience with upright faces (e.g., Balas & Saville, 2015; Diamond & Carey, 1986; Le Grand, Mondloch, Maurer, & Brent, 2001; 2004). Faces are more difficult to process in an inverted position (*inversion effect*) compared to non-face objects, although other objects of expertise (e.g., dogs, birds, cars) also generate a significant inversion effect amongst expert participants (e.g., Diamond & Carey, 1986) highlighting the role of experience.

Importantly, when it comes to individual differences in face processing, the role of experience is not always straightforward. For example, individuals with developmental prosopagnosia struggle with face processing despite normal exposure to faces (Behrmann & Avidan, 2005; Duchaine & Nakayama, 2006a), thus experience may not necessarily play a large role in this condition. On the other hand, SRs' superior face processing skills are yet to be fully investigated, as it is not clear how much of their face expertise can be attributed to experience or, potentially, to individual differences in neural/electrical activity. The experiments described in Chapter 5 aim to show whether SRs show superior face processing even for faces they have little experience with – infant faces, and whether this superiority, potentially modulated by experience, can be observed at the level of neural/electrical activity. This chapter thus explores the SRs' *Other Age Effect*.

5.0.1 The other age effect (OAE)

While the other race effect (own ethnicity faces are differentiated better than other ethnicity faces) is most commonly discussed to support the role of experience in face processing expertise (e.g., Brigham *et al.*, 2007; Wu *et al.*, 2012), research attention has shifted to another phenomenon demonstrating the influential nature of experience on face processing: the other age effect (OAE). OAE shows that, in general, people appear to be better at processing faces of their own age (Backman, 1991). In practice, it seems that young adults are generally worse at processing child and elderly faces compared to young adult faces (Macchi Cassia, Kuefner *et al.*, 2009; Kuefner *et al.*, 2008; Wiese *et al.*, 2012). This effect has been shown in older adults (Lamont *et al.*, 2005; Wright & Stroud, 2002) and children (Anastasi & Rhodes, 2005; Anastasi & Rhodes, 2006; Hills & Lewis, 2011). Furthermore, the OAE has been demonstrated for face recognition (e.g., Anastasi & Rhodes, 2005) and for face perception/matching (e.g., Macchi Cassia, Picozzi *et al.*, 2009; for a review see Macchi Cassia, 2011), and this chapter was designed to do the same in investigating SRs.

Several theories have been brought forward to account for this effect. *Social categorization theory* proposes that faces are automatically categorized as socially relevant or not (in-group versus out-group), whereby out-group faces are processed less effectively (e.g., Sporer, 2001). Consequently, since holistic processing is one of the core characteristics of good face processing (although parts-based processing has an undoubted influence as well), faces that are more relevant to us (i.e., people of our own age, or own race), appear to be processed more holistically (e.g., Macchi Cassia, Picozzi *et al.*, 2009; Tanaka *et al.*, 2004) and are thus better discriminated/differentiated and better recognized. On the other hand, *perceptual expertise theory* suggests that if there is a category of face that we are exposed to, to a greater extent, then we develop a perceptual expertise for such faces (e.g., Harrison & Hole, 2009). When these and other theories are compared, they appear to have similar elements to them, such as experience (i.e., exposure to certain types of faces) and motivation (i.e., social/personal interest in certain types of faces), allowing to devise hybrid models that combine these findings into one synthesised theory (for a review see Young *et al.*, 2012).

Critically, participants of different ages (children, young adults and elderly) in general appear to be very poor at newborn face processing (Kuefner *et al.*, 2008; Macchi Cassia, Picozzi *et al*., 2009), as these are often the least frequently encountered type of face. Another potential reason behind poor newborn face processing is the lack of feature and configuration variability ("they all look alike"), as hypothesised by Kuefner *et al.* (2008). Indeed, they suggested that older children's faces share more physical similarities with adult faces than newborn or infant faces (Kuefner *et al*., 2008). This notion is in line with the face space model (Valentine, 1991), which suggests that less distinct faces are harder to differentiate. Importantly, Macchi Cassia, Picozzi *et al.* (2009) show that newborn face processing improves if participants have daily exposure to such faces (paediatric nurses). On the other hand, women who had recently given birth are not good at processing newborn faces, as exposure to and learning of one newborn face does not result in generalised newborn differentiation proficiency (Macchi Cassia, Kuefner *et al*., 2009). Therefore, when it comes to investigating OAE across different age groups, newborn and young infant's faces appear to be the most optimal choice of stimuli as it is easier to control for previous exposure to this type of face.

It is noteworthy that OAE is a term that would be appropriate only if it was observed in all age groups. However, that is not always the case. For instance, when studies find an OAE in children (e.g., Anastasi & Rhodes, 2005), these findings are not always replicated by other studies (e.g., Kuefner *et al.*, 2008; Macchi Cassia, Pisacane, & Gava, 2012) challenging the existence and validity of a true OAE. Furthermore, some studies do not always provide appropriate control conditions. For instance, Susilo, Crookes, McKone, and Turner (2009) found that children are better than adults at child face processing, but they did not use adult face stimuli to see if children would be worse than adults at adult face processing, thereby making their findings inconclusive. Elderly participants similarly show inconsistent OAE (Lamont *et al.*, 2005; Perfect & Harris, 2003; Wright & Stroud, 2002), suggesting that this theoretical construct may not be universally applicable. Another challenging observation comes from studies which show that elderly faces are processed less holistically (perhaps reflecting the increased homogeneity of elderly faces similar to that of newborn faces, thereby encouraging parts-based processing) by both young and elderly participants (Wiese *et al.*, 2012; Wiese, Kachel, & Schweinberger, 2013), demonstrating that elderly participants struggle more with elderly face processing than adult face processing, thereby showing no OAE. Whether the lack of OAE in older adults is due to their greater interest in younger faces, or greater experience with younger faces, or the hypothesised homogeneity of elderly faces has not yet been clarified.

One of the reasons behind the inconsistent findings and opposing observations is the lack of control for individual experience with each age group. Not all studies allocate participants into appropriate groups (i.e., participants with adequate versus no exposure to a particular age group), and those studies that do, have no concise way of guaranteeing the extent of exposure. There is no way of ensuring that a specific participant group and/or individual in that group has had no adequate exposure to elderly or children, thereby failing to account for incidental exposure. This brings about another reason for inconsistent or non-existent findings with regards to OAE: the disproportionate exposure to young adult faces. There is no reason to expect children or elderly participants to generate poor performance on young adult face processing, as this is the most frequently encountered face type. In fact, Macchi Cassia *et al.* (2012) showed that 3 year olds are better at adult face processing than (older) child face processing. Therefore, children are usually good at child and adult face processing and the elderly are generally found to have good adult and elderly face processing, thereby demonstrating no OAE.

Importantly, those studies (e.g., Kuefner *et al.*, 2008; Macchi Cassia, Kuefner *et al*., 2009; Macchi Cassia, Picozzi *et al.*, 2009) that recruit participants with little exposure to specific age groups end up generating a significant OAE, demonstrating a crucial role played by experience. Furthermore, Kuefner *et al.* (2008) and Macchi Cassia, Kuefner *et al.* (2009) also employed inverted face processing in order to demonstrate that different age groups are processed differently. For instance, Kuefner *et al*. (2008) found that while young adult face discrimination was better than newborn and child face discrimination; the participants (young adults) generated significant inversion effects for young adult and children faces. Based on these findings it appears that young adults process newborn faces in a more parts-based manner (see also Susilo *et al.*, 2009). Similarly, Macchi Cassia, Kuefner *et al*. (2009) tested 3-year-old children who also demonstrated a selective inversion effect for young adult faces. Importantly, both studies divided their participants according to their individual experience with different age groups and found that experience did in fact attenuate the inversion effect. Namely, participants would only generate the inversion effect for age groups that they were exposed to on a daily basis. Thus controlling for specific age-group exposure is crucial when investigating the OAE, especially when exploring individual differences in SRs' face processing.

5.0.2 Neural markers of face processing and of the Other Age Effect

While SRs demonstrate an extraordinary recognition for faces, it remains to be seen whether this superiority can be observed at the level of neural activity and whether this superiority is modulated by experience on behavioural and neural levels. Electroencephalography (EEG) studies have demonstrated a number of face-related neural markers, which correlate with individual differences in face processing as well.

The first face-related Event Related Potential (ERP) is P1, which is a positive wave peaking at around 100msec after the stimulus onset, and is associated with pictorial encoding and attentional resource allocation (e.g., Luck, 2005). Turano *et al.* (2016) found that people with good face recognition have an enhanced P1 compared to individuals with poor recognition, potentially implying a more effective pictorial encoding on the part of the good recognisers.

Second, N170, a negative wave occurring at around 170ms is the most robust ERP related to face processing. It is associated with the structural encoding of a face (e.g., Bentin *et al.*, 1996), which is not usually modulated by the face identity (e.g., Eimer, 2000). Towler and Eimer (2012) in their review of EEG findings related to DPs (who are impaired in face recognition) showed that this component often shows similar reactions to upright faces between DPs and participants with normal face processing, suggesting that not all DPs struggle with facial encoding (see also Rivolta, Palermo, Schmalzl, & Williams, 2012). On the other hand, Turano *et al*. (2016) showed that this component can be modulated by face familiarity in good recognisers but not poor recognisers, implying that identity modulation of N170 is possible depending on the participants' recognition ability.

Third, N250, a component associated with implicit face identity discrimination and potentially attributed to Face Recognition Units (FRU, e.g., Bruce & Young, 1986; Kaufmann *et al.*, 2009) has been found to be more negative in amplitude for faces that are recognised with more ease, given that Eimer *et al*. (2012) found this component to generate weaker amplitudes in DPs compared to controls.

Finally, P600, a component associated with explicit face recognition and potentially attributed to Person Identity Nodes (PINs, e.g., Bruce & Young, 1986; Gosling & Eimer, 2011) has been shown to peak with more positive amplitude for stronger feelings of recognition, as demonstrated by Eimer *et al*. (2012) who found that DPs generate weaker P600 amplitudes compared to controls.

EEG studies have also shown that the OAE may have a neural correlate, as it appears to attenuate specific face-related Event Related Potentials (ERPs) (Wiese, 2012; Wiese *et al.*, 2012; Wiese *et al*., 2013). It appears that the connection between the behavioural aspect of OAE and the early ERP components associated with face processing (specifically pictorial and structural encoding), such as P1 and N170 (e.g., Bentin *et al*., 1996; Turano *et al*., 2016), has not yet been observed (Wiese, 2012; Wiese *et al.*, 2012; Wiese *et al*., 2013). For instance, while P1 and N170 do appear to be modulated by the age of face stimuli, this modulation is similar across different age group participants, suggesting this ERP modulation is not a reflection of the OAE, but instead is a reflection of neurons reacting to the superficial physical differences in stimuli. On the other hand, the characteristics of N250, a component associated with implicit face identity discrimination, appear to parallel the behavioural pattern of OAE. For instance, N250 becomes more negative in reaction to repeated (versus new) young faces, but not for old faces, when testing young participants (Wiese, 2012). This N250 repetition effect for young faces was also replicated in another study, while showing no such effect in older participants (Wiese *et al*., 2013). Attenuation of ERPs of later latencies, such as P600, a component associated with explicit face recognition, may also reflect the OAE. For example, Wiese *et al*. (2012) found an enhanced old/new parietal effect in young participants for young faces, demonstrating greater amplitude for hits. Interestingly, elderly participants from this study showed higher amplitudes for correct rejections of elderly face stimuli. Wiese *et al.* (2012) have suggested that this 'mirror' pattern found in elderly participants could reflect a different encoding strategy during the learning phase of own-age faces, consequently altering the neural reactions during exposure to new (correctly rejected) faces. Therefore, it may be worth examining the neural patterns of correct rejections as well as hits, when exploring SRs' OAE and its neural correlates.

5.0.3 The current study

In this study, the OAE was investigated in three experiments across three samples of participants divided into two groups: SRs and average controls. Experiment 5.1 employed adult and infant face recognition tests (old/new) to test a large sample of online participants (n = 820) to explore whether SRs' superiority in face processing persists when their recognition is tested on faces they have less experience with. Experiment 5.2 used the same tests as Experiment 5.1 to test laboratory participants' OAE (n = 48) with simultaneous EEG recording. The aim of Experiment 5.2 was to test whether SRs' superiority for adult and infant faces could be observed at the level of a neural/electrical activity and whether their OAE has a neural correlate. Experiment 5.3 used the adult and infant perception/matching tests in the upright and inverted orientations to test another sample of laboratory participants (n = 44). The first aim of Experiment 5.3 was to test whether SRs' recognition-based aspect of OAE observed in Experiments 5.1 and 5.2, could be observed on a perceptual level as well. The second aim was to test whether SRs' OAE could be associated with a differential holistic processing (measured by the inversion effect) employed for adult and infant face processing.

5.1 Experiment 1

Experiment 5.1 recruited a large sample of participants in order to explore the Other Age Effect (OAE) in SRs. Based on previous SR research demonstrating face specific superiority in recognition (Bobak, Bennetts *et al*., 2016; see also Experiments 4.1 and 4.2), it was hypothesised that SRs would demonstrate no or diminished OAE, thereby demonstrating that they have superior recognition of faces in general, even those that belong to a (social/demographic) out-group. On the other hand, if SRs demonstrate similar or even greater OAEs to that of controls, it would suggest that their face superiority is attenuated by experience and that their infant face processing is quantitatively or qualitatively less efficient than adult face processing.

5.1.1 Methods

5.1.1.1 Design

An independent-measures component, drawing on the inclusion criteria discussed in Chapter 3 (section 3.1.1) to allocate participants to groups, compared the performance of SRs and controls on the *Cambridge Face Memory Test: Extended (CFMT+)* and *adult and infant face recognition tests (old/new)*, with scores subtracted to compute *other age effect (OAE)*. A correlational component examined the relationships between performances on all measures.

5.1.1.2 Participants

The participants recruited for this online study were the same as in Experiment 4.1 and were tested during the same session.

5.1.1.3 Materials

Adult face recognition (old/new) test: The young adult faces (aged between 20 and 40 years old) were taken from the database of The Park Aging Mind Laboratory at The University of Texas at Dallas (Minear & Park, 2004). Adobe Photoshop was used to remove external features (e.g., hair) and distinguishing marks (e.g., freckles). The faces images uploaded online were approximately 6.5 cm x 9 cm.

The adult face recognition test was arranged in two phases (learning and recognition), and to avoid potential floor effects by asking participants to memorise 40 faces in one phase, it consisted of two learning blocks (20 trials per block) and two recognition blocks (40 trials per block). In the first learning phase the image appeared for 2 seconds on the screen followed by the two response options. Participants were required to respond whether the faces appeared 'older' or 'younger' than 30 years. Following a brief break (whereby participants were instructed to click on the 'Continue' button to indicate they were ready to proceed), in the recognition phase half the trials depicted faces seen in the learning phase, and participants were instructed to respond 'old' or 'new' for faces they recognised and did not recognise, respectively (Figure 5.1.1.3.1). The second learning and recognition block started shortly after completion of the first block.

Infant face recognition (old/new) test: The infant faces (n = 80, aged 4 and 6 months) were from the database kindly provided by Macchi Cassia, Picozzi *et al*. (2009). The images were approximately 9 cm x 9 cm. The design was virtually identical to the adult face test as it had the same stimuli numbers, blocks and procedure, except that participants reported whether infant faces were 'older or 'younger' than 5 months ('O' or 'Y') in the learning phase (Figure 5.1.1.3.1).

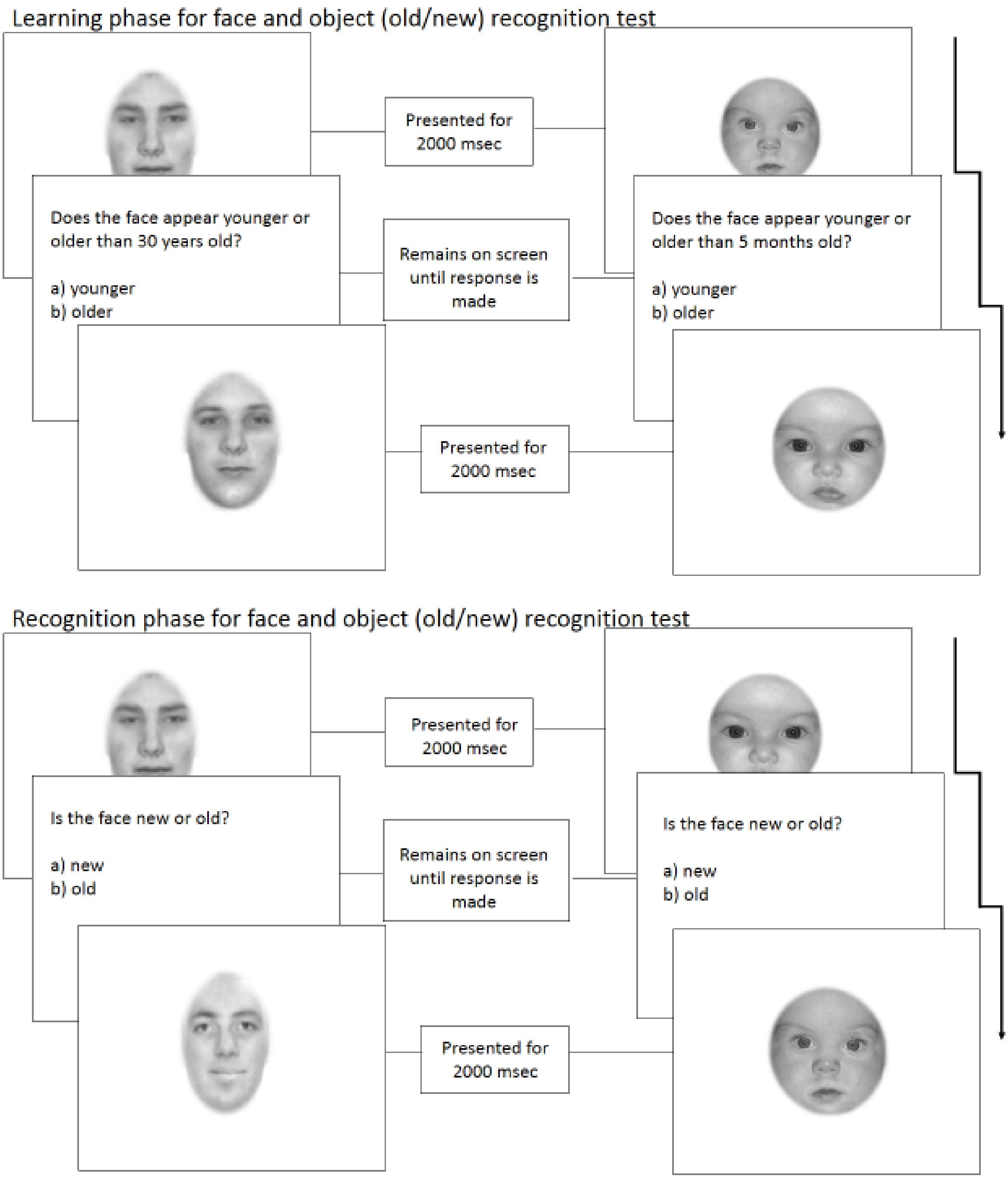


Figure 5.1.1.3.1. An example of the adult and infant face (old/new) recognition tests. The original facial identities were completely altered in Photoshop

Analyses were conducted of correct 'old' responses (hits), correct 'new' responses (correct rejections: CRs), and signal detection theory sensitivity ($d^{/}$) response bias (criterion: C) statistics (e.g., Green & Swets, 1966). High positive values of $d^{/}$ indicate good discrimination of 'old' and 'new' stimuli. Negative values of C are indicative of conservative response biases or a tendency to respond 'new' under conditions of uncertainty; positive values indicate liberal response biases or a tendency to respond 'old'. Note that no response times (RTs) were recorded in this online study.

To calculate the Other Age Effect (OAE), sensitivity scores ($d^{/}$) on the infant face recognition test (old/new) were subtracted from those on the adult face recognition test (old/new).

5.1.1.4 Procedure

After providing informed consent, participants first completed the online version of the CFMT+. They then proceeded to complete the old/new adult face recognition test and old/new infant face recognition test in a counterbalanced order. The entire experiment took approximately 90 minutes, and all participants were fully debriefed at the end.

5.1.2 Results

The mean performance of SRs and controls on adult and infant face recognition is shown in Table 5.1.2.1 Four mixed 2 (stimulus-type: adult, infant faces) x 2 (group: SR, control) ANOVAs were run to analyse group differences on hits, correct rejections, sensitivity index ($d^{/}$) and response bias (Criterion C).

Hits: this ANOVA showed a main effect of stimulus-type, F (1, 476) = 224.91, p <.001, η^2 = .32, whereby adult faces generated more hits than infant faces. There was a main effect of group, F (1, 476) = 162.24, p <.001, η^2 = .25, whereby SRs outperformed controls. There was no significant stimulus-type x group interaction, F (1, 476) < 1.

Correct rejections: this ANOVA showed a main effect of stimulus-type, F (1, 476) = 576.73, p < .001, η^2 = .55, with better performance for adult faces, and a main effect of group, F (1, 476) = 82.13, p < .001, η^2 = .15, with SRs showing better performance. There was no significant stimulus-type x group interaction, F (1, 476) = 1.44, p = .232, η^2 = .003.

Table 5.1.2.1. Mean performance on old/new adult and infant face recognition tests (online study, n = 478)

	SRs (n = 199)				Controls (n = 279)			
	M	(SD)	95% CI		M	(SD)	95% CI	
Adult Face Recognition Test (old/new)								
Hits	0.88	(0.08)	0.87,	0.89	0.77	(0.11)	0.76,	0.79
CR	0.90	(0.08)	0.88,	0.91	0.82	(0.11)	0.80,	0.83
d/	2.60	(0.55)	2.52,	2.67	1.78	(0.52)	1.71,	1.84
C	0.05	(0.31)	0.01,	0.09	0.09	(0.31)	0.05,	0.12
Infant Face Recognition Test (old/new)								
Hits	0.80	(0.10)	0.79,	0.82	0.70	(0.11)	0.68,	0.71
CR	0.77	(0.11)	0.76,	0.79	0.70	(0.11)	0.69,	0.72
d/	1.73	(0.51)	1.66,	1.80	1.12	(0.47)	1.06,	1.17
C	-0.06	(0.31)	-0.10,	-0.01	0.01	(0.25)	-0.02,	0.04
Other Age Effect								
d/	0.87	(0.54)	0.79,	0.94	0.66	(0.53)	0.60,	0.73

Sensitivity index (d/): this ANOVA showed a main effect of stimulus-type, F(1, 476) = 962.93, p < .001, η^2 = .67, showing better performance for adult faces, and a main effect of group, F(1, 476) = 313.21, p < .001, η^2 = .40, showing better performance in SRs. There was also a significant stimulus-type x group interaction, F(1, 476) = 17.09, p = .001, η^2 = .04. SRs, F(1, 476) = 529.64, p < .001, η^2 = .53, had a greater other age effect (OAE) than controls, F(1, 476) = 434.44, p < .001, η^2 = .48.

Response bias (criterion C): this showed a main effect of stimulus-type, F (1, 476) = 46.91, p < .001, η^2 = .09, whereby adult faces induced a more conservative response bias in participants. There was a main effect of group, F (1, 476) = 4.31, p = .039, η^2 = .009, whereby SRs were less conservative in their response than controls. There was no significant stimulus-type x group interaction, F(1, 476) = 1.23, p = .269, η^2 = .003.

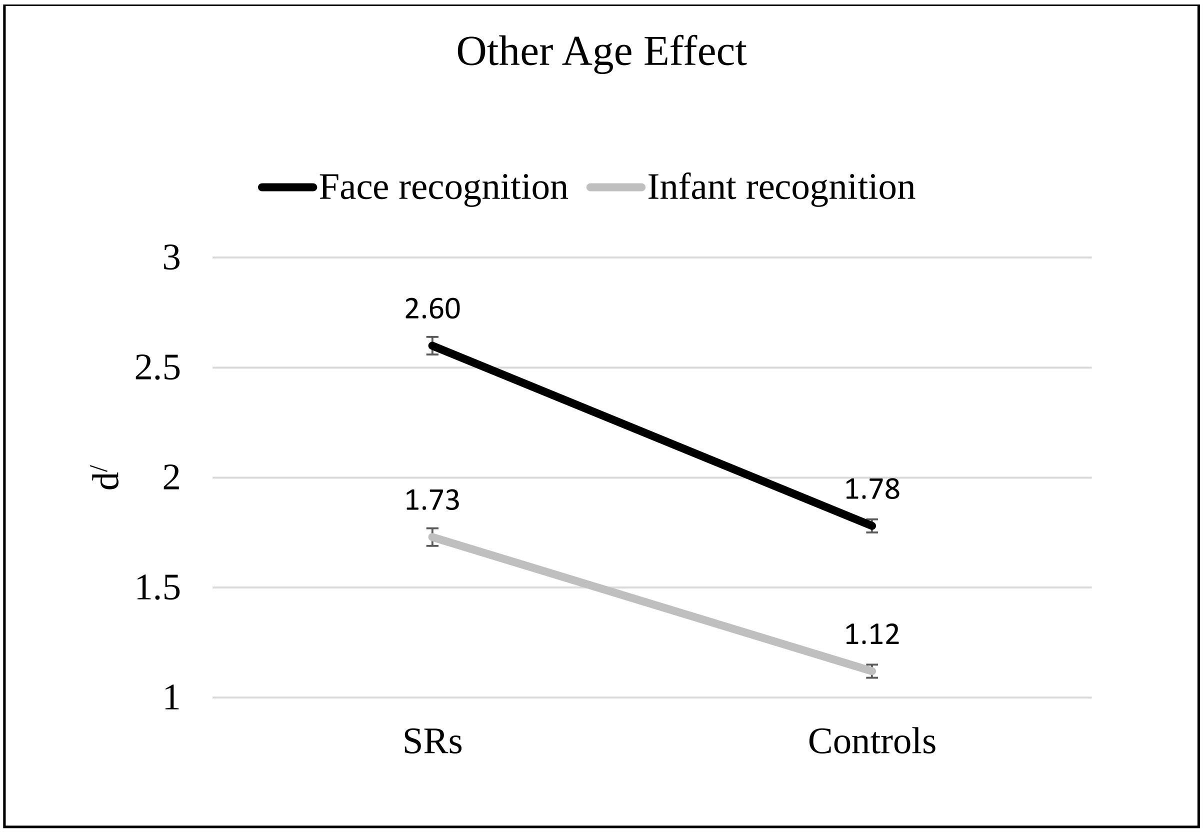


Figure 5.1.2.1. SRs' and controls' performance on adult and infant face recognition (d/). Error bars = standard error of the mean.

Correlational analyses

Table 5.1.2.2 summarises the correlational analyses across all measures. The correlations were found significant (p = .001) only after accounting for multiple comparisons (n = 45). The relationship between face recognition as measured by CFMT+ and the OAE was found to be small, but significant, $r(820) = .13$, $p < .001$. The small correlation between the CFMT+ and OAE is the result of CFMT+ showing a strong relationship with both adult face recognition performance, $r(820) = .49$, $p < .001$, and infant face recognition, $r(820) = .46$, $p < .001$, when considering sensitivity index (d/). In line with previous findings reported in Chapter 4 (Experiments 4.1 and 4.2), the current data demonstrates no relationship between hits and correct rejections for either adult faces or infant faces. Thus, as briefly discussed in the introduction (section 5.0.2), these two recognition-based responses appear to reflect dissociable processes.

Table 5.1.2.2 Correlational analyses for online measures (n=820)

	Adult Face				Infant Face				OAE
	Hits	CR	d'	C	hits	CR	d′	C	d′
CFMT+	0.33*	0.34*	0.49*	<0.01	0.36*	0.27*	0.46*	-0.07	0.13*
Adult Face									
Hits		0.04	0.69*	-0.67*	0.53*	0.03	0.41*	-0.36*	0.41*
CR			0.70*	0.67*	0.01	0.54*	0.38*	0.34*	0.45*
d′				0.01	0.38*	0.40*	0.57*	-0.01	0.62*
C					-0.38*	0.37*	-0.02	0.53*	0.03
Infant Face									
Hits						-0.05	0.71*	-0.74*	-0.24*
CR							0.64*	0.69*	-0.14*
d′								-0.09	-0.29*
C									0.08

*Correlation is significant at the 0.001 level (2-tailed).

5.1.3 Discussion

Experiment 5.1 recruited a substantial sample of participants to demonstrate that SRs' significantly enhanced recognition skills could be modulated by experience. Indeed, SRs' recognition for adult faces was significantly better than their recognition for infant faces, as reflected in hits, correct rejections and sensitivity index. Note however, that SRs' OAE was similar to that of controls when considering hits and correct rejections separately, while the combined sensitivity index showed a greater OAE in SRs. Whether the drop for infant face recognition performance was owing to participants' limited experience with infant faces or owing to the proposed homogeneity of infant faces (Kuefner *et al*., 2008), making them perceptually more difficult to process, remains unknown. Thus, while SR research to date has demonstrated their face processing proficiency (for a review see Noyes *et al*., 2017) and while Experiments 4.1 and 4.2 highlight SRs' general visual superiority of their recognition skills, Experiment 5.1 shows that SRs' face recognition is not absolute and can be modulated by the types of faces being shown. Experiment 5.2 attempted to show whether SRs' superiority in face recognition and OAE can be observed at the level of neural activity, using EEG recording during face recognition.

5.2 Experiment 2

Experiment 5.2 was set to replicate the findings of Experiment 5.1, using the same (old/new) adult and infant face recognition tests, while simultaneously recording the participants' EEG. Based on previous research (e.g., Eimer *et al*., 2012; Turano *et al*., 2016) it was hypothesised that SRs' recognition superiority would be observed at the level of neural activity, reflected in enhanced amplitude or earlier latencies for at least one of the face-related ERPs: P1 (attention allocation and pictorial processing), N170 (structural encoding), N250 (implicit face recognition) and P600 (explicit face recognition). Furthermore, given that SRs demonstrated a greater OAE ($d^{/}$) to that of controls in Experiment 5.1, it was hypothesised that this effect would be observed in attenuated ERPs, in that SRs were expected to show greater amplitude/latency differences between adult and infant faces compared to those of controls. Alternatively, it is possible that SRs and controls would demonstrate a neural correlate of the OAE which would be of similar magnitude in SRs and controls. Indeed, given that analyses of hits and correct rejections in Experiment 5.1 showed similar behavioural OAE in SRs and controls, it is possible that this pattern would be observed in EEG data as well, reflected in no between-group difference in the neural marker of the OAE.

5.2.1 Methods

5.2.1.1 Design

An independent-measures design was employed, drawing on inclusion criteria discussed in Chapter 3 to allocate participants to groups, to compare the performance of SRs and controls on the *Cambridge Face Memory Test: Extended (CFMT+)* and two *adult and infant recognition tests (old/new)*, with scores extracted to compute the *Other Age Effect (OAE*). The adult and infant face recognition tests were administered during EEG recording in order to measure neural correlates of the OAE. A correlational component explored the relationship between performances on all measures. Additional individual level analyses examined the homogeneity of SR responses.

5.2.1.2 Participants

The same participants (minus 7 individuals[10]) as in Experiment 4.2 were used for this study (CFMT+: 61 - 100; $M = 84.22$, $SD = 10.80$; 31 males, mean age = 39.77, $SD = 12.11$). Using the inclusion criteria discussed in Chapter 3, 19 SRs (CFMT+: 93 - 100; $M = 95.16$, $SD = 1.64$; 9 males, mean age = 38.53, $SD = 11.49$) and 28 controls (61 - 82; $M = 73.11$, $SD = 6.71$; 13 males, mean age = 41.38, SD = 14.06)[11] were included in the final between-group analyses.

Note that one SR was excluded from the correlational and group analyses given their significant exposure to infants in their place of work (paediatric hospital). This SR was however included in the individual analyses.

SRs and controls were matched on age, $t(43) < 1$, $p = .472$, gender, $\chi^2(1, n = 46) < 1$, $p = .676$, and Autism Q, $t(43) < 1$, $p = .531$. However, as predicted by previous research finding a positive relationship between empathy and face recognition (Bate *et al*., 2010), the current sample shows that SRs had significantly higher scores on Empathy, $t(42) = 2.48$, $p = .017$, Cohen's $d = .77$[12].

5.2.1.3 Materials

Adult face recognition (old/new) test: The same adult face recognition test (old/new) was used as in Experiment 5.1. The test was administered using the MATLAB 2014a (MathWorks, USA) extension Psychtoolbox (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007). The visual angle of image presentation was 4.9° and 5.72° (participants were situated 60 cm away from the computer screen).

As in Experiment 5.1, the test had 2 learning blocks (20 trials each) and 2 recognition blocks (40 trials each). Each trial began with a 500msec central fixation cross, followed by a 2000msec stimulus presentation. To ensure attention was paid to stimuli during the learning phase, participants pressed 'O' if faces appeared older than 30-years; 'Y' if younger (Note: Experiment 5.1 found no response bias when using these response options). Following a brief break, in the recognition phase half the trials depicted faces seen in Phase 1, and participants were instructed to respond 'O' for old and 'N' for new faces. The second learning and recognition block started shortly after completion of the first block.

[10] Note: due to participant time constraints, 7 participants were unable to continue the testing session comprising the tests forming Experiment 5.2.
[11] Note: gender was not recorded for one participant and age was not recorded for 2 participants in the control group
[12] Note: Autism and Empathy scores were not recorded for 3 participants.

Infant face recognition (old/new) test: The same infant face recognition test (old/new) was used as in Experiment 5.1. The visual angle of infant face presentation was 4.9° and 4.9°. The infant recognition test had the same design as the adult face recognition test, except the learning phase required participants to respond whether the faces appeared older or younger than 5 months (‘O’ or ‘Y’).

Analyses were conducted of correct ‘old’ responses (hits), correct ‘new’ responses (correct rejections: CRs), and signal detection theory sensitivity ($d^/$) response bias (criterion: C) statistics (e.g., Green & Swets, 1966), and response times (RTs).

To calculate OAE for the correlational component, as in Experiment 5.1, sensitivity scores ($d^/$) on the infant face recognition test (old/new) were subtracted from those on the adult face recognition test (old/new).

5.2.1.4 Procedure

After providing informed consent, laboratory participants completed the CFMT+. Upon completion, the EEG was set up, and the participants were situated approximately 60cm away from the computer screen. The participants performed the adult face recognition test and the infant face recognition test in a counterbalanced order. The entire experiment took approximately 40 minutes and all participants were fully debriefed at the end.

5.2.1.5 EEG recording

The EEG recording procedure is described in Chapter 3, section 3.3.2.

5.2.1.6 EEG pre-processing and analysis

Pre-processing of the EEG data is described in Chapter 3, section 3.3.2. In order to explore group differences, grand-averages were computed for all the encoding trials to measure participants’ early perceptual components, whereas during the recognition trials only the participants’ *Hits* and *Correct Rejections* were taken into account (Cohen 2014; Dickter & Kieffaber, 2014; Luck, 2005). Grand-averages were calculated for P1 and N170 for encoding trials only (40 trials per stimulus). Amplitude and latency for P1 were analysed at channels O1/O2 in the time range 70 – 160 msec. Amplitude and latency for N170 were analysed at channels T5/T6 in the time range 110 – 220 msec. Grand-averages were also calculated for hits and correct rejections to analyse P1, N170, N250 and P600. Amplitude and latency for N250 were analysed at channels T5/T6 in the time range 220 – 310msec. Amplitude and latency for P600 were analysed at channels P3/Pz/P4 in the time range 500 – 700msec. Channels of interest were selected based on previous research (see section 3.2.3.2). Note that one of the most common methods was used to measure amplitudes – *local peak amplitude measure*, where the maximum amplitude of the waveform (taking into account the average of 3 surrounding peaks on each side) was recorded from the time window of interest. To obtain latency measures, the latency of selected amplitude peak within a time window of interest was measured (Luck, 2005).

5.2.2 Results

Between-group analyses: The mean performance of SRs and controls on old/new adult and infant face recognition tests is shown in Table 5.2.2.1. A 2 (group: SR, control) x 2 (stimulus-type: adult, infant) ANOVA was performed for hits, correct rejections, sensitivity index, response bias and RTs.

Adult and infant face recognition (hits): this ANOVA found a main effect of stimulus-type was observed, $F(1, 43) = 5.15$, $p = .028$, $\eta^2 = .11$, hit rates were higher on adult face recognition than on infant face recognition. There was no main effect of group, $F(1, 43) = 2.16$, $p = .149$, $\eta^2 = .05$, nor stimulus-type x group interaction, $F(1, 43) < 1$.

Adult and infant face recognition (correct rejections): This ANOVA showed a main effect of stimulus-type, $F(1, 43) = 89.85$, $p < .001$, $\eta^2 = .68$, whereby CR rates were higher to adult faces compared to infant faces. There was a main effect of group, $F(1, 43) = 15.90$, $p < .001$, $\eta^2 = .27$, whereby SRs outperformed controls. A significant stimulus-type x group interaction was found, $F(1, 43) = 4.78$, $p = .034$, $\eta^2 = .10$, whereby SRs, $F(1, 43) = 56.69$, $p < .002$, $\eta^2 = .57$, tended to have more correct rejections for adult than infant faces, compared to controls, $F(1, 43) = 33.25$, $p < .001$, $\eta^2 = .44$.

Adult and infant face recognition (sensitivity index (d')): This ANOVA found a main effect of stimulus-type, $F(1, 43) = 114.57$, $p < .001$, $\eta^2 = .73$, whereby participants performed better on adult faces compared to infant faces. A main effect of group, $F(1, 43) = 40.42$, $p < .001$, $\eta^2 = .49$, showed that SRs outperformed controls. A stimulus-type x group interaction was also found, $F(1, 43) = 15.63$, $p < .001$, $\eta^2 = .27$, whereby SRs, $F(1, 43) = 89.51$, $p < .001$, $\eta^2 = .68$, demonstrated a larger OAE than controls, $F(1, 43) = 28.48$, $p < .001$, $\eta^2 = .40$.

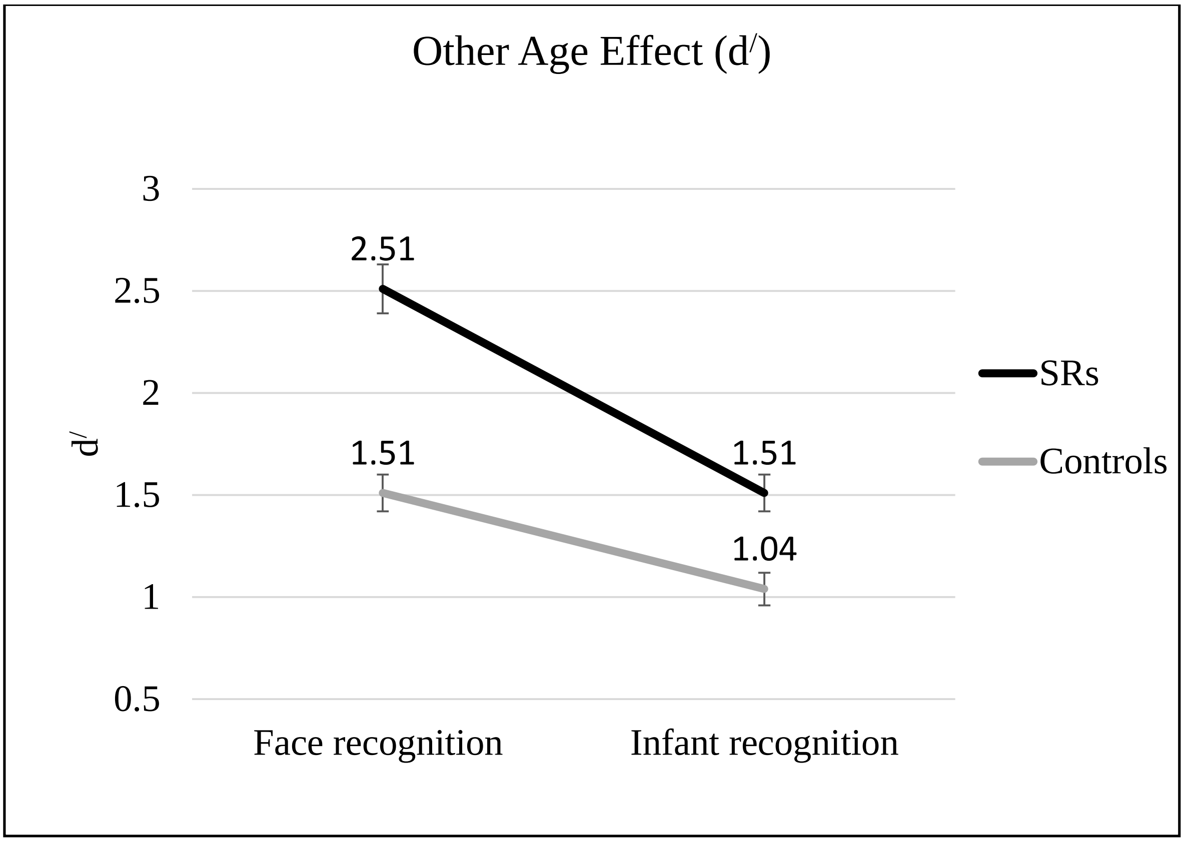


Figure 5.2.2.1. SRs' and controls' performance (d/) on adult and infant face recognition tests. Error bars = standard error of the mean

Adult and infant face recognition (response bias (criterion C)): This ANOVA showed a main effect of stimulus-type, $F(1, 43) = 19.70$, $p < .001$, $\eta^2 = .31$, whereby adult faces tended to induce a more conservative response bias from participants. There was only a marginally significant main effect of group, $F(1, 43) = 3.42$, $p = .071$, $\eta^2 = .08$, whereby SRs tended to be slightly more conservative in their responses than controls. A significant stimulus-type x group interaction, $F(1, 43) = 4.99$, $p = .031$, $\eta^2 = .10$, showed that SRs had a more conservative response bias for adult than infant stimuli, $F(1, 43) = 18.55$, $p < .001$, $\eta^2 = .30$, whereas that effect did not reach statistical significance for controls, $F(1, 43) = 3.04$, $p = .089$, $\eta^2 = .07$.

Adult and infant face recognition (RT): This ANOVA showed no main effect of stimulus-type, $F(1, 43) < 1$, no main effect of group, $F(1, 43) = 1.23$, $p =.273$, $\eta^2 = .03$, and no stimulus-type x group interaction, $F(1, 43) = 3.07$, $p = .087$, $\eta^2 = .07$.

Table 5.2.2.1. Mean performance on old/new adult and infant face recognition tests for adult and infant faces[13]

	SRs (n = 19)				Controls (n = 28)			
	M	(SD)	95% CI		M	(SD)	95% CI	
Adult Face Recognition Test (old/new)								
Hits	0.82	(0.12)	0.76,	0.88	0.77	(0.13)	0.72,	0.82
CR	0.91	(0.80)	0.87,	0.95	0.75	(0.09)	0.71,	0.78
d′	2.51	(0.51)	2.26,	2.76	1.51	(0.47)	1.32,	1.69
C	0.22	(0.43)	0.01,	0.44	-0.06	(0.30)	-0.18,	0.06
RT	0.72	(0.32)	0.56,	0.87	0.93	(0.48)	0.73,	1.12
Infant Face Recognition Test (old/new)								
Hits	0.79	(0.09)	0.74,	0.83	0.74	(0.12)	0.69,	0.79
CR	0.73	(0.15)	0.66,	0.81	0.63	(0.14)	0.58,	0.69
d′	1.51	(0.36)	1.33,	1.69	1.04	(0.41)	0.88,	1.21
C	-0.09	(0.36)	-0.27,	-0.09	-0.16	(0.32)	-0.28,	-0.03
RT	0.78	(0.36)	0.60,	0.96	0.82	(0.37)	0.66,	0.97
Other Age Effect								
d′	1.00	(0.45)	0.78,	1.23	0.46	(0.45)	0.28,	0.64
RT	0.07	(0.19)	-0.03,	0.16	-0.11	(0.40)	-0.27,	0.05

Correlational analyses: Correlations between all measures for all participants (n = 61) are presented in Table 5.2.2.2. Note that while CFMT+ performance significantly correlated with both adult and infant face (old/new) recognition scores, the relationship between CFMT+ and OAE did not reach statistical significance, $r(61) = 0.312$, $p = .014$, after accounting for multiple comparisons ($p = .001$). Another important observation from the correlational analyses is the negative relationship found between correct rejections and hits in infant face recognition. Note that this effect was not observed in Experiment 5.1 recruiting a larger participant sample (n = 820). Indeed Experiment 5.1 showed a lack of relationship between hits and correct rejections. The participants recruited in Experiment 5.2, on the other hand, appeared to have a higher hit rate because of a more liberal response bias, in that they were more likely to respond ‘old’, thereby increasing both hit rates and false alarm rates, and consequently reducing rates of correct rejections.

[13] Note that infant face recognition performance was not recorded for one SR and one control. RT data was not recorded for two controls.

Table 5.2.2.2. Correlations across all measures using the entire sample (n = 61).

	Adult face				Infant face				OAE
	hits	CR	d'	C	Hits	CR	d'	C	d'
CFMT	0.33	0.54*	0.62*	0.20	0.32	0.24	0.53*	0.01	0.32
Adult face									
Hits		0.07	0.67*	-0.63*	0.61*	-0.26	0.27	-0.47*	0.58*
CR			0.74*	0.68*	-0.09	0.66*	0.58*	0.47*	0.43*
d'				0.08	0.28	0.32	0.56*	0.07	0.79*
C					-0.41*	0.61*	0.27	0.62*	-0.09
Infant face									
Hits						-0.41*	0.46*	-0.80*	<0.01
CR							0.60*	0.87*	-0.06
d'								0.15	-0.06
C									-0.03

*Correlation is significant at the 0.001 level (2-tailed)

Individual analyses

Modified t-tests for single cases (e.g., Crawford *et al.*, 2010), compared the other age effect of SRs (*n* = 19) against the control mean. Note that data for infant face recognition was not recorded for one SR.

Figure 5.2.2.2 shows that the majority of SRs (*n* = 16, 88.89%) showed a greater OAE $_{\text{Accuracy}}$ compared to controls, with 4 SRs (22.22%) demonstrating a statistically significant difference, while none of the SRs showed a significantly different OAE $_{\text{RT}}$. The full statistical analyses can be found in the appendices (Tables A5.2.2.1 – A5.2.2.2). Note that SR number 13 (positioned 13th from the left, with the lowest confidence intervals) is the excluded SR based on their significant exposure to infants (see section 5.2.1.2).

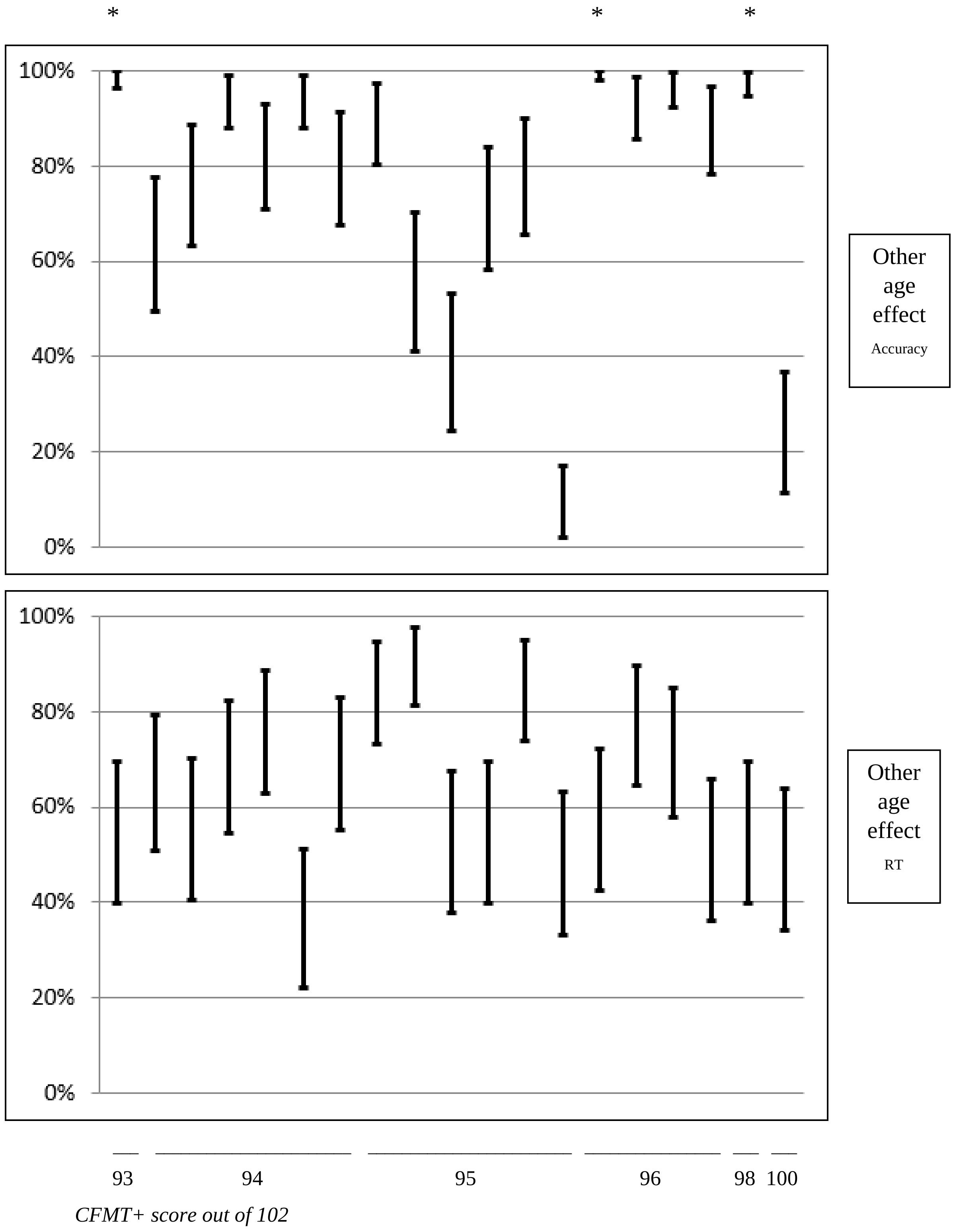


Figure 5.2.2.2. *Upper and lower bound confidence intervals (95%) of the estimated proportion of the general population expected to fall below each super-recogniser (SR, n = 19) based on their (a) Other Age Effect (OAE)* $_{Accuracy}$ *and (b) OAE* $_{RT}$*.*

Reliability and generalisability of the laboratory results: Comparing data from Experiment 5.1 and Experiment 5.2

In order to ensure that recruitment methods did not introduce bias and did not affect generalisability, the data from Experiments 5.1 and 5.2 were compared on the (old/new) adult/infant face recognition tests using a 2 (group: SR, control) x 2 (condition: online, laboratory) x (stimulus-type: face, object) ANOVA.

Adult and infant face recognition tests (old-new) comparisons: Hits: The stimulus-type main effect was significant, $F(1, 519) = 40.72$, $p < .001$, $\eta^2 = .07$. Hit rates for adult faces were higher than infant faces. The group effect was significant, $F(1, 519) = 28.26$, $p < .001$, $\eta^2 = .05$. SRs outperformed controls. There was no condition main effect, $F(1, 519) < 1$. There was a significant stimulus-type x condition interaction, $F(1, 519) = 5.94$, $p = .015$, $\eta^2 = .01$, and simple effects found that online participants demonstrated a larger other age effect, $F(1, 519) = 228.46$, $p < .001$, $\eta^2 = .31$, than laboratory participants, $F(1, 519) = 4.25$, $p = .040$, $\eta^2 = .01$. There was also a condition x group interaction, $F(1, 519) = 3.90$, $p = .049$, $\eta^2 = .01$. Online participants, $F(1, 519) = 156.23$, $p < .001$, $\eta^2 = .23$, showed a larger difference between SR performance and controls, than laboratory participants, $F(1, 519) = 3.05$, $p = .081$, $\eta^2 = .01$. There were no other interactions, $F(1, 519) < 1$.

CRs: The stimulus-type effect was significant, $F(1, 519) = 250.38$, $p < .001$, $\eta^2 = .33$. CRs for adult faces were higher than infant faces. The group effect was significant, $F(1, 519) = 50.82$, $p < .001$, $\eta^2 = .09$. SRs outperformed controls. The condition effect was significant, $F(1, 519) = 8.52$, $p = .004$, $\eta^2 = .02$; online participants outperformed lab participants. There was a significant stimulus-type x group interaction, $F(1, 519) = 5.66$, $p = .018$, $\eta^2 = .01$, and simple effects found that SRs, $F(1, 519) = 138.37$, $p < .001$, $\eta^2 = .21$, displayed a greater advantage for adult faces over infant faces ($CR_{\text{Faces}} – CR_{\text{Infants}} = CR_{\text{Difference}} = 12.67\%$) in comparison to controls ($CR_{\text{Difference}} = 11.05\%$), $F(1, 519) = 112.58$, $p < .001$, $\eta^2 = .18$. The group x condition interaction was marginally significant, $F(1, 519) = 3.77$, $p = .053$, $\eta^2 = .007$. SRs performed similarly in the laboratory and online, $F(1, 519) < 1$, while online controls significantly outperformed laboratory controls, $F(1, 519) = 14.71$, $p < .001$, $\eta^2 = .03$. The stimulus-type x condition interaction was only marginally significant, $F(1, 519) = 3.16$, $p = .076$, $\eta^2 = .006$. Laboratory participants showed a significantly reduced performance compared to online participants for infant faces, $F(1, 519) = 10.15$ $p = .002$, $\eta^2 = .02$, but only marginally so for adult faces, $F(1, 519) = 3.15$, $p = .076$, $\eta^2 = .01$. The three-way interaction was not significant, $F(1, 519) = 2.82$, $p = .094$, $\eta^2 = .005$.

Sensitivity ($d^{/}$): The stimulus-type effect was significant, $F(1, 519) = 270.64$, $p < .001$, $\eta^2 = .34$. Sensitivity for adult faces was higher than infant faces. The group effect was significant, $F(1, 519) = 125.66$, $p < .001$, $\eta^2 = .20$; SRs outperformed controls. The condition effect was significant, $F(1, 519) = 8.64$, $p = .003$, $\eta^2 = .02$; online participants outperformed lab participants. A significant stimulus-type x group interaction, $F(1, 519) = 26.63$, $p < .001$, $\eta^2 = .05$, and simple effects found that SRs ($d^{/}_{\text{Adult Faces}} - d^{/}_{\text{Infant Faces}} = d^{/}_{\text{Difference}} = 0.87$) possessed larger Other Age Effect, $F(1, 519) = 195.05$, $p < .001$, $\eta^2 = .27$, than controls ($d^{/}_{\text{Difference}} = 0.65$), $F(1, 519) = 79.41$, $p < .001$, $\eta^2 = .13$. The stimulus-type x condition interaction was not significant, $F(1, 519) = 1.57$, $p = .211$, $\eta^2 = .003$. There was no condition x group interaction, $F(1, 519) < 1$. The three-way interaction was significant, $F(1, 519) = 7.85$, $p = .005$, $\eta^2 = .02$. SRs showed a significant simple main effect of stimulus-type, $F(1, 215) = 203.48$, $p < .001$, $\eta^2 = .49$, with better performance for adult faces. SRs showed no stimulus-type x condition interaction, $F(1, 215) = 1.05$, $p = .307$, $\eta^2 = .005$. Controls showed a significant simple main effect of stimulus-type, $F(1, 304) = 77.15$, $p < .001$, $\eta^2 = .20$, with better performance for adult faces. The stimulus-type x condition interaction in controls was also significant, $F(1, 304) = 9.94$, $p = .002$, $\eta^2 = .03$. Online controls outperformed laboratory controls on adult faces, $t(305) = 3.78$, $p < .001$, Cohen's $d = .73$, but not on infant faces, $t(305) < 1$, thereby online controls showed a bigger OAE. Overall, as with correct rejections, the interaction indicates that the greater performance of online participants compared to lab participants was driven by controls, not SRs.

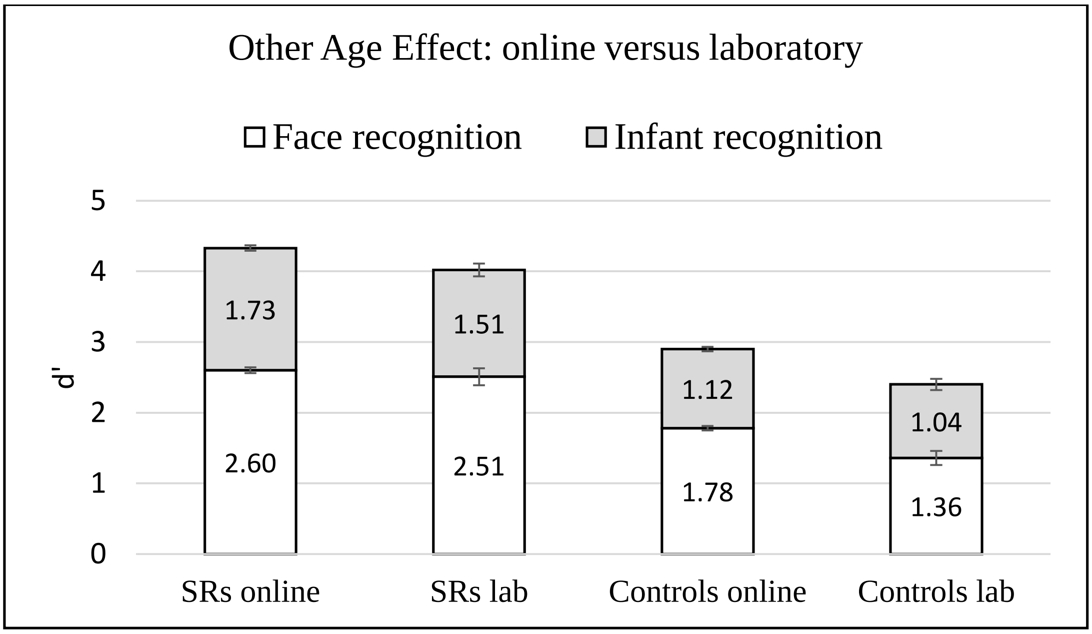


Figure 5.2.2.3. SRs' and controls' performance ($d^{/}$) on adult and infant face recognition in online and laboratory conditions.

Response bias (criterion C): The stimulus-type effect was significant, $F(1, 519) = 49.39$, $p < .001$, $\eta^2 = .09$. There were no group effect, $F(1, 519) = 1.09$, $p = .297$, $\eta^2 = .002$, or condition effect, $F(1, 519) < 1$. There was a significant group x condition interaction, $F(1, 519) = 5.05$, $p = .025$, $\eta^2 = .01$. Online controls were more conservative compared to laboratory controls $F(1, 519) = 4.79$, $p = .029$, $\eta^2 = .01$, whereas SRs showed a similar response bias across condition, $F(1, 519) = 1.24$, $p = .267$, $\eta^2 = .002$. There was a significant stimulus-type x condition interaction, $F(1, 519) = 10.32$, $p = .001$, $\eta^2 = .02$. Adult faces generated a similar response bias across conditions, $F(1, 519) = 1.25$, $p = .265$, $\eta^2 = .002$, while infant faces generated a more liberal response bias in laboratory participants compared to online participants, $F(1, 519) = 4.90$, $p < .027$, $\eta^2 = .01$. The stimulus-type x group interaction, $F(1, 519) = 2.68$, $p = .102$, $\eta^2 = .005$, and the three-way interaction, $F(1, 519) = 1.04$, $p = .308$, $\eta^2 = .002$, were not significant.

Overall, online participants were slightly better at the recognition tests than laboratory participants as indicated by hits, correct rejections, and sensitivity index. Note that the interactions indicated that controls' performances were significantly different across online and lab conditions (CRs, $d^{/}$, C), which appeared to be driven by a more conservative response bias in online compared to lab controls. SRs, on the other hand, appeared to perform similarly on most measures in online and lab conditions.

EEG analysis

The EEG data complemented the participants' behavioural performance to investigate neural markers of SRs' superiority in face recognition as well as the neural correlate of their OAE. The differences in neural/electrical activity observed between SRs and controls are shown in Figures 5.2.2.2 and 5.2.2.3. Other neural activity representations can be found in appendices (Figures A5.2.2.1 - A5.2.2.8)

Encoding adult and infant faces (Other age effect)

Note that 5 SRs and 1 control were removed from ERP analysis for encoding images (seen for the first time), as they did not generate a significant number of artefact-free trials.

P1 (pictorial encoding and attention resource allocation)

A 2 (stimulus-type: adult and infant faces) x 2 (hemisphere: left (channel O1), right (channel O2) x 2 (group: SR, control) mixed ANOVA was performed for *amplitude*, showing no main effects for either stimulus-type or hemisphere, $F(1, 34) < 1$, and no main effect of group, $F(1, 34) = 2.72$, $p = .108$, $\eta^2 = .07$. None of the interactions were significant ($p > .200$).

The same ANOVA was performed for *latency*, showing a main effect of hemisphere, $F(1, 34) = 11.98$, $p = .001$, $\eta^2 = .26$, whereby P1 peaked earlier in the right hemisphere (O2), demonstrating a right hemisphere dominance. There were no main effects of stimulus-type nor group, $F(1, 34) < 1$. There were no significant interactions ($p > .100$).

N170 (structural encoding)

A 2 (stimulus-type: adult and infant faces) x 2 (hemisphere: left (channel T5), right (channel T6)) x 2 (group: SR, control) mixed ANOVA was performed for *amplitude*, showing a main effect of stimulus-type, $F(1, 34) = 5.00$, $p = .032$, $\eta^2 = .13$, with a more negative amplitude for adult faces. There was also a main effect of hemisphere, $F(1, 34) = 4.45$, $p = .042$, $\eta^2 = .12$, whereby the amplitude was more negative in the right hemisphere (T6), demonstrating a right hemisphere dominance for N170. There was no main effect of group, $F(1, 34) = 1.18$, $p = .285$, $\eta^2 = .03$. None of the interactions were significant ($p > .200$).

The same ANOVA was performed for *latency*, showing no main effects of stimulus-type, hemisphere, or group, $F(1, 34) < 1$. There was only a marginal hemisphere x group interaction, $F(1, 34) = 3.62$, $p = .065$, $\eta^2 = .10$. While controls showed similar latencies across both hemispheres, $F(1, 34) < 1$, SRs had a slightly earlier N170 in the right hemisphere than the left, $F(1, 34) = 2.76$, $p = .106$, $\eta^2 = .08$, though this effect was found not significant. No more interactions were found ($p > .100$).

Overall, when participants saw faces for the first time, they demonstrated a right hemisphere dominance reflected in P1 peaking earlier, and in higher amplitudes generated in N170 in the right hemisphere compared to the left hemisphere. Furthermore, N170 was more negative for adult faces than for infant faces, potentially reflecting a neural reaction to superficial physical differences between adult and infant faces. None of the group differences reached statistical significance.

Note that 4 SRs and 3 controls were removed from analyses as they did not generate a significant number of artefact-free trials for hits for one or both stimuli types.

P1 (pictorial encoding and attention resource allocation)

A 2 (stimuli: adult and infant faces) x 2 (hemisphere: left (channel O1), right (channel O2) x 2 (group: SR, control) mixed ANOVA was performed for *amplitude*, showing no main effects for either stimulus-type or hemisphere, $F(1, 33) < 1$, but a main effect of group, $F(1, 33) = 5.37$, $p = .027$, $\eta^2 = .14$, with SRs showing a more positive amplitude for P1 than controls (See Figure 5.2.2.4). There were no significant interactions ($p > .180$).

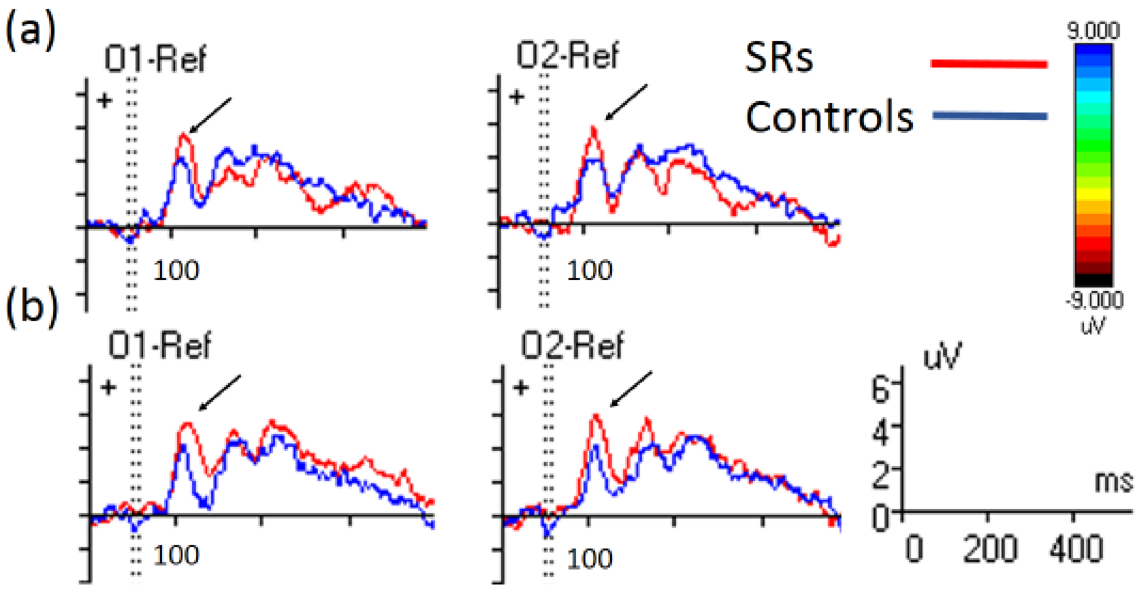


Figure 5.2.2.4. Average P1 amplitudes at channels O1/O2 during (a) adult and (b) infant face recognition (hits) in SRs and controls.

The same ANOVA was performed for *latency*, showing a main effect for hemisphere, $F(1, 33) = 5.58$, $p = .024$, $\eta^2 = .15$, whereby P1 peaked earlier in the right hemisphere (O2), demonstrating a right hemisphere dominance for P1. There were no main effects of stimulus-type nor group, $F(1, 33) < 1$. No interactions were found ($p > .200$).

N170 (structural encoding)

A 2 (stimulus-type: adult and infant faces) x 2 (hemisphere: left (channel T5), right (channel T6)) x 2 (group: SR, control) mixed ANOVA was performed for *amplitude*, showing no main effects of stimulus-type, hemisphere, nor group, $F(1, 33) < 1$. There was a marginal stimulus-type x group interaction, $F(1, 33) = 4.04$, $p = .053$, $\eta^2 = .11$, whereby SRs showed a marginally less negative amplitude than controls for infant faces, $F(1, 33) = 3.52$, $p = .070$, $\eta^2 = .10$, but similar amplitudes for adult faces, $F(1, 33) < 1$. There were no significant interactions ($p > .150$).

The same ANOVA was performed for *latency*, showing no main effects of stimulus-type, group, $F(1, 33) < 1$, or hemisphere, $F(1, 33) = 1.04$, $p = .315$, $\eta^2 = .03$. There were no interactions, $F(1, 33) < 1$.

N250 (implicit face identity discrimination)

A 2 (stimulus-type: adult and infant faces) x 2 (hemisphere: left (channel T5), right (channel T6)) x 2 (group: SR, control) mixed ANOVA was performed for *amplitude*, showing no main effects for either stimulus-type, $F(1, 33) = 2.10$, $p = .157$, $\eta^2 = .06$, hemisphere or group, $F(1, 33) < 1$. None of the interactions were significant ($p > .180$).

The same ANOVA was performed for *latency*, showing a main effect of stimulus-type, $F(1, 33) = 5.23$, $p = .029$, $\eta^2 = .14$, whereby adult faces generated earlier N250 than infant faces, potentially reflecting the OAE. There was also a main effect of hemisphere, $F(1, 33) = 7.51$, $p = .010$, $\eta^2 = .19$, whereby the left hemisphere generated an earlier N250 than the right hemisphere. No main effect of group was found, $F(1, 33) < 1$. None of the interactions were significant ($p > .200$).

P600 (explicit face identity discrimination)

A 2 (stimulus-type: adult and infant faces) x 3 (channel: P3, P4, Pz) x 2 (group: SR, control) mixed ANOVA was performed for *amplitude*, showing no main effects stimulus-type, $F(1, 33) < 1$. There was a main effect of group, $F(1, 33) = 4.74$, $p = .037$, $\eta^2 = .13$, with SRs showing higher amplitudes for P600 than controls (See Figure 5.2.2.5). There was a main effect of channel, $F(2, 33) = 22.77$, $p < .001$, $\eta^2 = .41$, with Pz generating greater amplitudes than P4, $t(34) = 6.94$, $p < .001$, Cohen's $d = 1.26$, and than P3, $t(34) = 5.50$, $p < .001$, Cohen's $d = 1.02$, while there was no difference in amplitude generated by P3 and P4, $t(34) < 1$. None of the interactions were significant ($p > .200$).

The same ANOVA was performed for *latency*, showing no main effects of stimulus-type, $F(1, 33) < 1$, channel, $F(1, 33) = 1.07$, $p = .350$, $\eta^2 = .03$, or group $F(1, 33) = 3.11$, $p = .087$, $\eta^2 = .09$. None of the interactions were significant ($p > .190$).

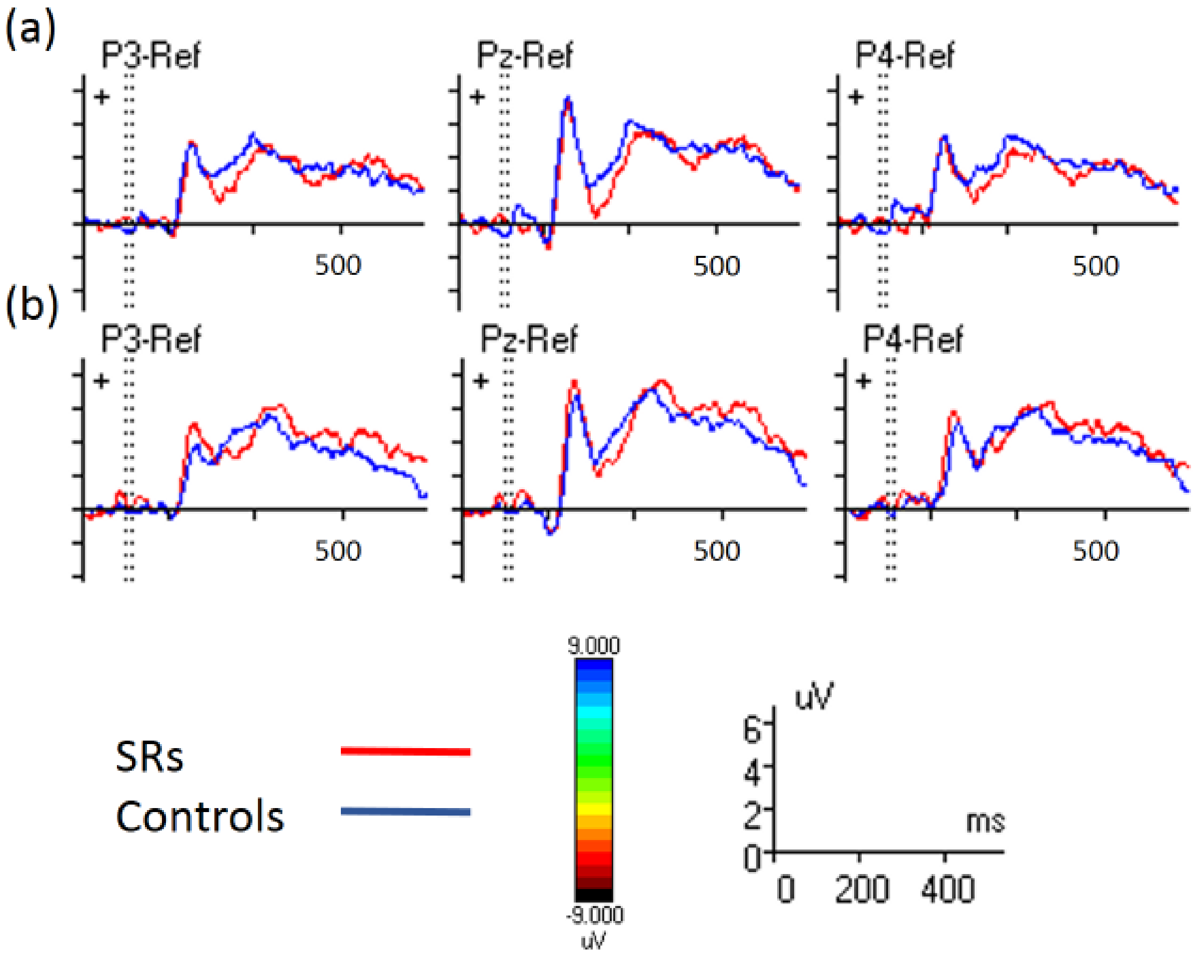


Figure 5.2.2.5. Average P600 amplitudes at P 3/z/4 channels during (a) adult and (b) infant face recognition (hits) in SRs and controls.

Overall, during recognition trials participants again demonstrated a right hemisphere dominance for face processing reflected in an earlier peak of P1 in the right hemisphere compared to the left hemisphere. Importantly, SRs demonstrated overall higher amplitudes in P1, reflecting a more effective pictorial encoding of recognised faces. While no significant results were found for N170 (see section 5.2.3 for a discussion), N250 demonstrated a neural marker of OAE in participants overall, reflected in earlier N250 peak for adult faces compared to infant faces. Furthermore, while participants demonstrated that explicit recognition is more prominent in the central site (Pz), SRs' recognition superiority was reflected in higher amplitudes generated in P600 compared to controls.

Recognising adult and infant faces: Other age effect -Correct rejections

Note that 5 SRs and 2 controls were removed from analysis as they did not generate a significant number of trials for correct rejections for one or both stimuli.

P1 (pictorial encoding and attention resource allocation)

A 2 (stimuli: adult and infant faces) x 2 (hemisphere: left (channel O1), right (channel O2) x 2 (group: SR, control) mixed ANOVA was performed for *amplitude*, showing no main effects for either stimulus-type or group, $F(1, 33) < 1$, but a main effect of hemisphere, $F(1, 33) = 4.48$, $p = .042$, $\eta^2 = .11$, with bigger amplitudes generated in the left hemisphere. There were no interactions ($p > .250$).

The same ANOVA was performed for *latency*, showing no main effects of stimulus-type, hemisphere, $F(1, 33) < 1$, or group, $F(1, 33) = 2.49$, $p = .123$, $\eta^2 = .07$. The hemisphere x group interaction was only marginally significant, $F(1, 33) = 3.93$, $p = .055$, $\eta^2 = .10$. The left hemisphere showed a difference in latency between groups, $F(1, 33) = 4.76$, $p = .036$, $\eta^2 = .12$, with slightly later latencies in SRs, while the right hemisphere showed no differences in latency, $F(1, 33) < 1$. There were no other interactions ($p > .100$).

N170 (structural encoding)

A 2 (stimulus-type: adult and infant faces) x 2 (hemisphere: left (channel T5), right (channel T6)) x 2 (group: SR, control) mixed ANOVA was performed for *amplitude*, showing no main effects of stimulus-type, or group, $F(1, 33) < 1$, and only a marginal effect of hemisphere, $F(1, 33) = 3.60$, $p = .066$, $\eta^2 = .09$, with slightly more negative amplitudes in the right hemisphere. There were no two-way interactions, $F(1, 33) < 1$. The three-way interaction was significant, $F(1, 33) = 9.41$, $p = .004$, $\eta^2 = .21$. SRs showed no main effect of stimulus-type, $F(1, 14) = 2.12$, $p = .166$, $\eta^2 = .12$, or hemisphere, $F(1, 14) = 2.51$, $p = .134$, $\eta^2 = .14$, and only a marginal interaction, $F(1, 14) = 3.72$, $p = .073$, $\eta^2 = .20$. SRs showed a slightly more negative amplitude for adult faces than for infant faces, but this difference was only significant in the left hemisphere, $F(1, 14) = 5.29$, $p = .036$, $\eta^2 = .26$, and not the right hemisphere, $F(1, 14) < 1$. Controls showed no main effects of stimulus-type, $F(1, 19) < 1$, or hemisphere, $F(1,$

19) = 1.04, p = .321, η^2 = .05, but a significant interaction, F(1, 19) = 6.09, p = .023, η^2 = .23. The right hemisphere had more negative amplitudes for adult faces, F(1, 19) = 3.17, p = .090, η^2 = .14, though not reaching statistical significance, and similar amplitudes were observed for infant faces, F(1, 19) < 1.

The same ANOVA was performed for *latency*, showing no main effects, F(1, 33) < 1. There was no stimulus-type x hemisphere interaction, F(1, 33) < 1, and the stimulus-type x group interaction was not significant, F(1, 33) = 3.06, p = .089, η^2 = .08. There was a hemisphere x group interaction, F(1, 33) = 4.94, p = .033, η^2 = .12. The left hemisphere, F(1, 33) = 3.91, p = .056, η^2 = .10, but not the right hemisphere, F(1, 33) = 1.23, p = .274, η^2 = .03, showed a marginal group difference with marginally earlier latencies in controls. The three-way interaction was not significant, F(1, 33) = 3.19, p = .083, η^2 = .08.

N250 (implicit face identity discrimination)

A 2 (stimulus-type: adult and infant faces) x 2 (hemisphere: left (channel T5), right (channel T6)) x 2 (group: SR, control) mixed ANOVA was performed for *amplitude*, showing no main effects for either stimulus-type, F(1, 33) = 1.12, p = .298, η^2 = .03, hemisphere, F(1, 33) = 1.09, p = .304, η^2 = .03, or group, F(1, 33) < 1. The hemisphere x group interaction was not significant, F(1, 33) = 2.84, p = .101, η^2 = .08. There were no other interactions (p > .350).

The same ANOVA was performed for *latency*, showing no main effects for either stimulus-type, group, or hemisphere, F(1, 33) < 1. There were no two-way interactions, F(1, 33) < 1. The three-way interaction was only marginally significant, F(1, 33) = 4.07 p = .051, η^2 = .10, and further analysis showed no statistically significant results.

P600 (explicit face identity discrimination)

A 2 (stimulus-type: adult and infant faces) x 3 (channel: P3, P4, Pz) x 2 (group: SR, control) mixed ANOVA was performed for *amplitude*, showing a main effect of stimulus-type, F(1, 33) = 8.53, p = .006, η^2 = .20, whereby adult faces had lower amplitude than infant faces, thereby reflecting an inverse OAE. There was a main effect of channel, F(2, 33) = 30.79, p < .001, η^2 = .47, with Pz generating higher amplitudes than P4, t(34) = 8.62, p < .001, Cohen's d = 1.30, and P3, t(34) = 7.35, p < .001, Cohen's d = 1.47, while there was no difference between amplitudes generated by P3 and P4, t(34) < 1. There was no main effect of group, F(1, 33) < 1. There were no significant interactions (p > .140).

The same ANOVA was performed for *latency*, showing no main effects and no interactions, $F(1, 33) < 1$.

Overall, analyses of correct rejections revealed a number of 'mirror effects' whereby neural results were opposite to those generated by hits. First, participants' correct rejections appeared to demonstrate a left hemisphere dominance, as they generated higher amplitudes for P1 in the left hemisphere compared to the right hemisphere. Second, the correct rejections generated an inverse OAE whereby infant faces induced higher amplitudes in P600 than adult faces. Other results did not reach statistical significance.

5.2.3 Discussion

Experiment 5.2 demonstrated that SRs while outperforming controls on both adult and infant face recognition, also showed a significantly greater *other age effect (OAE)* than controls. It is noteworthy though, that some of this effect is a result of SRs being more accurate in correctly classifying stimuli as 'new' and being more conservative in their responses to adult faces. Importantly, a much larger sample of SRs (n = 199) in Experiment 5.1 also demonstrated a significant OAE, and unlike the laboratory sample, their OAE was reflected in attenuated hit rates as well. However, when comparing SRs' OAE to that of controls on a bigger scale (Experiment 5.1), the group difference, as with the laboratory analysis (Experiment 5.2), was only demonstrated using the sensitivity index, but not when analysing hits. Thus, it appears that SRs' greater OAE is mostly the result of a more conservative and cautious approach to adult face recognition compared to that of controls. Importantly, as discussed later, this lack of a between-group 'pure' OAE difference was accompanied by a lack of group differences in OAE at the level of neural activity as well.

There were a number of important findings associated with SRs' superiority in face processing at the level of neural activity. Firstly, while P1 and N170, the earliest face-related ERPs related to pictorial and facial structure encoding (e.g., Luck, 2005; Turano *et al*., 2016) showed the expected right hemisphere dominance, there were no differences observed for neural/electrical activity between SRs and controls when they viewed face identities for the first time (during the encoding trials).

However, when P1 was analysed for hits, SRs showed an increased amplitude for this component. This finding is in line with previous research, showing how familiarity of a face can modulate face perception and perception-related ERPs (e.g., Herzmann & Sommer, 2010; Turano *et al*., 2016). It is possible that SRs' recognition is more effective as it is potentially induced by a more powerful activation of pictorial processing of faces they have been previously exposed to (and required to memorise). This is the first neural indication of SRs' advantage in face processing, and it takes place at the level of the earliest face-related component. Furthermore, in line with predictions, SRs' recognition superiority was reflected in the neural group differences observed at P600, a component associated with explicit recognition, as SRs' P600 amplitudes were more positive than those generated by controls. Thus, SRs' superior face recognition was accompanied by a more substantial activation of a recognition-related neural network, potentially reflecting a more effective activation of Person Identity Nodes (Bruce & Young, 1986). It is noteworthy, that the neural/electrical increase observed at the level of P600 could potentially be attributed to the neural increase observed at the level of P1, as earlier ERPs are thought to contribute to the processing of the ERPs observed at the later stage.

Furthermore, Experiment 5.2 found several neural correlates of the OAE, but they were only present when examining both controls and SRs together, a possible consequence of increased statistical power. The first neural marker of OAE was observed in N250, as this recognition -related component peaked significantly earlier for adult faces than it did for infant faces. It is argued that earlier latencies indicate more efficient processing (e.g., Kaltwasser *et al.*, 2013) as they allow for the subsequent face processing stage to begin earlier, whereas longer latencies may indicate a more demanding processing (Bentin *et al.*, 1996; Eimer *et al.*, 2012; Rivolta *et al.*, 2012; for review see Towler & Eimer, 2012). Given that N250 is associated with implicit face discrimination (e.g., Eimer & Gosling, 2012; Kaufmann *et al.*, 2009; Pfutze *et al.*, 2002; Schweinberger *et al.*, 2004), and assuming that earlier latencies are potentially indicative of more efficient processing, these neural results suggest that the internally stored face representations of the experimentally learnt faces were potentially activated with more ease for adult faces than for infant faces. Note that in line with previous EEG research (e.g., Pierce *et al.*, 2011; Tanaka *et al.*, 2006) this study found that face recognition at the level of N250 showed a left hemisphere dominance, as indicated by earlier latencies generated for recognised faces. Therefore it appears that not all stages of face processing show a right hemisphere dominance.

The second OAE neural marker was observed for correct rejections, in that correctly rejected infant faces generated higher amplitudes at the level of P600, a component known as the parietal old/new effect, associated with explicit face recognition (e.g., Rugg & Allan, 2000; Rugg & Curran, 2007). Higher P600 amplitudes are expected to accompany more efficient recognition, at least when analysing hits (e.g., Eimer *et al.*, 2012), thus it is unclear why correct rejections of infant faces induced higher P600 amplitudes, especially since behavioural findings indicate a higher rate of correct rejections for adult faces, not infant faces. Given that hits and correct rejections appear to reflect different types of processing, as indicated by the findings reported in Experiments 4.1 and 5.1, hits and correct rejections cannot be directly compared and neural correlates of hits should not be expected to show similar patterns in neural correlates of correct rejections. Indeed, Experiment 5.2 also showed that correct rejections induced a left hemisphere dominance for P1, as opposed to the prominent right hemisphere dominance reported in face processing literature (e.g., Watanabe, *et al.*, 1999; Yovel & Kanwisher, 2004; see also Collins & Olson, 2014). Thus, it appears that correct rejections tend to induce a 'mirror effect' (opposite pattern) when compared to hits, as reflected in the inverse hemisphere dominance in P1 and the inverse OAE in P600 (see also General Discussion in section 5.4).

Note that N170, a component associated with the structural encoding of faces (e.g., Bentin *et al*., 1996), was the earliest ERP to demonstrate a different neural reaction in response to the stimuli age groups, as it generated more negative amplitudes for adult faces compared to infant faces. However, in line with previous research (Wiese *et al*., 2012; Wiese *et al*., 2013), this ERP modulation most likely reflected the superficial difference in the faces' appearance. For instance, previous EEG studies (e.g., Wiese *et al.*, 2012) found a similar N170 modulation in response to elderly faces, but this modulation was observed for both young and elderly participants, suggesting this ERP modulation is not a reflection of the OAE. Thus, the N170 modulation observed in Experiment 5.2 should not be viewed as a neural marker of the OAE.

Overall, SRs demonstrated two neural markers of their face recognition superiority, providing evidence that their neural differences start at the earliest stage of face processing. Furthermore, the OAE was demonstrated at the level of neural activity only when taking both controls and SRs into account. Importantly, the lack of group difference in the neural correlates of OAE was in line with the lack of group difference in behavioural OAE, at least when considering hits, rather than sensitivity. Experiment 5.3 was set to explore the perceptual aspect of OAE, while also testing the participants' holistic processing of adult and infant faces in an attempt to justify a potential difference in their performances.

5.3 Experiment 3

Experiments 5.1 and 5.2 showed that SRs outperform controls on both adult and infant face recognition while also demonstrating a *recognition-based* aspect of the other age effect (OAE), in that their adult face recognition was superior to their infant face recognition when considering sensitivity index. Experiment 5.3 was designed to test whether SRs' OAE can be observed on the *perceptual* level as well and whether it was accompanied by a reduced holistic processing of infant faces compared to adult faces, by looking at the difference in the inversion effects (IE). It was hypothesised that SRs would demonstrate a significant OAE for face perception/matching, replicating the recognition-based OAE found in Experiments 5.1 and 5.2. It was also predicted that SRs' OAE would be accompanied by a reduced IE for infant faces compared to adult faces.

5.3.1 Methods

5.3.1.1 Design

An independent-measures design was employed, drawing on inclusion criteria discussed in Chapter 3 to allocate participants to SR and control groups. SRs and controls were compared on the *adult and infant face matching tests* in *upright* and *inverted* orientations, in order to measure their upright face matching, inversion effects (IE), and other age effect (OAE). Additional individual level analyses examined the homogeneity of SR responses.

5.3.1.2 Participants

The same participants as in Experiment 4.3 were recruited. Twenty-four SRs (CFMT+: 94 - 101; M = 96.78, SD = 2.31; 12 males, mean age = 37.42, SD = 8.38) and 20 controls (65 - 81; M = 72.69, SD = 4.68; 6 males, mean age = 29.35, SD = 10.29) were included in the final between-group analyses.

Participants were matched on gender, $\chi^2(1, n = 44) = 1.81$, $p = .179$, Empathy $t(24) < 1$, $p = .503$, and Autism Quotients, $t(24) < 1$, $p = .911$. Participant groups were not matched on age, $t(42) = 2.87$, $p = .006$, $d = .86$, as SRs were significantly older than controls. This limitation is acknowledged in the General Discussion (section 5.4).

5.3.1.3. Materials

Adult/infant face matching test: The test comprised two stimuli types: infant and adult faces. The infant faces (aged 4 and 6 months) were obtained from the database provided by Macchi Cassia, Picozzi *et al*. (2009) and adult face stimuli were taken from the database of The Park Aging Mind Laboratory at The University of Texas at Dallas (Minear & Park, 2004). Adobe Photoshop was used to crop the images to remove hairstyle and other external features and all distinctive marks were removed to avoid aiding matching. The visual angle of image presentation was 4.9° by 5.72° for adult faces and 4.9° by 4.9° for infant faces.

The test included two blocks (48 trials each) per stimulus condition, with an opportunity to take a break between each block (infant face block and adult face block). The order of blocks was not counterbalanced (i.e., the test always began with the infant face blocks), which is acknowledged as a potential limitation in the General Discussion. Each trial consisted of a fixation cross (500msec), followed first by a target face (500msec) and then a probe face (500msec) with a short inter-stimulus interval (500msec). The probe image was followed by another fixation cross which stayed on screen until a response was made. The participants were required to respond as fast as they could whether the two face images were same ('S') or different ('D'). The target and the probe images were different in size (by 24%) in each trial as to encourage same/different judgement based on identity, and not on image variation, as the two images were shown in the same place on the screen (which made it easy to spot the difference when images were of equal size).

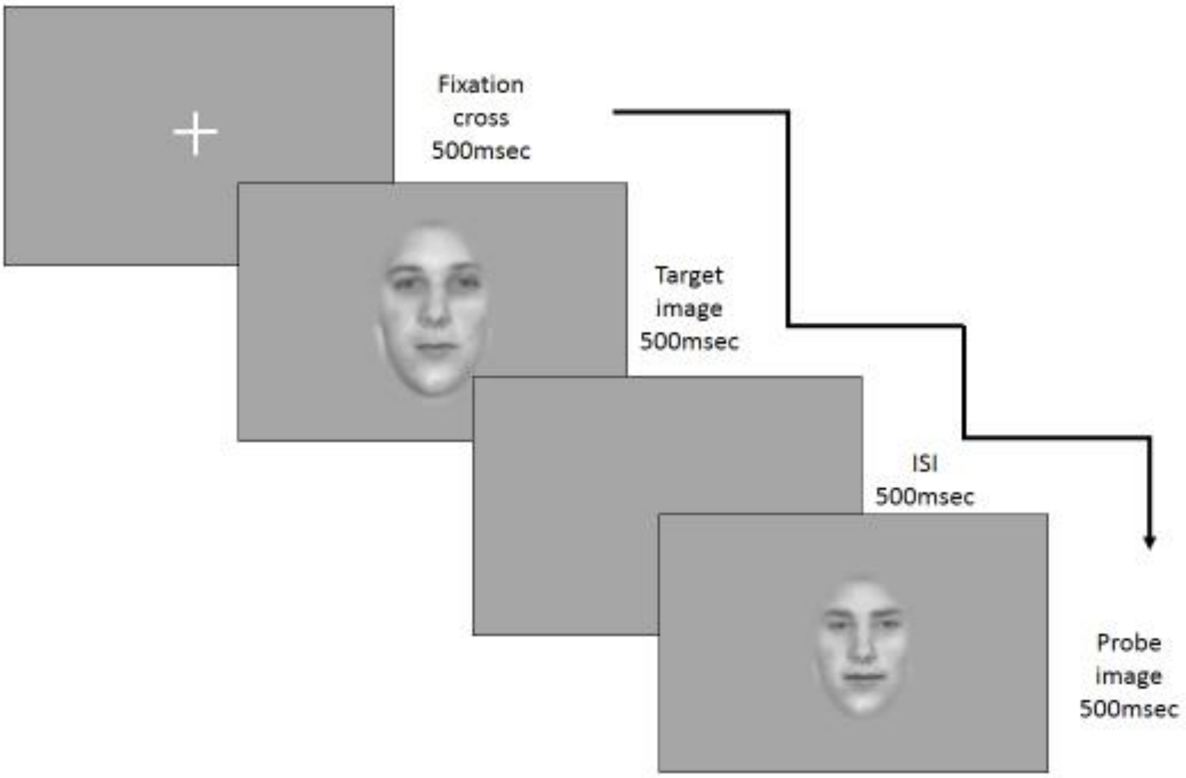


Figure 5.3.1.3.1. An example of the adult/infant face matching test: the adult face block. The original facial identities were completely altered in Photoshop

Adult/infant face matching test – inverted: The same test was administered in an inverted orientation where all stimuli were rotated 180°. The design was identical to that of the upright orientation.

Note that the adult/infant face matching test is not a purely perceptual task in that it employs sequential presentation of stimuli, rather than having the target and two probes on the screen at the same time. This design allowed for the separation of participants' correct responses into correct identification and correct rejections, and to obtain signal detection theory measures (sensitivity index and response bias), thereby allowing more in-depth analyses. Furthermore, given the rapid presentation of targets and probes, participants' reliance on memorising was minimised.

Analyses were conducted of correct 'same' responses (hits), correct 'different' responses (correct rejections: CRs), and signal detection theory sensitivity ($d^{/}$) response bias (criterion: C) statistics (e.g., Green & Swets, 1966), and response times (RTs).

To calculate the OAE for individual analyses, sensitivity scores ($d^{/}$) on the infant face matching block were subtracted from those on the adult face matching block in the upright orientation only. To calculate the inversion effects (IE), sensitivity scores ($d^{/}$) on the inverted adult face matching block were subtracted from those on the upright adult face matching block. The same calculation was performed for the infant IE, subtracting infant inverted sensitivity score from infant upright sensitivity score. The same individual analyses were performed for RT.

5.3.1.4 Procedure

After providing informed consent participants were situated 60cm away from the computer screen and performed the *adult/infant face matching test - upright*, and *adult/infant face matching test -inverted* in a counterbalanced order. The entire experiment took approximately 30 minutes after which participants were fully debriefed.

5.3.2 Results

The participants' other age effect (OAE) and the difference in inversion effects (IE) between the two stimuli were analysed with a 2 (stimulus-type: adult, infant faces) x 2 (orientation: upright, inverted) x 2 (group: SR, control) ANOVA. The same ANOVA was run for hits (Figure 5.3.2.1), correct rejections (Figure 5.3.2.2), sensitivity index (Figure 5.3.2.3), response bias (Figure 5.3.2.4), and RTs (Figure 5.3.2.5).

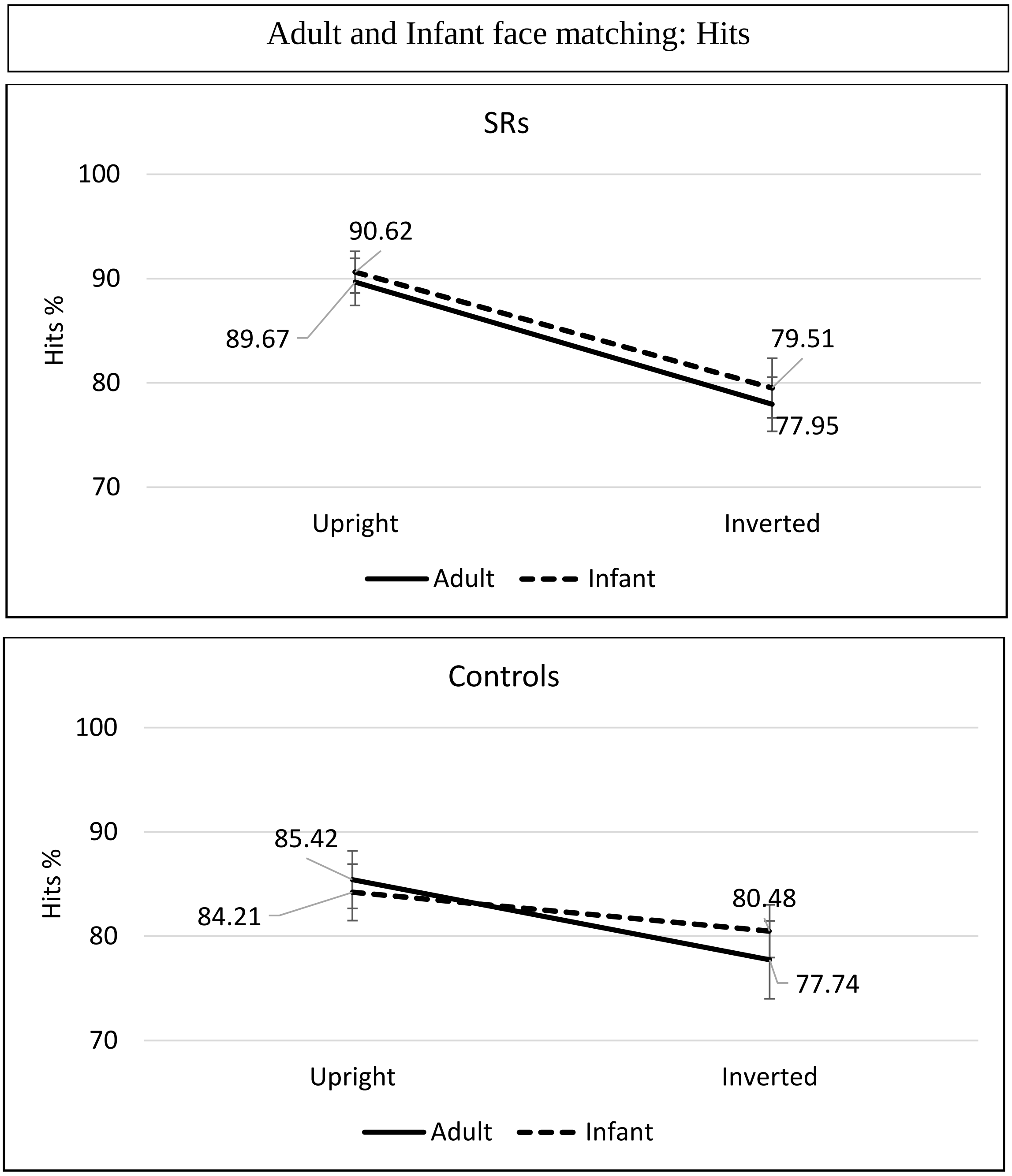


Figure 5.3.2.1. Mean hits by SRs and controls for adult and infant faces in upright and inverted orientations. Error bars = standard error of the mean.

Hits: This ANOVA found a main effect of orientation, $F(1, 41) = 52.61$, $p < .001$, $\eta^2 = .56$, whereby upright faces generated higher hits. There was no main effects of stimulus-type or group, $F(1, 41) < 1$. There were no stimulus-type x group, $F(1, 41) < 1$, or stimulus-type x orientation, $F(1, 41) = 1.46$, $p = .234$, $\eta^2 = .03$ interactions. There was a significant orientation x group interaction, $F(1, 41) = 5.86$, $p = .020$, $\eta^2 = .13$, whereby SRs had a larger drop in performance from upright to inverted stimuli, $F(1, 41) = 52.95$, $p < .001$, $\eta^2 = .56$, than controls,

$F(1, 41) = 10.46$, $p = .002$, $\eta^2 = .20$. There was no stimulus-type x orientation x group interaction, $F(1, 41) < 1$.

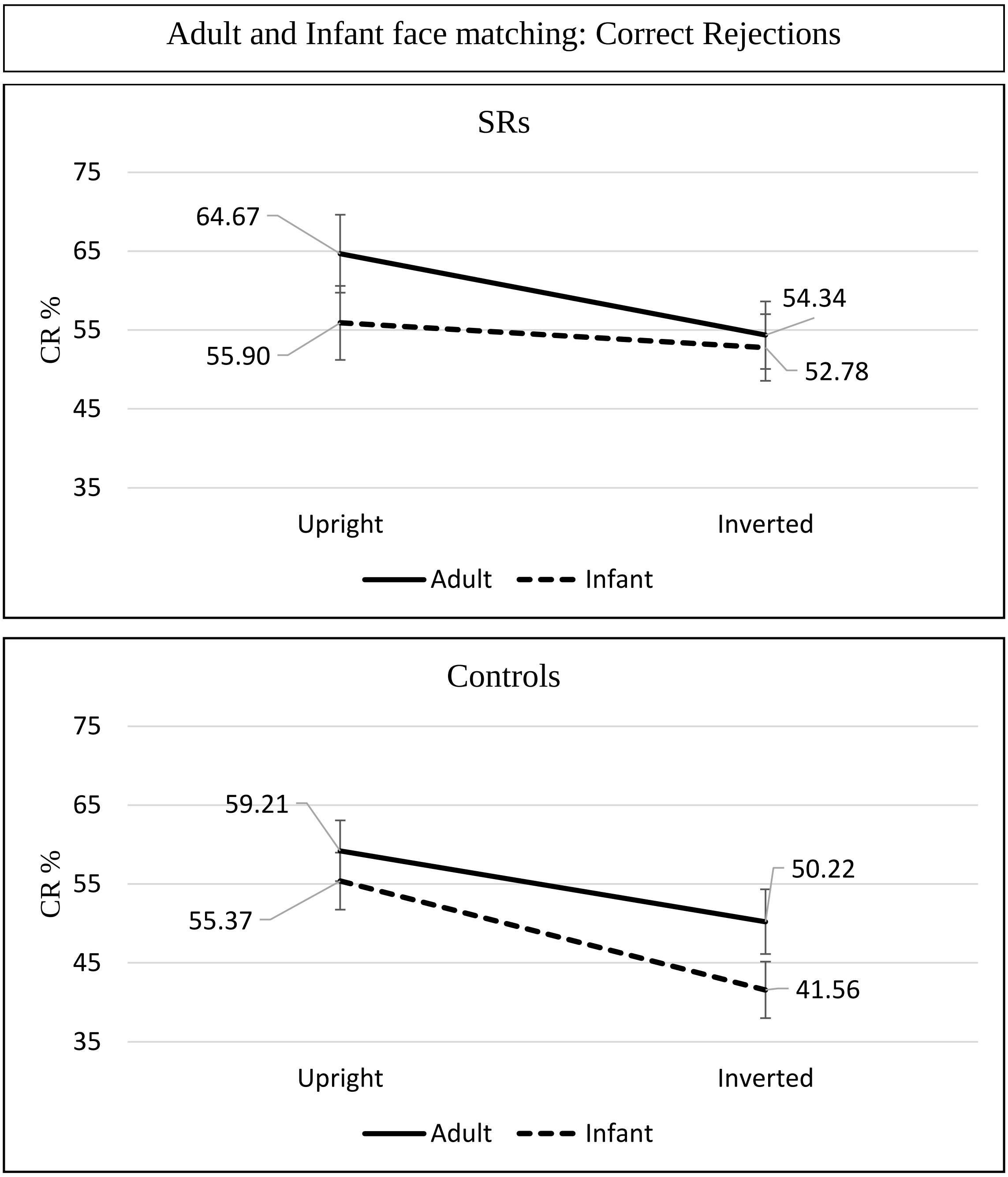
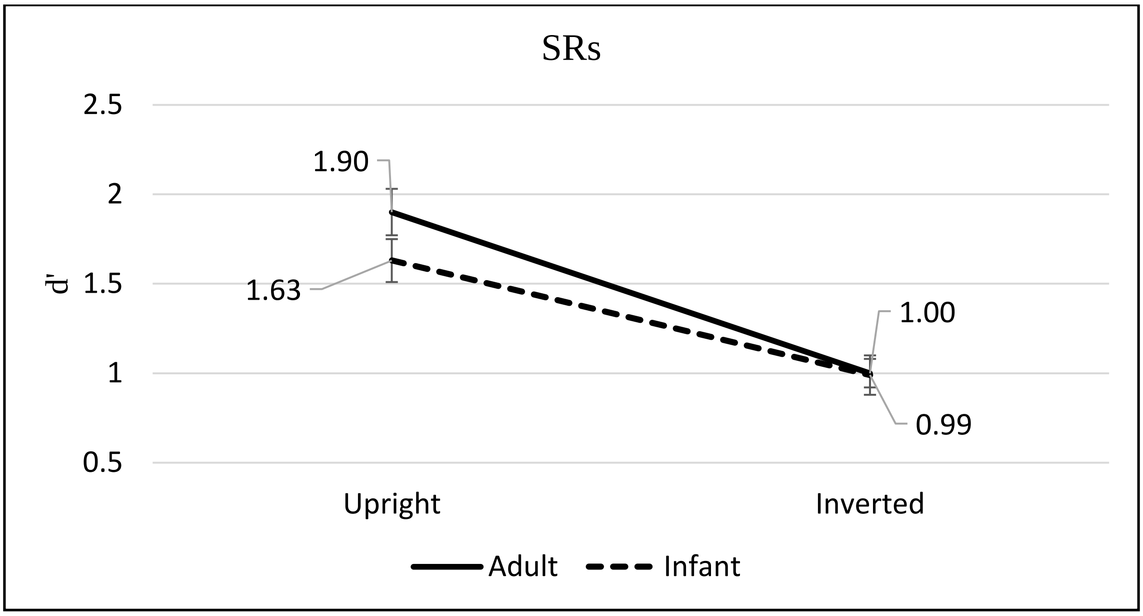


Figure 5.3.2.2. Mean correct rejections by SRs and controls for adult and infant faces in upright and inverted orientations. Error bars = standard error of the mean.

Correct rejections: This ANOVA found a main effect of orientation, $F(1, 41) = 21.65$, $p < .001$, $\eta^2 = .34$, whereby upright faces generated higher correct rejections. There was also a main effect of stimulus-type, $F(1, 41) = 18.44$, $p < .001$, $\eta^2 = .31$, whereby adult faces generated more correct rejections than infant faces. There was no main effect group, $F(1, 41) < 1$. There were no stimulus-type x group, $F(1, 41) < 1$, stimulus-type x orientation, $F(1, 41) < 1$, or group x orientation, $F(1, 41) = 1.43$, $p = .239$, $\eta^2 = .03$ interactions There was a significant three-way interaction, $F(1, 41) = 7.81$, $p = .008$, $\eta^2 = .16$. SRs showed a significant simple main effect of stimulus-type, $F(1, 23) = 8.32$, $p = .008$, $\eta^2 = .27$, whereby correct rejections were higher for adult faces. SRs also showed a significant simple main effect of orientation, $F(1, 23) = 4.81$, $p = .039$, $\eta^2 = .17$, whereby upright faces generated more correct rejections. The stimulus-type x orientation interaction was also significant in SRs, $F(1, 23) = 6.67$, $p = .017$, $\eta^2 = .23$, whereby adult faces generated a significant inversion effect, $t(23) = 3.41$, $p = .002$, Cohen's $d = .71$, but not infant faces, $t(23) < 1$. Within the same three-way interaction, controls showed a significant main effect of stimulus-type, $F(1, 18) = 10.26$, $p = .005$, $\eta^2 = .36$, with more correct rejections generated by adult faces. Controls also showed a significant simple main effect of orientation, $F(1, 18) = 30.43$, $p < .001$, $\eta^2 = .63$, with more correct rejections for upright presentation. Unlike with SRs, controls showed no stimulus-type x orientation interaction, $F(1, 18) = 2.12$, $p = .163$, $\eta^2 = .11$. Overall, while SRs and controls demonstrated higher performance for adult faces and for the upright orientation, unlike controls, SRs showed no inversion effect for infant faces.

Sensitivity index (d'): This ANOVA found a main effect of orientation, $F(1, 41) = 62.09$, $p < .001$, $\eta^2 = .60$, whereby upright faces generated higher performance than inverted faces. There was also a main effect of stimulus-type, $F(1, 41) = 5.60$, $p = .023$, $\eta^2 = .23$, whereby adult faces generated a better performance than infant faces. There was a main effect of group, $F(1, 41) = 7.48$, $p = .009$, $\eta^2 = .15$, whereby SRs outperformed controls. There were no stimulus-type x group, $F(1, 41) < 1$, stimulus-type x orientation, $F(1, 41) = 2.20$, $p = .146$, $\eta^2 = .05$, or group x orientation, $F(1, 41) = 2.42$, $p = .127$, $\eta^2 = .06$ interactions. The three-way interaction was not significant, $F(1, 41) = 1.66$, $p = .205$, $\eta^2 = .04$.

Adult and Infant face matching: Sensitivity Index



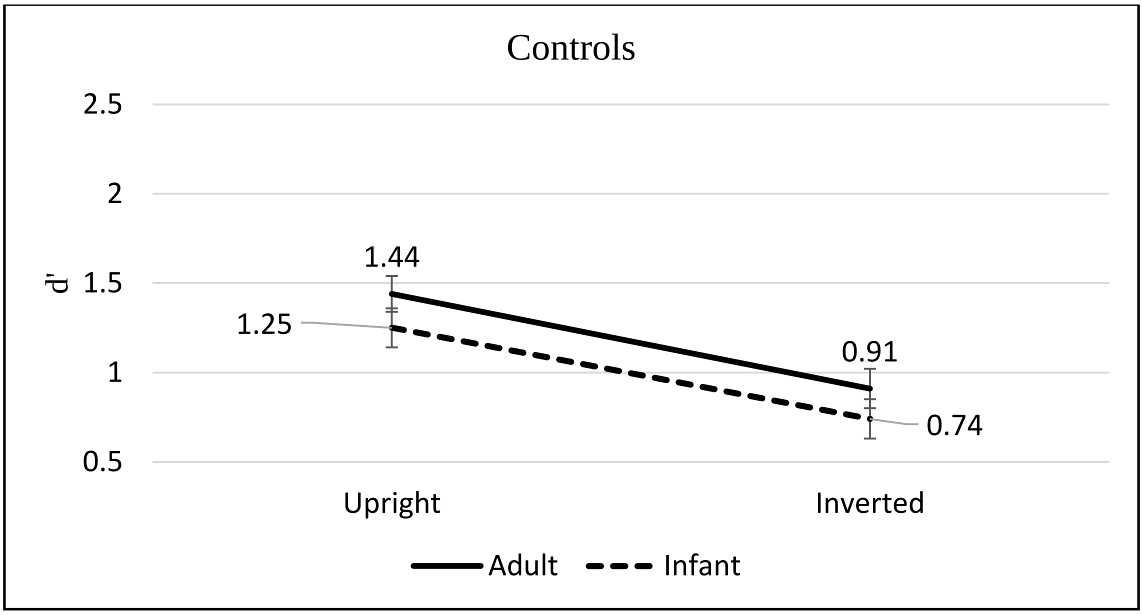


Figure 5.3.2.3. Mean sensitivity index scores ($d^{/}$) by SRs and controls for adult and infant faces in upright and inverted orientations. Error bars = standard error of the mean.

Response bias (Criterion C): This ANOVA found a significant main effect of stimulus-type, $F(1, 41) = 5.54$, $p = .024$, $\eta^2 = .12$, whereby adult faces generated a more conservative response than infant faces. The main effect of orientation was not significant, $F(1, 41) = 3.14$, $p = .084$, $\eta^2 = .06$. There was no main effect of group, $F(1, 41) < 1$, or stimulus-type x group and stimulus-type x orientation interactions, $F(1, 41) < 1$. There was a significant orientation x group interaction, $F(1, 41) = 8.39$, $p = .006$, $\eta^2 = .17$, whereby SRs, $F(1, 41) = 12.34$, $p < .001$,

η^2 = .23, had a significantly more conservative response for inverted face matching than upright face matching, whereas in contrast controls, $F(1, 41) < 1$, had a similar response type for both orientations.

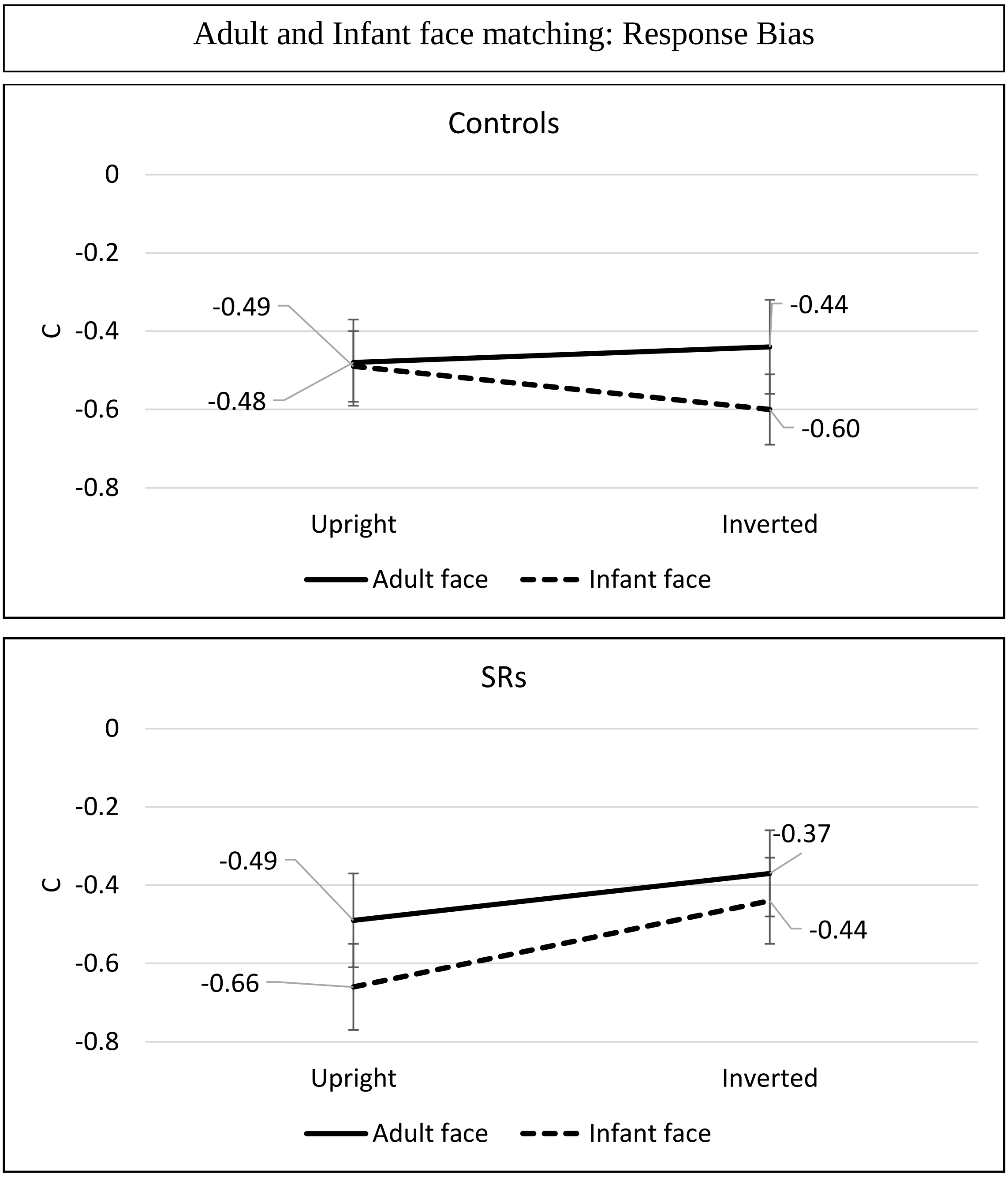


Figure 5.3.2.4. Mean response bias scores (C) by SRs and controls for adult and infant faces in upright and inverted orientations. Error bars = standard error of the mean.

The three-way interaction was only marginally significant, $F(1, 41) = 3.66$, $p = .063$, η^2 = .08. SRs showed a significant simple main effect of stimulus-type, $F(1, 23) = 5.01$, $p = .035$,

η^2 = .18, whereby responses were more conservative for adult faces. SRs also showed a significant simple main effect of orientation, $F(1, 23) = 10.79$, $p = .003$, $\eta^2 = .32$, whereby inverted presentation generated more conservative responses. There was no significant stimulus-type x orientation interaction in SRs, $F(1, 23) = 1.32$, $p = .262$, $\eta^2 = .05$. Controls showed no simple main effects of stimulus-type, $F(1, 18) = 1.42$, $p = .250$, $\eta^2 = .07$, or orientation, $F(1, 18) < 1$, nor significant stimulus-type x orientation interaction, $F(1, 18) = 2.38$, $p = .140$, $\eta^2 = .12$.

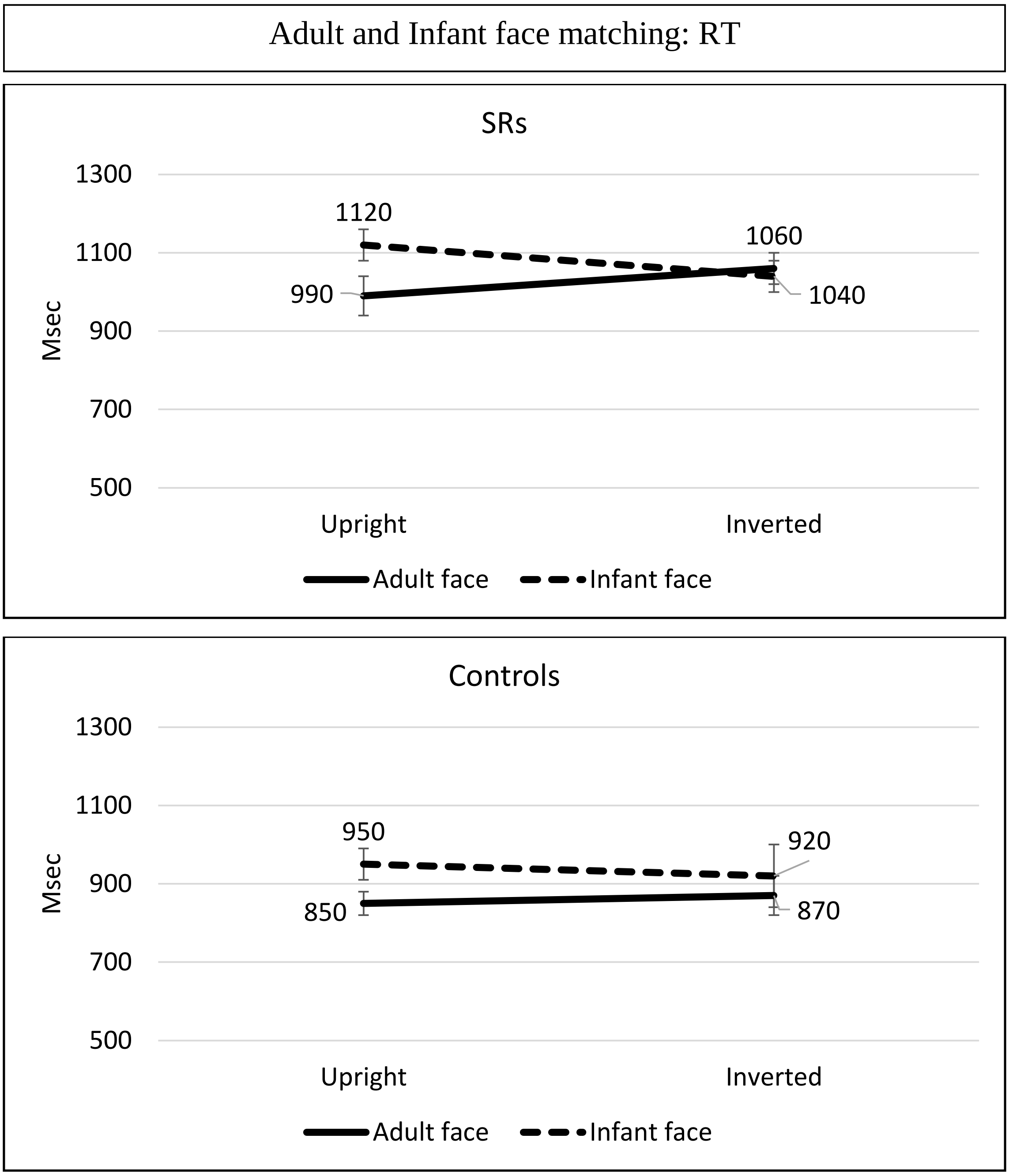


Figure 5.3.2.5. Mean RT scores by SRs and controls for adult and infant faces in upright and inverted orientations. Error bars = standard error of the mean.

Adult and Infant face matching: (RT): This ANOVA found a main effect of stimulus-type, $F(1, 40) = 14.32$, $p = .001$, $\eta^2 = .26$, whereby adult faces were processed faster. There was also a main effect of group, $F(1, 40) = 4.99$, $p = .031$, $\eta^2 = .11$, whereby SRs generated longer RTs. There was no main effect of orientation, $F(1, 40) < 1$. There were no stimulus-type x group or orientation x group interactions, $F(1, 40) < 1$. The stimulus-type x orientation interaction was significant, $F(1, 40) = 7.17$, $p = .011$, $\eta^2 = .15$. Infant faces generated longer RTs in the upright orientation, $F(1, 40) = 25.91$, $p < .001$, $\eta^2 = .39$, but the inverted orientation generated no between stimulus-type differences in RTs, $F(1, 40) < 1$. There was no three-way interaction, $F(1, 40) = 1.63$, $p = .209$, $\eta^2 = .04$.

Individual analyses

Modified t-tests for single cases (e.g., Crawford *et al.*, 2010), compared the OAE scores (Accuracy (d') and RT) as well as the inversion effect (IE) scores (Accuracy (d') and RT, adult and infant faces) of SRs against the control mean.

Figure 5.3.2.6 shows the SRs' OAE compared to that of controls. In accuracy, only one out of 24 SRs showed a significantly smaller OAE compared to controls, while the other SRs demonstrated similar scores to controls. In RT, the majority of SRs demonstrated similar performance to that of controls. Only six out of 24 SRs showed a significantly different score than controls, three of whom were in the unexpected direction – with the advantage for infant face matching. The discrepancy in these individual scores could be, for example, a result of tiredness, demonstrated by both SRs and controls, and are discussed in sections 5.3.3 and 5.4. (For a more detailed statistical analysis see Appendix for Tables A5.3.2.1 and A5.3.2.2).

Figure 5.3.2.7 shows the SRs' IE for adult faces. In accuracy, only six SRs showed a significantly greater IE, while the rest demonstrated similar performance to that of controls. In RT, four SRs showed a significantly different score than controls, two of which were in the unexpected direction – *paradoxical inversion effect*. Again, see sections 5.3.3 and 5.4 for a discussion. (For a more detailed statistical analysis see Appendix for Tables A5.3.2.3 and A5.3.2.4).

Figure 5.3.2.8 shows the SRs' IE for infant faces. In accuracy, most of the SRs performed similarly to controls, with only two showing a greater IE and one showing the paradoxical IE. In RT, none of the 24 SRs showed a significantly different score compared to controls.

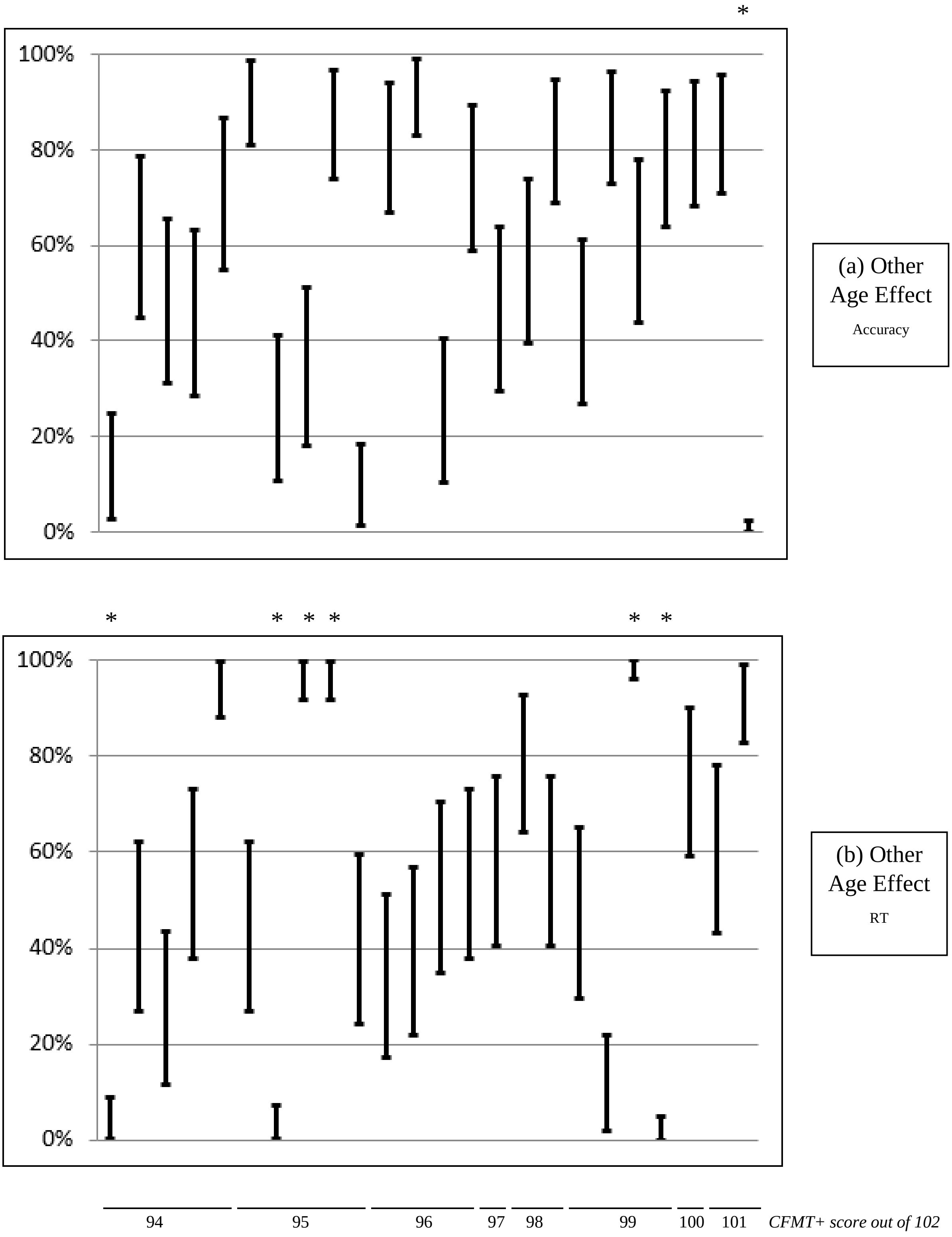


Figure 5.3.2.6. Upper and lower bound confidence intervals (95%) of the estimated proportion of the general population expected to fall below each super-recogniser (SR, n = 24) based on their (a) Other Age Effect $_{Accuracy}$ and (b) Other Age Effect $_{RT}$. To enhance interpretability, the SRs are ordered based on their CFMT+ scores, with low SR scorers at the left – high at the right.

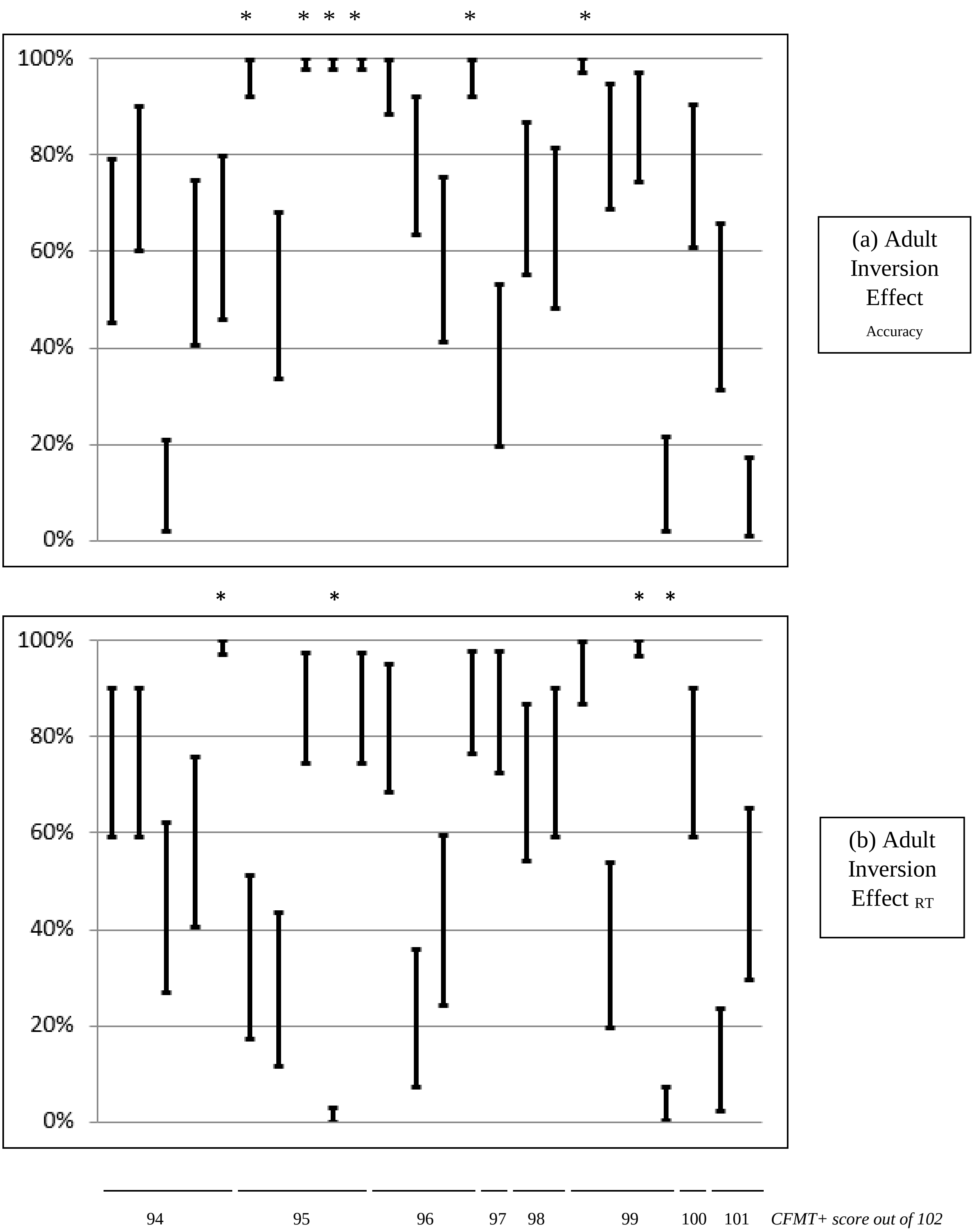


Figure 5.3.2.7. Upper and lower bound confidence intervals (95%) of the estimated proportion of the general population expected to fall below each super-recogniser (SR, n = 24) based on their (a) Adult Inversion Effect $_{Accuracy}$ and (b) Adult Inversion Effect $_{RT}$. To enhance interpretability, the SRs are ordered based on their CFMT+ scores, with low SR scorers at the left – high at the right.

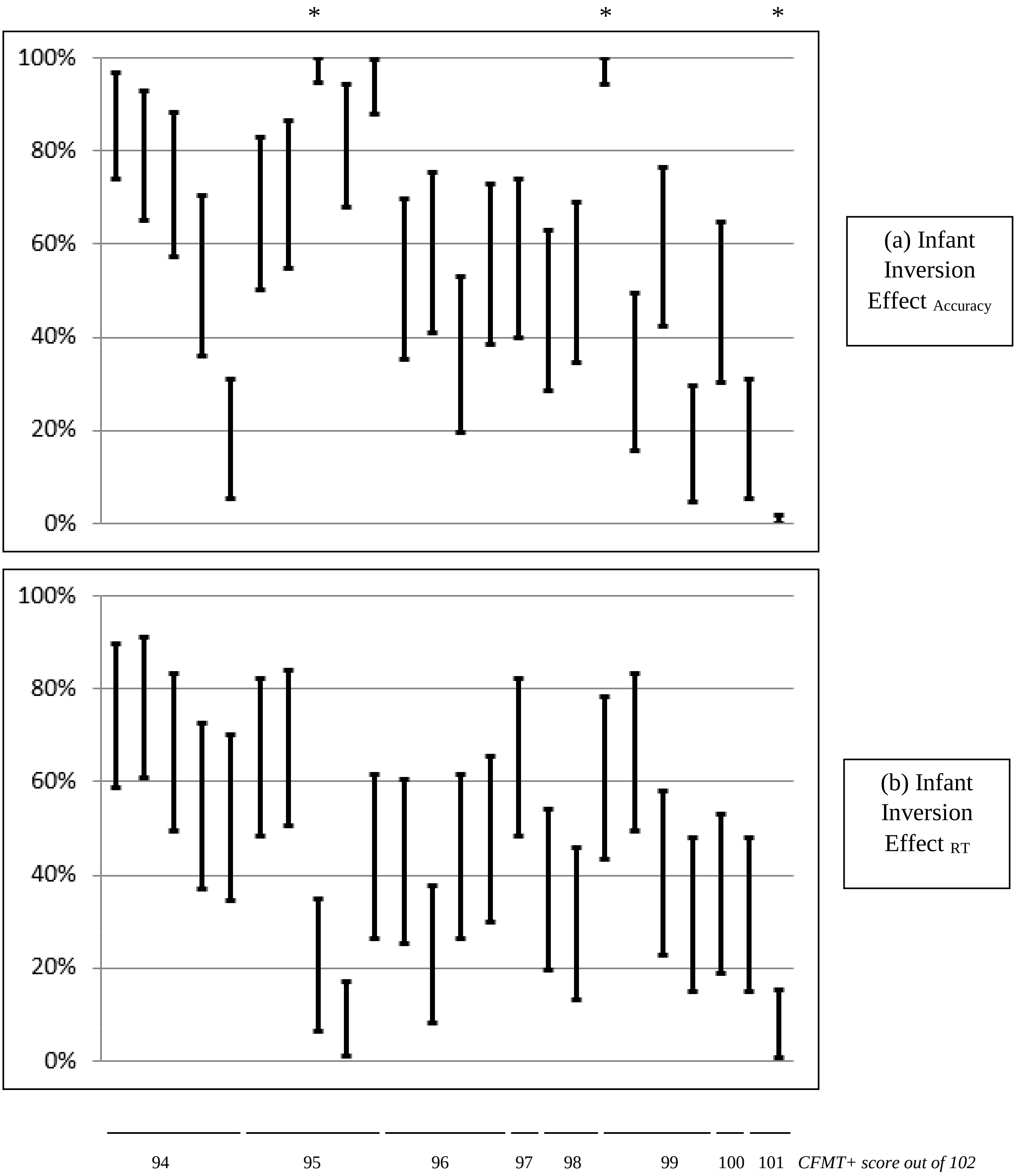


Figure 5.3.2.8. Upper and lower bound confidence intervals (95%) of the estimated proportion of the general population expected to fall below each super-recogniser (SR, n = 24) based on their (a) Infant Inversion Effect $_{Accuracy}$ and (b) Infant Inversion Effect $_{RT}$. To enhance interpretability, the SRs are ordered based on their CFMT+ scores, with low SR scorers at the left – high at the right.

Note that the infant IE (accuracy and RTs) shows a pattern whereby SRs with greater CFMT+ scores have lower IE than lower CFMT+ achievers. Indeed, SRs showed a strong negative correlation between CFMT+ scores and infant IE $_{\text{Accuracy}}$, $r(24) = -.49$, $p = .014$, but only a marginal one between CFMT+ and infant IE $_{\text{RT}}$, $r(24) = -.40$, $p = .053$. These results suggest that higher CFMT+ score SRs process infant faces in a more parts-based manner (For a more detailed statistical analysis see Appendix for Tables A5.3.2.5 and A5.3.2.6).

5.3.3 Discussion

Experiment 5.3 showed a number of relevant findings. First of all, when examining SRs and controls together, they demonstrated a significant *other age effect (OAE)*, whereby their adult upright matching was significantly better than their infant upright matching, though again, this effect was not observed for hits, but only correct rejections, thereby attenuating sensitivity index scores. Indeed, the overall OAE observed for participants was driven by a greater rate of correct rejections for adult faces compared to infant faces, in that participants were better at identifying adult faces they have not seen before (correct rejections), rather than by recognising the previously seen faces (hits). This observation is also in line with the findings from Experiment 5.2.

Next, while participants overall demonstrated holistic processing as reflected in a general worsening for inverted stimuli matching, SRs showed a bigger drop in performance for inverted stimuli than controls when examining their hit rates, mirroring the findings of SRs' greater recognition-based Inversion Effect (IE) in Experiment 4.2. Importantly, when examining correct rejections, SRs' OAE was accompanied by a selective IE for adult faces but not for infant faces, unlike controls who showed significant IE for both age groups. This potentially suggests that a greater holistic processing for adult faces maybe contributes to SRs correctly identifying probes/distractors as new faces and not targets. In fact, individual analyses of SRs' performance showed that higher CFMT+ achievers were less likely to display the infant IE (as measured by the sensitivity index subtractions), potentially implying that higher CFMT+ scorers process infant faces in a parts-based manner. That said, this was the only suggestion of differential holistic processing observed between adult and infant faces. Indeed the difference in sensitivity index between the two stimuli was not accompanied by the difference in holistic processing. This discrepancy is discussed in more detail in the General Discussion.

The individual analyses showed similar OAE ($d^{/}$) across SRs and controls, with several exceptions, which may potentially reflect a fatigue effect or other factors such as unintentional mistakes (e.g., participants often claimed to have pressed the wrong key). On the other hand, the perceptual component of the OAE only demonstrated group differences in correct rejections, thus individual analyses of SRs' OAE ($d^{/}$) was not expected to generate a distinct pattern of results.

5.4 General Discussion

This study was designed to investigate whether SRs' enhanced face processing could be observed for faces they have little experience with, infant faces. The *other age effect (OAE)* was explored in SRs at the levels of recognition and perception/matching.

First of all, SRs' superiority in face recognition is indeed attenuated by experience, as their performance suffered for faces they encounter less often on a daily basis. This OAE was demonstrated for hits and correct rejections in a large sample of participants, and partly replicated in the laboratory, where the OAE was only demonstrated for sensitivity index which was driven by SRs' higher rates of correct rejections of adult faces versus infant faces. This difference in results could potentially be due to statistical power limitations. On the other hand, finding no laboratory group difference in OAE for hits could also suggest that the laboratory participants were not representative of the wider population. However, given the comparison of data generated by Experiments 5.1 and 5.2, this seems unlikely. Taken together, these findings demonstrate that SRs' recognition of faces is not absolute, as they are not equally good at recognising all types of faces. Importantly, when considering the participants' hit rates together with their correct rejections (sensitivity index), SRs demonstrated a greater OAE than controls, which is not a mere consequence of their superior adult face recognition. In fact, SRs' OAE was greater despite their superior performance on infant face recognition. Thus, even with faces they have less experience with, SRs still outperform controls.

Given that SRs' greater OAE than that of controls was not observed for hits, it is perhaps not surprising that this group difference in OAE was not observed at the level of neural activity either. Indeed, N250, a component associated with Face Recognition Units and implicit identity discrimination (e.g., Eimer & Gosling, 2012; Kaufmann *et al.*, 2009; Pfutze *et al.*, 2002; Schweinberger *et al.*, 2004), was modulated by the age group of face stimuli without taking participant groups into account. N250 peaked earlier for adult faces than for infant faces, and it has been argued that earlier latencies in ERPs indicate a more effective processing of information (Bentin *et al.*, 1996; Eimer *et al.*, 2012; Kaltwasser *et al.*, 2013; Rivolta *et al.*, 2012), as they allow for the following stage of face processing to start more quickly and effectively. Therefore, these earlier latencies could indicate a more rapid and/or a more effective activation of internally stored representations of faces when participants view adult faces, thereby implying that infant face recognition is more demanding. When considering correct rejections, P600, a component known as the parietal old/new effect, associated with explicit face recognition (e.g., Rugg & Allan, 2000; Rugg & Curran, 2007), was also modulated by the age group of face stimuli. However, counter to predictions, P600 amplitudes were greater for infant faces correctly classified as 'new'. Previous research suggests that greater amplitudes in P600 usually accompany stronger recognition effects (e.g., Eimer *et al.*, 2012; Parketny *et al*., 2015). However, EEG findings analysing hits cannot be directly compared to EEG findings analysing correct rejections, as research shows that these measures can have a 'mirror' or an opposite effect (e.g., Wiese *et al*., 2012). In fact, when EEG data demonstrated an opposite pattern between hits and correct rejections in their participant groups, Wiese *et al.* (2012) proposed that it could reflect the participants' difference in encoding strategies for a specific stimulus type. Thus, it is possible that infant faces generated greater amplitudes from current participants because they employed a different strategy when memorising them. Indeed, when participants memorised faces in the encoding trials, N170 was smaller in amplitude for infant faces compared to adult faces, suggesting either a neural reaction to the physical differences between adult and infant faces, or a difference in the participants' encoding strategy. The N170 in reaction to non-face object stimuli is often found to be smaller in amplitude compared to faces' N170 (e.g., Bentin *et al*., 1996), and as object recognition is not thought to require holistic processing to the same level as faces, it is possible that infant faces were encoded in a more parts-based manner than adult faces. That said, this study provides no direct evidence to support this claim.

While the neural marker of the OAE showed no group differences, there were a number of important findings demonstrating SRs' superiority in face processing at the level of neural activity. First of all, P1, the earliest face related component, associated with pictorial encoding (e.g., Luck, 2005; Turano *et al*., 2016) was greater in amplitude for correctly recognised faces in SRs compared to controls. This observation potentially reflects an early perceptual advantage in this group, implying they are more effective in beginning the face processing chain of events, which may or may not contribute to the neural activity increase observed at the next stages of face processing. Note, however, that this effect was only observed for hits (recognised faces), thereby taking face familiarity into account. While many studies have found no effect of face familiarity on early ERPs (e.g., Pfutze *et al.*, 2002; Tanaka *et al.*, 2006), these findings are not always replicated (e.g., Herzmann & Sommer, 2010) and Turano *et al.* (2016) suggest that this effect can probably be only observed in individuals with good recognition ability. Taken together, these findings indicate that SRs did not necessarily demonstrate a more effective encoding of faces, but instead more effective face recognition, potentially aided by this early increase in neural activity observed only for recognised faces. Indeed, SRs' advantage in face processing was also reflected in greater amplitudes at P600, a component associated with explicit recognition. Thus, SRs' superior face recognition was accompanied by a more substantial activation of recognition-related neural network, potentially reflecting a more effective activation of internally stored face representations, or Person Identity Nodes (Bruce & Young, 1986). Note, however, that given the increased amplitudes of P1, it is possible that this early increase in electrical activity contributed to the later increase in P600 amplitudes, as the efficiency of one stage is usually dependent on the efficiency of previous stages (Luck, 2005).

While SRs demonstrated a neural correlate of their behavioural advantage for face processing, their OAE, while greater in sensitivity index to that of controls, showed no significant group differences in hits, in either behavioural or neural/electrical comparisons. Importantly, similar observations were made on a perceptual/matching level. Indeed, SRs and controls showed similar hit rate for adult and infant face matching, and only the sensitivity index found a significant OAE of similar magnitude in both groups. Again, the OAE observed for both SRs and controls was driven by a greater rate of correct rejections for adult faces compared to infant faces, in that participants were better at identifying adult faces they have not seen before, rather than by recognising the previously seen faces. Importantly, the OAE, as demonstrated by the sensitivity index, was not accompanied by a difference in holistic processing, in that both face types induced a similar inversion effect (IE). Given that previous studies (Kuefner *et al*., 2008; Macchi Cassia, Picozzi *et al.,* 2009) found both different hit rates and different IEs for adult and infant faces, the similar hit rates and similar IEs observed in this study do not necessarily reflect the same holistic processing induced by both stimuli types. It is possible that the tests employed in this study were not sensitive enough to tease out potential group differences, and statistical power limitations could be further induced by the low number of participants. Indeed, given that a large sample of participants in Experiment 5.1 demonstrated the OAE when analysing the recognition hits, it is possible that the null findings for *recognition-hits* in Experiment 5.2 and *matching-hits* in Experiment 5.3 were due to low statistical power. On the other hand, Experiment 5.3 showed that holistic processing was modulated by the stimuli's age group when looking at correct rejections. SRs' correct rejections of infant faces showed no IE, potentially suggesting that they correctly identify 'new' infant faces using a more parts-based manner, while relying more on holistic processing in correctly rejecting adult faces. Furthermore, individual analysis of IEs (as measured by the sensitivity index), suggests that higher CFMT score SRs process infants in a more parts-based manner. Together these findings indicate that certain SRs do not process adult and infant faces in a similar manner, potentially explaining their heterogeneous findings on the OAE.

There are some limitations to this study. First, as mentioned before, statistical power may be low as a consequence of sample size. While the online study was used to partially confirm the reliability of the recognition component of the OAE in SRs (Experiment 5.2), the reliability of the perception/matching aspect of the OAE (Experiment 5.3) remains to be tested. Furthermore, the limitations of statistical power may have also affected the neural findings discussed in Experiment 5.2. While EEG studies typically employ as few as 10 individuals per group, when atypical populations are investigated, the fact that this study used as few as 16 SRs for EEG analysis, is nevertheless an important limitation to acknowledge – particularly, as implied by the results, SR may not be a homogeneous construct. In addition, EEG findings can further be compromised by the low number of trials being averaged out per condition for each participant. While this study retained all participants with approximately 20 artefact-free trials per condition, the statistical power of the EEG findings could have been greater if there were more artefact-free trials available to include in the analyses. Indeed, analyses of N170 showed a marginally significant group difference between adult and infant faces, whereby SRs but not controls had slightly more negative amplitudes for adult faces. This trend, which potentially reflected a neural marker of OAE in SRs, could have reached statistical significance had the experiment employed more participants with more artefact-free trials.

Next, the lack of counterbalancing order of adult and infant face blocks in Experiment 5.3 may have attenuated individual and group results reflecting a potential order effect. While participants demonstrated the expected OAE, whereby their performance was better for adult than for infant faces, it is unknown whether this limitation resulted in the observed lack of group differences in the magnitude of the OAE.

Another limitation to this study is that SRs (M = 37.42, SD = 8.38) were as a group significantly older than controls (M = 29.35, SD = 10.29) in Experiment 5.3. This could potentially be a confounding factor in interpreting the results of Experiment 5.3. However, given that there were no outstanding group differences observed in this experiment, and given that only 2 out of 24 SRs were older than 50 (53 years old), it is unlikely that age had a significant effect on the results. Furthermore, while age is positively correlated with face recognition and is thought to peak in early 30s (e.g., Susilo *et al*., 2013), face processing appears to decline after the age of 50 (e.g., Crook & Larrabee, 1992), thus while age may have attenuated some of the participants' performance, it is unlikely that age differences observed in Experiment 5.3 contributed significantly to the outcome.

Overall, SRs superiority in face recognition transcends to faces they have significantly less exposure to as they outperformed controls on both adult and infant face recognition. Importantly, SRs' superiority in face recognition was complemented by neural findings which indicated that their recognition advantage is reflected in more effective pictorial processing (P1) of faces they have seen before, potentially, but not necessarily, contributing to their more effective activation of Person Identity Nodes (P600). However, experience does attenuate SRs' recognition performance as their infant face recognition suffered in comparison to adult face recognition. Importantly, SRs' OAE was greater to that of controls (d'), however the lack of group differences in OAE recorded for hits was observed in EEG data as well. Finally, SRs demonstrated a similar OAE to that of controls on the perceptual level, thereby showing a discrepancy between perception and recognition.

6.0 Introduction

While Chapter 5 explored face recognition and found recognition related neural dissociations that accompanied group differences in performance, the present chapter was designed to examine neural activity during face recognition in more detail. Since recognition can be subdivided into different cognitive components, exploring this distinction further could potentially uncover new factors contributing to the differences found between SRs and individuals with average face recognition ability.

6.0.1 Recollection and familiarity

Recognition has been subdivided into at least two cognitive constructs – *recollection* and *familiarity* (Jacoby, 1991; Tulving, 1985; Yonelinas, 2001; see also Mandler, 1980). Recollection is described as conscious recognition of a stimulus followed by a concrete recollection of additional information associated with the said stimulus. In the case of face recognition, recollection of faces is accompanied by recollection of semantic information related to that identity. This semantic information may include the person's name, occupation, first impression, or anything else which allows the memory trace to be consolidated during the initial encounter. Familiarity, on the other hand, is a state which has been referred to as automatic (as opposed to a more explicit recognition) and it is generally more ambiguous as it is not accompanied by recollection of any additional content or context. The common example describing this state of familiarity is Mandler's (1980) 'butcher on the bus': when you encounter someone in an unexpected context, you have a feeling of knowing this person without remembering who they are or where you know them from. Research clearly shows the distinction between these two recognition states, using different types of stimuli (i.e., words, pictures, faces; Baddeley, 2002; Düzel, Vargha-Khadem, Heinze, & Mishkin, 2001; Martin *et al*., 2011a; Tulving, 2002) and different types of participants (i.e., typical and clinical populations; Burns *et al.*, 2014; Lombardi *et al.*, 2016; Martin *et al.*, 2011a). The discrepancy between the two states, for example, has been demonstrated in amnesic patients, who demonstrate an impaired recollection with a spared familiarity of stimuli (Baddeley, 2002; Düzel *et al*., 2001; Tulving, 2002). Other studies found a similar pattern in schizophrenic participants who demonstrate normal familiarity for words and faces, albeit with a diminished recollection of these items (Martin *et al*., 2011a).

While the distinction between recollection and familiarity is agreed upon, researchers have been debating about whether the two constructs stand for separate processes (i.e., dual-process theories: e.g., Düzel *et al*., 1997; MacKenzie & Donaldson, 2007; Selmeczy & Dobbins, 2014), or if they belong to one recognition system which is activated differently according to the strength of each recognition (e.g., Knowlton, 1998; Smith, 1993; Trott, Friedman, Ritter, Fabiani, & Snodgrass, 1999). While it seems that recognition experience based on how confident the participant feels about seeing a face, may be quantitative in nature (thereby implying it is a unidimensional system), Selmeczy and Dobbins (2014) showed that there is a qualitative difference between high confidence recognition and low confidence recognition, demonstrated through participants' justification of each response. Thus recollection/familiarity and confidence-based recognition can both be explained by dual-process theories. That said they should not be viewed as direct measures of one another, as the evidence to date remains weak (e.g., Martin *et al*., 2011b). Importantly, if recollection and familiarity are indeed two separate processes then the relationship between the two remains to be clarified (see also Wixted & Mickes, 2010).

6.0.2 Remember/Know paradigm

Tulving (1985) has described a paradigm to test different recognition states, which have been used to explore the distinction between recollection and familiarity. A typical experiment involving this paradigm instructs participants to respond 'remember' for items they remember memorising during the encoding stage (usually providing additional information about recognised items), while responding 'know' if they recognise the item while having no concrete recollection about it (Gardiner, 1988; Tulving, 1985). It is important to bear in mind that the idea of this paradigm reflecting the difference between recollection and familiarity is only an assumption, thus regardless of what some studies conclude, participants' performance on remember/know tests is not a direct measure of recollection and familiarity. That said, research employing remember/know paradigms has managed to demonstrate, in both behavioural and imaging studies, that familiarity and recollection are experienced differently by participants, and are also affected differently by experimental manipulations (e.g., Koen & Yonelinas, 2014; McCabe, Roediger, & Karpicke, 2011; Smith, 1993; Trott *et al.,* 1999; Yovel & Paller, 2004).

For example, McCabe *et al.* (2011) showed that dividing attention during the encoding stage only reduced recollection responses while having no significant effect on familiarity responses. These results are in line with research findings attributing recollection to a conscious aspect of recognition thereby relying more on attentional resources than familiarity which is thought to be more automatic. Furthermore, one cross-sectional study showed that recollection appears to be less effective at older ages, whereas familiarity feelings remain constant across different age groups (Koen & Yonelinas, 2014). This finding is in line with other research pointing out that episodic memory in general declines with age, leaving more automatic aspects of recognition relatively intact (e.g., Schonfield & Robertson, 1966; Spencer & Raz, 1995; for a review see Yonelinas, 2002)

Electroencephalography (EEG) studies have also attempted to differentiate between recollection and familiarity. For instance, several experiments demonstrated that recollection ('remember' responses), interchangeably referred to as parietal old/new effect, generates higher ERP amplitudes at posterior sites compared to familiarity ('know' responses) (Smith, 1993; Trott *et al*., 1999; Yovel & Paller, 2004). Yovel and Paller (2004) also pointed out that the greater positivity in amplitude associated with recollection lasted longer than for familiarity. Importantly these studies emphasise the lack of topographical differences between recollection and familiarity, suggesting that the two recognition states are likely to be generated by the same neural population, at least in those neural areas measurable by EEG. MacKenzie and Donaldson (2007; see also Burns *et al*., 2014; Yovel & Paller, 2004) found that while recollection and familiarity responses were associated with enhanced positivity at posterior sites, recollection was also associated with enhanced frontal positivity.

It is noteworthy that Burns *et al*. (2014) used the remember/know paradigm to explore potential quantitative and qualitative differences in face recognition between people with Developmental Prosopagnosia (DP) and controls. They found that while DPs' recollection seemed to parallel recollection of controls (though limited to posterior effects and demonstrating a general delay in face-network activations), DPs' familiarity of faces displayed far weaker activation covering less of the scalp compared to controls. Importantly, DPs familiarity for faces appeared to resemble their familiarity for objects, which was reflected in the frontal positive activity, which Burns *et al*. (2014) only observed for objects in controls. This finding is in line with Curran and Hancock (2007), who also found frontal positivity for faces and objects, though their results were criticised for not cropping face images to eliminate external features and other non-facial cues, which may have induced object-like neural processing. Thus, DPs from Burns *et al.* (2014) study appeared to have used object-like processing when viewing faces, thereby demonstrating quantitative as well as qualitative differences in face processing.

Given that DPs represent one end of the face recognition spectrum, and that the remember/know paradigm was successful in demonstrating their qualitatively different approach to viewing faces at the level of neural activity, the study reported in this chapter set out to explore potential qualitative differences in processing faces in SRs, who occupy the opposite end of the face recognition spectrum.

6.1 Experiment 1

Experiment 6.1 employed the remember/know paradigm to explore SRs' recognition of faces and objects while measuring their neural correlates via EEG. Based on previous research and Experiment 4.1, it was hypothesised that SRs would have a higher accuracy for faces than objects, which would be reflected in earlier (latency) and/or bigger (amplitude) ERPs. It was hypothesised that SRs would demonstrate a high 'remember' to 'know' ratio for faces and potentially for objects, while controls would show a similar rate of 'remember' and 'know' responses for types of stimuli. Given that recollection is associated with the parietal old/new effect, potentially reflecting explicit recognition, SRs, in line with previous research (e.g., Eimer *et al*., 2012; Parketny *et al.*, 2015) and findings in Experiment 5.2, were also predicted to have the parietal old/new effect of higher amplitude than controls for faces and/or for objects.

6.1.1. Methods

6.1.1.1 Design

An independent measures design employed the inclusion criteria discussed in Chapter 3 (section 3.1.1) to allocate participants to SR and control groups and the remember/know test for faces and objects to measure the participants' ratio of remember to know responses. The group differences were analysed on behavioural (hits, correct rejections, sensitivity index ($d^{/}$), response bias (criterion C)) level and at the level of neural/electrical activity (amplitude and latency at 300-500msec and 500-700msec time intervals), as these time frames have been repeatedly examined with regard to familiarity and recollection, respectively (e.g., Burns *et al*., 2014; MacKenzie & Donaldson, 2007; Yovel & Paller, 2004; see section 3.3.2).

6.1.1.2 Participants

Forty-three participants[14] were recruited for this study (CFMT+: 65 - 101; *M* = 86.26, *SD* = 11.68; males = 18, mean age = 34.08, *SD* =9.97). Based on the inclusion criteria described in Chapter 3, the final groups comprised 20 SRs (CFMT+: 93 - 101; *M* = 96.16, *SD* = 2.29; males = 10, mean age = 35.84, *SD* =7.23), and 18 controls (CFMT+: 65 - 81; *M* = 73.50, *SD* = 4.23; males = 7, mean age = 30.13, *SD* =10.68) with normal or corrected vision.

SRs and controls were closely matched on age[15], $t(33) = 1.88$, $p = .069$, Cohen's $d = .63$, and gender proportions, $\chi^2(1, n = 43) = 1.59$, $p = .451$. The 5 participants not included in the between-groups analyses were removed based on their CFMT+ scores, non-Caucasian ethnicity, or vision-related problems.

6.1.1.3 Materials

Face Remember/Know Test: This test used 320 face stimuli of adult faces which were acquired from the Investigative Interviewing Research Laboratory (Meissner, Brigham, & Butz, 2005) and from the database of The Park Aging Mind Laboratory at The University of Texas at Dallas (Minear & Park, 2004). Adobe Photoshop was used to crop the images, leaving only internal facial features. The full grey scale images were evened out in terms of luminance. The visual angle of presentation was 3.5° by 4.5°, though the images randomly changed in size each trial between 95% and 105%. The stimuli were presented using the MATLAB 2014a (MathWorks, USA) extension Psychtoolbox (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007).

The test was divided into 8 blocks (480 trials in total). Each block consisted of one encoding (20 trials) and one recognition stage (40 trials). In each trial, a small fixation cross at the centre of the black screen (the duration of which randomly varied between 900-1100 msec) was followed by a 2000msec presentation of a face stimulus, followed by a fixation cross which stayed on screen until the response was made. In the encoding stage, participants were required to judge each stimulus as 'pleasant' (P) or 'unpleasant' (U). In the recognition stage, participants responded 'remember' (R), 'know' (K) or 'new' (N), based on the instructions they were given at the beginning of the test as well as at the beginning of each recognition block (Figure 6.1.1.3.1).

[14] Note: Most of the participants (86%) recruited for this study were the same as participants from Experiments 4.3 and 5.3. Due to participant time constraints, not all could finish the testing session comprising the tests forming Experiment 6.1.
[15] Note: age was not recorded for 3 participants

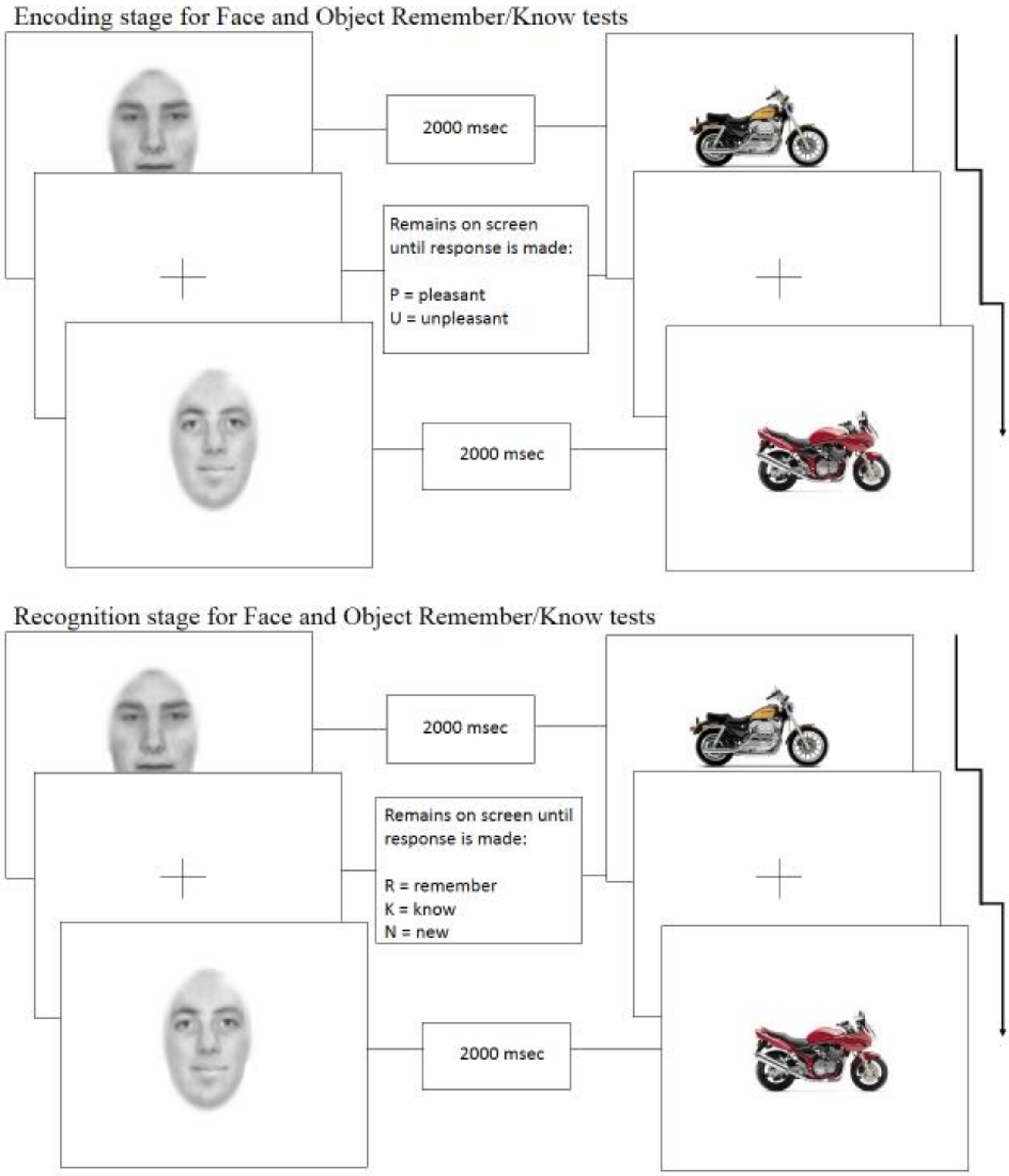


Figure 6.1.1.3.1. An example of the Face and Object Remember/Know tests

Participants were informed that they were required to respond 'remember' to faces only if their recognition was accompanied by additional contextual information. Examples included: "I recognise this face because 1) I remember thinking 'they looked like my cousin'; 2) I remember it was the first/last image presented in the encoding stage; 3) because I remember being annoyed by this mouth/nose". On the other hand, participants were required to respond 'know' if they knew they had seen the face in the encoding stage, without having any additional contextual information about said face. Participants were required to respond ‘new’ to faces they did not recognise. An interactive practice run was administered with 10 encoding trials and 20 recognition trials. Participants were asked to justify their responses to the experimenter, to ensure that they understood the instructions accordingly.

Object Remember/Know Test: A similar test was also administered to test participants’ object recollection and familiarity (Figure 6.1.1.3.1). The same number of object stimuli (320) were collected from the internet (public domain images), comprising 8 types of object (one type per test block), which included cars, apples, mushrooms, motorbike, chairs, houses, pens and butterflies. The design of the object remember/know test was identical to the face remember/know test. The visual angle of presentation was 2.9° by 3.8°, as with faces, the object images randomly changed in size each trial between 95% and 105%.

Note that a shorter version of the Face Remember/Know Test, using only 80 face targets was used as a pilot to check the design feasibility on a different sample of SR and control participants. The participants’ individual performance can be found in the appendices (see Table A6.1.2.1).

6.1.1.4 Procedure

As discussed in previous chapters, after providing informed consent, laboratory participants were set up with the EEG, and seated approximately 60cm away from the computer screen. Upon receiving written and verbal instructions to the Remember/Know test, explaining the difference between ‘remember’, ‘know’ and ‘new’ responses, the participants underwent interactive practice trials (using faces only) to ensure they understood the instructions. Once familiarised with the instructions, they proceeded to the main tests. The face and object remember/know tests were administered in a counter balanced order. The entire experiment took approximately 100 minutes, and all participants were fully debriefed at the end.

6.1.1.5 EEG recording

The same EEG recording technique was used as in Experiment 5.2, fully described in Chapter 3, section 3.3.2.

6.1.1.6 EEG pre-processing and analysis

EEG pre-processing was identical to that of Experiment 5.2 and is fully described in Chapter 3, section 3.3.2. Grand-averages were computed for hits and correct rejections. Hits were classified as either correct ‘remember’ or ‘know’ responses, and correct rejections were selected from correct ‘new’ responses. The study attempted to explore the difference between remember/know responses and the correct rejections, as this difference may demonstrate the pure activity related to recollection and familiarity (Burns *et al*., 2014).

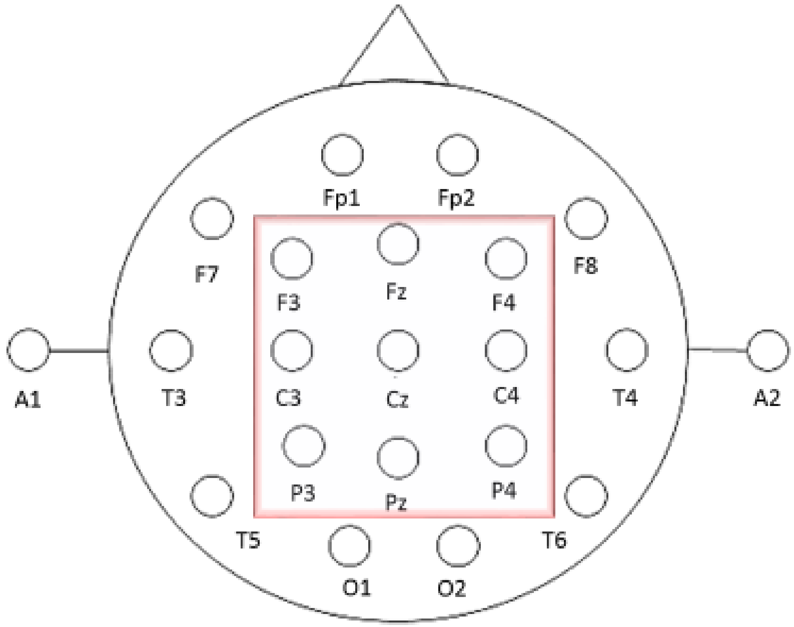


Figure 6.1.1.6.1. The channels selected for EEG analysis framed in the red square.

Amplitude and latency of ERPs for ‘remember’, ‘know’, and ‘correct rejections’ responses were extracted from channels P (3/z/4), C (3/z/4) and F (3/z/4), which are shown in Figure 6.1.1.6.1, since these regions have been previously linked to recollection and familiarity (Burns *et al*., 2014; MacKenzie & Donaldson, 2007; Yovel & Paller, 2004). Note that amplitude and latency were extracted from these channels at two time intervals, 300-500msec and 500-700msec after the stimulus onset, as familiarity has been linked to neural activity peaking during the 300-500msec time line, while recollection has been linked to neural activity during both 300-500msec and 500-700msec time lines (Burns *et al.*, 2014; MacKenzie & Donaldson, 2007; Yovel & Paller, 2004). This experiment attempted to replicate the study investigating recollection and familiarity in DPs (Burns *et al*., 2014).

6.1.2 Results

For the final behavioural and EEG analyses, three participants were removed from the group analyses as their object recognition could not be recorded for technical reasons. Note that the pilot testing of the Face Remember/Know Test showed that 4 participants generated 15 or less 'remember' responses, and 9 participants generated 15 or less 'know' responses. Similarly, some of the current participants generated a low number of one or more response types ('remember', 'know', or 'new') for one or both stimulus types (face or object), thereby partially constraining the EEG analysis.

Behavioural results: Recollection versus familiarity

Figures 6.1.2.1 – 6.1.2.4 depict the participants' (n = 34) mean performance on the Face and Object Remember/Know Tests.

Hits: A 2 (stimulus-type: face or object) x 2 (response: 'remember', 'know') x 2 (group: SR, control) ANOVA found a main effect of response, $F(1, 32) = 5.08$, $p = .031$, $\eta^2 = .14$, whereby hit rates to 'remember' responses were greater than 'know' responses. There was a main effect of group, $F(1, 32) = 4.82$, $p = .035$, $\eta^2 = .13$, whereby SRs generated more hits than controls. No main effect of stimulus-type was found, $F(1, 32) < 1$. There was a significant stimulus-type x group interaction, $F(1, 32) = 4.89$, $p = .034$, $\eta^2 = .13$, whereby SRs significantly outperformed controls on faces, $F(1, 32) = 9.07$, $p = .005$, $\eta^2 = .22$, but not on objects, $F(1, 32) = 1.02$, $p = .321$, $\eta^2 = .03$. The response x group interaction, $F(1, 32) = 1.65$, $p = .208$, $\eta^2 = .05$, stimulus-type x response interaction, $F(1, 32) = 1.29$, $p = .264$, $\eta^2 = .04$, and the three-way interaction, $F(1, 32) < 1$, were not significant.

Remember and Know responses: Hits

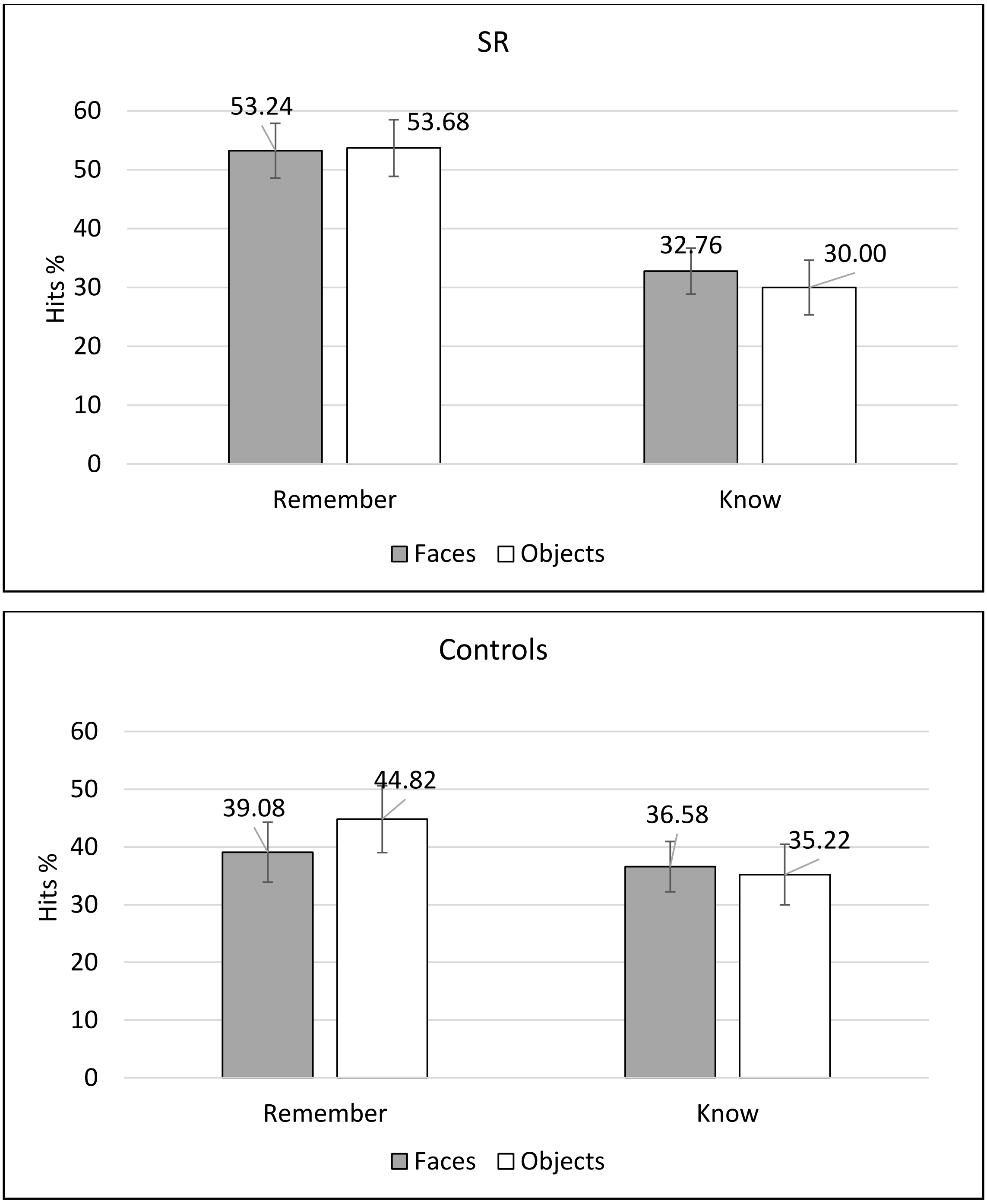


Figure 6.1.2.1. Mean performance of 'Remember' and 'Know' hits in SRs and controls. Error bars = standard error of the mean.

Correct rejections: A 2 (stimulus-type: face or object) x 2 (group: SR, control) ANOVA found a main effect of group, $F(1, 32) = 7.10$, $p = .012$, $\eta^2 = .18$, whereby SRs made more correct rejections than controls. The main effect of stimulus-type was only marginally significant, $F(1, 32) = 3.72$, $p = .063$, $\eta^2 = .09$, whereby correct rejection rates were slightly greater for faces than for objects. There was no significant interaction, $F(1, 32) = 1.01$, $p = .322$, $\eta^2 = .03$.

Remember and Know responses: Correct Rejections

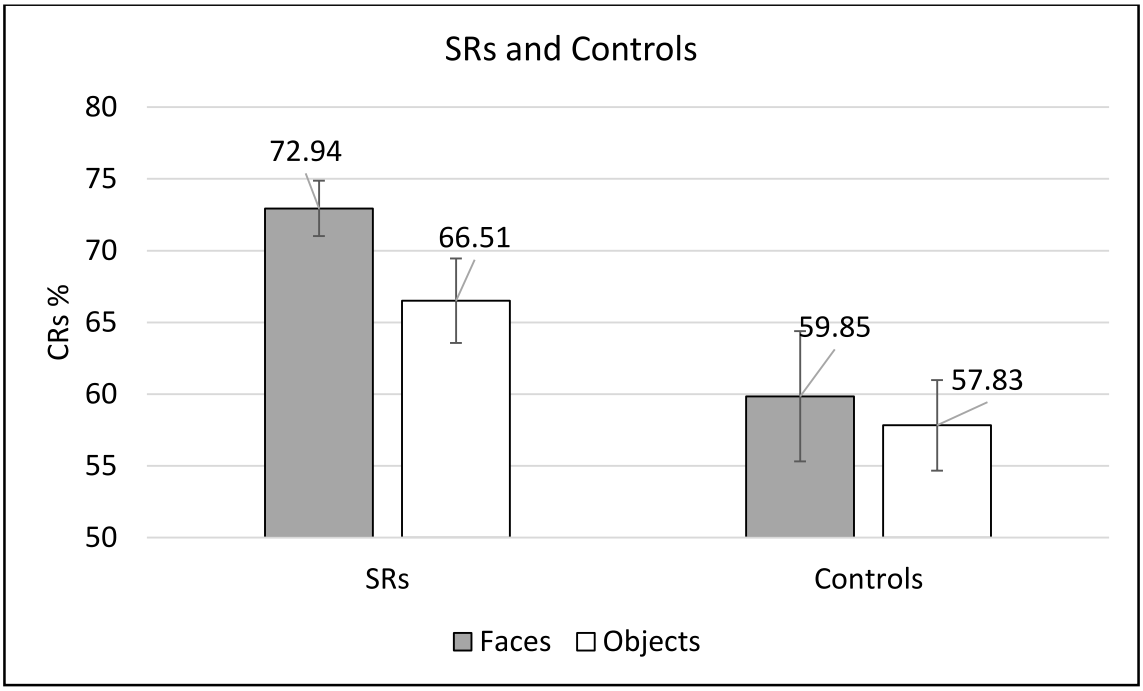


Figure 6.1.2.2. Mean performance of correct rejections in SRs and controls. Error bars = standard error of the mean.

Sensitivity index: A 2 (stimulus-type: face or object) x 2 (response: R or K) x 2 (group: SR, control) ANOVA found a main effect of response, $F(1, 32) = 76.00$, $p < .001$, $\eta^2 = .70$, whereby R responses were more accurate than K responses. A main effect of group was found, $F(1, 32) = 18.83$, $p < .001$, $\eta^2 = .37$, whereby SRs showed higher discriminability than controls. There was no main effect of stimulus-type, $F(1, 32) <1$. There was a marginally significant stimulus-type x group interaction, $F(1, 32) = 4.00$, $p = .054$, $\eta^2 = .11$, whereby SRs, $F(1, 32) = 4.38$, $p = .046$, $\eta^2 = .12$, but not controls, $F(1, 32) < 1$, had a greater discriminability of faces over objects. There was a significant response x group interaction, $F(1, 32) = 87.40$, $p = .010$, $\eta^2 = .19$. While SRs and controls had similar low discriminability for ‘know’ responses, $F(1, 32) < 1$, SRs had a higher sensitivity for ‘remember’ responses than controls, $F(1, 32) = 19.16$,

$p < .001$, $\eta^2 = .37$. The stimulus-type x response interaction, $F(1, 32) = 1.03$, $p = .318$, $\eta^2 = .03$, was not significant. There was no three-way interaction, $F(1, 32) < 1$.

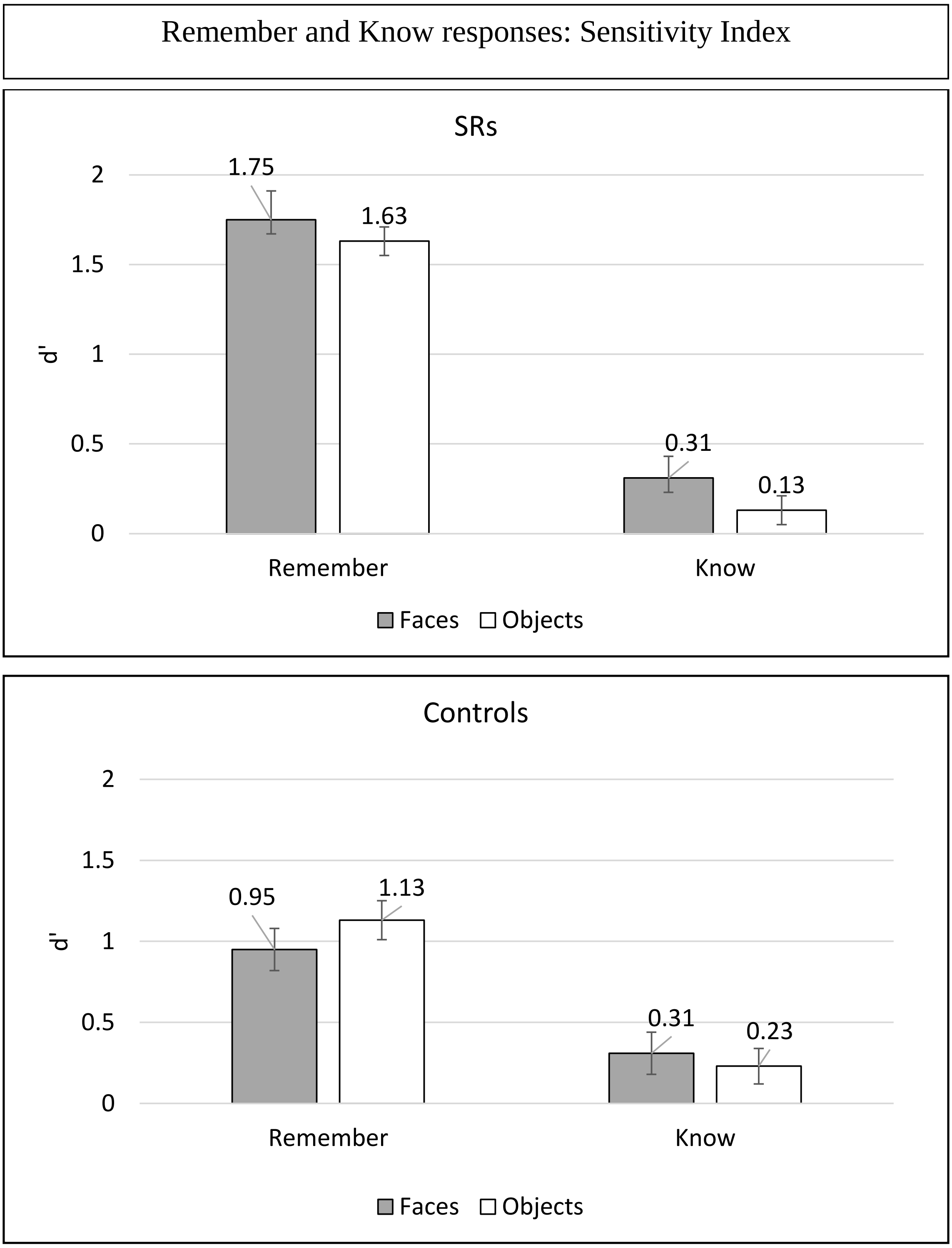


Figure 6.1.2.3. Mean performance of 'Remember' and 'Know' sensitivity index ($d^{/}$) in SRs and controls. Error bars = standard error of the mean.

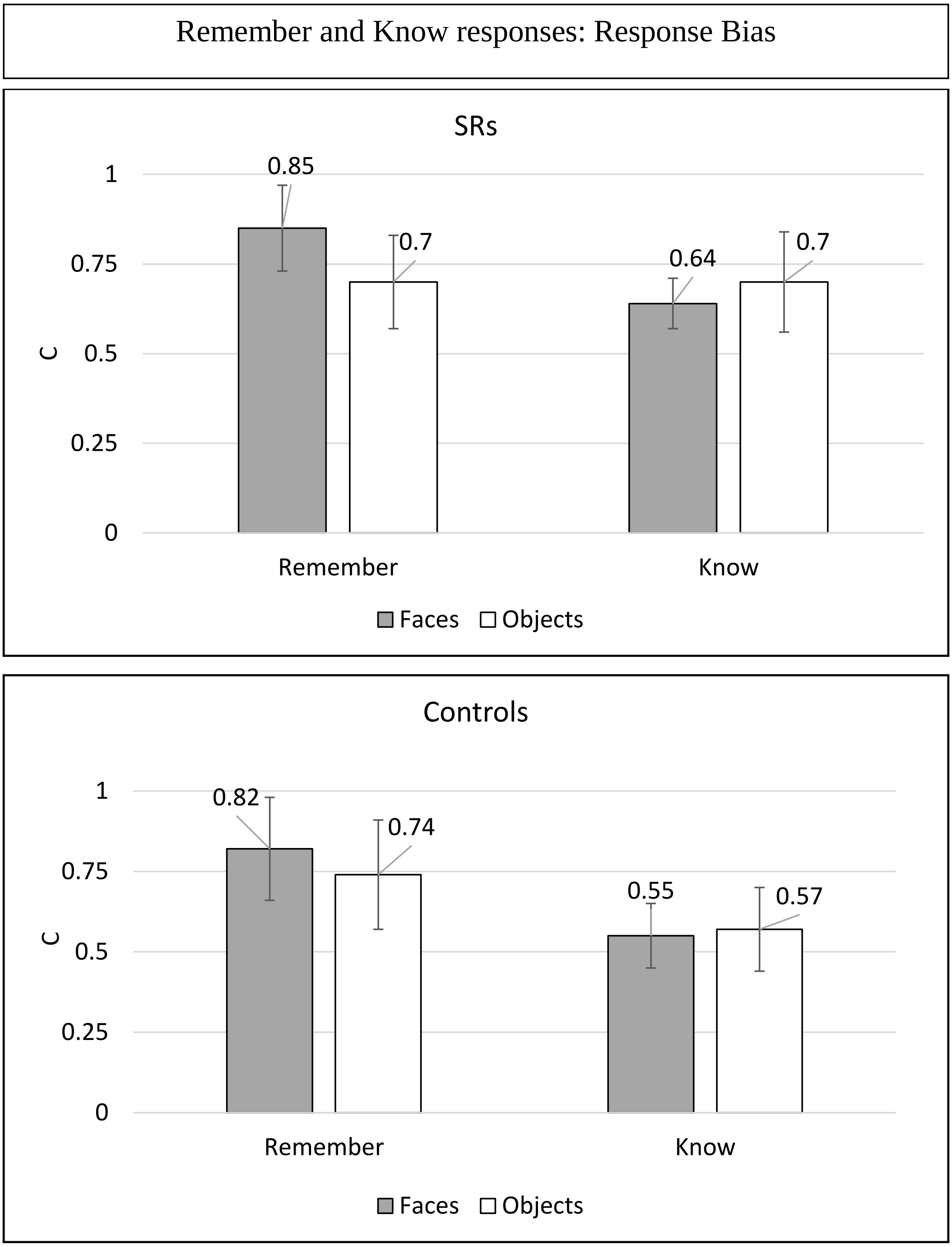


Figure 6.1.2.4. Mean performance of 'Remember' and 'Know' response bias (C) in SRs and controls. Error bars = standard error of the mean.

Response bias: A 2 (stimulus-type: face or object) x 2 (response: R or K) x 2 (group: SR, control) ANOVA found no main effects of response, $F(32) = 1.05$, $p = .313$, $\eta^2 = .03$, stimulus-type, $F(1, 32) = 1.28$, $p = .276$, $\eta^2 = .04$, or group, $F(1, 32) < 1$. There were no stimulus-type x group and response x group interactions, $F(1, 32) < 1$. The stimulus-type x response interaction was not significant, $F(32) = 2.44$, $p = .128$, $\eta^2 = .07$. There was no three-way interaction, $F(1, 32) < 1$.

EEG results

Note that given the constraints of the experiment some participants generated a low number of one response type (‘remember’, ‘know’, or correct rejection) for at least one stimulus type (face or object). Furthermore, given that a lot of EEG data (trials) were lost owing to EEG noise/artefact, the data retained for analyses were generated by a relatively low number of clean/noise-free trials. Only participants with at least 15 noise-free trials ($n = 33$) were retained for final analyses (See Appendix for a descriptive Table A6.1.2.2.).

Given that the main aim of the study was to explore differences in neural/electrical activity between SRs and controls, all main effects were reported, but only interactions of interest were discussed (i.e., with the ‘group’ variable). The representation of participants’ neural/electrical activity distributions during different types of recognition in the 300-500msec time range is shown in Figure 6.1.2.5. See Appendix for more Figures depicting neural activity distributions in SRs and controls (Figures A6.1.2.1 - A6.1.2.24).

A mixed 2 (stimulus-type: faces, objects) x 2 (responses: R, K, CR) x 3(hemisphere: right, left, central) x 3(location: P channels (3,4,z), C channels (3,4,z), F channels (3,4,z)) x 2 (group: SR, control) ANOVAs examined group differences in amplitude and latency for two time intervals, 300-500msec and 500-700msec. Note that when correcting for multiple comparisons, the mean correlation between all the variables involved in the comparisons was taken into account.

300-500msec interval: amplitude: This ANOVA showed a main effect of stimulus-type, $F(1, 31) = 13.95$, $p = .001$, $\eta^2 = .31$, with larger amplitudes for objects than for faces. There was a main effect of response, $F(2, 31) = 4.57$, $p = .014$, $\eta^2 = .13$. Amplitudes for R responses, $t(32) = 2.90$, $p = .007$, Cohen’s $d = 0.50$, and K responses, $t(32) = 3.42$, $p = .002$, Cohen’s $d = 0.61$, were greater than CR responses, while there was no difference between R and K amplitudes $t(32) < 1$ (corrected $p = .032$). There was a main effect of hemisphere, $F(2, 31) = 9.13$, $p < .001$, $\eta^2 = .23$. Central sites generated greater amplitudes than the left hemisphere, $t(32) = 4.36$, $p < .001$, Cohen’s $d = 0.90$, and marginally greater amplitudes than the right hemisphere, $t(32) = 2.02$, $p = .051$, Cohen’s $d = 0.38$, while the right hemisphere generated greater amplitudes than the left hemisphere, $t(32) = 2.23$, $p = .033$, Cohen's $d = 0.42$ (corrected $p = .047$). There was a main effect of location, $F(2, 31) = 18.05$, $p < .001$, $\eta^2 = .37$, with posterior channels (P) generating greater amplitudes than C channels, $t(32) = 5.98$, $p < .001$, Cohen's $d = 1.05$, and F channels, $t(32) = 3.97$, $p < .001$, Cohen's $d = 0.70$, while F and C channels showed no difference in amplitude, $t(32) < 1$ (corrected $p = .033$). There was no main effect of group, $F(1, 31) = 1.41$, $p = .245$, $\eta^2 = .04$. There were no two-way interactions ($p > .200$).

The stimulus-type x location x group interaction was significant, $F(2, 31) = 3.23$, $p = .047$, $\eta^2 = .09$. SRs showed no main effect of stimulus-type, $F(1, 15) = 3.00$, $p = .104$, $\eta^2 = .17$, but they did show a main effect of location, $F(2, 15) = 10.44$, $p < .001$, $\eta^2 = .41$. Posterior channels (P) generated higher amplitudes than C channels, $t(15) = 6.55$, $p < .001$, Cohen's $d = 1.66$, and F channels, $t(15) = 2.78$, $p = .014$, Cohen's $d = 0.85$, while there were no difference in amplitude generated by channels F and C, $t(15) < 1$ (corrected $p = .033$). SRs showed no stimulus-type x location interaction, $F(2, 15) = 2.19$, $p = .130$, $\eta^2 = .13$. Controls showed a main effect of stimulus-type, $F(1, 16) = 12.92$, $p = .002$, $\eta^2 = .45$, with higher amplitudes for objects. Controls also showed a main effect of location, $F(2, 16) = 9.90$, $p < .001$, $\eta^2 = .38$. Posterior channels (P) generated higher amplitudes than C channels, $t(16) = 3.86$, $p = .001$, Cohen's $d = 0.98$, and F channels, $t(16) = 3.04$, $p = .008$, Cohen's $d = 0.74$, while there were no difference in amplitude generated by channels F and C, $t(16) = 1.27$, $p = .221$ (corrected $p = .033$). Controls showed a stimulus-type x location interaction, $F(2, 16) = 10.64$, $p < .001$, $\eta^2 = .40$. They showed a difference in amplitude between faces and objects in posterior channels (P), $F(1, 16) = 20.59$, $p < .001$, $\eta^2 = .56$, in central channels (C), $F(1, 16) = 12.44$, $p = .003$, $\eta^2 = .44$, and only marginally so for anterior channels (F), $F(1, 15) = 4.15$, $p = .059$, $\eta^2 = .21$. Note that this suggests that the higher amplitude for objects is mainly driven by controls' neural activity.

The hemisphere x location x group interaction was significant, $F(4, 31) = 3.70$, $p = .007$, $\eta^2 = .11$. As reported above, SRs showed a main effect of location, $F(2, 15) = 10.44$, $p < .001$, $\eta^2 = .41$, with higher amplitudes in posterior channels (P). SRs also showed a main effect of hemisphere, $F(2, 15) = 4.83$, $p = .015$, $\eta^2 = .243$. Central site (channels Z) generated greater amplitudes than channels in the left hemisphere, $t(15) = 3.03$, $p = .008$, Cohen's $d = 0.94$, but similar amplitudes to the right hemisphere channels, $t(15) = 1.97$, $p = .068$, and there was no difference in amplitude generated by the right and left hemisphere channels, $t(15) = 1.47$, $p = .162$ (corrected $p = .045$). SRs also showed a hemisphere x location interaction, $F(4, 15) = 7.79$, $p < .001$, $\eta^2 = .34$. Posterior channels, $F(2, 14) = 13.43$, $p = .001$, $\eta^2 = .66$, showed a difference in amplitude across hemispheres. Post hoc tests showed that the right hemisphere had a significantly higher amplitude than the left hemisphere, $t(15) = 3.42$, $p = .004$, Cohen's $d = .87$, and the central site generated higher amplitudes than the left hemisphere, $t(15) = 5.34$, $p < .001$, Cohen's d = 1.42, but the difference between the central site and the right hemisphere was not significant, $t(15) = 2.05$, $p = .059$, Cohen's d = .52 (corrected $p = .030$). Anterior channels, $F(2, 15) = 5.88$, $p = .014$, $\eta^2 = .46$, showed a difference in amplitude across hemispheres as well. Post hoc tests showed that the central site generated higher amplitudes than the right hemisphere, $t(15) = 2.88$, $p = .012$, Cohen's d = .72, while right versus left hemisphere, $t(15) < 1$, and the central site versus left hemisphere showed no difference in amplitude, $t(15) = 1.44$, $p = .171$, Cohen's d = .42 (corrected $p = .030$). Central channels, $F(2, 15) = 1.90$, $p = .186$, $\eta^2 = .21$, generated similar amplitudes across hemispheres. As SRs, controls also showed a main effect of hemisphere, $F(2, 16) = 4.35$, $p = .021$, $\eta^2 = .21$. Central site (channels Z) generated greater amplitudes than channels in the left hemisphere, $t(16) = 3.28$, $p = .005$, Cohen's d = 0.90, but similar amplitudes to the right hemisphere channels, $t(16) < 1$, while there was no difference in amplitude generated by the right and left hemisphere channels, $t(16) = 1.70$, $p = .108$ (corrected $p = .045$). Controls also showed a main effect of location, $F(2, 16) = 9.90$, $p < .001$, $\eta^2 = .38$, with bigger amplitudes generated in posterior channels (P), as reported above. They showed a hemisphere x location interaction, $F(4, 16) = 5.25$, $p = .001$, $\eta^2 = .25$. Posterior channels, $F(2, 16) = 24.19$, $p < .001$, $\eta^2 = .76$, showed a difference in amplitude across hemispheres. Post hoc tests showed that central sites generated higher amplitudes than the right hemisphere, $t(16) = 3.86$, $p = .001$, Cohen's d = .99, and the left hemisphere, $t(16) = 6.79$, $p < .001$, Cohen's d = 1.82. The right and left hemispheres showed no difference in amplitude, $t(16) < 1$ (corrected $p = .030$). Anterior channels, $F(2, 16) = 2.35$, $p = .129$, $\eta^2 = .24$, and central channels, $F(2, 16) = 2.34$ $p = .130$, $\eta^2 = .24$, generated similar amplitudes across hemispheres. Overall, SRs and controls demonstrated recognition-related activity was at maximum in posterior channels (P) and central sites (Z). However, while controls' amplitudes were strongest in the central site (Pz), SRs' neural activity spread from the central site (Pz) to the right hemisphere (P4) as well. There were no more significant interactions ($p > .130$)

In summary, in line with previous research investigating recognition, the amplitudes were higher for 'remember' and 'know' responses, in central sites and posterior channels. Contrary to predictions, objects generated higher amplitudes than faces, however this anomaly was shown to be induced by controls, who potentially found object recognition easier than face recognition (see General Discussion 6.1.3). Furthermore, while controls showed bigger amplitudes generated in the central site (channels Z), SRs amplitudes were greater in the right hemisphere as well as the central site when examining P channels.

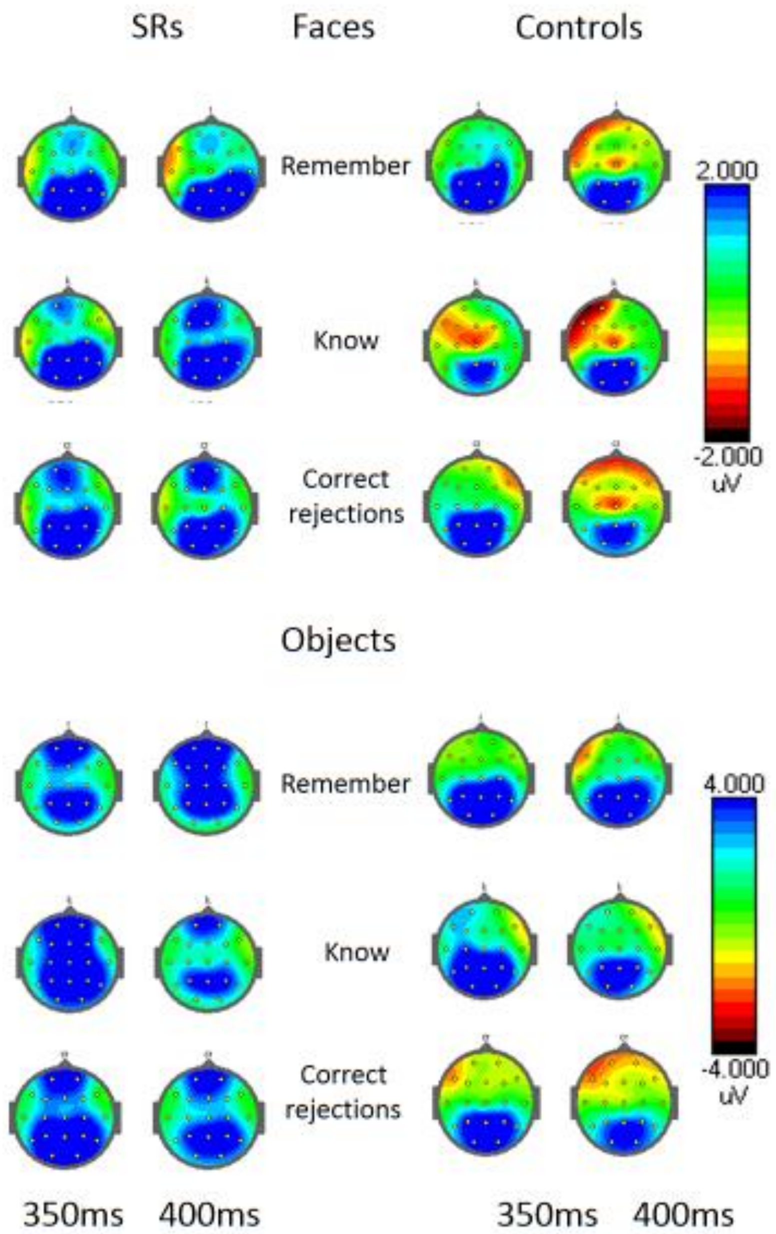


Figure 6.1.2.5. SRs' and controls' neural/electrical activity distributions during different types of recognition in the 300-500msec time range for faces and objects.

300-500msec interval: latency: This ANOVA showed a main effect of group, $F(1, 31) = 9.54$, $p = .004$, $\eta^2 = .24$, with SRs displaying earlier latencies. There was a main effect of hemisphere, $F(2, 31) = 4.48$, $p = .015$, $\eta^2 = .13$. Central channels (Z) generated later latencies than right, $t(32) = 3.33$, $p = .002$, Cohen's $d = 0.58$, and left hemisphere channels, $t(32) = 2.67$, $p = .012$, Cohen's $d = 0.47$, while there was no difference in latencies between left and right hemisphere, $t(32) < 1$ (corrected $p = .043$). The main effect of location was not significant, F(2,

31) = 2.58, p = .104, η^2 = .08. There were no main effects of stimulus-type F(1, 31) < 1, nor response, F(2, 31) < 1.

There was a stimulus-type x group interaction, F(1, 31) = 8.11, p = .008, η^2 = .21. The between-groups latencies for faces were virtually identical, F(1, 31) < 1. However, controls showed later latencies than SRs for objects, F(1, 31) = 30.15, p < .001, η^2 = .49. The response x group interaction was not significant, F(2, 31) = 1.69, p = .193, η^2 = .05. There were no hemisphere x group, location x group interactions, F(2, 31) < 1. There were no three-way interactions (p > .250).

There was one four-way (stimulus-type x response x location x group) interaction, F(4, 31) = 3.21, p = .015, η^2 = .09. SRs showed no main effects of stimulus-type, F(1, 15) = 4.04, p = .063, η^2 = .21, response, F(2, 15) = 2.97, p = .067, η^2 = .17, or location, F(2, 15) < 1. The stimulus-type x response interaction was not significant, F(2, 15) = 2.28, p = .120, η^2 = .13, and there was no stimulus-type x location interaction, F(2, 15) < 1. The response x location interaction was significant, F(4, 15) = 4.31, p = .004, η^2 = .22. The three responses generated similar latencies at posterior channels, F(2, 15) < 1, but different latencies at central, F(2, 15) = 4.16, p = .038, η^2 = .37, and anterior channels, F(2, 15) = 4.31, p = .035, η^2 = .38. Post hoc tests showed that at C channels, K responses generated earlier latencies than R responses, t(15) = 2.55, p = .022, Cohen's d = .78, and only marginally earlier latencies than CRs, t(15) = 2.31, p = .036, Cohen's d = .64 (corrected p = .033). There were no differences in latencies between R responses and CRs, t(15) < 1. The same pattern of results was observed for anterior channels, with K responses peaking earlier than R responses, t(15) = 2.56, p = .022, Cohen's d = .67, and earlier than CRs, t(15) = 2.82, p = .013, Cohen's d = .71, with no difference between R responses and CRs, t(15) < 1 (corrected p = .033). The three-way interaction was significant, F(4, 15) = 2.67, p = .040, η^2 = .15. In P channels, R responses, F(2, 15) = 5.25, p = .037, η^2 = .26, and K responses, F(2, 15) = 5.64, p = .031, η^2 = .27, generated earlier latencies for objects than for faces, but not CRs, F(2, 15) = 1.14, p = .303, η^2 = .07. The same pattern of results was found in C channels, but with reduced statistical power. Objects marginally generated earlier latencies for R responses, F(2, 15) = 3.67, p = .075, η^2 = .20, and K responses, F(2, 15) = 4.47, p = .052, η^2 = .23, while no differences were found for CRs, F(2, 15) < 1. In channels F, only K responses generated significantly earlier latencies for objects, F(2, 15) = 9.47, p = .008, η^2 = .39, while other responses generated similar latencies, F(2, 15) < 1. Within the same four-way interaction, controls showed only marginal main effects of stimulus-type, F(1, 16) = 4.12, p = .059, η^2 = .21, and location, F(2, 16) = 2.88, p = .071, η^2 = .15, with only slightly earlier latencies for faces and posterior channels, but no main effect of response, F(2, 16) < 1. Controls showed no two-way interactions, F(1, 16) < 1. The three-way interaction was not significant, F(4, 16)

= 1.39, p = .248, η^2 = .08. Overall, SRs but not controls, generated slightly earlier ‘know’ responses for objects compared to other response types, specifically in anterior channels (F), while other observations did not reach statistical significance when applying Bonferroni corrections (p = .05 divided by the number of post hoc comparisons while taking into account the mean correlation of the variables involved). There were no more four-way or five-way interactions (p > .250).

In summary, SRs generated overall earlier latencies than controls, potentially implying either different or more effective processing for visual stimuli recognition. Note that while controls generated greater amplitudes for objects, SRs generated earlier latencies for objects compared to controls. Furthermore, SRs appeared to show earlier latencies for ‘know’ responses compared to other responses, though this effect was strongest at central and anterior channels and absent at posterior channels. Furthermore, it appears that this early ‘know’ response latency was induced by object stimuli.

500-700msec interval: amplitude: This ANOVA showed a main effect of stimulus-type, $F(1, 31)$ = 10.33, p = .003, η^2 = .25, with bigger amplitudes for objects. There was a main effect of response, $F(2, 31)$ = 10.21, p < .001, η^2 = .25. R responses, $t(32)$ = 4.24, p < .001, Cohen’s d = 0.85, and K responses, $t(32)$ = 4.13, p < .001, Cohen’s d = 0.74, generated greater amplitudes than CR responses, while there was no difference in amplitudes generated by R and K responses, $t(32)$ < 1 (corrected p = .036). There was a main effect of hemisphere, $F(2, 31)$ = 14.14, p < .001, η^2 = .31. Central sites generated greater amplitudes than the right hemisphere, $t(32)$ = 4.00, p < .001, Cohen’s d = 0.70, and left hemisphere channels, $t(32)$ = 5.49, p < .001, Cohen’s d = 1.12, while there was no difference between amplitudes generated in the right and left hemispheres, $t(32)$ = 1.63, p = .112 (corrected p = .046). There was a main effect of location, $F(2, 31)$ = 5.59, p = .019, η^2 = .15. P channels generated greater amplitudes than C channels, $t(32)$ = 2.91, p = .007, Cohen’s d = 0.51, and F channels, $t(32)$ = 2.37, p = .024, Cohen’s d = 0.41, while there was no difference between amplitudes generated in channels C and F, $t(32)$ = 1.10, p = .278 (corrected p = .036). There was no main effect of group, $F(1, 31)$ < 1.

There was a stimulus-type x group interaction, $F(1, 31)$ = 8.35, p = .007, η^2 = .21. SRs had a similar amplitude for faces and objects, $F(1, 31)$ < 1, while controls had a similar face amplitude to SRs, $F(1, 31)$ < 1, their object amplitudes were significantly bigger than their face amplitude, $F(1, 31)$ = 19.22, p < .001, η^2 = .38. Again, the effects point out that the overall higher amplitudes for objects is mainly driven by controls. There were no other two-way interactions (p > .180).

There was a stimulus-type x hemisphere x group interaction, $F(2, 31) = 5.04$, $p = .014$, $\eta^2 = .14$. SRs showed no main effect of stimulus-type, $F(1, 15) < 1$, with similar amplitudes for faces and objects. SRs showed a main effect of hemisphere, $F(2, 15) = 5.26$, $p = .011$, $\eta^2 = .26$. Central sites (Z) generated greater amplitudes than the right hemisphere, $t(15) = 3.10$, $p = .007$, Cohen's $d = 0.79$, and the left hemisphere, $t(15) = 3.14$, $p = .007$, Cohen's $d = 1.04$, while there was no difference between amplitudes generated by the right and left hemisphere channels, $t(15) < 1$ (corrected $p = .044$). SRs showed no stimulus-type x hemisphere interaction, $F(2, 15) = 1.35$, $p = .275$, $\eta^2 = .08$. Controls on the other hand, showed a main effect of stimulus-type, $F(1, 16) = 20.09$, $p < .001$, $\eta^2 = .56$, with bigger amplitudes for objects, and a main effect of hemisphere, $F(2, 16) = 9.13$, $p = .001$, $\eta^2 = .36$. Central sites (Z) generated greater amplitudes than the right hemisphere, $t(16) = 2.74$, $p = .015$, Cohen's $d = 0.67$, and the left hemisphere, $t(16) = 2.74$, $p < .001$, Cohen's $d = 1.21$, while there was no difference between amplitudes generated by the right and left hemisphere channels, $t(16) = 1.41$, $p = .177$ (corrected $p = .044$). Unlike SRs, controls had a stimulus-type x hemisphere interaction, $F(2, 16) = 4.81$, $p = .015$, $\eta^2 = .23$. Controls showed greater amplitude variability across the hemispheres for faces, $F(2, 16) = 16.47$, $p < .001$, $\eta^2 = .69$, than for objects, $F(2, 16) = 8.54$, $p = .003$, $\eta^2 = .53$. For faces, post hoc tests showed that the left hemisphere generated lower amplitudes than the right hemisphere, $t(16) = 3.62$, $p = .002$, Cohen's $d = .90$, and lower amplitudes than the central site, $t(16) = 5.65$, $p < .001$, Cohen's $d = 1.47$, whereas there was no difference in amplitudes between the right hemisphere and the central site, $t(16) = 1.14$, $p = .272$, Cohen's $d = .28$ (corrected p value = .040). For objects, post hoc tests showed that the left hemisphere and right hemispheres generated similar amplitudes, $t(16) < 1$, and that the central site generated greater amplitudes than the left hemisphere, $t(16) = 3.33$, $p = .004$, Cohen's $d = .83$, and greater amplitudes than the right hemisphere, $t(16) = 3.26$, $p = .005$, Cohen's $d = .84$ (corrected p value = .040). Overall, controls, but not SRs, showed higher amplitudes for faces in central and right sites, and higher amplitudes for objects in central sites only.

There were no more three-way interactions ($p > .100$). The response x hemisphere x location x group interaction was only marginally significant, $F(8, 31) = 1.87$, $p = .066$, $\eta^2 = .06$, and was not analysed further. There were no more four-way or five-way interactions ($p > .150$).

In summary, as with the earlier time range, 'remember' responses, posterior channels, and central site generated higher amplitudes. Again, the greater amplitude in object processing was potentially induced by controls, as SRs amplitude for faces and objects was similar.

500-700msec interval: latency: This ANOVA showed a main effect of stimulus-type, $F(1, 31) = 4.99$, $p = .033$, $\eta^2 = .14$, with earlier latencies for objects. There was a main effect of response, $F(2, 31) = 4.48$, $p = .015$, $\eta^2 = .13$. R responses generated earlier latencies than CR responses, $t(32) = 2.75$, $p = .010$, Cohen's $d = 0.46$, but similar latencies to K responses, $t(32) = 1.44$, $p = .160$, while K and CR responses also generated similar latencies, $t(32) = 1.15$, $p = .257$ (corrected $p = .036$). There was a main effect of location, $F(2, 31) = 12.30$, $p < .001$, $\eta^2 = .28$. P channels generated earlier latencies than C channels, $t(32) = 4.58$, $p < .001$, Cohen's $d = 0.81$, and F channels, $t(32) = 3.19$, $p = .003$, Cohen's $d = 0.57$, while there was no difference in latencies generated in C and F channels, $t(32) < 1$ (corrected $p = .036$). There were no group, $F(1, 31) < 1$, or hemisphere main effects, $F(2, 31) < 1$. The stimulus-type x group interaction was not significant, $F(1, 31) = 3.09$, $p =.089$, $\eta^2 = .09$, and there were no other two-way interactions ($p > .100$). There were no three-way ($p > .100$), four-way or five-way interactions ($p > .100$).

In summary, 'remember' responses and objects generated earlier latencies. Earlier latencies for object recognition potentially suggest a difference in neural processing induced by faces and objects (see section 6.1.3).

6.1.3 General Discussion

This study was designed to explore whether SRs' recognition of faces derives from a concrete recollection of visual stimuli or a sense of familiarity and whether this distinction has different behavioural and neural patterns to that of individuals within the average range of face recognition ability.

First, SRs demonstrated more accurate 'remember' responses than controls, while their 'know' responses were similar in discriminability ($d^{/}$). Given that recollection is a recognition aspect that is often compromised by age (e.g., Koen & Yonelinas, 2014), by dividing attention (e.g., McCabe *et al*., 2011) and by medical conditions (e.g., Burns *et al*., 2014; Martin *et al*., 2011a), including amnesia (e.g., Baddeley, 2002; Tulving, 2002; Düzel *et al*., 2001), unlike familiarity which is viewed as an automatic and a relatively resilient aspect of recognition (e.g., Koen & Yonelinas, 2014; Martin *et al*., 2011a; McCabe *et al.*, 2011), recollection appeared to be a more probable component contributing to SRs' recognition superiority. Thus, in line with predictions, SRs' recognition for faces (and objects) seems to derive from a stronger sense of recollection, rather than a sense of familiarity. Therefore, SRs' recognition of faces is often accompanied by contextual/semantic information, in that they remember more than just the face's identity. Importantly, this aspect of recognition is especially applicable in forensic settings. Whether this is a result of more effective encoding, or merely a stronger activation of contextual associations with the said face remains to be investigated. Furthermore, in line with the findings reported in Chapter 4, this recollection superiority observed in SRs was not face-specific, as SRs generated an overall greater discriminability for visual stimuli. Indeed, SRs showed a similar performance on face and object recognition as indicated by hits, correct rejections and sensitivity index. Note that in line with earlier findings demonstrated in this thesis (Chapters 4 and 5), SRs generated higher rates of correct rejections for visual stimuli in comparison to controls, which is further discussed in Chapter 7.

Second, behavioural results showed that SRs outperformed controls on face recognition, but not significantly so on object recognition, as indicated by hit rates. Given the findings of Chapter 4 (Experiments 4.1 and 4.2), SRs were expected to show enhanced object recognition in Experiment 6.1 as well. It is possible that the similar object recognition performance between the participant groups in this study was owing to the varying difficulty level of the tests. The object test in this chapter was substantially easier than the test used in Chapter 4, as indicated by controls' performance. Indeed, while research shows that neuro-typical participants tend to process faces more effectively than objects (e.g., Diamond & Carey, 1986; Tanaka & Farah, 1993; Yin, 1969; see also Experiments 4.1 and 4.2), controls' average performance in Experiment 6.1 was slightly (not significantly so) greater for objects than faces. Furthermore, while both faces and objects were divided into 8 blocks of encoding and recognition, object types were different across the 8 blocks, making the object condition less demanding than the face condition, in that images from previous blocks were not confounding recognition decisions from the current block.

Importantly, differences in object and face recognition were observed at the level of neural/electrical activity, whereby the amplitudes related to recognition (as measured by correct rejections, 'remember' and 'know' responses), counter to predictions, were greater for objects than faces. While caution must always be exercised assuming function from EEG waveforms, these amplitude differences may potentially provide supporting evidence of the 'face' condition being more demanding. Furthermore, analyses indicated that this amplitude advantage for objects was mainly driven by controls. Thus, while SRs generated similar amplitudes for faces and objects (not necessarily reflecting similar processing styles, see Experiment 4.1), controls appeared to have struggled with faces more than with objects. Again, given that each block had new types of objects to memorise, participants' cognitive and memory load was not as strongly affected by previous blocks' images, as it potentially was for faces. Another interesting observation regarding objects is the fact that while controls generated greater amplitudes for recognising objects, presumably suggesting that they found object recognition easier than face recognition, SRs showed earlier latencies for object recognition. Given that earlier latencies are associated with faster/more efficient processing (e.g., Bentin *et al*., 1996; Eimer *et al*., 2012; Kaltwasser *et al*., 2013; Rivolta *et al*., 2012), EEG findings suggest that object recognition was easier for SRs than it was for controls, mirroring the findings from Experiments 4.1 and 4.2.

Next, in line with previous research (e.g., Smith, 1993; Trott *et al*., 1999; Yovel & Paller, 2004), all recognition related neural activity was most prominent in posterior channels, with an emphasis on the central site (i.e., channel Pz). Note, that these observations were prominent in both time ranges (300-500msec and 500-700msec), further consolidating the theoretical implications of these brain regions in visual recognition. Importantly, SRs, but not controls, showed strong recognition related activity in the central site (Pz) as well as in the right hemisphere (P4), suggesting their recognition related neural activity spreads across a larger scalp area, while controls' neural activity remained in the central sites (Pz). Note, however, that SRs' implication of the right hemisphere should not be viewed as a qualitative difference in neural processing during recognition. It seems that the neural processing related to recognition takes place in the same brain regions in all participants, with a merely stronger propagation or resonance in SRs than controls, thereby suggesting a quantitative difference in processing. Note that this stronger activation of neural networks related to recognition in SRs is in line with findings in Chapter 5 (Experiment 5.2), where a different sample of SRs demonstrated higher amplitudes in P600, a component associated with explicit recognition. Furthermore, the current study demonstrated a distinction between the two recognition components, in that 'remember' responses generated stronger amplitudes than 'know' responses (and correct rejections). Given that recollection is a more concrete feeling associated with explicit recognition, unlike a more ambiguous feeling of familiarity, stronger amplitudes for 'remember' responses were anticipated. However, this study failed to demonstrate any group differences between amplitudes generated by 'remember' and 'know' responses. Thus counter to predictions, 'remember' responses did not generate higher amplitudes in SRs compared to controls, potentially implicating statistical power limitations. Indeed, both the pilot test and the current test suggest that a significant number of participants failed to generate a substantial number of either 'remember' or 'know' response for either faces or objects.

While SRs and controls generated similar amplitudes across 'remember' and 'know' responses, there was a significant group difference found for 'know' responses when analysing latency. Indeed, the 'know' responses appeared to peak earlier than other responses related to recognition, in SRs, but not controls. In line with previous research on familiarity associated with the 300-500msec time line of neural processing (e.g., Yovel & Paller, 2004), SRs demonstrated earlier familiarity in the 300-500msec time range, but not in the later time range. Furthermore, the earlier familiarity peak in SRs found in the current study was found in central and anterior channels, and appeared to be mostly induced by objects, and not faces. Research suggests that object familiarity is associated with activity in anterior brain regions (e.g., Curran & Hancock, 2007). Taken together these findings potentially suggest that SRs are quicker to reach a feeling of familiarity for objects. Note that Curran and Hancock (2007) suggested that 'know' responses are potentially easier to induce in participants when using a more heterogeneous set of stimuli, and given that the current study used 8 different categories of objects across 8 blocks, with only 2 categories for faces (i.e., gender), it is possible that the object condition was more sensitive at teasing out group differences. Thus if the face condition had used a more heterogeneous set of faces, making it easier for participants (i.e., faces with more distinct features and more obvious within-stimuli differences), it is possible that faces would have induced an earlier familiarity effect as well. Nevertheless, SRs reaching the state of object familiarity earlier than controls, could potentially contribute to their general superiority in visual recognition, but not necessarily to their face recognition superiority. Indeed, findings from Experiment 4.1 and previous research (e.g., DeGutis *et al*., 2013) suggest that general parts-based processing makes minimal contribution to the participants' face recognition ability. However, this was not directly tested using the stimuli from the current experiment.

Finally, in line with research associating recollection with the parietal old/new effect occurring between 500msec and 700msec, the present study found that 'remember' responses peaked at earlier latencies in the 500-700msec range. Therefore it appears that neural networks react earlier to visual stimuli which are recollected than those that induce a sense of familiarity or are recognised as 'new' (correct rejections). Note, however, that, just as in the earlier time range, this recollection effect showed no group differences. Thus, while SRs demonstrated a stronger propagation of neural activity related to recognition ('remember' responses, 'know' responses and correct rejections taken together) in the 300-500msec time range, this study showed no neural advantage for recollection in SRs.

There are limitations to the study. First, as discussed above, the different level of tests' difficulty (faces versus objects) does not allow for a direct neural comparison of different stimuli processing in SRs. Indeed, given that EEG studies require a large number of trials (and stimuli), acquiring 320 objects (160 targets and 160 distractors) belonging to the same object category was not feasible. Note however, that in this study, generating a more heterogeneous set of faces would have been more beneficial than finding one category of objects, given that the more informative group differences were generated by the object condition, not the face condition. Next, it was problematic to guarantee a specific number of artefact-free trials for each response (correct rejections, 'remember', and 'know' responses), each stimulus-type (faces and objects) and for each participant, since the latter show significant individual differences, in that some do not rely much on recollection ('remember' responses) when recognising faces and/or objects, while others show the opposite pattern. This issue was anticipated based on the pilot testing, however increasing the number of trials for the actual tests, and thereby increasing the frequency of each response (and the number of noise-free trials), did not solve the problem completely, limiting statistical power. Finally, given that 'SR' may be an atypical group, the statistical power was also compromised by the small participant sample. Taken together, these limitations suggest that there may be other potential group differences that remained unmeasured.

Finally, it should be acknowledged that the distinction between 'remember' and 'know' responses, along with the EEG representations of these responses, was based on the participants' understanding of the test's instructions. Indeed, participants demonstrated an adequate understanding of what type of contextual information is meant to accompany their experience of recollection (e.g., I remember seeing that face because it reminded me of my friend, etc.) during the interactive practice trials. However, during the actual testing session, the experimenter had no insight into whether the participants' 'remember' responses were accompanied by a specific association.

Overall, SRs showed that their recognition is often accompanied by contextual information, suggesting they remember more than just the stimuli's identity. Furthermore, SRs demonstrated a stronger propagation of neural activity related to recognition of visual stimuli by spreading from central sites to the right hemisphere, while controls only generated activity in the central site. Finally, SRs appeared to reach the state of familiarity of object stimuli earlier than controls, which may or may not contribute to their general superiority in visual recognition.

Chapter 7 – General Discussion and Conclusions on Super-Recognition (SR)

7.0 Introduction

The aim of this thesis was to explore potential *recognition-based* and *perceptual* reasons behind *Super-Recognisers' (SR)* exceptional face recognition ability. Only a few published studies have previously examined SR. This chapter briefly summarises the existing literature on SR and proceeds to incorporate the findings from Chapters 4 – 6 to further add to the current understanding of what is *SR* and what distinguishes SRs from individuals with average face processing ability. This chapter also discusses the applicability of this thesis' findings, as well as the design's limitations and new potential directions for future research.

7.1 Existing literature on Super-Recognition

Russell *et al*. (2009) were the first researchers to empirically test individuals with exceptionally good ability in face recognition. Their study described four individuals who significantly outperformed participants with average face recognition skills on three tests, Cambridge Face Memory Test (CFMT+), Cambridge Face Perception Test and Before They Were Famous Test. The authors suggested that face recognition ability appeared to be distributed on a spectrum, with atypically poor ability at one end – Developmental Prosopagnosia (DP), and atypically good ability at the other end – Super-Recognition (SR). To further demonstrate that DP and SR belong on the same spectrum of face recognition ability as the individuals with average face recognition, Russell *et al*. (2012) found no differences in perceptual viewing strategies between SRs, DPs and controls during face processing. Indeed, when asked to match two faces that only differed either in pigmentation (surface reflectance) or feature shape dimension, all three participant groups demonstrated a greater reliance on feature cues during face matching. This suggested that DPs and SRs show only quantitative difference in performance compared to individuals with average face recognition ability.

SRs' purely quantitative superiority was also proposed by Bobak *et al*. (2017) who found that SRs, while demonstrating typical fixation patterns during spontaneous face scanning, spent relatively more time looking at the nose than controls. Studies examining holistic processing similarly showed no indication of qualitative differences in face processing between SRs and typical individuals. While the Composite Face Test showed no difference in holistic processing between SRs and controls (Bobak, Bennetts et al., 2016), the Inversion Effect (as measured by upright and inverted versions of the Cambridge Face Perception Test) appears to be greater in SRs (Bobak, Bennetts *et al*., 2016; Russell *et al*., 2009). However, a greater Inversion Effect cannot be viewed as a direct measure of qualitative difference in face processing (Russell *et al.*, 2009; see also Noyes *et al*., 2017). Indeed, when SRs and controls demonstrate an Inversion Effect, it implies that their upright face processing benefits from an effective integration of features/parts and their spatial configurations. Importantly, the magnitude of the Inversion Effect appears to correlate with face recognition ability across the entire range of normal face recognition ability (i.e., in participant samples including DPs, general population and SRs). Thus researchers propose that this continuous distribution of Inversion Effects from low to top end suggests that SRs' superiority is quantitative in nature (Noyes *et al.*, 2017; Russell *et al*., 2009). Note, however, that individuals with Acquired Prosopagnosia (AP), who are argued to process faces in a qualitatively different manner (Busigny *et al.*, 2014; Van Belle *et al*., 2010), would still be expected to demonstrate a similar pattern of results to that of DPs (i.e., a significantly reduced or an absent Inversion Effect), a group argued to demonstrate a quantitative inferiority. Therefore findings on the Inversion Effects alone do not provide any clarification on whether SRs' superiority is quantitative or qualitative in nature.

Importantly, while SRs are defined as individuals with superior face *recognition,* studies have demonstrated that SRs' superiority is generally found for face perception/matching as well. As mentioned before, Russell *et al.* (2009) showed that SRs outperformed controls on the Cambridge Face Perception Test, where participants' face matching skills are tested without implicating their recognition ability. Bobak, Hancock *et al*. (2016) and Bobak, Dowsett *et al.* (2016) also demonstrated a group advantage for face matching. However, not all SRs demonstrate a perceptual/matching advantage, as was demonstrated by Bobak, Bennetts *et al*. (2016), and Davis *et al.* (2016). Face recognition and face perception are two stages of face processing which are found to correlate with one another (e.g., Veld *et al*., 2012), however research into prosopagnosia also shows that these stages show dissociations (e.g., Dalrymple *et al.*, 2014; De Renzi *et al*., 1991; Fox *et al.*, 2008). Indeed, if DPs may show normal face perception with a selective impairment in face recognition, SRs are likely to demonstrate similar dissociations, with normal perception and a selective superiority in face recognition. Consequently, while it is possible that some SRs' exceptional recognition ability is aided by their superior perceptual skills, there are also those SRs whose superior face recognition cannot be attributed to a perceptual advantage. Indeed, it is possible that for some SRs, this extraordinary face recognition ability is merely a result of a more effective storage of facial percepts or a stronger activation of recognition related storage units. It is, however, worth considering that some of these individuals who demonstrate high CFMT+ scores but average face perception/matching may not be SRs. Indeed, as discussed in section 7.2.1, the CFMT and CFMT+ have been used as classification tools for DPs and SRs, respectively, but research (e.g., Esins *et al.*, 2016; Horry *et al.*, 2014) suggests that this test is not without limitations and both DPs and SRs are able to generate relatively high scores which do not necessarily reflect their face-processing proficiency. On the other hand, given that previous studies recruited small numbers of SRs, it remains unclear whether relatively low scores on individual tests (e.g., face matching) demonstrated by SRs is a result of their actual ability or if it was potentially caused by fatigue or other attention-related factors.

Previous research has also provided mixed findings on the face-specificity of SRs' exceptional ability. For instance, Bobak, Bennetts *et al.* (2016) found only two out of six SRs to exceed controls on object processing, while Davis *et al*. (2016) found two out of ten SRs to exceed controls on object recognition.

Finally, it should also be pointed out that SRs' visual processing is not absolute as they do not always exceed controls on all the measures (see Noyes *et al.*, 2017). Thus, not only are SRs almost never 100% accurate in their visual processing performance, they sometimes generate average scores. Note, however, that this so called imperfection could partly reflect the demanding nature of the tests' design, further discussed in section 7.3.2.1, thereby suggesting that for some, face processing performance could have been compromised by factors such as fatigue and concentration.

7.2 The thesis's findings and their contribution to the existing knowledge on Super-Recognition (SR)

The existing research findings on SRs (e.g., Russell *et al.*, 2012; Bobak, Bennetts *et al*., 2016; Davis *et al*., 2016) give rise to a number of questions about the nature of their extraordinary face recognition skills and the current thesis attempted to answer some of these. Given the heterogeneous performance patterns found by previous investigations it remains to be clarified what should be the definition of SR, and what aspects of visual processing distinguish SRs from individuals with average ability in face recognition.

7.2.1 The definition/classification of Super-Recognisers (SRs)

The notion of face recognition ability being distributed on a spectrum, with DPs at the low end, and SRs at the other end, has been brought about by measuring individuals' recognition skills with the CFMT+. This test first developed by Duchaine and Nakayama (2005) has been further updated by Russell *et al*. (2009) making it more difficult by adding more trials and thereby more sensitive at distinguishing individuals with extraordinary face recognition from individuals with very good face recognition. This is the most prominent test to date for measuring individual differences in face recognition ability, and for classifying participants into DP (e.g., DeGutis *et al.*, 2007; DeGutis *et al.*, 2012; Russell *et al.*, 2012) and SR (e.g., Bobak, Bennetts *et al*., 2016; Davis *et al*., 2016; Russell *et al*., 2009, 2012) groups.

As discussed in Chapter 3, this test is believed to be the most valid measure of face recognition ability created to date, as it demonstrates a number of good qualities. First, given the test's relatively delayed recognition paradigms (blocks 2, 3 and 4); it indirectly demonstrates whether participants have had the chance to create an internal visual representation of the faces in the first block. Therefore, introducing a gradual delay between memorising and recognising allows testing of participants' capacity to store visual representations of faces for a relatively long period of time. Furthermore, employing different images of the same identities enforces identity recognition rather than image matching or image recognition, which also indirectly reflects whether an internal representation of that identity has been successfully stored (Bruce & Young, 1986).

Second, the test is argued to be a more valid measure of face recognition ability owing to its focus on face-specific rather than general visual components. For instance, the face-specificity of the test images is strengthened by removing external features/cues from the learning stages (blocks 1, 2, and 3), potentially aiding memorising and recognizing of non face-specific parts (e.g., hair). Furthermore, the 'noise' paradigm (images with visual artefacts) introduced in the last two blocks is argued to increase reliance on holistic processing (Duchaine & Nakayama, 2006b; see also McKone, Martini, & Nakayama, 2001), a process thought to be the hallmark of face processing (e.g., Avidan, *et al*., 2011; Busigny *et al.*, 2010; Wang *et al*., 2012). It is noteworthy that the first two blocks of the CFMT+ also induce holistic processing, as Duchaine and Nakayama (2006b) demonstrated significant inversion effects across participants for each test block. The same study also demonstrated that with each block, performance on the upright version decreased while inversion effects increased, and the authors concluded that the upright face specificity of the test increases with each testing block. Finally, DeGutis *et al*. (2013) demonstrated that both holistic processing and parts-based processing related to faces (as opposed to general parts-based processing) explain a significant portion of the CFMT score variance. Indeed, Chapter 4 (Experiment 4.1) showed that general parts-based processing (object recognition) made no additional contribution to predicting CFMT+ scores. Therefore, CFMT+ scores appear to reflect face specific recognition ability.

Finally, the effectiveness of CFMT+ as an appropriate classification tool is supported by the fact that most of the reported SRs who have contacted research labs claiming to have an exceptionally good face recognition ability have shown appropriately high scores on the CFMT+ (minimum score of 92/102). Only five participants who contacted our research lab claiming to be SR generated average performance on CMFT+. In addition, there were no SRs with high CFMT+ scores (>92/102) who were not already aware of their superior face recognition ability, therefore CFMT+ performance appears to match SRs' self-reports on their ability.

Thus, the CFMT+ attributes can be summarised as follows:

1) Storage of internal face representations is tested via the delayed recognition paradigm and via different view/image presentation
2) Face specificity of individual recognition ability is tested via the visual noise paradigm and removal of external features
3) CFMT+ performance closely matches self-reports of SRs

Importantly, all published work on SR to date has employed inclusion criteria of self-reports of extraordinary ability and a CFMT+ cut-off point of 90/102 (Bobak Dowsett, *et al.,* 2016; Bobak, Hancock, *et al*., 2016; Bobak *et al.*, 2017; Russell, *et al*., 2009; Russell *et al*., 2012), as this score was at least 1 standard deviation above the sample mean score recorded by previous research. However, despite the undoubted attributes of the CMFT+ as a diagnostic/classifying tool, it has a number of shortcomings that must be acknowledged.

First, Esins *et al.* (2016) and Horry *et al*. (2014) have shown that there are a few DPs who do not score in the expected low range on the CFMT. Furthermore, some CFMT+ defined SRs do not score highly on alternative face recognition tests, as this thesis demonstrates (see also Davis *et al*., 2016), suggesting their high recognition on CFMT+ does not necessarily reflect their true face recognition ability. Together these observations suggest that CFMT and CFMT+ are not perfect tests in that they may induce artificially high scores in rare cases. Indeed, given that it is a multiple choice test, some lucky participants may guess the correct response.

Second, while CFMT+ employs the relatively delayed recognition paradigm, it fails to consider the long-term aspect of face recognition. In fact, the aspect of long-term recognition for faces has been eluded by previous SR research and the current thesis, and is discussed in more detail in section 7.3.2.1. Given that long-term recognition is more closely related to the pure definition of memory (i.e., the reliable formation and storage of internal representations of specific stimuli), as short-term recognition for faces is perhaps too momentary and too similar to perception/matching, it should be considered as an additional potential criteria to classify SRs.

Thus, the CFMT+ shortcomings can be summarised as follows:

1) The test does not always reflect accurate face recognition ability
2) The test does not examine long-term recognition

With these points in mind, even though all previous researchers (e.g., Bobak, Bennetts *et al.*, 2016; Davis *et al*., 2016; Russell *et al*., 2012), used the CFMT+ to classify participants as SRs, it is arguable that CFMT+ may not always accurately define SR on its own. For this reason, in this thesis, a second face recognition test was employed alongside the CFMT+, in order to verify that the participants' CFMT+ scores reflected true face recognition ability.

Importantly, the previously agreed upon CFMT+ cut-off point (90/102) for SR has also been criticised. Bobak, Pampoulov *et al*. (2016) recently published a study recruiting 254 student age participants (Mean CFMT+ = 70.7, *SD* = 12.3) and suggested a stricter cut-off point of 95/102 for SR, indicative of 2 standard deviations above the sample mean – as they argue that their sample provides a more representative estimate of the population mean than previous research. However, given the findings presented in this thesis, there are two important factors suggesting that the 95/102 cut-off point is unnecessarily too strict. First, it appears that face processing studies tend to attract people who are interested in faces and who believe they are good at face recognition, thereby introducing a bias in recruitment. For instance, of approximately 280,000 people who attempted a 'teaser' face recognition test consisting of 14 trials, only 16,794 responded to an invitation to participate in the online studies presented in Chapter 4 (Experiment 4.1) and Chapter 5 (Experiment 5.1). Of these 16,794 individuals, only 820 finished both studies, and indeed, Experiments 4.1 and 5.1 showed a clearly inflated sample mean on the CFMT+ (n = 820, M = 84.3, SD = 10.7), almost a standard deviation above that reported in previous research, suggesting that many lower performing individuals drop out, or do not even take part in the first place, inevitably introducing a recruitment bias. Thus, given that people who are poor at and/or not interested in face recognition avoid participating in such research, it is probable that CFMT+ scores reported to date have been inflated, making the cut-off point for SR potentially too strict. The second, and more important reason to suggest that 95/102 cut-off point is too high is the fact that in all the research reported in this thesis, individuals with scores of 93 and 94 display a similar performance on the *old/new face recognition tests* (employing adult and infant faces as stimuli) as individuals with 95+ scores.

Furthermore, the only difference observed between the ‘low’ (93/94) and ‘high’ (95+) scorers was the performance on the *old/new object recognition test*, whereby 95+ scorers had a slightly better object recognition. These findings (see appendix for Table A7.2.1.1) demonstrate that the individuals with 93/94 scores are as good at face recognition as SRs classified according to the strict cut-off point. The important difference between the ‘low’ and ‘high’ scorers is that high scorers are more likely to be superior in general visual recognition, given their slightly higher performance on object processing. This observation appears to be in agreement with researchers who point out that CFMT is not a face-specific measurement in a pure sense (Esins *et al.*, 2016; Horry *et al*., 2014; Richler *et al.*, 2015). Thus it is possible that for those who rely solely on their face-specific strategies can reach only a certain level of performance (i.e., 93/94), whereas even higher scorers rely on both face-specific and general visual processing. Therefore, if SRs are investigated on their face processing skills, the cut-off point of 93/102 appears to be an adequate threshold. Note that the cut-off point used in this thesis (93/102) was selected based on the means and standard deviations of CMFT+ scores reported by previous studies (See Table 3.1.1 in Chapter 3), and as argued above, can be considered an appropriate inclusion criterion for studying SR.

Note that in order to ensure an appropriate investigation into SRs’ face recognition superiority, their performance should be compared to an appropriate control group, which specifically comprises individuals with average face recognition ability. Accordingly, the studies described in this thesis ensured that controls were within one standard deviation of the CFMT+ mean reported by Bobak, Pampoulov *et al.* (2016), who argue that their sample provides a relatively representative estimate of the population mean (Mean CFMT+ = 70.7, *SD* = 12.3). Furthermore, just as SRs’ ability is proposed to be verified with a second face recognition test, the same is suggested for controls in future research, thereby confirming that their face processing ability is ‘average’.

Taken together, the factors discussed in this section propose that the CFMT+, given its attributes and shortcomings, cannot accurately define SR on its own, suggesting an additional face recognition test is needed to complement SR classification. Furthermore, when it comes to face processing research, the cut-off point of 93/102, which was applied throughout this thesis, seems to be an appropriate threshold for SR classification. The following sections discuss the present thesis’ findings which complement the current understanding of what drives SRs’ enhanced face recognition.

7.2.2 Perceptual processes in Super-Recognisers (SRs): holistic and parts-based processing in face perception and recognition

Chapter 4 presented an extensive investigation of SRs' holistic and parts-based processing in face perception and recognition in order to clarify whether they demonstrate any qualitative differences in face processing compared to individuals with average face processing.

First, in line with previous research (Bobak, Bennetts, *et al.*, 2016; Bobak, Dowsett, *et al.*, 2016; Bobak, Hancock, *et al.*, 2016; Davis *et al.*, 2016), SRs demonstrated superior recognition as well as superior perception/matching of faces (Experiments 4.1, 4.2 and 4.3). However, there were a few SRs who performed similarly to controls on face matching, supporting previous findings (Bobak, Dowsett, *et al.*, 2016; Bobak, Hancock, *et al.*, 2016; Davis *et al.*, 2016), suggesting SR could be a heterogeneous concept.

Next, in line with previous research (Bobak, Bennetts *et al.*, 2016; Russell *et al.*, 2009), holistic face processing, as measured by the Inversion Effect (IE), appears to be associated with SRs' superior face recognition ability. Indeed, SRs demonstrated a larger IE than controls, which was clear from group and individual analyses. Thus it is arguable that SRs' superior recognition of faces is advantaged by a more effective integration of upright facial features and their configurations (Bobak *et al.*, 2016; Russell *et al.*, 2009). Given that DPs display a reduced IE (e.g., Behrmann & Avidan, 2005), and SRs – a larger IE (Bobak, Bennetts *et al.*, 2016; Russell *et al.*, 2009), compared to average-ability controls, and since the IE significantly correlated with face recognition ability (CFMT+ and face recognition (old/new) test) in Experiment 4.2, it appears that IE is an informative aspect of face processing which reflects individual differences in face recognition ability. It is also noteworthy that SRs' greater IE was demonstrated at the perceptual level as well, in that accuracy differences between their upright face matching and their inverted face matching was greater than controls (Experiment 5.3). Thus, SRs' greater IE suggests that their upright face processing benefits from generally more effective holistic processing compared to controls. Importantly, while IE has been argued to reflect the disruption of holistic processing (e.g., Rossion, 2009), research shows that parts-based processing also contributes to the magnitude of the IE (e.g., Civile *et al.*, 2014). Therefore it is possible that SRs' greater IE is a result of their greater reliance on holistic processing as well as more effective parts-based analysis during upright face processing.

SRs also demonstrated a significant Part-Whole Effect (PWE) $_{\text{Accuracy}}$, which is indicative of effective holistic processing, but contrary to IE findings, their PWE was not greater than that of controls. Given that IE was demonstrated in a recognition component, and PWE –

in a perceptual component, there is a plausible reason to expect a discrepancy in the performance, demonstrating dissociations between perception and recognition. Furthermore, previous research suggests that different measures of holistic processing do not always correlate as they may be measuring different aspects of holistic processing by employing different designs and requiring different approaches from participants. Indeed, despite showing a greater performance on the 'whole' condition, SRs' showed similar PWE to that of controls. Thus, SRs' greater performance on the 'part' condition seemed to have attenuated their PWE. It is possible that SRs' enhanced parts-based processing on the inverted version of CFMT+ likewise attenuated their IE. However, potentially owing to different task designs, the magnitude of this attenuation was not as substantial as it was in the Part-Whole Test. Indeed, SRs' IE was still greater than that of controls despite their greater performance on the inverted condition.

Counter to predictions, while SRs demonstrated enhanced holistic processing in the *recognition* component of face processing (IE), and normal holistic processing in the *perceptual* component (PWE), SRs as a group demonstrated a significantly *smaller* Composite Face Effect (CFE) $_{accuracy}$ than controls (Experiment 4.2). While effect sizes were smaller than those for the IE, it is arguable that SRs may be less susceptible to the holistic perceptual mechanisms of the Composite Face Test. This test employs the intervening nature of holistic processing whereby the bottom halves of incongruent trials interfere with participants' matching decisions, yet SRs do not seem to be affected by this interference to the same extent as individuals with average face processing. Importantly, this diminished interference may partly be driven by enhanced parts-based processing, as was demonstrated by SRs' enhanced inverted face recognition and object recognition in the same study (Experiment 4.2). Furthermore, SRs' enhanced matching skills (e.g., Bobak, Dowsett *et al.*, 2016) may also contribute to SRs' performance on the Composite Face Test, thereby attenuating their CFE. Note that the discrepancy between PWE and CFE findings were expected. Unlike the Composite Face Test which uses incongruent trials to intervene with participants' matching decisions, the 'whole' condition of the Part-Whole Test is facilitating in nature, in that the whole face facilitates feature matching. Thus, while SRs' presumed enhanced parts-based processing potentially allows them to overcome the interfering property of the Composite Face Test, there is no reason for it to affect the facilitating 'whole' condition of the Part-Whole Test. Note that when Bobak, Bennetts *et al*. (2016) tested six SRs on the Composite Face Test, counter to their predictions, and counter to the present findings, all SRs demonstrated a CFE $_{accuracy}$ similar in magnitude to that of controls. While SRs in the present study (Experiment 4.2) demonstrated a reduced CFE as well as enhanced object and inverted face recognition, potentially suggesting an enhanced parts-based processing, only two out of six SRs in Bobak, Bennetts *et al*. (2016) demonstrated enhanced object processing.

Therefore, unlike the current sample of SRs with enhanced object recognition, it is arguable that there was no reason to expect Bobak, Bennetts *et al.*'s (2016) SR sample to demonstrate a reduced CFE.

Importantly, SRs in the present study (Experiment 4.3) demonstrated superior individual feature matching in the 'part' condition of the Part-Whole Test, which supports the aforementioned hypothesis of SRs' enhanced parts-based processing. And while Noyes *et al*. (2017) suggested in their review that SRs' upright face recognition superiority does not transcend to other stimuli, this thesis clearly indicates otherwise, as they exceeded controls on inverted face recognition, object recognition and individual feature matching. It is possible that previous research failed to find similar results owing to smaller sample sizes (Bobak, Bennetts *et al.*, 2016, n = 6; Bobak, Dowsett *et al*., 2016, n = 7; Bobak, Hancock *et al*., 2016, n = 7; Bobak *et al*., 2017, n = 8; Davis *et al*., 2016, n = 10; Russell *et al*., 2012, n = 6), as even disregarding the online study that recruited 199 SRs (Experiment 4.1), Experiments 4.2 and 4.3 still recruited significantly larger numbers of SRs (n = 20, and n = 24, respectively) compared to previous studies which were limited by the small SR sample sizes.

Thus it appears that SRs' enhanced face recognition ability may be at least partly explained by enhanced parts-based processing. Indeed, Royer *et al*. (2015) demonstrated that individuals with good face recognition require very little facial information for successful recognition. Thus it is possible that SRs manage to activate their internal representations of recently learnt faces more effectively, relying on both individual features and the holistic aspects of faces.

Overall, most of the SRs in the current research demonstrated either normal or enhanced holistic processing, indicated by a normal PWE and a stronger IE, respectively. However, SRs' superiority in face recognition appears to benefit from a more effective parts-based processing as well, as indicated by their enhanced inverted face recognition, enhanced object recognition, enhanced feature matching, and their reduced $CFE_{Accuracy}$. As proposed by previous authors (e.g., Russell *et al*., 2012; Noyes *et al*., 2017), these findings indicate no qualitative differences in viewing faces between SRs and individuals with average face recognition, but this thesis demonstrates that SRs may present a combination of enhanced holistic processing and superior parts-based processing.

7.2.3 Super-Recognisers' (SRs) enhanced visual recognition: object recognition and correct rejections

This thesis demonstrated novel findings concerning SRs' recognition superiority. First, SRs as a group exceeded controls on object (motorbike) recognition, a finding observed for a large online SR sample (*n* = 199, Experiment 4.1) as well as a smaller SR sample tested in the laboratory (*n* = 20, Experiment 4.2). Importantly, SRs as a group also demonstrated greater face-specific recognition (measured by subtracting object recognition scores from face recognition scores). Therefore, while SRs' visual recognition superiority is general, in that it is observed for other visual stimuli and not exclusively upright faces, their superiority appears to be more pronounced for faces. Therefore, while Bobak, Bennetts *et al.* (2016) only tested six SRs and demonstrated a general trend of face-specific superiority, this thesis (Experiments 4.1 and 4.2) clarifies the matter and demonstrates that SRs as a group on a larger scale (*n* = 219) possess visual recognition superiority is general rather than it only being face-specific.

It is noteworthy that SRs' face recognition superiority may be independent from their object recognition superiority, as Experiment 4.1 found only a small relationship between face recognition (measured by CFMT+) and object recognition, $r(820) = .15$, $p < .001$. More importantly, performances at object recognition did not predict CFMT+ performance variance, suggesting that the processes involved in face recognition measured by CFMT+ are not the same as processes involved in motorbike recognition measured by the object old/new test.

Another novel finding observed in SRs' superiority in visual recognition concerns correct rejections. Indeed, the results reported in all seven experiments indicate that SRs demonstrate a higher rate of correct rejections for both adult and infant faces as well as objects. Thus, SRs appear to show a general advantage in identifying stimuli that they have not been exposed to. Note that correctly identifying stimuli as 'new' draws on different processes than correctly identifying stimuli as 'old' (e.g., Wiese *et al.*, 2012), and indeed, Chapters 4 and 5 demonstrated that the two responses did not correlate for either faces or objects. Thus SRs appear to be super-rejecters as well, which appears to contribute to their overall visual discriminability (d').

7.2.4 Super-Recognisers' (SRs) enhanced visual recognition is observed at the level of neural/electrical activity

In this thesis, SRs' extraordinary recognition of faces was investigated with *Electroencephalography* (*EEG*) in order to explore the neural correlates of their superiority. Bruce and Young (1986) described a model subdividing familiar face recognition into distinct stages, and some of the neural activity findings reported in Experiments 5.2 and 6.1 appear to map onto this model. Bruce and Young (1986) propose that face processing commences with pictorial processing and structural encoding, followed by activation of Face Recognition Units where a face percept is matched across an array of previously stored face templates for each identity. Note that activation of Face Recognition Units does not necessarily result in explicit recognition of faces. Indeed research suggests that Face Recognition Units are associated with activity recorded at the level of N250 (e.g., Kaufmann *et al*., 2009), an Event Related Potential (ERP) component associated with implicit face recognition (e.g., Eimer *et al.*, 2012). When a face percept is matched appropriately to a specific stored representation, it may or may not activate Person Identity Nodes, reflecting the actual recognition of the identity in question thereby inducing a feeling of conscious/explicit identity recognition. Finally, identity recognition is complemented with background information derived from Semantic Information Units, which induce a more concrete feeling of recollection. Note that while this face processing model (Bruce & Young, 1986) discusses familiar face recognition, experimentally learnt face recognition (via one encoding exposure) bypasses Face Recognition Units as these are only formed for numerously encountered identities (under different viewing conditions). Furthermore, Semantic Information in experimentally learnt face recognition is generally discussed when employing such designs as the Remember/Know paradigm, where participants are encouraged to form contextual associations.

Chapter 5 demonstrated that SRs' recognition may be more effective at the level of pictorial processing of faces (Bruce & Young, 1986; Turano *et al*., 2016) they have been previously exposed to and correctly recognised. Indeed, while N170, the most prominent *Event Related Potential (ERP)* discussed in face processing and associated with structural encoding (Bentin *et al*., 1996), showed no group differences in comparison to controls, SRs demonstrated an important enhancement in neural activity at the earlier stage of face processing. SRs generated greater amplitudes in P1, the earliest ERP linked to face processing, and associated with a positive peak over Occipital regions of the brain around 100msec after image presentation (see sections 2.2.1 and 3.2.3.2). Given that Turano *et al.* (2016) found greater amplitudes at P1 in individuals with good face recognition over individuals with poor face recognition (1 standard deviation above and below the estimated population mean, respectively), this ERP was a good candidate to demonstrate a difference in neural activity between SRs and controls. Furthermore, while several researchers insist that early ERPs are not modulated by face identity (e.g., Pfütze *et al*., 2002; Tanaka *et al.*, 2006; but see Herzmann & Sommer, 2010; Kloth *et al*., 2006; Shen *et al*., 2016), Turano *et al.* (2016) and the findings from this thesis suggest that this identity modulation is perhaps only traceable in individuals whose face recognition is better than average. Thus, one of the important findings of this thesis is that this stronger activation of pictorial processing occurring at the level of the earliest face-related neural component is the first neural correlate of SRs' advantage in face processing.

In line with predictions, SRs' recognition superiority was also reflected in the increased neural activity derived from P600, an ERP associated with explicit recognition (e.g., Rugg & Allan, 2000; Rugg & Curran, 2007). Indeed, SRs' P600 amplitudes were more positive for recognised faces than those generated by controls, and this observation is in line with previous EEG findings comparing typical individuals to DPs on their explicit recognition, in that the latter appear to generate weaker levels at P600 (Eimer *et al.*, 2012; Parketny *et al*., 2015). Given that this ERP is thought to accompany stronger recognition performance, this component was expected to correlate with SRs' behavioural recognition advantage. Thus, SRs' superior face recognition was accompanied by stronger activation of a recognition-related neural network, potentially reflecting a more effective activation of internally stored face representations or Person Identity Nodes (Bruce & Young, 1986). Note that the earlier increase in neural activity observed for P1 could very likely contribute to the neural activity increase observed for P600, as earlier ERPs are thought to contribute to the processing of the ERPs observed at latter stages (Luck, 2005).

Counter to predictions, N250, an ERP related to implicit identity discrimination (e.g., Eimer & Gosling, 2012; Kaufmann *et al.*, 2009; Pfutze *et al*., 2002; Schweinberger *et al.*, 2004) and Face Recognition Units (Bruce & Young, 1986; Kaufmann *et al*., 2009) showed no between-group differences. Thus, while SRs appeared to have demonstrated a more effective pictorial processing, this increase in neural activity (P1) did not resonate in an increase at the level of N250. Previous studies have demonstrated that N250 amplitudes in relation to a recognised face becomes greater with each exposure to that identity (e.g., Kaufmann *et al.*, 2009). Indeed, Face Recognition Units are generally discussed with familiar face recognition, or face recognition of identities that have been presented on numerous occasions. Thus, it is possible that N250, unlike other ERPs, is particularly dependent on the frequency of exposure to facial identities, therefore the lack of group differences reported for this ERP could potentially be owing to a single exposure (i.e., single encoding opportunity) of each identity employed in this study.

Chapter 6 also explored whether SRs' recognition of faces derives from a concrete *recollection* of visual stimuli or a sense of *familiarity* and whether this distinction (e.g., Jacoby, 1991; Mandler, 1980; Tulving, 1985; Yonelinas, 2001) has a different behavioural and neural pattern to that of controls. SRs demonstrated a more accurate (d') recollection of faces and objects than controls, while SRs' and controls' discriminability of familiar stimuli was relatively low. Therefore, SRs' recognition of faces (and objects) is often accompanied by contextual information, in that they remember more than just the stimuli's identity. More accurate recollection in SRs potentially indicates that they are more effective in activating Semantic Information Units, the last stage in the face processing model (Bruce & Young, 1986; Burton *et al.,* 1990). Importantly, this aspect of recognition is especially applicable in forensic settings, which is further elaborated on in section 7.3. Indeed, SRs were expected to demonstrate greater recollection than controls since this aspect of recognition has been found to generate individual differences in performance across age (Koen & Yonelinas, 2014), attentional manipulations (McCabe *et al.*, 2011), and neurological conditions (Baddeley, 2002; Düzel *et al*., 2001; Martin *et al*., 2011a), unlike familiarity which appears to generate no group differences across studies (Koen & Yonelinas, 2014; Martin *et al*., 2011a; McCabe *et al.*, 2011), given that it is more of an automatic aspect of recognition.

Importantly, while controls' neural activity related to recognition (recollection, familiarity and correct identification of 'new'/unseen faces) remained in the central sites (i.e., channels Pz), SRs showed stronger recognition related activity in the central site (channel Pz) as well as in the right hemisphere (channel P4), suggesting their recognition-related neural activity spreads across a larger scalp area compared to controls. Note, however, that SRs' 'activation' of the right hemisphere during visual recognition should not be viewed as a qualitative difference in neural processing during recognition. It seems that the neural processing related to recognition takes place in the same brain region in all participants, with a merely stronger propagation or resonance in SRs than controls, potentially suggesting a quantitative superiority in processing. Furthermore, this stronger activation of neural networks related to recognition in SRs is in line with findings in Chapter 5 in which a different sample of SRs demonstrated higher amplitudes in P600, a component associated with explicit recognition.

As expected, given its more concrete feeling associated with explicit recognition, recollection generated stronger amplitudes (in the 300-500msec time line) and earlier latencies (in the 500-700msec time line) than familiarity. However, this study failed to demonstrate any group differences between amplitudes generated by these two aspects of recognition. Thus counter to predictions and counter to EEG findings reported in Experiment 5.2, recollection did not generate higher amplitudes in SRs compared to controls. This lack of group differences could be a result of statistical power limitations (further discussed in section 7.3.2.1), or a result of different tasks designs across Experiments 5.2 and 6.1. Indeed, the Remember/Know Test reported in Experiment 6.1 employed complex instructions and specific response options which induced a different type of cognitive load on participants compared to the basic (adult/infant) old/new tests employed in Experiment 5.2. Thus making direct comparisons of the EEG findings reported in Chapters 5 and 6 is problematic.

It is noteworthy, that while familiarity seemed similar in discriminability between SRs and controls on the behavioural level, SRs demonstrated earlier neural activity associated with familiarity. Indeed, in line with previous research on familiarity associated with the 300-500msec time line of neural processing (e.g., Yovel & Paller, 2004), SRs demonstrated earlier familiarity-induced neural activity in the 300-500msec time range, but not in the later time range. Importantly, this familiarity effect was mostly dominated by SRs' object processing than face processing, and indeed, in line with previous findings on familiarity for objects (Curran & Hancock, 2007), this effect was mostly observed in anterior channels. Thus SRs appear to be quicker to reach the feeling of familiarity for objects, and it is possible that this effect could potentially contribute to their general superiority in visual recognition, including face recognition. Indeed, SRs' neural activity showed an overall greater ease of object processing than controls as they showed earlier neural activity for object recognition overall (recollection, familiarity and correct identification of unseen stimuli taken together). Thus these EEG findings complement the results from Chapter 4 whereby SRs showed better object recognition performance than controls.

Overall, SRs demonstrated two neural markers of their face recognition superiority (P1 and P600), providing evidence that their behavioural advantage is reflected in neural activity at the earliest stage of face processing (Chapter 5). In addition, their recognition is often accompanied by contextual information/associations, suggesting they remember more than just the stimuli's identity (Chapter 6), though whether this is a result of a more effective encoding, or merely stronger activation of contextual associations with the said stimulus remains unclarified. Importantly, SRs demonstrated a stronger propagation of neural activity related to recognition of visual stimuli by spreading from central sites to the right hemisphere, which was not observed in controls, who only generated activity in the central sites. Finally, SRs appeared to reach the state of familiarity of object stimuli earlier than controls, which may or may not contribute to their general superiority in visual recognition. In line with findings discussed in section 7.2.2, neural findings related to SRs' face recognition suggest no qualitative differences compared to controls, demonstrating only a quantitative superiority.

7.2.5 Super-Recognisers' (SRs) visual recognition is not absolute: infant face processing

This thesis demonstrated that while SRs exceeded controls on most measures, results nevertheless indicated that their visual processing superiority is not absolute. Indeed, findings reported in Chapter 5 show that SRs' recognition for faces appears to be attenuated by experience, in that their recognition for infant faces significantly suffered in comparison to their recognition for adult faces. Thus, even though SRs outperformed controls at infant face recognition, they demonstrated a greater *Other Age Effect (OAE)* as measured by sensitivity index (d'). Whether the drop for infant face recognition performance was owing to participants' limited experience with infant faces or owing to the relative homogeneity of infant faces, making them perceptually more difficult to process, remains unknown. It is noteworthy that one SR was excluded from group analyses given their daily exposure to infants (paediatric hospital). Highlighting the role of individual experience in attenuating the OAE (e.g., Kuefner *et al*., 2008; Macchi Cassia, Picozzi *et al*., 2009), this SR alone demonstrated similar performance on adult and infant face recognition.

Importantly, the recognition-based OAE demonstrated in Experiments 5.1 and 5.2 was also observed at the level of perception in Experiment 5.3, in that SRs were more accurate at adult face matching than infant face matching. However, this OAE observed for both SRs and controls was potentially driven by a more conservative response bias during adult face matching, which induced a more accurate recognition of previously unseen adult faces. It is possible that SRs' drop in performance for infant faces is owing to a reduced holistic processing of infant faces, though this effect was only observed for correct rejections. Thus it appears that adult faces induced a more effective holistic processing in SRs, which made them more conservative in their adult face matching decisions compared to the infant condition. An interesting observation from the SR individual analyses was that the higher their CFMT+ score, the less likely they were to display the IE (d') for infant faces, potentially implying that exceptional SRs process infant faces in a parts-based manner. This reduced IE for infant faces mirrors the reduced IE observed for faces of other ethnicities (e.g., Hancock & Rhodes, 2008; Rhodes, Tan, Brake, & Taylor, 1989), which are also argued to induce a more parts-based processing (less effective holistic processing) compared to own ethnicity faces. Note that section 7.2.1 revealed that 95+ CFMT+ scorers demonstrate better object processing than 93/94 CFMT+ scorers, indicative of a more effective parts-based processing. This potentially suggests that higher scorers were more likely to employ their presumably greater parts-based processing during infant face matching.

Importantly, the OAE demonstrated by both SRs and controls was observed in their neural activity as well. For instance, N250, associated with implicit face discrimination (e.g., Eimer & Gosling, 2012; Kaufmann *et al.*, 2009; Pfutze *et al*., 2002; Schweinberger *et al.*, 2004) was shown to peak earlier for adult faces than for infant faces. Given that earlier latencies are potentially indicative of a more efficient processing (e.g., Kaltwasser *et al.*, 2013), it appears that the internal representations of adult faces were potentially activated with more ease than internal representations of infant faces.

The second OAE neural marker was observed for correct rejections, in that correctly rejected infant faces generated higher amplitudes at the level of P600. When analysing hits (faces correctly identified as previously seen before) higher P600 amplitudes are expected to accompany more efficient recognition. If the same interpretation could be implied for correct rejections (faces correctly identified as 'new'), then higher P600 amplitudes for infant faces would indicate that infant faces were easier to recognise as 'new'. Note however, that hits and correct rejections should not be directly compared to one another, as they appear to reflect different processes (Experiments 4.1 and 5.1). Importantly, behavioural findings of this study (Experiment 5.2) indicate that infant face processing induced a more liberal response bias in participants, with fewer correct rejections recorded than for adult faces. Why a more liberal response bias for infant face recognition (a tendency to press 'old' – hits, rather than 'new'- correct rejections) would result in higher amplitudes at P600 for correct rejections, is unclear. This reverse pattern of neural findings for correct rejections could potentially suggest that participants employed different strategies during infant face processing, thereby attenuating how they recognised infant faces as 'new'. A similar point was made by Wiese *et al*. (2012) who found higher amplitudes for hits in young adults during young adult face processing, and higher amplitudes for correct rejections in elderly participants during elderly face processing. Most importantly, though, the neural markers of the OAE were only significant and observed for participants as a whole, without taking groups into account (but see section 7.3.2.1), and this lack of group difference in neural OAE mirrored the lack of group difference in behavioural OAE (hits) observed in this study (Experiments 5.2 and 5.3).

7.3 Applicability, limitations and future directions

To conclude on the findings of the experiments conducted as part of this thesis, this final section discusses potential applications in forensic and clinical settings, while also acknowledging the thesis' design limitations and suggesting relevant factors to consider in future investigations.

7.3.1 Forensic and clinical applications of this thesis' findings

There are several ways to consider the applicability of this thesis's findings. First, there is a need for new visual processing tests to be developed. Indeed, experiments described in this thesis recruited a substantial number of participants with exceptional CFMT+ scores, yet employing a second face recognition test to verify ability demonstrated that CFMT+ does not always accurately identify SR (see sections 4.1.1.2, 4.2.1.2 and 7.2.1). Improved tests are needed to facilitate the appropriate allocation of individuals to employment positions in forensic contexts, while also removing unsuitable individuals from key positions involving face discrimination decisions. Indeed, research has shown that sometimes trained passport officers (regardless of their job experience) are no better at matching passport photos as untrained controls from the general population (e.g., White *et al.,* 2014). Given the variety of tests employed in this thesis with controls sometimes generating SR-like performance, it is important to tease out the tests' specific aspects where guess work is minimised and only exceptional and informative scores related to face processing are highlighted.

Next, while the SR teams in police force are very effective at using their skill to arrest culprits, in order for these cases to progress to court/trial hearings other relevant evidence must be provided. For instance, evidence of greater recollection in SRs, whereby they remember factors other than identity (Experiment 6.1), suggests that they are more likely to know/suggest where to obtain other evidence in relation to a specific case.

Finally, clinical applications may be considered as well given that any investigation into individual differences in face processing provide insight into training and improvement paradigms to assist clinical groups who suffer from face processing impairments. For instance, in line with previous research (e.g., Chan *et al.*, 2016; Lobmaier *et al.*, 2010; Pizzamiglio *et al.*, 2015), this thesis highlights that attention to individual features enhances face processing (Experiments 4.2 and 4.3). Note, however, that Ramon *et al.* (2016) demonstrated that *Super-Memorisers*, who, over the years of training, demonstrate extraordinary general recognition ability, generated average performance on CFMT+. Ramon *et al.* (2016) thus suggest that face recognition ability is unlikely to be significantly improved by mnemonic techniques in the neuro-typical population.

7.3.2 Limitations and future directions

There are several limitations in the design of the experiments reported throughout the thesis which must be acknowledged so that the results are interpreted with caution, and so that these factors are considered in future research.

7.3.2.1 Design and measurements: validity and reliability

One of the limitations of the thesis's design is the small number of participants recruited to be tested in the laboratory, suggesting that generalisation of the results may be in question, and indeed, the individual analyses demonstrate that not all SRs showed the same consistent pattern of results. Indeed, while online testing reported in Chapters 4 and 5 (Experiments 4.1 and 5.1) partly confirmed that laboratory SRs were representative of SRs on a grander scale, their EEG findings could not be confirmed (Experiments 5.2 and 6.1), as well as their performance on the matching tests employed in Chapters 4 (Experiments 4.2 and 4.3) and 5 (Experiment 5.3). However, as this thesis recruited far larger numbers of SRs ($n > 20$) than has been reported in existing published research (see section 7.2.2), and given that SR is an atypical group, the findings discussed in this thesis undoubtedly contribute to the existing knowledge on SR. It should be noted, however, that laboratory SRs showed a slightly inferior performance on some measures to SRs in the wider population. Therefore, the significant differences found between controls and SRs in the laboratory tests may have been greater if superior SRs had been recruited. Though as mentioned in Chapter 4, the online participants could have performed slightly better than the laboratory participants given that the images uploaded online were greater in size compared to those displayed on the laboratory computer.

Second, the limitations of statistical power may have also affected the EEG findings discussed in Chapters 5 and 6. While EEG studies typically employ as few as 5-10 individuals per group, when atypical populations are investigated, the fact that Experiments 5.2 and 6.1 used as few as 17 SRs for EEG analyses, is nevertheless an important limitation to acknowledge. EEG findings can also be compromised by the low number of trials being averaged out per condition for each participant. For instance, Experiment 6.1 proved to be problematic in guaranteeing a specific number of artefact-free trials for each condition. Indeed participants were expected to generate a significant number of three response-types ('remember', 'know' and 'new' responses) for each stimulus-type (faces and objects). However, participants showed significant individual differences, in that some did not rely much on recollection ('remember' responses) when recognising faces and/or objects, while others showed the opposite pattern. This issue was anticipated based on pilot testing, however even though the number of trials was increased, thereby increasing the frequency of each response (and the number of noise-free trials), this increase did not solve the problem completely, limiting statistical power. Furthermore, while Experiment 5.2 found several informative group differences between SRs and controls in neural activity, and the study retained only participants with at least 15-20 artefact-free trials per condition, the statistical power of the EEG findings could have been greater if there were more artefact-free trials available. Indeed, there was a specific trend in the data that did not reach statistical significance. For instance, N170, the most prominent face-related ERP, associated with structural encoding (e.g., Bentin *et al*., 1996), showed marginal group differences, whereby SRs showed marginally weaker N170 amplitudes compared to controls during infant face recognition. This effect, possibly underlying the neural indication of SRs' OAE may have been stronger if more artefact-free trials or more participants were included in the analysis.

Next, another design limitation is discussed in Chapter 6 where the constraining nature of the tests made it difficult to tease out SRs' differences in neural/electrical activity between face and object processing. Indeed, the face condition of the *Remember/Know Test* (using two face categories: male and female) was judged to be more challenging for participants than the object condition (using eight categories of objects), making a direct neural comparison of different stimuli processing in SRs problematic. Furthermore, given the heterogeneous nature of the object stimuli and a relatively homogeneous nature of face stimuli used in this study, EEG analysis showed more neural group differences for objects, than for faces. This limitation, taken together with a relatively low number of trials generated by participants, suggests that there may be other potential group differences that remained unidentified.

It should also be pointed out that all of the laboratory tests discussed throughout the thesis were administered in two independent sessions (session one – Experiments 4.2 and 5.2; session two – Experiments 4.3, 5.3 and 6.1), therefore each participant underwent over two hours of testing. Thus, given the demanding nature of some of the tests, the fatigue effects could have attenuated individual performance generated by SRs and controls, thereby potentially explaining the individual analyses differences. Therefore, employing such long testing sessions comes with a cost, whereby face recognition ability is tested alongside resilience, vigilance and other attention-related factors. The same applies for online studies reported in Experiments 4.1 and 5.1, where participants were administered four recognition tests (CFMT+, (adult and infant) face and object (old/new) recognition tests) amounting to 90min of testing. Furthermore, the time participants were given to memorise target images (2 seconds per image) in all recognition tests employed throughout the thesis, could be conceived as too brief. Thus, in order to maximise SRs' performance in future studies, shorter testing sessions are proposed to avoid fatigue effects while allowing more encoding time for target images. Allowing more time to memorise images may potentially encourage deeper processing/encoding of faces, thereby increasing recognition performance (e.g., Marzi & Viggiano, 2010). However, it is difficult to predict if and how much longer encoding sessions would attenuate group differences when comparing SRs to controls. Therefore future studies should test SRs under different timing conditions to explore whether both SRs and controls benefit from longer encoding sessions and if these potential effects are of similar magnitude.

Finally, one important limitation of the current design in exploring SR, is foregoing the use of any long-term recognition tests. Indeed, most face processing research employs only briefly delayed paradigms in testing participants' recognition (although see Joyce & Kutas, 2005). While SRs are expected to show enhanced long-term face recognition than individuals with average face recognition, there is no published evidence to suggest that all or even most SRs would demonstrate this superiority. This is an important aspect of face processing that has been excluded by all previous research on SR and should be included in future investigations. Indeed, it could be considered an important criterion for SR classification.

7.3.2.2 Group differences unrelated to visual processing: age and motivation

Another limitation to this study is the age difference observed between groups in Experiments 4.3 and 5.3, in which SRs (mean age = 37.42, *SD* = 8.38) were older than controls (mean age = 29.35, *SD* = 10.29). Given that age has been found to positively correlate with face recognition, at least up to mid-30's (e.g., Susilo *et al*., 2013), and that face processing appears to decline after the age of 50 (e.g., Bowles *et al*., 2009; Crook & Larrabee, 1992), this could potentially suggest that the group differences found between SRs and controls were at least partly owing to SRs' greater age. If this were the case, SRs' superiority in face processing could be deemed a natural consequence of their recognition improving with age, thereby implying that if they were tested at a younger age, they would show similar performance to that of controls. However, while age undoubtedly attenuated some of the participants' performance in Experiments 4.3 and 5.3, it is unlikely that age contributes significantly to SRs' extraordinary face processing ability. Indeed, 13 out of 24 SRs were within 1 SD of the control mean age in Experiment 4.3, and only 2 out of 24 SRs were older than 50 (53 years old) in Experiment 5.3. Furthermore, individual analyses of SRs' performance indicated no visible pattern whereby age could attenuate performance. Finally, young SRs are also prevalent in all experiments described in this thesis, as well as published research, thus it is unlikely that age had a significant effect on the results.

Motivation is another factor that could potentially contribute to participants' performance on the visual processing tests employed in this thesis. This was not controlled for. It is arguable that SRs as a group would be more motivated than controls to perform better on the tests which are explicitly designed to investigate their extraordinary skills in face processing (see Noyes *et al*., 2017). Thus the interpretation of SRs' enhanced performance on face processing tests is always partly confounded by the fact that their motivation-driven attention to tests potentially helps them outperform controls. However, counter to the previous proposal of SRs being a more motivated group compared to controls, it is possible that SRs are neither more nor equally motivated as controls. Given the little resemblance of laboratory tests to the natural environment scenarios, many potential SRs and trained police officers may find the laboratory testing a too narrow approach, potentially failing to demonstrate their skills appropriately, thereby demotivating them. Indeed, the exceptional work carried out by police officers on the SR units involves a number of factors that are barely touched upon in research investigations, including the long-term recognition of briefly seen identities, as well as processing moving or poor quality images, while considering factors other than faces, such as body and gait.

Importantly, Bobak, Dowsett *et al*. (2016) attempted to experimentally control for motivation by means of monetary incentives, and found that 'motivated' controls performed similarly to 'non-motivated' controls. However, this lack of motivation-driven difference in performance cannot transcend to all studies using SRs and controls. Note that the majority of participants recruited for studies described in this thesis were only compensated for their travel, and only a few were granted course credits, thus monetary incentive was not applied in this research, potentially suggesting similarly motivated participation based on the interest in the topic. Furthermore, online participants (SRs and controls) recruited for Experiments 4.1 and 5.1 could be viewed as equally motivated, assuming that they were all interested in the topic of face processing and believed themselves to be good at face recognition. Indeed, unmotivated individuals would be unlikely to complete a testing session over one hour long.

Thus, while motivation demonstrated by participants described in this thesis could be viewed as reasonably similar across SRs and controls, it is nevertheless a possibility that motivation attenuated individual scores on experimental tests in this thesis. Future studies could employ an additional questionnaire with several questions intended to indirectly measure the participants' motivation (and reason for their participation), in order to eventually exclude unmotivated individuals from group analysis.

7.4 Conclusion

This thesis was designed to explore what perceptual and recognition-based aspects of face processing distinguish SRs from individuals with average face recognition. The thesis set out to clarify whether SRs' superiority is of quantitative nature or if they demonstrate qualitatively different processing styles when viewing faces. Furthermore, the examination of individual differences in face processing reported throughout this thesis was complemented by electrophysiological recordings, in order to demonstrate whether SRs' superiority in face processing could be observed at the level of EEG activity as well. Taken together, the findings reported in this thesis demonstrate that SRs' extraordinary face processing ability is a result of a quantitative superiority, demonstrated at the level of behavioural and neural activity.

First, Chapter 4 presented an extensive exploration of SRs' holistic and parts-based processing in order to examine potential qualitative and quantitative differences in SRs' perceptual processing. Chapter 4 showed that some SRs rely on holistic processing to a greater extent than controls, which was demonstrated by a greater Inversion Effect (IE). Furthermore Chapter 4 showed that SRs demonstrate an enhanced parts-based processing, as was reflected in their enhanced object recognition, enhanced inverted face recognition, enhanced feature matching and *reduced* Composite Face Effect (CFE). Indeed, it is possible that SRs' enhanced parts-based processing attenuated their Part-Whole effect (PWE), to a greater extent than it potentially attenuated their IE, resulting in similar holistic processing observed for perceptual PWE and increased holistic processing observed for recognition-based IE.

Second, Chapters 5 and 6 demonstrated that SRs' exceptional face recognition ability is indeed observed at the level of neural/electrical activity, as they showed several neural markers of their visual recognition superiority. Indeed, SRs' face recognition superiority is reflected in neural differences observed at the earliest stage of face processing, as reflected in an enhanced P1, a component associated with pictorial encoding. SRs' neural differences are also observed at a later stage, reflected in greater P600, a component associated with explicit recognition of faces. Furthermore, the neural activity related to recognition of visual stimuli appears to spread from central sites to the right hemisphere in SRs, while remaining in the central sites in controls. Finally, Chapter 6 also showed that while SRs' recognition is often accompanied by contextual associations, suggesting they remember more than just the stimuli's identity, they also appear to reach the state of familiarity of object stimuli earlier than controls, reflected in earlier latencies in anterior channels for stimuli classified as familiar. It is possible that this earlier familiarity effect may contribute to SRs' general superiority in visual recognition.

Third, Chapter 4 also showed that SRs' superiority in face recognition is observed at the face perception stage as well, with the latter potentially contributing to the effectiveness of the former. Indeed, it is possible that SRs' recognition superiority is a result of their perception superiority. However, there were a few SRs who demonstrated average face perception despite superior face recognition, thereby potentially attributing their recognition superiority to a more effective activation of internal face representations. This observation suggests that SR, similar to DP, is not a homogeneous construct, and that some SRs excel at recognition and perception, while others only excel at recognition. Importantly, SRs' heterogeneity was observed for other aspects of visual processing, in that their individual performances varied within each SR sample on most measures. Furthermore, while SRs' exceptional face processing skills are often observed at the level of recognition and perception, this thesis also demonstrated that their superiority transcends to stimuli other than upright faces. Indeed, SRs significantly outperformed controls on object recognition (Chapter 4) and on recognition of faces they have relatively less experience with – infant faces (Chapter 5).

Fourth, SRs appear to be super-rejecters as well, as they persistently demonstrated superior rate of correct rejections for adult and infant faces as well as objects. This particular advantage potentially contributes to their overall visual discriminability.

Finally, this thesis demonstrated that SRs' visual processing superiority is not absolute. Indeed Chapter 5 demonstrated that SRs' face recognition superiority can be modulated by individual experience, whereby their performance significantly suffers for faces they have less exposure to, thereby demonstrating the other age effect (OAE).

In conclusion, SRs showed no evidence of qualitative differences in face processing compared to individuals with average recognition ability, in that they demonstrated similar perceptual processes, similar neural activity and similar performance modulation/hindrance when stimuli other than upright faces are employed. Thus while showing no qualitative differences; SRs demonstrate behavioural and neural superiority in face recognition ability which appears to be purely quantitative in nature.

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Appendix 3.2.1

Participant Additional Information
Your personal code…………………………………………………
Date of birth………………………………………………………
Gender……………………………………………………………
Which hand do you write with?..
Ethnicity………………………………………………………….
Visual acuity………..……..……………………………………
Medication………………………………………………………..
Neurological/psychiatric conditions……………………………………
Occupation………………………………………………………..
If you have any young children in the family (e.g., nephews/nieces or other), what is their age?……………….………………………………

Figure A3.2.1.1 Additional information sheet for participant selection

Appendix 4.2.2.

Table A4.2.2.1. Individual SR performance on Face-specific recognition (FSR) d/ *against the control mean (Experiment 4.2)*

SRs	CFMT + (102)	test score FSR d/	significance t value	p value		Effect size Z-cc	population % falling below	95% confidence Interval	
1	93	1.73	1.25	0.221		1.27	88.96	78.86,	95.75
2	94	0.67	-0.22	0.826		-0.23	41.29	28.46,	54.85
3	94	0.92	0.13	0.901		0.13	54.93	41.42,	68.02
4	94	1.24	0.57	0.573		0.58	71.33	58.10,	82.71
5	94	1.87	1.44	0.159		1.47	92.06	83.28,	97.46
6	94	2.39	2.17	0.038	*	2.20	98.10	94.02,	99.77
7	94	1.25	0.58	0.564		0.59	71.79	58.60,	83.10
8	94	1.20	0.51	0.611		0.52	69.44	56.10,	81.10
9	95	1.33	0.69	0.493		0.70	75.36	62.47,	86.03
10	95	1.36	0.74	0.467		0.75	76.63	63.88,	87.05
11	95	1.04	0.29	0.773		0.30	61.37	47.80,	73.97
12	95	0.60	-0.32	0.752		-0.32	37.58	25.09,	51.14
13	95	0.63	-0.28	0.783		-0.28	39.16	26.51,	52.73
14	95	0.74	-0.13	0.901		-0.13	45.07	31.98,	58.58
15	96	2.38	2.15	0.039	*	2.18	98.04	93.89,	99.75
16	96	1.79	1.33	0.192		1.35	90.39	80.84,	96.57
17	96	1.52	0.96	0.346		0.97	82.72	70.92,	91.65
18	96	0.68	-0.21	0.836		-0.21	41.82	28.95,	55.39
19	98	2.63	2.50	0.018	*	2.54	99.11	96.59,	99.94
20	100	0.30	-0.74	0.467		-0.75	23.37	12.95,	36.12

*p < .05 **

Table A4.2.2.2. Individual SR performance on Inversion Effect (IE) against the control mean (Experiment 4.2)

SRs	CFMT + (102)	test score IE (%)	significance t value	p value	Effect size Z-cc	population % falling below	95% confidence Interval
1	93	16.67	-0.24	0.809	-0.25	40.43	27.49, 54.21
2	94	23.53	0.75	0.457	0.77	77.16	64.26, 87.60
3	94	33.34	2.18	0.037*	2.21	98.15	94.06, 99.79
4	94	40.20	3.18	0.003*	3.23	99.83	99.07, 100.0
5	94	31.38	1.90	0.067	1.93	96.63	90.82, 99.39
6	94	45.10	3.89	< 0.001**	3.95	99.97	99.82, 100.0
7	94	33.34	2.18	0.037*	2.21	98.15	94.06, 99.79
8	94	28.43	1.47	0.153	1.49	92.37	83.57, 97.67
9	95	18.62	0.04	0.969	0.04	51.55	37.94, 65.03
10	95	48.04	4.32	< 0.001**	4.39	99.99	99.94, 100.0
11	95	43.14	3.61	0.001**	3.66	99.95	99.64, 100.0
12	95	40.20	3.18	0.003*	3.23	99.83	99.07, 100.0
13	95	39.22	3.04	0.005*	3.08	99.76	98.74, 100.0
14	95	42.16	3.46	0.002*	3.52	99.92	99.50, 100.0
15	96	26.47	1.18	0.247	1.20	87.67	76.95, 95.06
16	96	27.45	1.32	0.195	1.34	90.23	80.45, 96.55
17	96	40.20	3.18	0.003*	3.23	99.83	99.07, 100.0
18	96	33.34	2.18	0.037*	2.21	98.15	94.06, 99.79
19	98	40.20	3.18	0.003*	3.23	99.83	99.07, 100.0
20	100	13.73	-0.67	0.507	-0.68	25.33	14.38, 38.50

*p < .05 * p < .001*

Table A4.2.2.3. Individual SR performance on Composite face effect $_{Accuracy}$ against the control mean (Experiment 4.2)

SRs	CFMT + (102)	test score CFE (%)	significance t value	p value	Effect size Z-cc	population % falling below	95% confidence Interval	
1	93	7.50	-1.23	0.227	-1.25	11.34	4.35,	21.73
2	94	10.00	-1.10	0.282	-1.11	14.09	6.07,	25.34
3	94	10.00	-1.10	0.282	-1.11	14.09	6.07,	25.34
4	94	10.00	-1.10	0.282	-1.11	14.09	6.07,	25.34
5	94	15.00	-0.82	0.419	-0.83	20.95	10.93,	33.59
6	94	22.50	-0.41	0.688	-0.41	34.41	22.08,	48.12
7	94	30.00	0.01	0.993	0.01	50.35	36.78,	63.88
8	94	42.50	0.70	0.490	0.71	75.51	62.42,	86.29
9	95	22.50	-0.41	0.688	-0.41	34.41	22.08,	48.12
10	95	-14.50	-2.45	0.020*	-2.49	1.01	0.07,	3.81
11	95	0.00	-1.65	0.110	-1.67	5.48	1.37,	12.99
12	95	12.50	-0.96	0.346	-0.97	17.30	8.25,	29.30
13	95	22.50	-0.41	0.688	-0.41	34.41	22.08,	48.12
14	95	70.00	2.22	0.034*	2.25	98.29	94.40,	99.81
15	96	10.00	-1.09	0.282	-1.11	14.09	6.07,	25.34
16	96	10.00	-1.09	0.282	-1.11	14.09	6.07,	25.34
17	96	12.50	-0.96	0.346	-0.97	17.30	8.25,	29.30
18	96	15.00	-0.82	0.419	-0.83	20.95	10.93,	33.59
19	98	35.00	0.29	0.778	0.29	61.11	47.34,	73.92
20	100	12.50	-0.96	0.346	-0.97	17.30	8.25,	29.30

*p < .05 **

Table A4.2.2.4. Individual SR performance on Composite face effect $_{RTs}$ against the control mean (Experiment 4.2)

SRs	CFMT+ (102)	test score CFE (RT)	significance t value	p value		Effect size Z-cc	population % falling below	95% confidence Interval	
1	93	0.13	0.57	0.572		0.58	71.38	58.15,	82.75
2	94	-0.11	-0.67	0.505		-0.68	25.26	14.46,	38.21
3	94	-0.02	-0.21	0.837		-0.21	41.85	28.98,	55.41
4	94	-0.20	-1.14	0.262		-1.16	13.12	5.53,	23.90
5	94	0.11	0.47	0.644		0.47	67.80	54.38,	79.69
6	94	-0.04	-0.31	0.758		-0.32	37.89	25.36,	51.45
7	94	0.04	0.10	0.918		0.11	54.10	40.61,	67.24
8	94	0.24	1.14	0.262		1.16	86.88	76.10,	94.47
9	95	-0.11	-0.67	0.505		-0.68	25.26	14.46,	38.21
10	95	0.14	0.62	0.538		0.63	73.09	59.99,	84.18
11	95	0.04	0.10	0.918		0.11	54.10	40.61,	67.24
12	95	0.07	0.26	0.797		0.26	60.15	46.57,	72.85
13	95	0.28	1.35	0.187		1.37	90.65	81.21,	96.71
14	95	0.24	1.14	0.262		1.16	86.88	76.10,	94.47
15	96	-0.04	-0.31	0.758		-0.32	37.89	25.36,	51.45
16	96	0.05	0.16	0.877		0.16	56.13	42.60,	69.15
17	96	-0.03	-0.26	0.797		-0.26	39.85	27.15,	53.43
18	96	0.45	2.23	0.033	*	2.26	98.35	94.62,	99.82
19	98	0.65	3.27	0.003	*	3.32	99.87	99.25,	100.0
20	100	0.32	1.56	0.130		1.58	93.52	85.52,	98.16

*p < .05 **

Table A4.2.2.5. SRs' and controls' mean scores of the standardised Inversion Effect (IE)

Standardised Inversion Effect	SRs (*n* = 20)	Controls (*n* = 32)	t-tests *t* value	*p* value	Effect size *d*
Mean	0.36	0.25	3.75	< .001	1.14
(SD)	(0.11)	(0.08)	.	.	.
95% Confidence	0.31	0.22	.	.	.
Interval	0.41	0.29	.	.	.

Table A4.2.2.6. Individual SR performance on the standardised Inversion Effect against the control mean (Experiment 4.2)

SRs	CFMT + (102)	IE (normalised)	significance t value	p value	Effect size Z-cc	population % falling below	95% confidence Interval
1	93	0.18	-0.86	.396	-0.88	19.78	10.05, 32.24
2	94	0.36	1.35	.186	1.38	90.72	81.15, 96.82
3	94	0.44	2.34	.026 *	2.38	98.71	95.42, 99.89
4	94	0.49	2.95	.006 *	3.00	99.70	98.52, 99.99
5	94	0.34	1.11	.276	1.13	86.18	75.01, 94.11
6	94	0.36	1.35	.186	1.38	90.72	81.15, 96.82
7	94	0.31	0.74	.466	0.75	76.71	63.76, 87.25
8	94	0.26	0.12	.903	0.13	54.86	41.14, 68.15
9	95	0.46	2.59	.015 *	2.63	99.27	97.02, 99.96
10	95	0.43	2.22	.034*	2.25	98.29	94.39, 99.81
11	95	0.52	3.32	.002 *	3.38	99.89	99.32, 100.0
12	95	0.42	2.09	.045 *	2.13	97.77	93.18, 99.70
13	95	0.20	-0.62	.542	-0.63	27.14	15.86, 40.47
14	95	0.45	2.46	.019*	2.50	99.02	96.29, 99.93
15	96	0.35	1.23	.228	1.25	88.62	78.22, 95.63
16	96	0.43	2.22	.034*	2.25	98.29	94.39, 99.81
17	96	0.29	0.49	.626	0.50	68.70	55.11, 80.63
18	96	0.28	0.37	.714	0.38	64.28	50.54, 76.76
19	98	0.42	2.09	.045 *	2.13	97.77	93.18, 99.70
20	100	0.14	-1.35	.186	-1.38	9.28,	3.18, 18.85

Appendix 4.3.2.

Table A4.3.2.1. Individual SR scores on face matching against the control mean (Experiment 4.3)

SRs	CFMT+ (102)	test score Face matching (%)	significance t value	p value		Effect size Z-cc	population % falling below	95% confidence Interval	
1	94	72.22	-0.19	0.849		-0.20	42.47	25.81,	60.22
2	94	80.56	0.72	0.480		0.74	75.98	58.78,	89.27
3	94	87.50	1.48	0.156		1.52	92.20	80.03,	98.52
4	94	84.72	1.18	0.255		1.21	87.26	72.61,	96.35
5	94	80.56	0.72	0.480		0.74	75.98	58.78,	89.27
6	95	81.94	0.87	0.395		0.89	80.26	63.70,	92.23
7	95	88.89	1.63	0.120		1.68	94.01	83.17,	99.11
8	95	94.44	2.24	0.038	*	2.30	98.11	92.22,	99.92
9	95	86.11	1.33	0.201		1.36	89.97	76.51,	97.63
10	95	87.50	1.48	0.156		1.52	92.20	80.03,	98.52
11	96	86.11	1.33	0.201		1.36	89.97	76.51,	97.63
12	96	93.06	2.09	0.051		2.14	97.44	90.45,	99.85
13	96	87.50	1.48	0.156		1.52	92.20	80.03,	98.52
14	96	95.83	2.39	0.028	*	2.46	98.61	93.74,	99.96
15	97	90.28	1.79	0.091		1.83	95.44	85.94,	99.49
16	98	77.78	0.42	0.682		0.43	65.89	48.05,	81.38
17	98	95.83	2.39	0.028	*	2.46	98.61	93.74,	99.96
18	99	88.89	1.63	0.120		1.68	94.01	83.17,	99.11
19	99	84.72	1.18	0.255		1.21	87.26	72.61,	96.35
20	99	70.83	-0.35	0.734		-0.35	36.71	20.80,	54.57
21	99	93.06	2.09	0.051		2.14	97.44	90.45,	99.85
22	100	94.44	2.24	0.038	*	2.30	98.11	92.22,	99.92
23	101	86.11	1.33	0.201		1.36	89.97	76.51,	97.63
24	101	90.28	1.79	0.091		1.83	95.44	85.94,	99.49

*p < .05 **

Table A4.3.2.2. Individual SR performance on feature matching against the control mean (Experiment 4.3)

SRs	CFMT+ (102)	test score feature matching (%)	significance t value	p value		Effect size Z-cc	population % falling below	95% confidence Interval	
1	94	70.83	1.07	0.300		1.10	85.01	69.61,	95.15
2	94	83.33	2.54	0.020	*	2.61	98.98	94.97,	99.98
3	94	76.39	1.72	0.102		1.77	94.90	84.85,	99.36
4	94	68.06	0.74	0.468		0.76	76.60	59.47,	89.71
5	94	62.50	0.09	0.932		0.09	53.38	35.81,	70.46
6	95	72.22	1.23	0.234		1.26	88.30	74.08,	96.87
7	95	73.61	1.40	0.180		1.43	91.01	78.11,	98.07
8	95	76.39	1.72	0.102		1.77	94.90	84.85,	99.36
9	95	61.11	-0.08	0.939		-0.08	46.94	29.84,	64.49
10	95	70.83	1.07	0.300		1.10	85.01	69.61,	95.15
11	96	75.00	1.56	0.136		1.60	93.18	81.70,	98.86
12	96	76.39	1.72	0.102		1.77	94.90	84.85,	99.36
13	96	75.00	1.56	0.136		1.60	93.18	81.70,	98.86
14	96	75.00	1.56	0.136		1.60	93.18	81.70,	98.86
15	97	63.89	0.25	0.806		0.26	59.72	41.90,	76.12
16	98	66.67	0.58	0.571		0.59	71.46	53.85,	85.87
17	98	90.28	3.36	0.003	*	3.45	99.83	98.74,	100.0
18	99	61.11	-0.08	0.939		-0.08	46.94	29.84,	64.49
19	99	84.72	2.71	0.015	*	2.78	99.27	96.10,	99.99
20	99	72.22	1.23	0.234		1.26	88.30	74.08,	96.87
21	99	83.33	2.54	0.020	*	2.61	98.98	94.97,	99.98
22	100	79.17	2.05	0.055		2.10	97.24	89.94,	99.82
23	101	72.22	1.23	0.234		1.26	88.30	74.08,	96.87
24	101	69.44	0.90	0.378		0.93	81.10	64.71,	92.78

*p < .05 **

Table A4.3.2.3. Individual SR scores of the Part-Whole Effect $_{Accuracy}$ against the control mean (Experiment 4.3)

SRs	CFMT+ (102)	test score PWE (%)	significance t value	p value		Effect size Z-cc	population % falling below	95% confidence Interval	
1	94	9.72	-0.21	0.838		-0.21	41.90	25.30,	59.67
2	94	11.11	-0.07	0.947		-0.07	47.37	30.23,	64.90
3	94	-1.39	-1.33	0.199		-1.37	9.97	2.34,	23.40
4	94	5.56	-0.63	0.538		-0.65	26.88	12.85,	44.37
5	94	-1.39	-1.05	0.307		-1.08	15.37	5.07,	30.89
6	95	-4.17	-1.61	0.124		-1.66	6.20	0.95,	17.22
7	95	4.17	-0.77	0.452		-0.79	22.59	9.71,	39.61
8	95	15.28	0.36	0.727		0.36	63.67	45.81,	79.52
9	95	19.44	0.78	0.448		0.80	77.62	60.63,	90.43
10	95	6.94	-0.49	-0.631		-0.50	31.54	16.51,	49.31
11	96	4.17	-0.77	0.452		-0.79	22.59	9.71,	39.61
12	96	22.22	1.06	0.304		1.09	84.79	69.32,	95.02
13	96	18.06	0.64	0.532		0.65	73.38	55.91,	87.34
14	96	15.28	0.36	0.727		0.36	63.67	45.81,	79.52
15	97	33.33	2.18	0.043	*	2.24	97.87	91.57,	99.90
16	98	0.00	-1.19	0.249		-1.22	12.45	3.50,	26.98
17	98	4.17	-0.77	0.452		-0.79	22.59	9.71,	39.61
18	99	27.78	1.62	0.122		1.66	93.87	82.92,	99.07
19	99	-5.56	-1.75	0.096		-1.80	4.82	0.58,	14.60
20	99	-1.39	-1.33	0.199		-1.37	9.97	2.34,	23.40
21	99	13.89	0.22	0.833		0.22	58.37	40.59,	74.94
22	100	15.28	0.36	0.727		0.36	63.67	45.81,	79.52
23	101	4.17	-0.77	0.452		-0.79	22.59	9.71,	39.61
24	101	22.22	1.06	0.304		1.09	84.79	69.32,	95.02

*$p < .05$ **

Table A4.3.2.4. Individual SR scores of the Part-Whole Effect $_{RT}$ against the control mean[16]*(Experiment 4.3)*

SRs	CFMT+ (102)	test score PWE (sec)	significance t value	p value		Effect size Z-cc	population % falling below	95% confidence Interval	
1	94	-0.84	-1.78	0.091		-1.83	4.57	0.52,	14.10
2	94	0.07	0.38	0.708		0.39	64.59	46.74,	80.30
3	94	-0.57	-1.14	0.269		-1.17	13.44	4.01,	28.34
4	94	.	.	.		.	.	.	.
5	94	0.01	0.24	0.815		0.24	59.26	41.45,	75.72
6	95	-0.40	-0.74	0.471		-0.76	23.53	10.38,	40.68
7	95	0.11	0.48	0.640		0.49	67.99	50.21,	83.11
8	95	-3.22	-7.44	<0.001	**	-7.63	<0.01	0.00,	0.00
9	95	-2.40	-5.49	<0.001	**	-5.63	<0.01	0.00,	0.01
10	95	-0.28	-0.45	0.657		-0.46	32.84	17.57,	50.66
11	96	-2.05	-4.66	<0.001	**	-4.78	0.01	0.00,	0.08
12	96	-1.18	-2.59	0.018	*	-2.66	0.92	0.01,	4.66
13	96	-0.64	-1.31	0.208		-1.34	10.37	2.52,	24.00
14	96	-1.32	-2.92	0.009	*	-3.00	0.45	0.00,	2.73
15	97	0.23	0.76	0.457		0.78	77.17	60.11,	90.12
16	98	-0.51	-1.00	0.331		-1.02	16.56	5.77,	32.41
17	98	-3.67	-8.51	<0.001	**	-8.73	<0.01	0.00,	0.00
18	99	-0.92	-1.97	0.064		-2.02	3.20	0.25,	11.12
19	99	-0.83	-1.76	0.096		-1.81	4.78	0.57,	14.51
20	99	-0.71	-1.47	0.158		-1.51	7.89	1.51,	20.12
21	99	-0.77	-1.62	0.123		-1.66	6.17	0.94,	17.15
22	100	.	.	.		.	.	.	.
23	101	-0.55	-1.09	0.289		-1.12	14.43	4.54,	29.66
24	101	-0.83	-1.76	0.096		-1.81	4.78	0.57,	14.51

*$p < .05$ *, $p < .001$ ***

[16] Note that RT data was not recorded for 2 SRs.

Appendix 5.2.2.

Table A5.2.2.1. SR individual scores on OAE $_{Accuracy}$ against the control mean (Experiment 5.2)

SRs	CFMT+ (102)	test score OAE (d/)	significance t value	p value		Effect size Z-cc	population % falling below	95% confidence Interval	
1	93	1.64	2.58	0.016	*	2.62	99.20	96.51,	99.97
2	94	0.63	0.37	0.714		0.38	64.32	49.35,	77.79
3	94	0.81	0.76	0.452		0.78	77.41	63.31,	88.57
4	94	1.27	1.77	0.089		1.80	95.56	88.05,	99.20
5	94	0.92	1.00	0.325		1.02	83.76	70.82,	93.10
6	94	1.27	1.77	0.089		1.80	95.56	88.05,	99.20
7	94	0.87	0.89	0.379		0.91	81.04	67.52,	91.24
8	95	1.09	1.38	0.181		1.40	90.95	80.48,	97.30
9	95	0.53	0.15	0.880		0.16	56.01	41.08,	70.32
10	95	0.32	-0.31	0.762		-0.31	38.12	24.36,	53.12
11	95	0.74	0.61	0.547		0.62	72.68	58.09,	84.13
12	95	0.84	0.83	0.415		0.84	79.27	65.45,	89.96
***13	95	-0.22	-1.48	0.150		-1.51	7.49	1.97,	17.15
14	96	1.80	2.92	0.007	*	2.98	99.65	98.14,	99.99
15	96	1.21	1.64	0.114		1.67	94.31	85.82,	98.77
16	96	1.41	2.07	0.048		2.11	97.59	92.23,	99.74
17	96	1.05	1.29	0.209		1.31	89.54	78.43,	96.58
18	98	1.53	2.34	0.027	*	2.38	98.62	94.80,	99.91
19	100	0.11	-0.76	0.452		-0.78	22.59	11.43,	36.69

***Excluded SR based on their daily exposure to infants *$p < .05$ **

Table A5.2.2.2. SR individual scores on OAE $_{RT}$ against the control mean

SRs	CFMT+ (102)	test score OAE (RT)	significance t value	p value	Effect size Z-cc	population % falling below	95% confidence Interval	
1	93	-0.06	0.12	0.903	0.13	54.83	39.66,	69.49
2	94	0.06	0.42	0.680	0.43	65.99	50.77,	79.47
3	94	-0.05	0.15	0.884	0.15	55.79	40.59,	70.37
4	94	0.10	0.52	0.611	0.53	69.45	54.37,	82.41
5	94	0.20	0.76	0.454	0.78	77.30	62.90,	88.66
6	94	-0.26	-0.37	0.716	-0.38	35.80	22.08,	51.06
7	94	0.11	0.54	0.594	0.55	70.29	55.25,	83.11
8	95	0.34	1.10	0.280	1.13	85.99	73.37,	94.65
9	95	0.47	1.42	0.167	1.45	91.64	81.28,	97.71
10	95	-0.08	0.07	0.942	0.08	52.90	37.80,	67.70
11	95	-0.06	0.12	0.903	0.13	54.83	39.66,	69.49
12	95	0.35	1.13	0.270	1.15	86.51	74.05,	94.96
***13	95	-0.13	-0.05	0.961	-0.05	48.06	33.21,	63.12
14	96	-0.03	0.20	0.846	0.20	57.70	42.45,	72.12
15	96	0.22	0.81	0.426	0.83	78.71	64.51,	89.72
16	96	0.14	0.61	0.545	0.63	72.74	57.87,	85.11
17	96	-0.10	0.03	0.981	0.03	50.97	35.95,	65.88
18	98	-0.06	0.12	0.903	0.13	54.83	39.66,	69.49
19	100	-0.12	-0.03	0.981	0.03	49.03	34.12,	64.05

***Excluded SR based on their daily exposure to infants

Table A5.2.2.3. Participants' EEG trial numbers during face encoding and face recognition (Experiment 5.2)

	Adult faces			Infant faces		
Participants	Encoding	Hits	Correct Rejections	Encoding	Hits	Correct rejections
SRs[17]						
1	✓	✓	✓	✓	✓	✓
2	✓	✓	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	✓
4	✓	✓	✓	✓	✓	✓
5	✓	✓	✓	✓	✓	✓
6	*	*	✓	*	*	✓
7	✓	✓	✓	✓	✓	✓
8	✓	✓	✓	✓	✓	✓
9	✓	✓	✓	✓	✓	*
10	✓	✓	✓	✓	✓	**
11	**	**	**	**	**	**
12	✓	✓	✓	✓	✓	✓
13	✓	✓	✓	✓	✓	✓
14	-	-	-	-	-	-
15	**	✓	✓	**	**	*
16	✓	*	*	✓	✓	✓
17	✓	✓	✓	✓	✓	✓
18	✓	✓	✓	✓	✓	✓
19	*	✓	✓	✓	✓	✓
Controls						
1	✓	✓	✓	✓	✓	*
2	*	✓	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	✓
4	✓	✓	✓	✓	✓	✓
5	✓	✓	✓	✓	✓	✓
6	✓	✓	✓	✓	✓	✓
7	✓	✓	✓	✓	✓	*
8	✓	**	✓	✓	**	✓
9	✓	✓	✓	✓	✓	*
10	✓	✓	✓	✓	✓	*
11	✓	✓	✓	✓	✓	✓
12	✓	✓	✓	✓	✓	✓
13	*	✓	*	✓	✓	✓
14	✓	✓	✓	✓	✓	✓
15	✓	✓	✓	✓	✓	*
16	✓	*	*	✓	*	*
17	✓	*	✓	✓	*	✓
18	✓	✓	✓	✓	✓	✓
19	✓	✓	*	✓	*	**
20	*	*	*	✓	**	✓
21	✓	*	✓	✓	✓	✓
22	✓	✓	✓	✓	*	*

✓ 20 < trials per condition; * 20 > trials per condition; ** 15 > trials per condition

[17] Note that performance for infant face recognition was not recorded for SR number 14

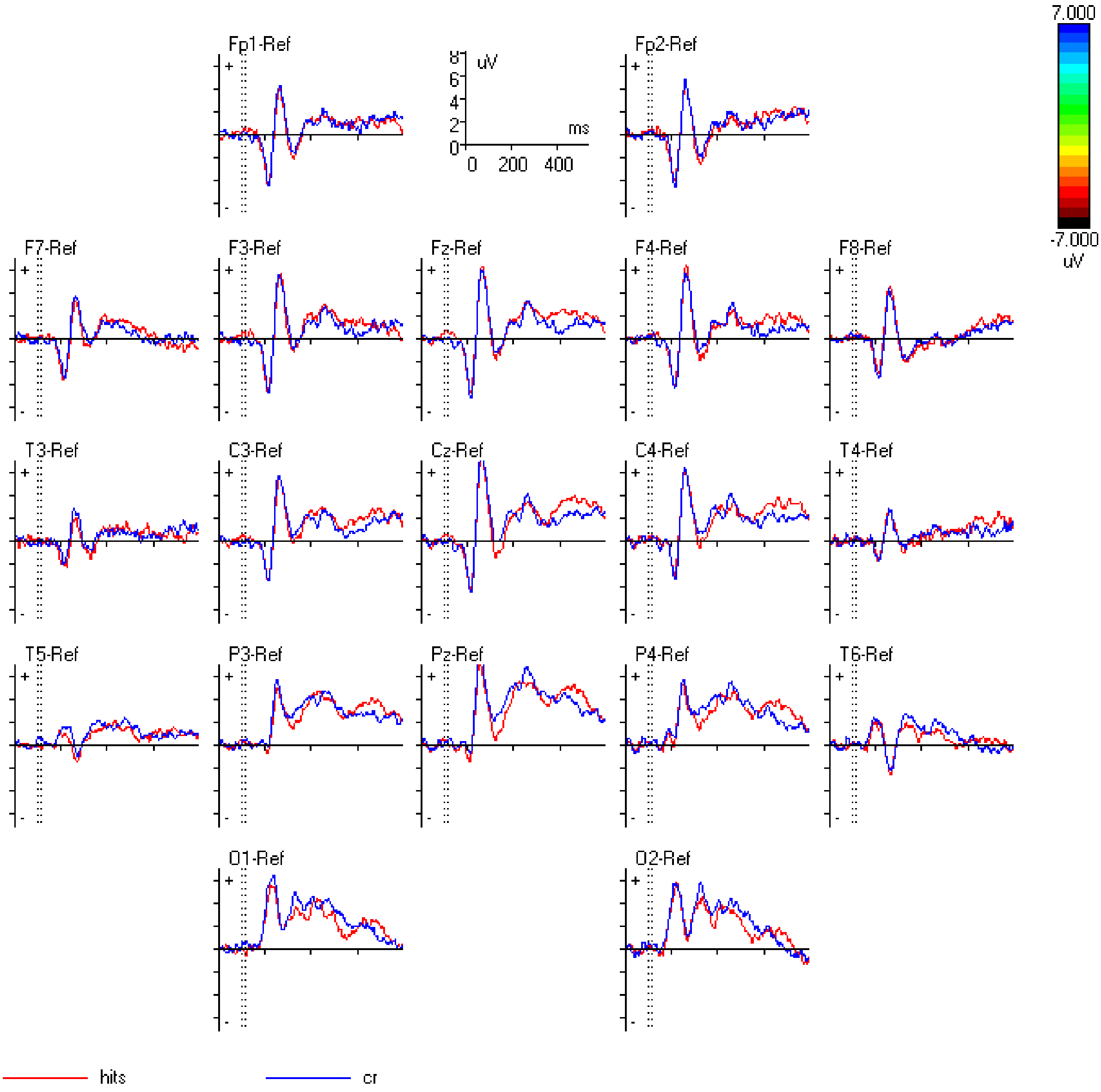

Figure A5.2.2.1. SRs' hits and correct rejections during adult face recognition (ERPs)

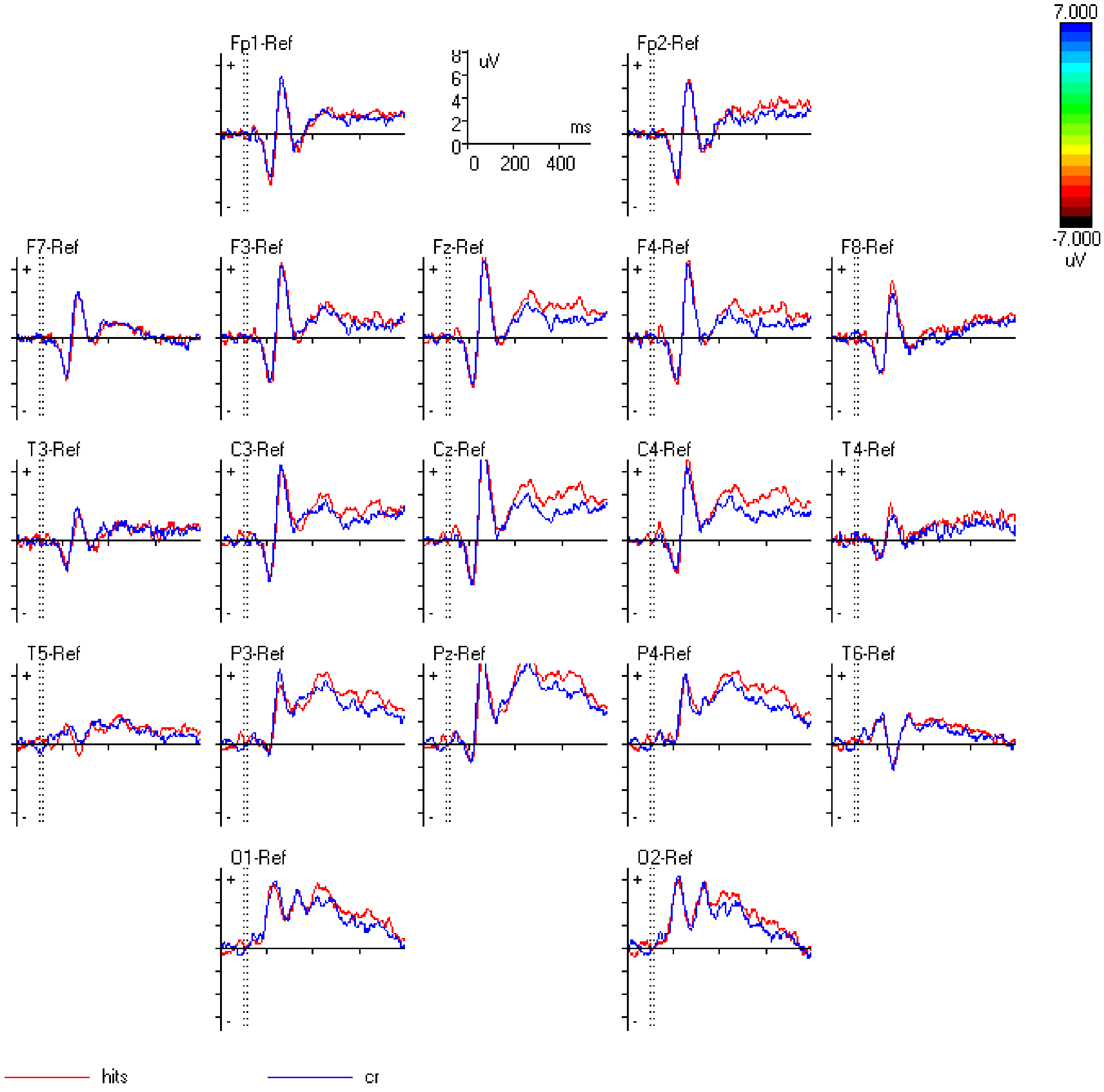

Figure A5.2.2.2. SRs' hits and correct rejections during infant face recognition (ERPs)

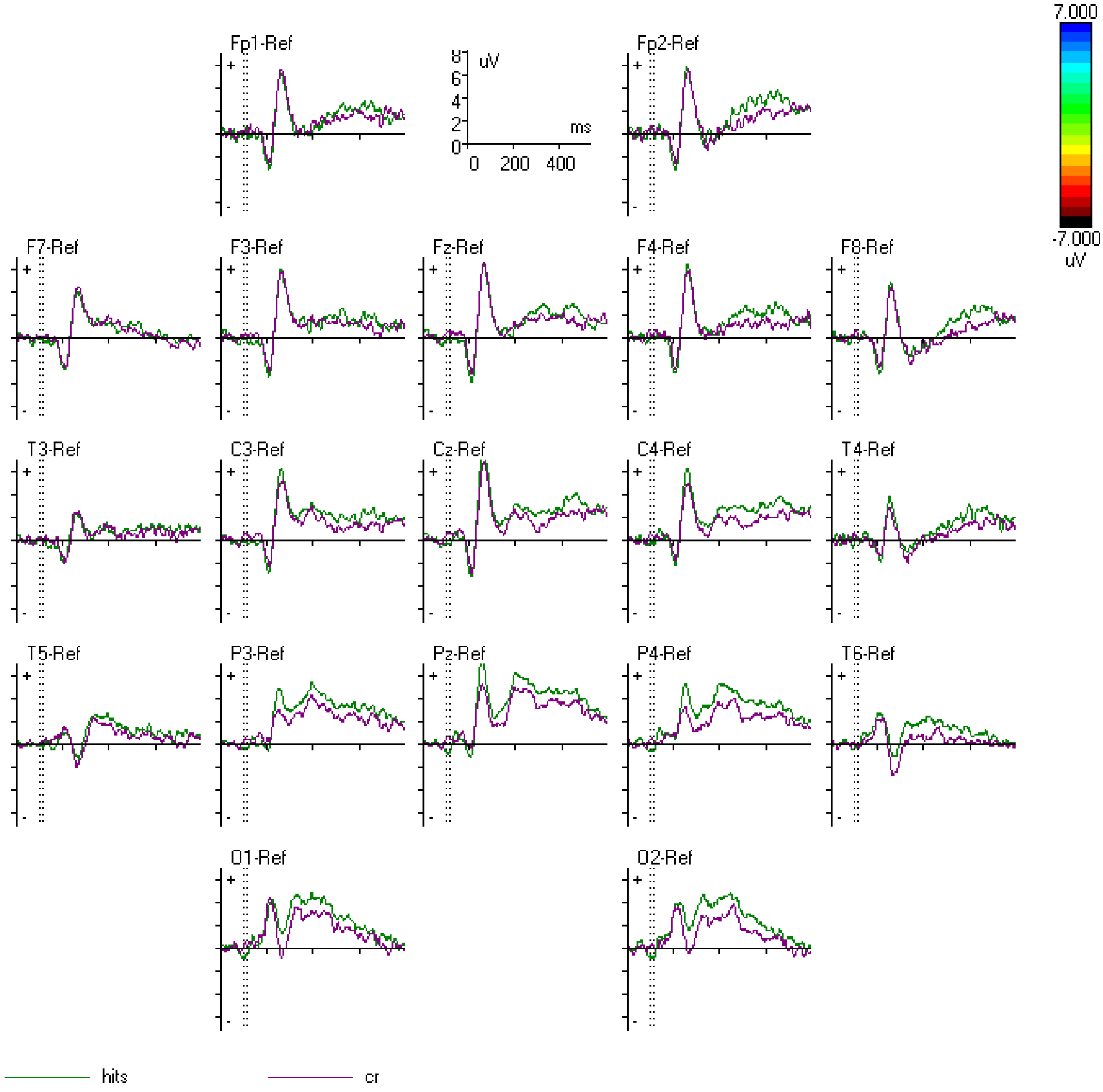

Figure A5.2.2.3. Controls' hits and correct rejections during adult face recognition (ERPs)

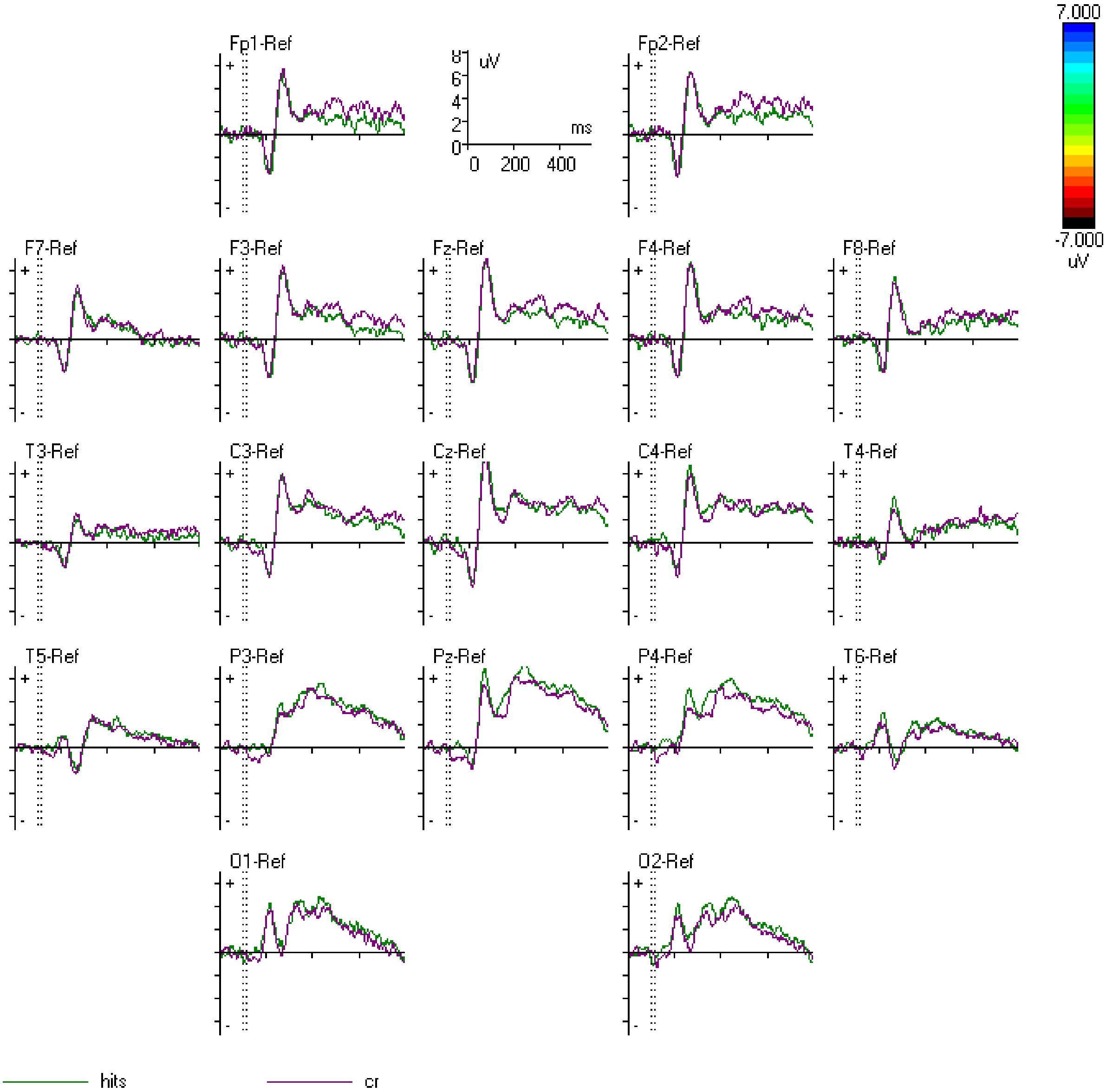

Figure A5.2.2.4. Controls' hits and correct rejections during infant face recognition (ERPs)

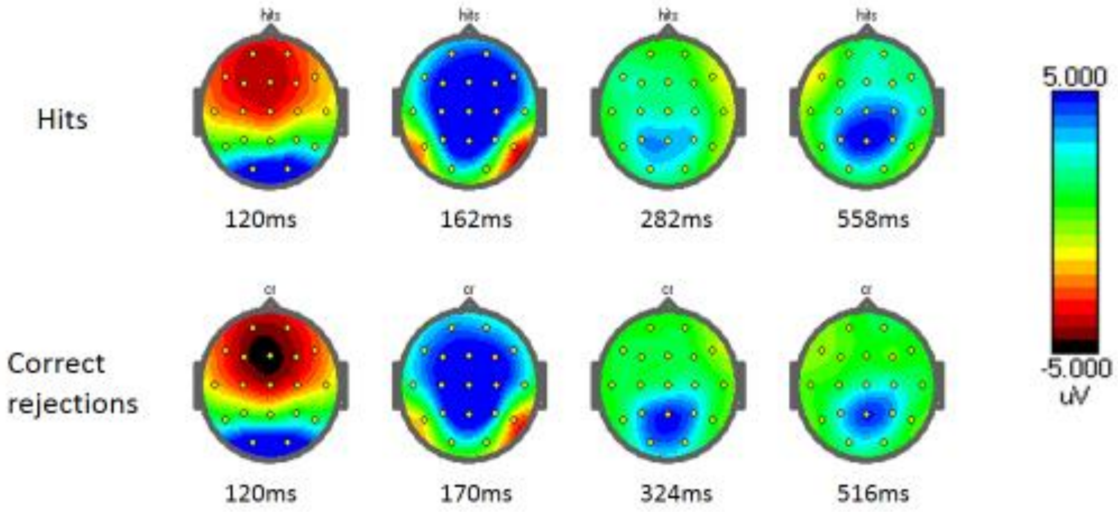

Figure A5.2.2.5. SRs' hits and correct rejections during adult face recognition

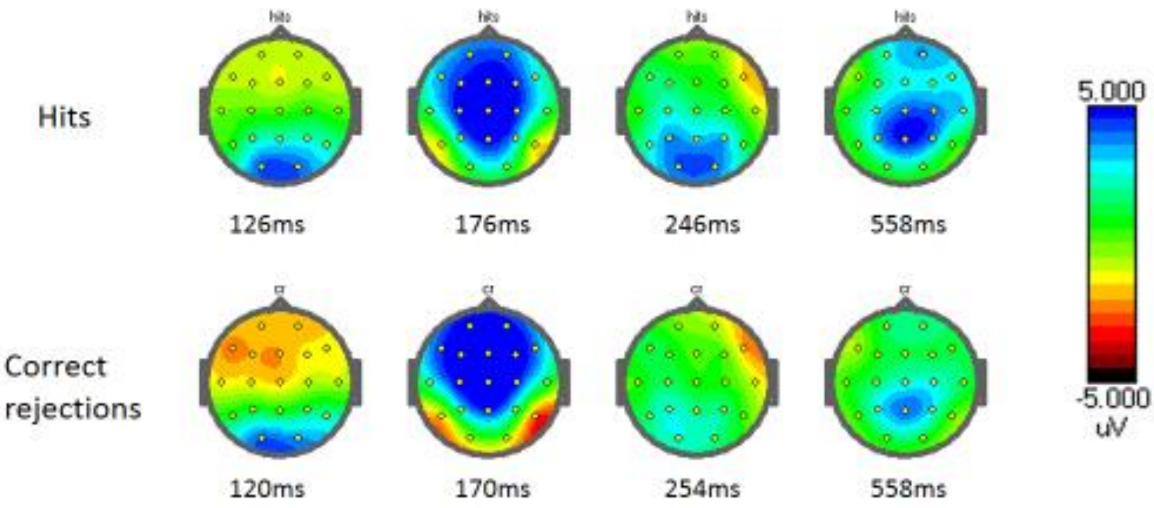

Figure A5.2.2.6. Controls' hits and correct rejections during adult face recognition

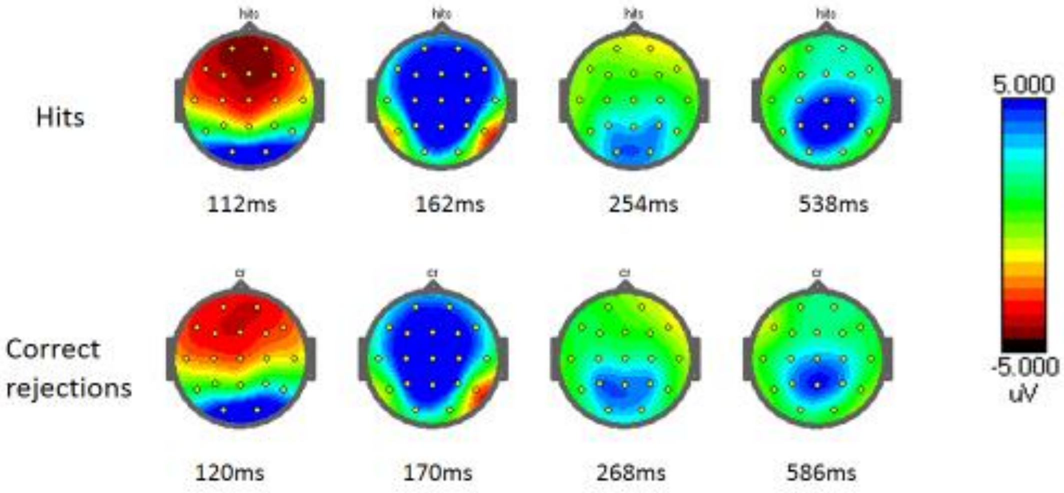

Figure A5.2.2.7. SRs' hits and correct rejections during infant face recognition

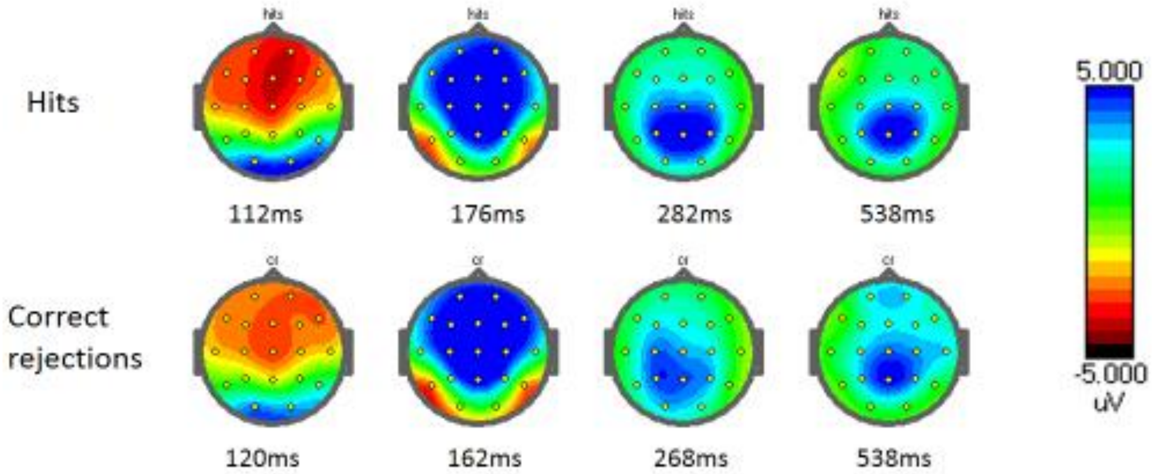

Figure A5.2.2.8. Controls' hits and correct rejections during infant face recognition

Appendix 5.3.2

Table A5.3.2.1. Individual SR performance on OAE ($d^{/}$) against the control mean (Experiment 5.3)

SRs	CFMT+ (102)	test score OAE ($d^{/}$)	significance t value	p value		Effect size Z-cc	population % falling below	95% confidence Interval
1	94	-0.36	-1.28	0.218		-1.31	10.90	2.75, 24.78
2	94	0.33	0.33	0.749		0.33	62.55	44.69, 78.57
3	94	0.17	-0.05	0.963		-0.05	48.17	30.96, 65.65
4	94	0.14	-0.12	0.909		-0.12	45.45	28.48, 63.08
5	94	0.45	0.60	0.554		0.62	72.31	54.76, 86.53
6	95	0.85	1.53	0.143		1.57	92.85	81.12, 98.75
7	95	-0.12	-0.72	0.481		-0.74	24.06	10.76, 41.26
8	95	0	-0.44	0.665		-0.45	33.23	17.89, 51.05
9	95	0.72	1.23	0.235		1.26	88.27	74.03, 96.86
10	95	-0.48	-1.56	0.137		-1.60	6.87	1.16, 18.40
11	96	0.61	0.98	0.343		1.00	82.87	66.88, 93.89
12	96	0.89	1.62	0.122		1.67	93.92	83.00, 99.09
13	96	-0.13	-0.74	0.467		-0.76	23.36	10.26, 40.49
14	96	0.50	0.72	0.481		0.74	75.94	58.74, 89.24
15	97	0.15	-0.09	0.927		-0.10	46.35	29.30, 63.94
16	98	0.27	0.19	0.855		0.19	57.26	39.51, 73.95
17	98	0.64	1.04	0.310		1.07	84.49	68.93, 94.85
18	99	0.12	-0.16	0.873		-0.17	43.64	26.85, 61.35
19	99	0.70	1.18	0.252		1.21	87.40	72.81, 96.43
20	99	0.32	0.30	0.766		0.31	61.68	43.83, 77.82
21	99	0.57	0.88	0.389		0.91	80.53	64.02, 92.40
22	100	0.63	1.02	0.321		1.05	83.96	68.25, 94.54
23	101	0.67	1.11	0.280		1.14	86.00	70.91, 95.69
24	101	-1.10	-2.99	0.008	*	-3.07	0.39	0.00, 2.43

*$p < .05$ **

Table A5.3.2.2. Individual SR performance on OAE $_{RT}$ against the control mean (Experiment 5.3)

SRs	CFMT+ (102)	test score OAE (sec)	significance t value	p value		Effect size Z-cc	population % falling below	95% confidence Interval
1	94	-0.17	-2.17	0.044	*	-2.23	2.22	0.09, 8.91
2	94	0.10	-0.15	0.883		-0.15	44.14	26.88, 62.29
3	94	0.03	-0.67	0.509		-0.69	25.47	11.49, 43.34
4	94	0.14	0.15	0.883		0.15	55.86	37.71, 73.12
5	94	0.38	1.95	0.068		2.00	96.59	88.09, 99.75
6	95	0.10	-0.15	0.883		-0.15	44.14	26.88, 62.29
7	95	-0.19	-2.32	0.033	*	-2.39	1.65	0.05, 7.27
8	95	0.42	2.25	0.038	*	2.31	98.09	91.95, 99.93
9	95	0.42	2.25	0.038	*	2.31	98.09	91.95, 99.93
10	95	0.09	-0.23	0.825		-0.23	41.25	24.32, 59.52
11	96	0.06	-0.45	0.659		-0.46	32.95	17.30, 51.26
12	96	0.08	-0.30	0.768		-0.31	38.41	21.87, 56.74
13	96	0.13	0.08	0.941		0.08	52.94	34.94, 70.49
14	96	0.14	0.15	0.883		0.15	55.86	37.71, 73.12
15	97	0.15	0.23	0.825		0.23	58.75	40.48, 75.67
16	98	0.24	0.90	0.381		0.92	80.93	64.00, 92.91
17	98	0.15	0.23	0.825		0.23	58.75	40.48, 75.67
18	99	0.11	-0.08	0.941		-0.08	47.06	29.51, 65.06
19	99	-0.07	-1.42	0.173		-1.46	8.65	1.68, 21.77
20	99	0.49	2.77	0.013	*	2.85	99.35	96.27, 100.0
21	99	-0.23	-2.62	0.018	*	-2.70	0.90	0.01, 4.70
22	100	0.22	0.75	0.464		0.77	76.79	59.18, 90.13
23	101	0.16	0.30	0.768		0.31	61.59	43.26, 78.13
24	101	0.34	1.65	0.118		1.70	94.11	82.97, 99.21

*p < .05 **

Table A5.3.2.3. Individual SR performance on Adult IE ($d^{/}$) against the control mean (Experiment 5.3)

SRs	CFMT+ (102)	test score IE ($d^{/}$)	significance t value	p value		Effect size Z-cc	population % falling below	95% confidence Interval	
1	94	0.69	0.34	0.739		0.35	63.07	45.21,	79.01
2	94	0.89	0.76	0.455		0.78	77.23	60.18,	90.16
3	94	-0.15	-1.44	0.167		-1.48	8.34	1.68,	20.85
4	94	0.63	0.21	0.835		0.22	58.27	40.49,	74.84
5	94	0.70	0.36	0.722		0.37	63.86	46.00,	79.68
6	95	1.58	2.23	0.039	*	2.28	98.04	92.05,	99.92
7	95	0.54	0.02	0.983		0.02	50.83	33.42,	68.12
8	95	1.99	3.09	0.006	*	3.17	99.69	97.96,	100.0
9	95	1.96	3.03	0.007	*	3.11	99.64	97.72,	100.0
10	95	1.97	3.05	0.007	*	3.13	99.66	97.80,	100.0
11	96	1.45	1.95	0.067		2.00	96.65	88.53,	99.73
12	96	0.94	0.87	0.396		0.89	80.18	63.61,	92.18
13	96	0.64	0.23	0.818		0.24	59.08	41.28,	75.56
14	96	1.59	2.25	0.038	*	2.30	98.13	92.28,	99.92
15	97	0.35	-0.38	0.707		-0.39	35.37	19.67,	53.22
16	98	0.82	0.61	0.547		0.63	72.67	55.14,	86.80
17	98	0.73	0.42	0.677		0.44	66.16	48.33,	81.61
18	99	1.90	2.90	0.009	*	2.98	99.53	97.17,	100.0
19	99	1.02	1.04	0.313		1.07	84.35	68.75,	94.77
20	99	1.12	1.25	0.227		1.28	88.64	74.55,	97.03
21	99	-0.14	-1.42	0.173		-1.46	8.64	1.79,	21.34
22	100	0.90	0.78	0.443		0.80	77.84	60.88,	90.59
23	101	0.51	-0.04	0.967		-0.04	48.33	31.11,	65.80
24	101	-0.23	-1.61	0.125		-1.65	6.24	0.96,	17.27

*p < .05 **

Table A5.3.2.4. Individual SR performance on Adult IE $_{RT}$ against the control mean (Experiment 5.3)

SRs	CFMT+ (102)	test score IE (sec)	significance t value	p value		Effect size Z-cc	population % falling below	95% confidence Interval	
1	94	0.13	0.75	0.464		0.77	76.79	59.18,	90.13
2	94	0.13	0.75	0.464		0.77	76.79	59.18,	90.13
3	94	0.01	-0.15	0.883		-0.15	44.14	26.88,	62.29
4	94	0.06	0.23	0.825		0.23	58.75	40.48,	75.67
5	94	0.42	2.92	0.001	**	3.00	99.52	97.07,	100.0
6	95	-0.03	-0.45	0.659		-0.46	32.95	17.30,	51.26
7	95	-0.06	-0.67	0.509		-0.69	25.47	11.49,	43.34
8	95	0.20	1.27	0.220		1.31	88.99	74.61,	97.34
9	95	-0.36	-2.92	0.010	*	-3.00	0.48	> 0.01,	2.93
10	95	0.20	1.27	0.220		1.31	88.99	74.61,	97.34
11	96	0.17	1.05	0.309		1.08	84.54	68.51,	95.08
12	96	-0.09	-0.90	0.381		-0.92	19.07	7.09,	36.00
13	96	0.00	-0.23	0.825		-0.23	41.25	24.33,	59.52
14	96	0.21	1.35	0.195		1.39	90.23	76.46,	97.87
15	97	0.19	1.20	0.247		1.23	87.63	72.66,	96.70
16	98	0.11	0.60	0.557		0.62	72.15	54.08,	86.72
17	98	0.13	0.75	0.464		0.77	76.79	59.18,	90.13
18	99	0.28	1.87	0.079		1.92	96.07	86.93,	99.66
19	99	-0.02	-0.37	0.713		-0.39	35.64	19.52,	53.98
20	99	0.41	2.85	0.011	*	2.92	99.44	96.69,	100.0
21	99	-0.28	-2.32	0.033	*	-2.39	1.65	0.05,	7.26
22	100	0.13	0.75	0.464		0.77	76.79	59.18,	90.13
23	101	-0.15	-1.35	0.195		-1.39	9.77	2.13,	23.54
24	101	0.02	-0.08	0.941		-0.08	47.06	29.51,	65.06

*$p < .05$ *, $p < .001$ ***

Table A5.3.2.5. Individual SR performance on Infant IE ($d^{/}$) against the control mean (Experiment 5.3)

SRs	CFMT+ (102)	test score IE ($d^{/}$)	significance t value	p value		Effect size Z-cc	population % falling below	95% confidence Interval	
1	94	1.22	1.24	0.232		1.27	88.38	74.18,	96.91
2	94	1.04	0.92	0.368		0.95	81.58	65.29,	93.08
3	94	0.90	0.68	0.506		0.70	74.70	57.36,	88.34
4	94	0.56	0.09	0.932		0.09	53.42	35.85,	70.49
5	94	-0.09	-1.04	0.310		-1.07	15.51	5.15,	31.07
6	95	0.78	0.47	0.644		0.48	67.80	50.01,	82.95
7	95	0.86	0.61	0.550		0.63	72.50	54.96,	86.67
8	95	1.96	2.52	0.021	*	2.59	98.94	94.84,	99.98
9	95	1.09	1.01	0.326		1.04	83.69	67.91,	94.38
10	95	1.61	1.92	0.072		1.96	96.42	88.02,	99.69
11	96	0.55	0.07	0.945		0.07	52.74	35.20,	69.87
12	96	0.64	0.23	0.824		0.23	58.82	41.03,	75.33
13	96	0.29	-0.38	0.706		-0.39	35.31	19.62,	53.17
14	96	0.60	0.16	0.877		0.16	56.14	38.43,	72.95
15	97	0.62	0.19	0.850		0.20	57.48	39.73,	74.15
16	98	0.44	-0.12	0.904		-0.13	45.22	28.27,	62.86
17	98	0.54	0.05	0.959		0.05	52.05	34.56,	69.25
18	99	1.93	2.47	0.024	*	2.54	98.82	94.42,	99.97
19	99	0.23	-0.49	0.632		-0.50	31.59	15.56,	49.37
20	99	0.66	0.26	0.797		0.27	60.15	42.32,	76.49
21	99	-0.12	-1.10	0.287		-1.13	14.37	4.51,	29.58
22	100	0.47	-0.07	0.945		-0.07	47.26	30.13,	64.80
23	101	-0.09	-1.04	0.310		-1.07	15.51	5.15,	31.07
24	101	-1.35	-3.24	0.005	*	-3.32	0.23	0.00,	1.58

*p < .05 **

Table A5.3.2.6. Individual SR performance on Infant IE $_{RT}$ against the control mean (Experiment 5.3)

SRs	CFMT + (102)	test score IE (sec)	significance t value	p value	Effect size Z-cc	population % falling below	95% confidence Interval
1	94	0.19	0.74	0.470	0.76	76.48	58.84, 89.92
2	94	0.21	0.81	0.432	0.83	78.42	61.04, 91.26
3	94	0.11	0.47	0.644	0.48	67.78	49.49, 83.29
4	94	0.01	0.13	0.895	0.14	55.26	37.13, 72.58
5	94	-0.01	0.07	0.947	0.07	52.64	34.66, 70.21
6	95	0.10	0.44	0.668	0.45	66.60	48.28, 82.33
7	95	0.12	0.50	0.621	0.52	68.94	50.70, 84.22
8	95	-0.31	-0.94	0.361	-0.97	18.03	6.44, 34.72
9	95	-0.52	-1.65	0.118	-1.69	5.92	0.80, 17.08
10	95	-0.08	-0.17	0.869	-0.17	43.44	26.26, 61.62
11	96	-0.09	-0.20	0.843	-0.21	42.14	25.11, 60.38
12	96	-0.28	-0.84	0.413	-0.86	20.65	8.12, 37.87
13	96	-0.08	-0.17	0.869	-0.17	43.44	26.26, 61.62
14	96	-0.05	-0.07	-0.947	-0.07	47.36	29.79, 65.34
15	97	0.10	0.44	0.668	0.45	66.60	48.28, 82.33
16	98	-0.14	-0.37	0.717	-0.38	35.83	19.68, 54.17
17	98	-0.21	-0.60	0.554	-0.62	27.69	13.15, 45.74
18	99	0.06	0.30	0.766	0.31	61.69	43.35, 78.21
19	99	0.11	0.47	0.644	0.48	67.78	49.49, 83.29
20	99	-0.11	-0.27	0.792	-0.28	39.58	22.87, 57.89
21	99	-0.19	-0.54	0.598	-0.55	29.91	14.87, 48.11
22	100	-0.15	-0.40	0.692	-0.41	34.61	18.66, 52.95
23	101	-0.19	-0.54	0.598	-0.55	29.91	14.87, 48.11
24	101	-0.55	-1.75	0.099	-1.79	4.95	0.56, 15.20

Appendix 6.1.2

Table A6.1.2.1. Participants' individual performance on the Face Remember/Know Test (Pilot Test)

SRs (*n* = 15)				Controls (*n* = 17)			
CFMT+	New	Remember	Know	CFMT+	New	Remember	Know
95	66	40	30	62	49	19	15
95	53	44	26	81	61	15	38
95	45	67	10	74	46	64	4
95	67	56	13	81	74	1	53
98	54	60	14	74	39	41	28
94	76	48	19	72	38	45	15
94	70	13	54	74	58	25	34
94	60	38	39	77	55	43	20
94	39	73	4	75	54	32	32
95	68	27	28	77	34	16	60
94	37	74	5	74	43	47	24
96	62	22	54	62	64	38	16
94	34	53	22	62	40	41	20
96	27	47	31	81	34	50	26
94	53	13	60	72	33	68	8
-	-	-	-	82	40	31	38
-	-	-	-	73	51	34	25

Table A6.1.2.2. Participants' EEG trial numbers during face/object encoding and recognition (Experiment 6.1)

	Faces			Objects		
Participants	Remember Hits	Know Hits	Correct rejections	Remember Hits	Know Hits	Correct rejections
SRs						
1	✓	✓	✓	✓	*	✓
2	✓	✓	✓	✓	✓	✓
3	✓	✓	✓	**	*	*
4	✓	✓	✓	✓	✓	✓
5	✓	✓	✓	✓	✓	✓
6	✓	✓	✓	✓	✓	✓
7	✓	✓	✓	**	✓	*
8	*	*	✓	**	✓	✓
9	**	✓	✓	✓	✓	✓
10	✓	*	✓	✓	**	✓
11	✓	*	✓	✓	*	✓
12	✓	✓	✓	✓	**	✓
13	✓	✓	✓	✓	✓	✓
14	✓	✓	✓	✓	0	✓
15	✓	**	✓	✓	**	✓
16	✓	✓	✓	✓	✓	✓
17	✓	✓	✓	✓	✓	✓
Controls						
1	✓	✓	✓	✓	✓	✓
2	✓	✓	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	✓
4	**	**	✓	**	**	*
5	**	✓	✓	*	✓	✓
6	✓	✓	✓	✓	✓	✓
7	✓	*	✓	✓	*	✓
8	*	*	✓	**	**	**
9	*	✓	✓	**	✓	✓
10	✓	**	✓	✓	**	✓
11	✓	**	✓	✓	**	✓
12	*	✓	✓	✓	*	✓
13	✓	✓	✓	*	✓	✓
14	**	✓	✓	✓	✓	✓
15	✓	✓	✓	✓	✓	✓
16	**	**	✓	**	*	✓
17	✓	✓	✓	✓	**	✓

✓ 20 < trials per condition; * 20 > trials per condition; ** 15 > trials per condition

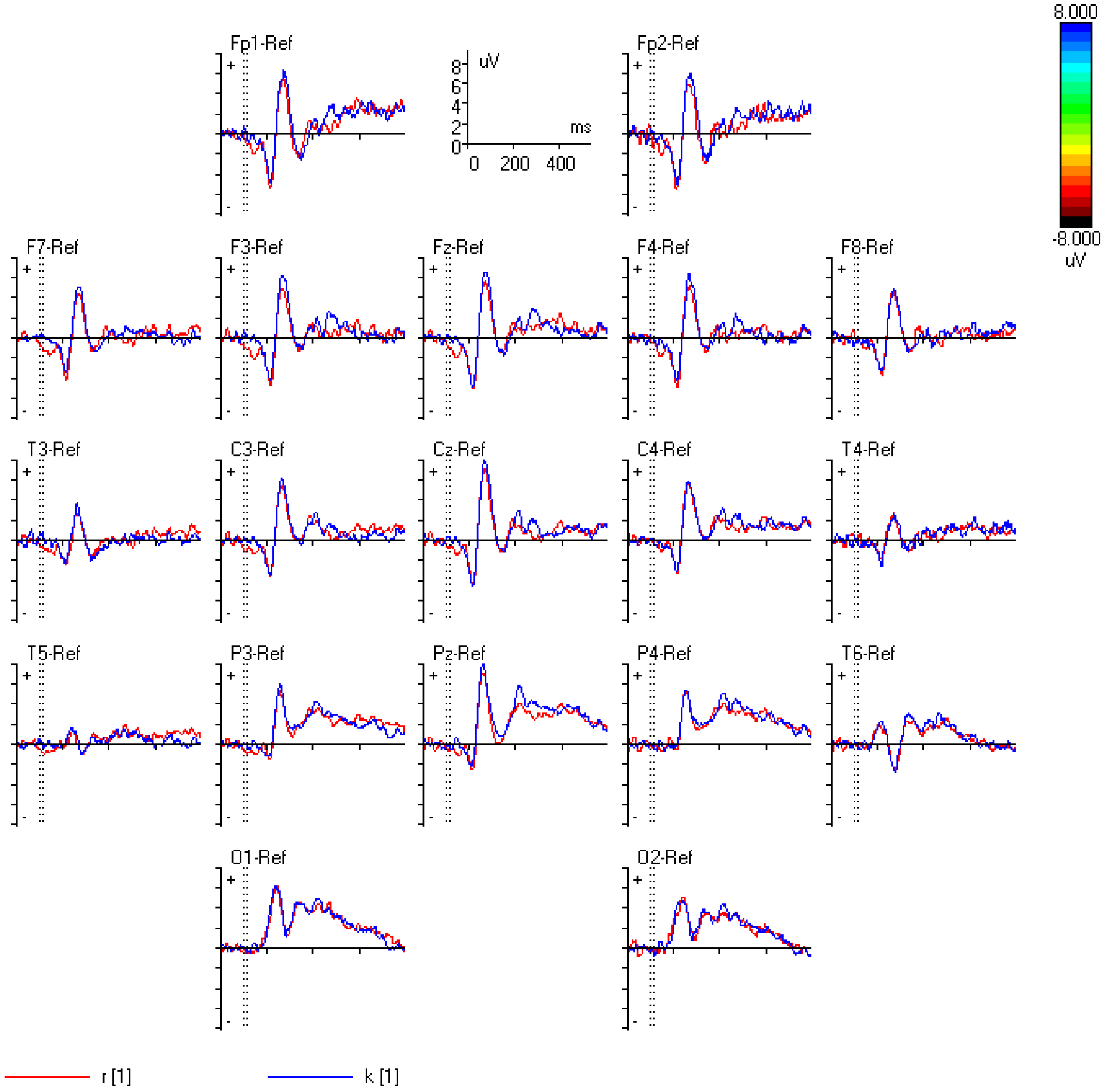

Figure A6.1.2.1. SR grand-averages for 'remember' and 'know' responses during face recognition

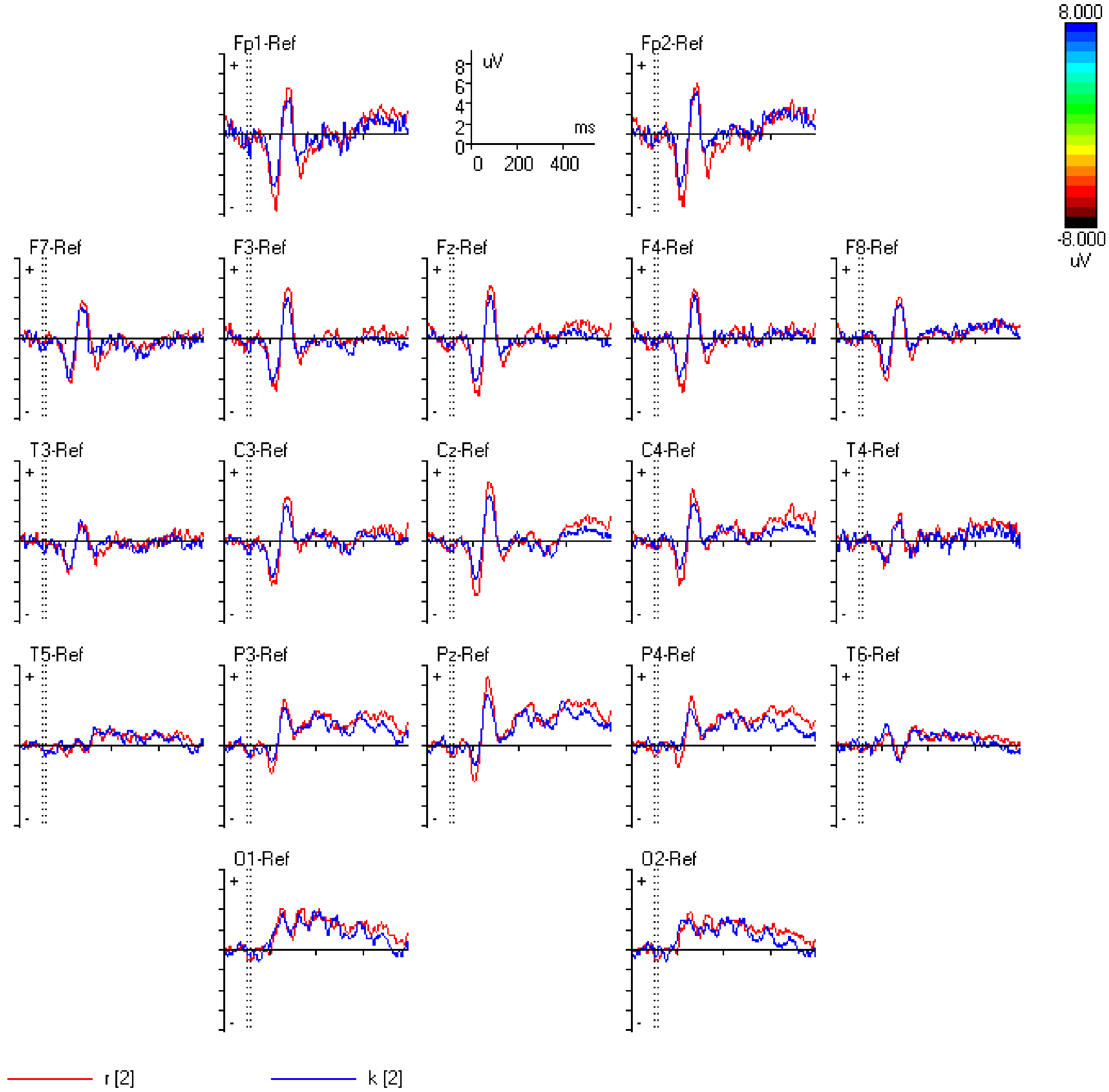

Figure A6.1.2.2. Control Grand-averages for 'remember' and 'know' responses during face recognition

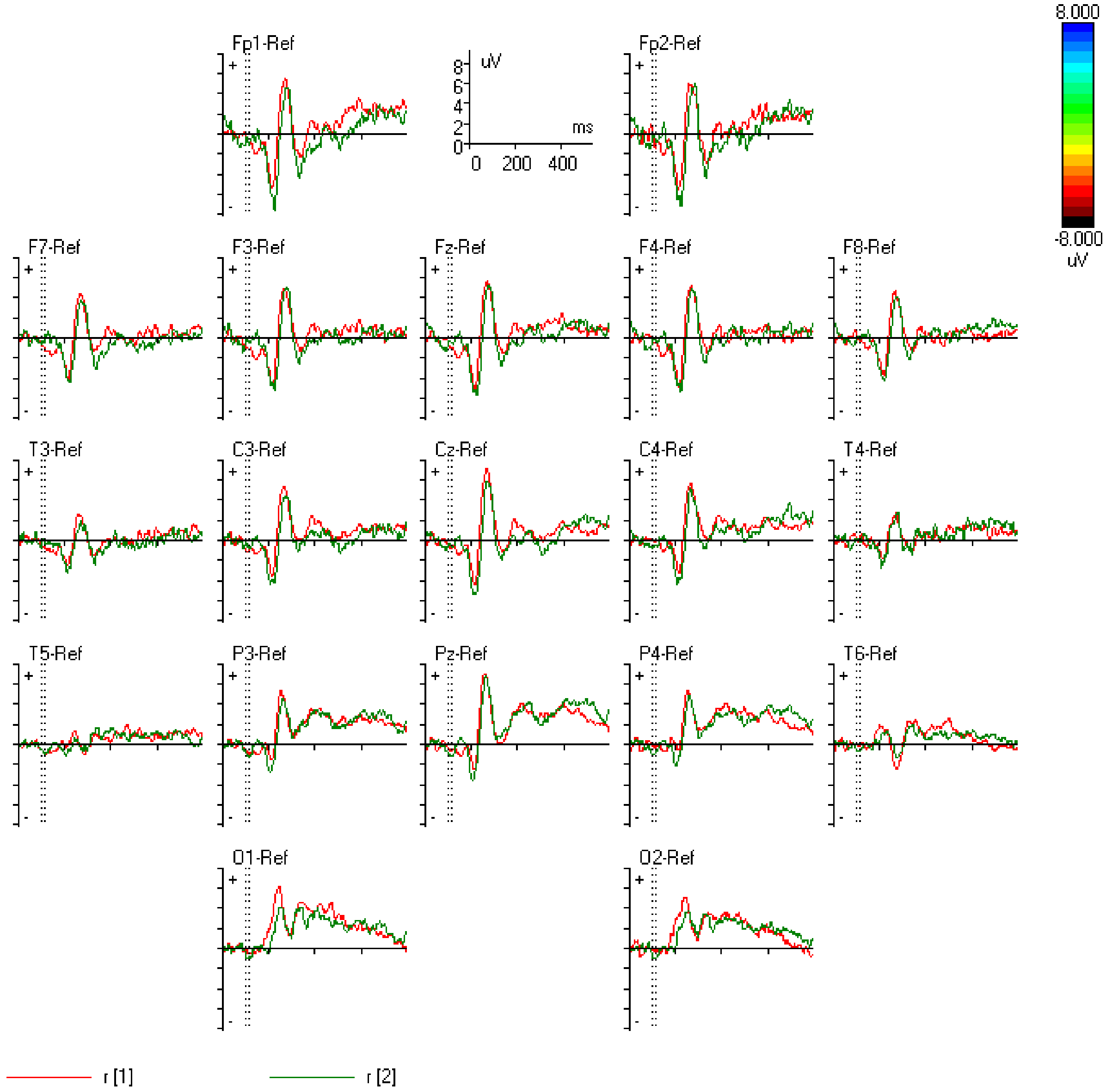

Figure A6.1.2.3. SR (red) and control (control) grand-averages for 'remember' responses during face recognition

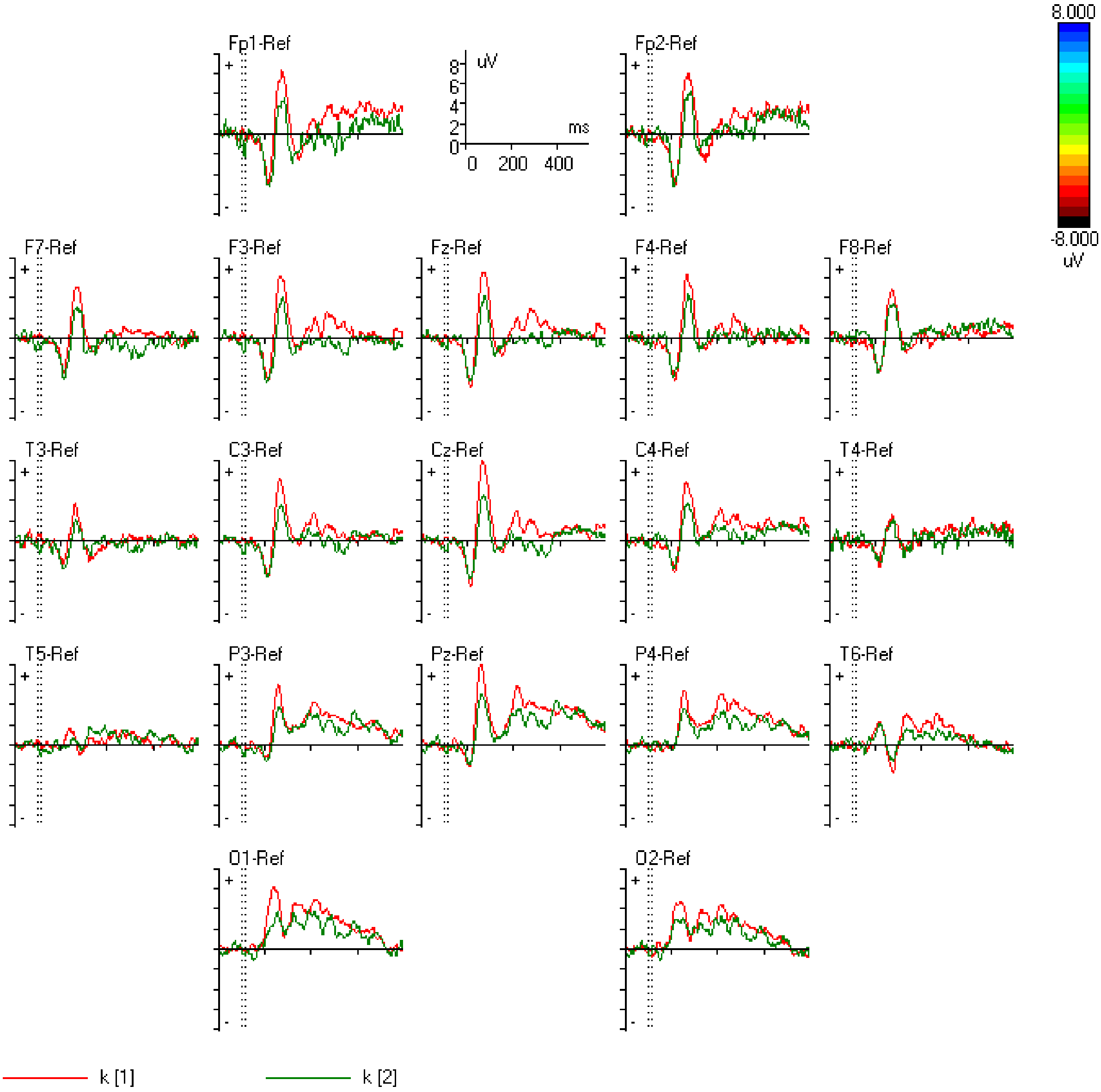

Figure A6.1.2.4. SR (red) and control (control) grand-averages for ‘know’ responses during face recognition

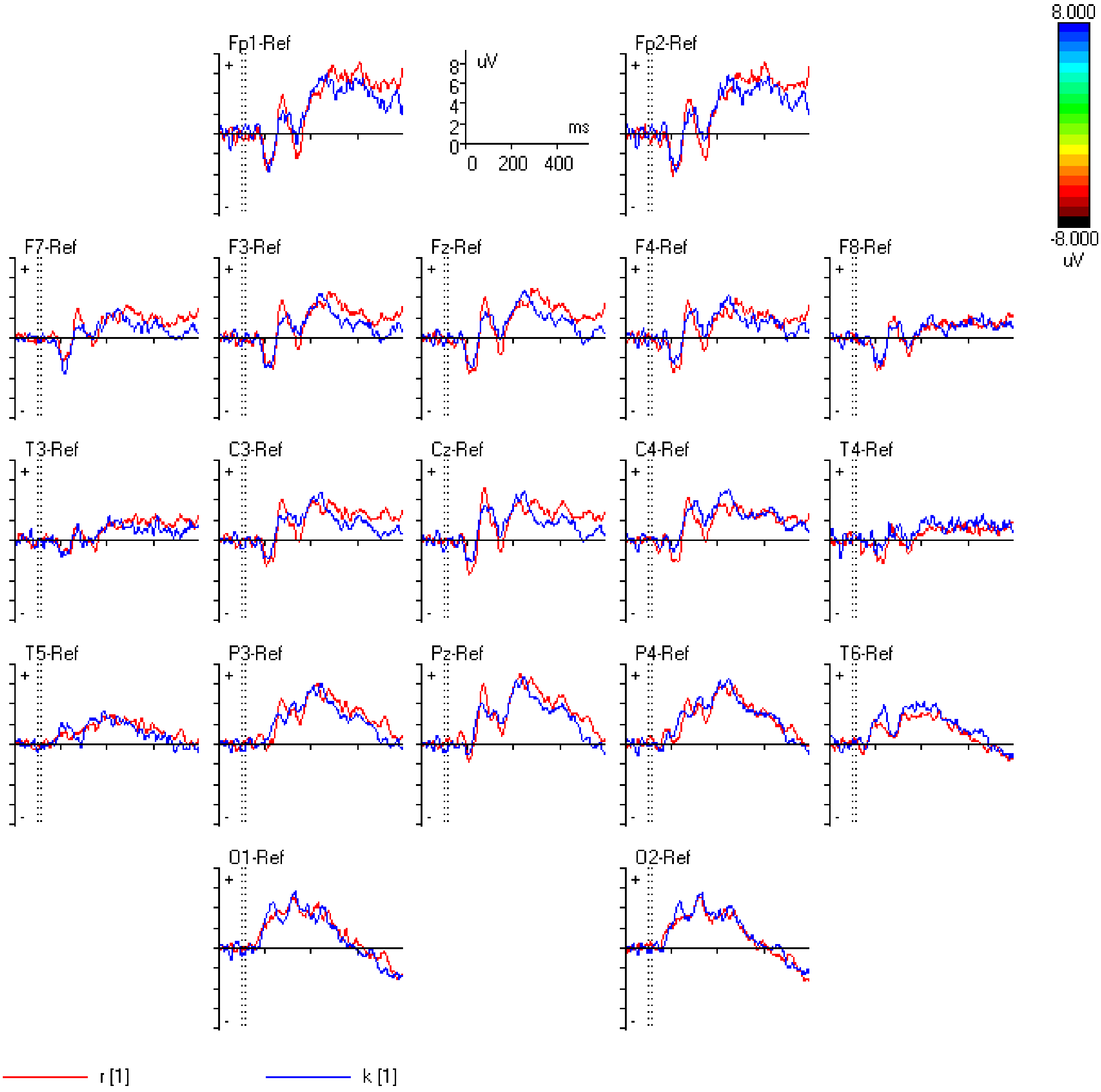

Figure A6.1.2.5. SR grand-averages for 'remember' and 'know' responses during object recognition

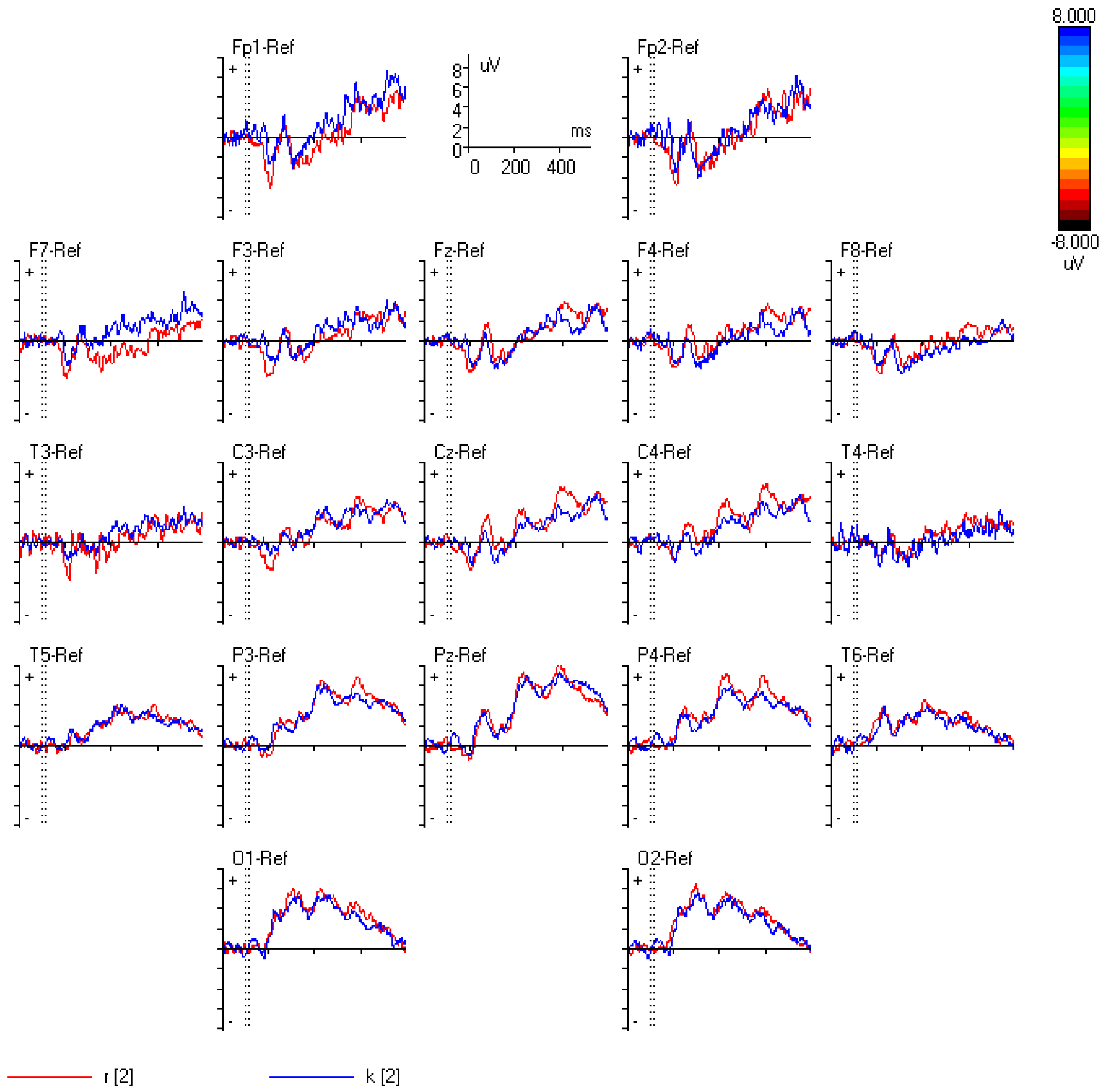

Figure A6.1.2.6. Controls grand-averages for 'remember' and 'know' responses during object recognition

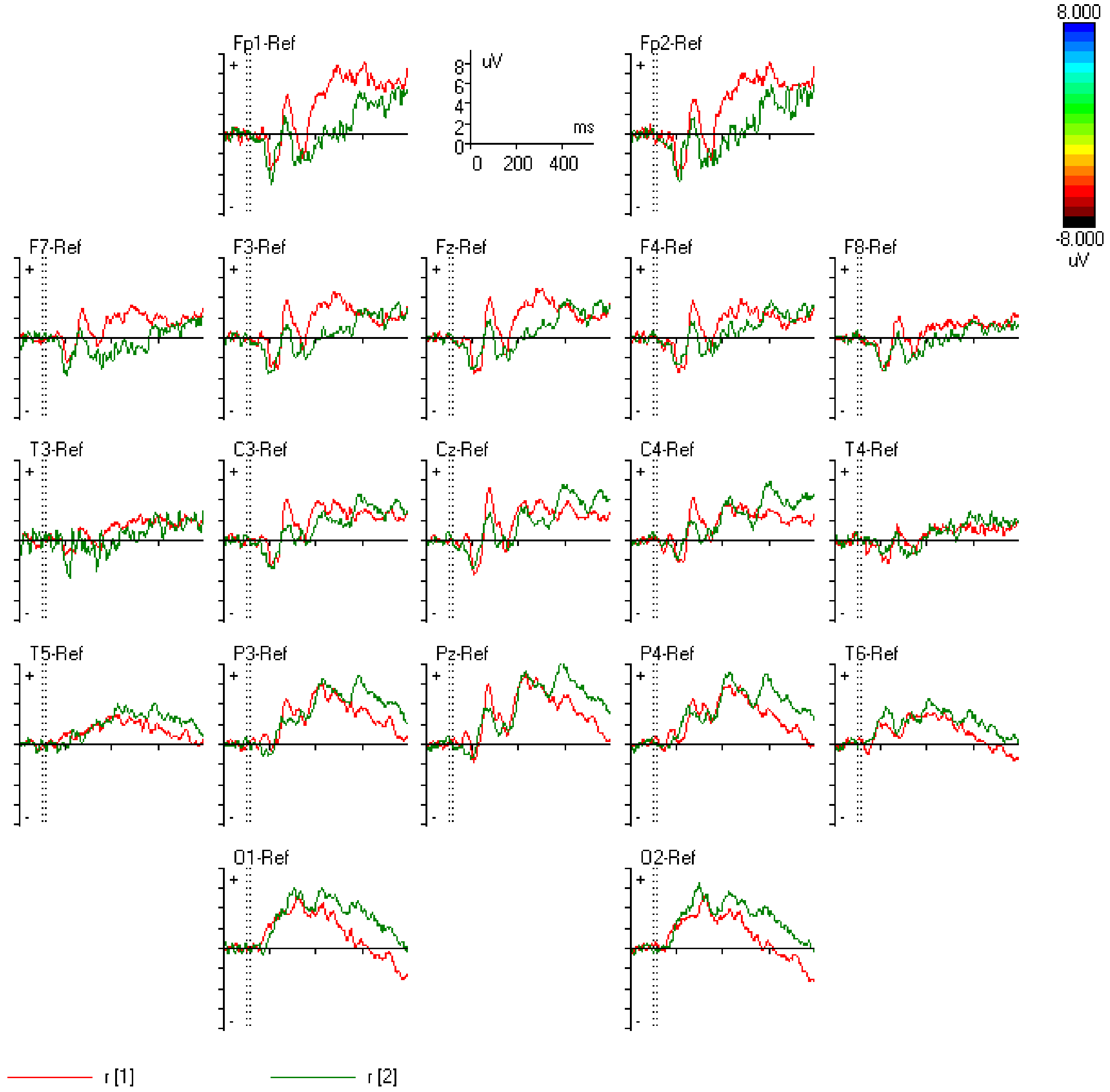

Figure A6.1.2.7. SR (red) and control (green) grand-averages for 'remember' responses during object recognition

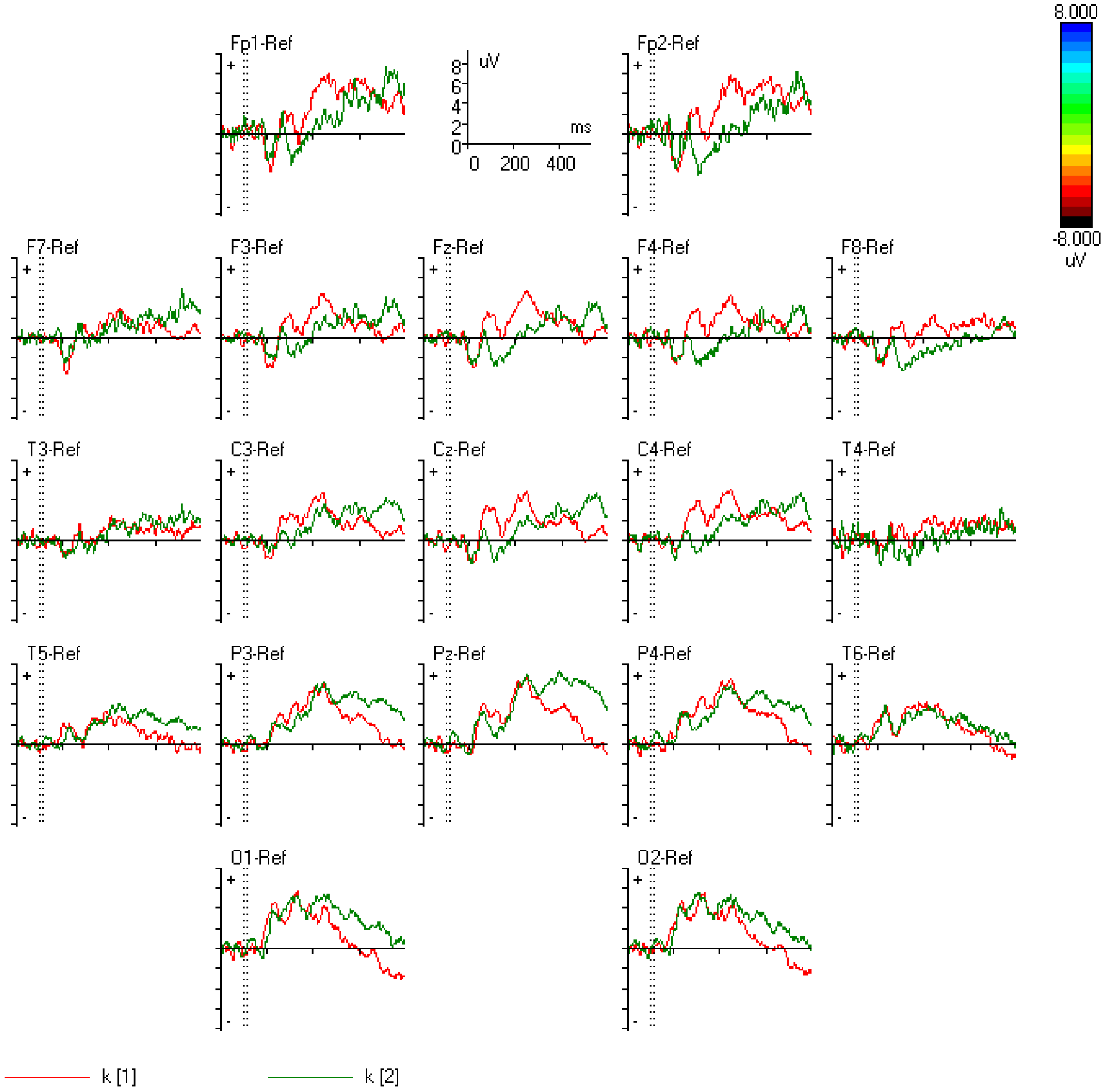

Figure A6.1.2.8. SR (red) and control (green) grand-averages for 'know' responses during object recognition

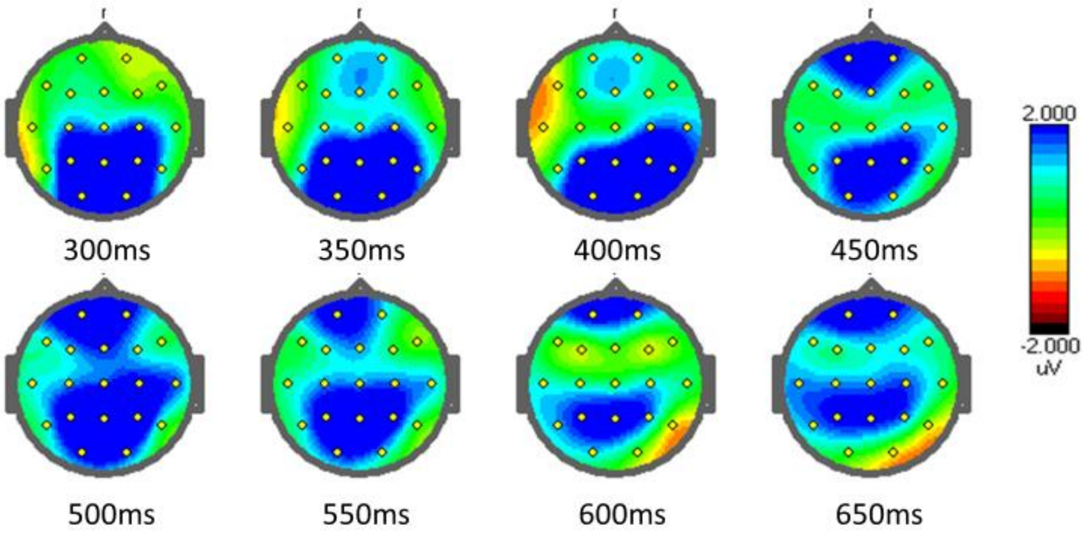

Figure A6.1.2.9. SRs' 'Remember' responses for faces at different time ranges

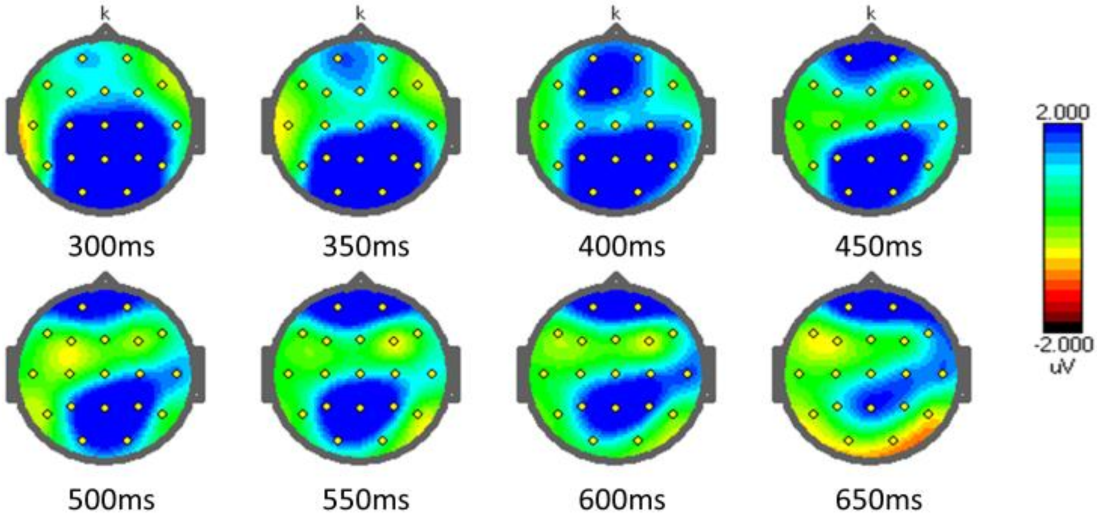

Figure A6.1.2.10. SRs' 'Know' responses for faces at different time ranges

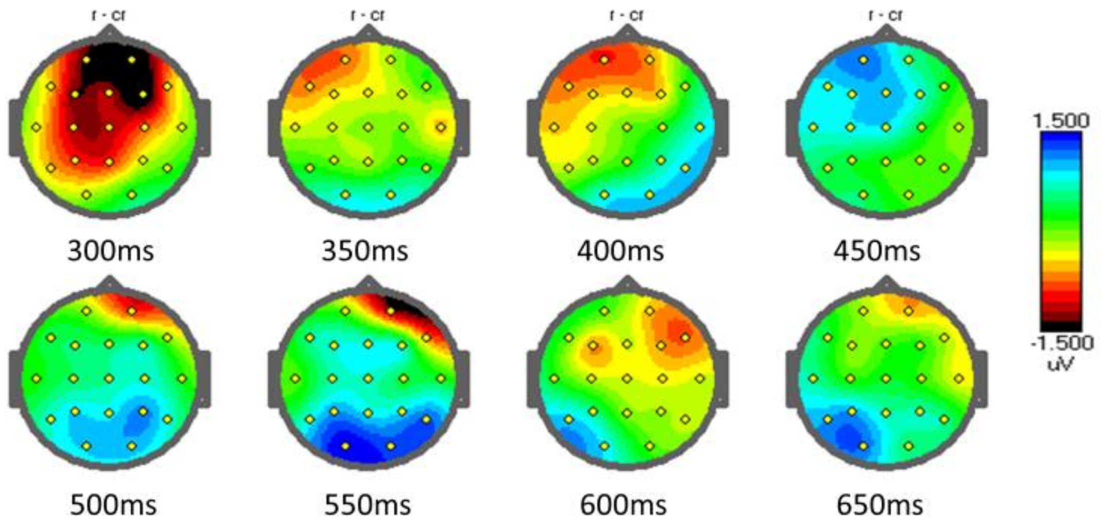

Figure A6.1.2.11. SRs' 'Remember – Correct rejections' for faces at different time ranges

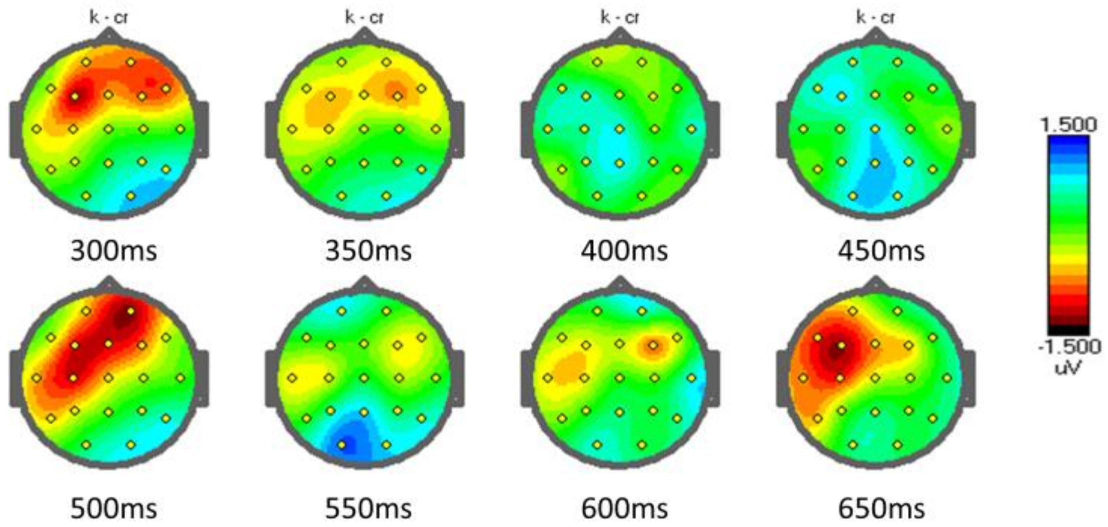

Figure A6.1.2.12. SRs' 'Know – Correct rejections' for faces at different time ranges

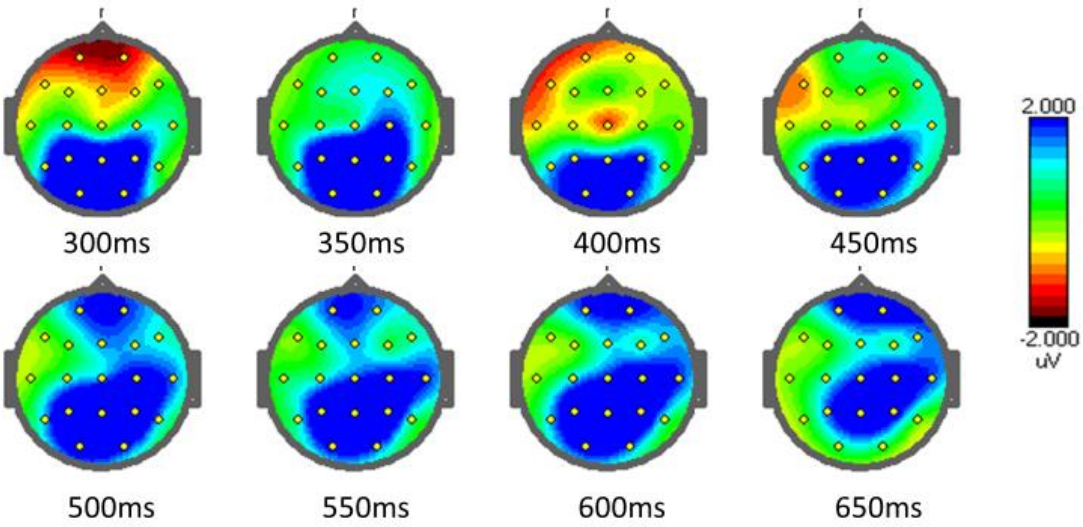

Figure A6.1.2.13. Controls' 'Remember' responses for faces at different time ranges

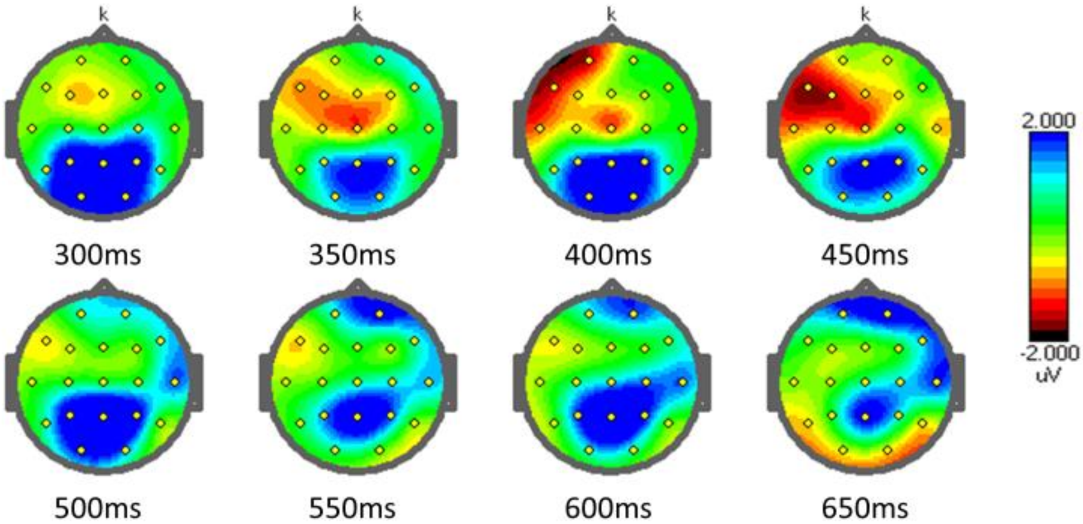

Figure A6.1.2.14. Controls' 'Know' responses for faces at different time ranges

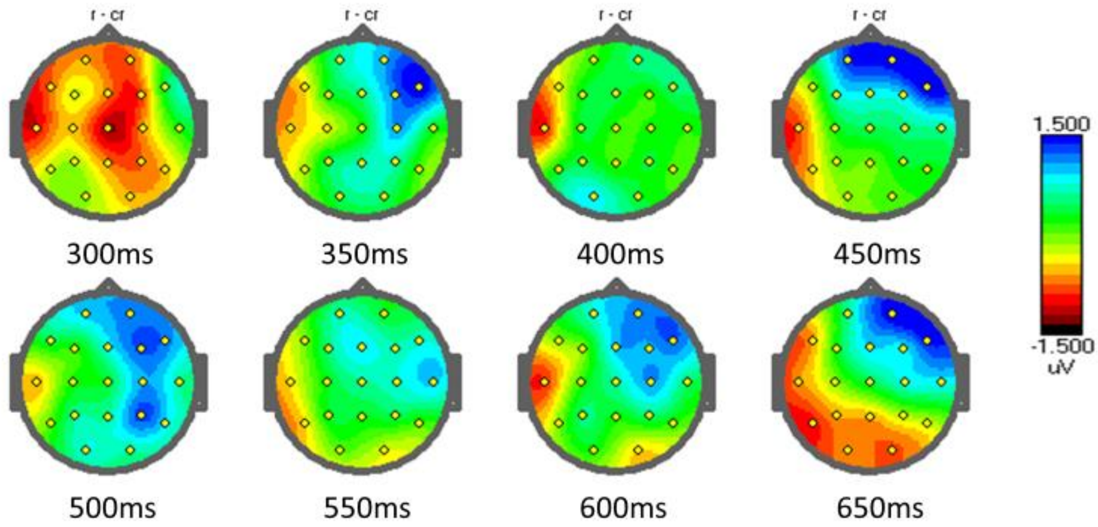

Figure A6.1.2.15. Controls' 'Remember – Correct rejections' for faces at different time ranges

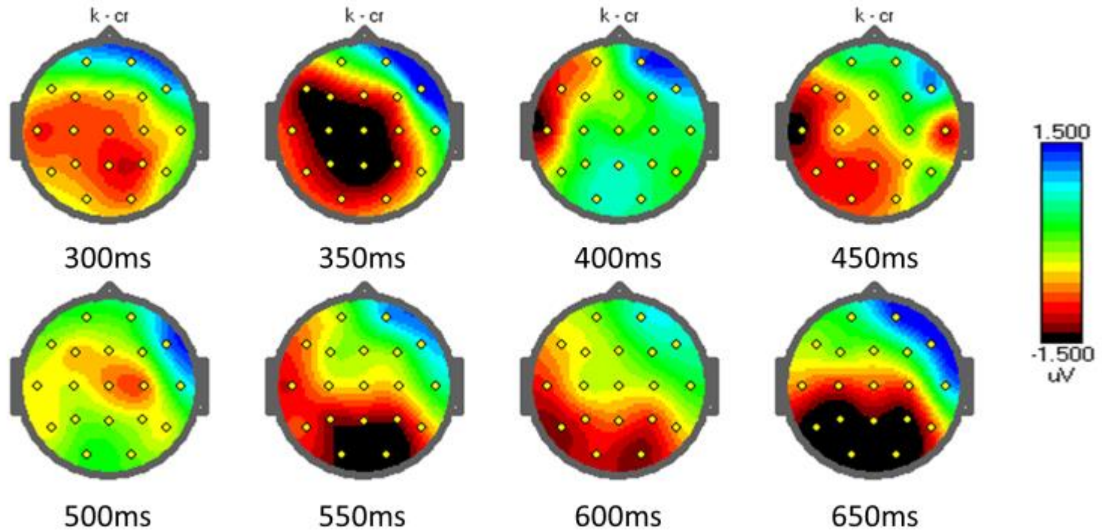

Figure A6.1.2.16. Controls' 'Know – Correct rejections' for faces at different time ranges

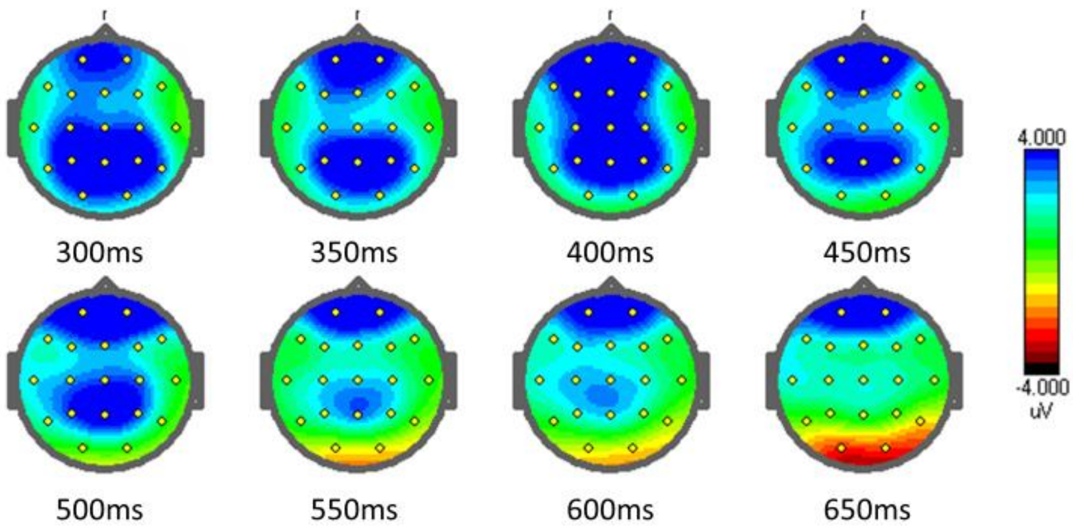

Figure A6.1.2.17. SRs' 'Remember' responses for objects at different time ranges

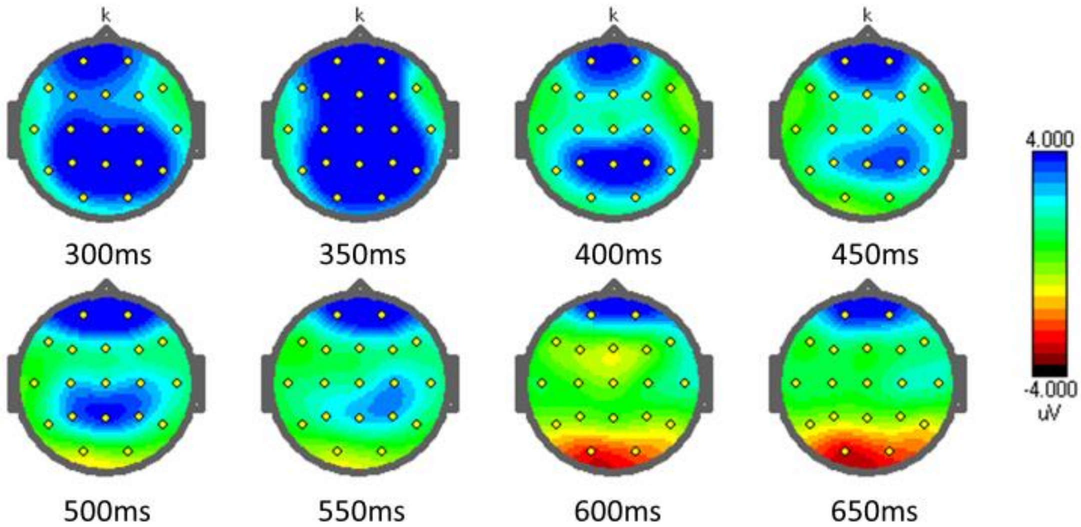

Figure A6.1.2.18. SRs' 'Know' responses for objects at different time ranges

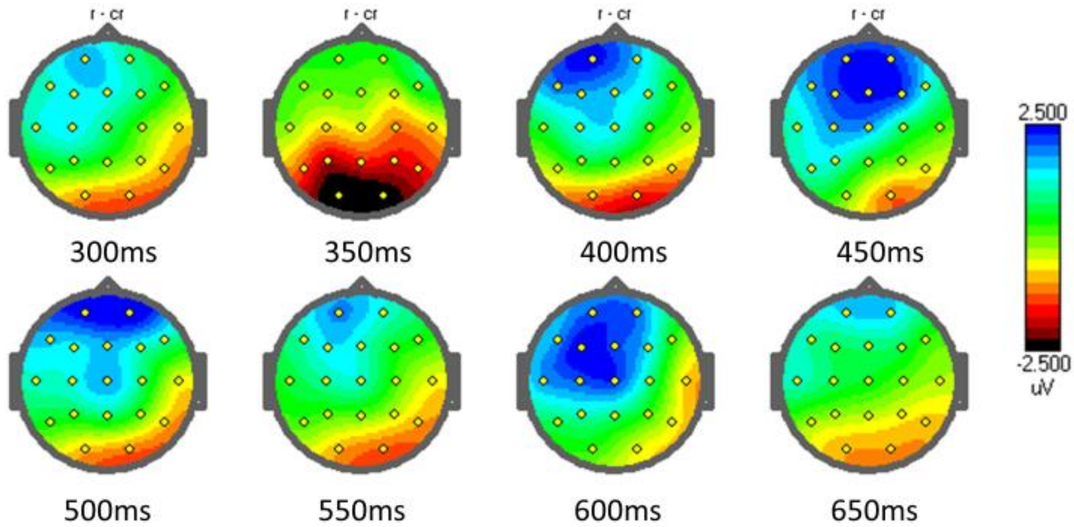

Figure A6.1.2.19. SRs' 'Remember – Correct rejections' for objects at different time ranges

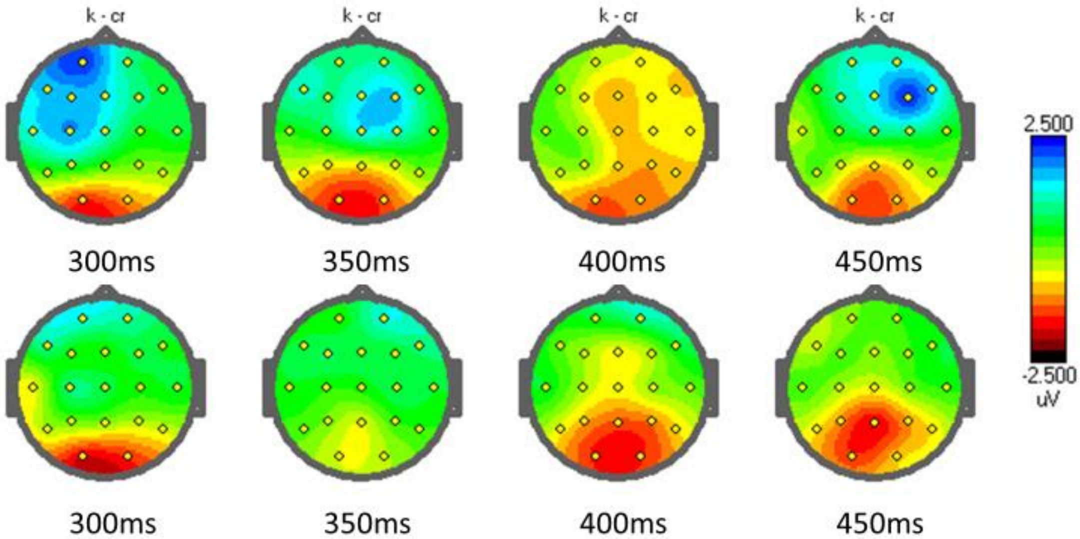

Figure A6.1.2.20. SRs' 'Know – Correct rejections' for objects at different time ranges

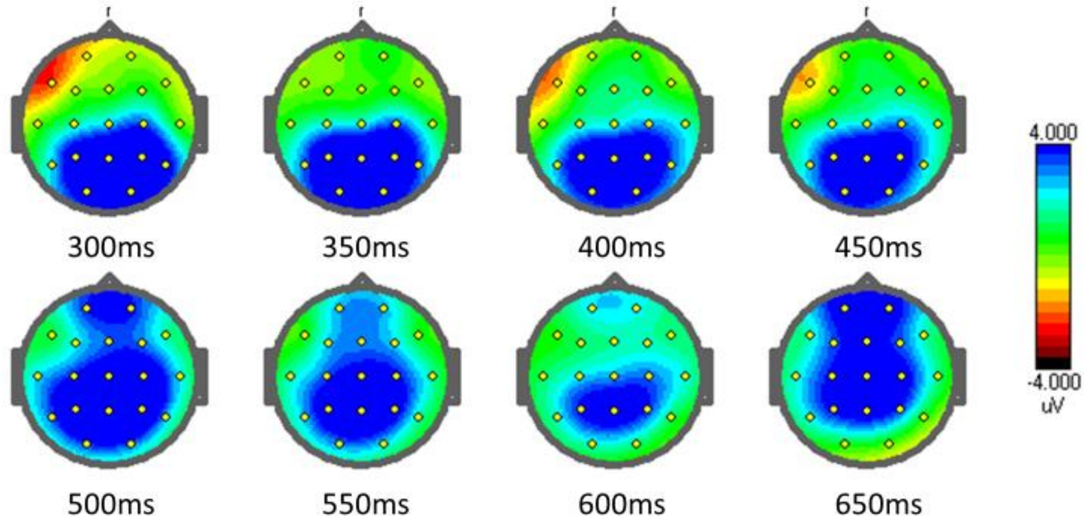

Figure A6.1.2.21. Controls' 'Remember' responses for objects at different time ranges

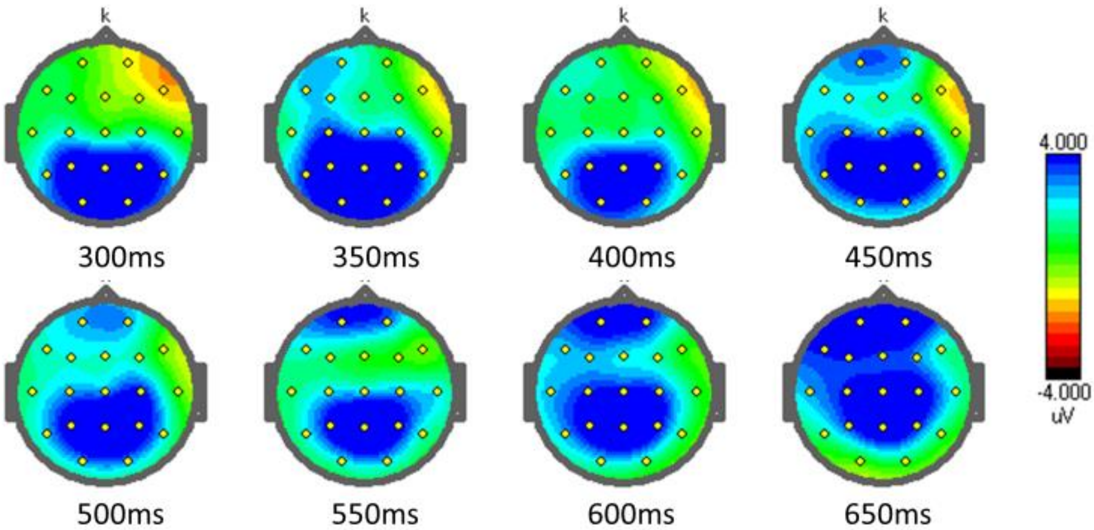

Figure A6.1.2.22. Controls' 'Know' responses for objects at different time ranges

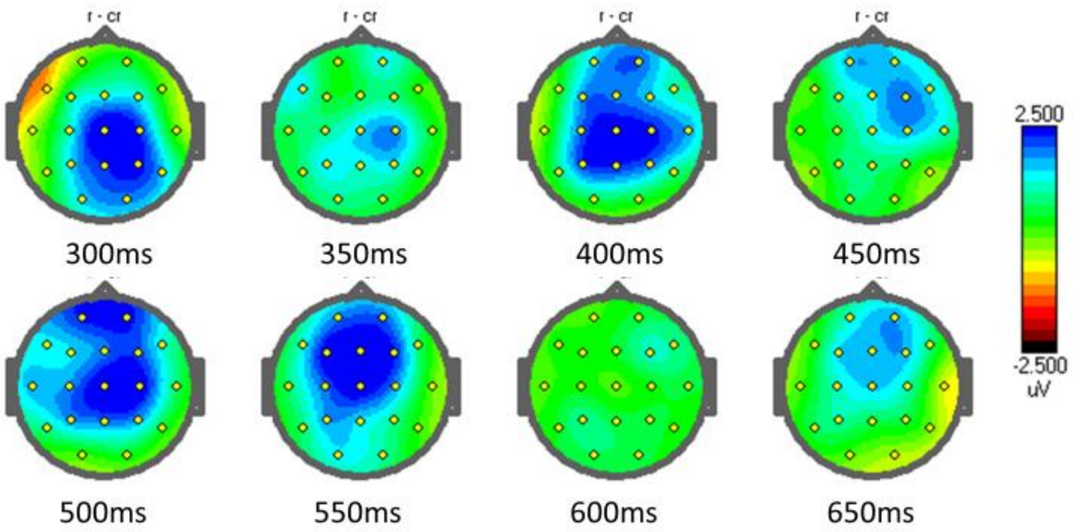

Figure A6.1.2.23. Controls' 'Remember – Correct rejections' for objects at different time ranges

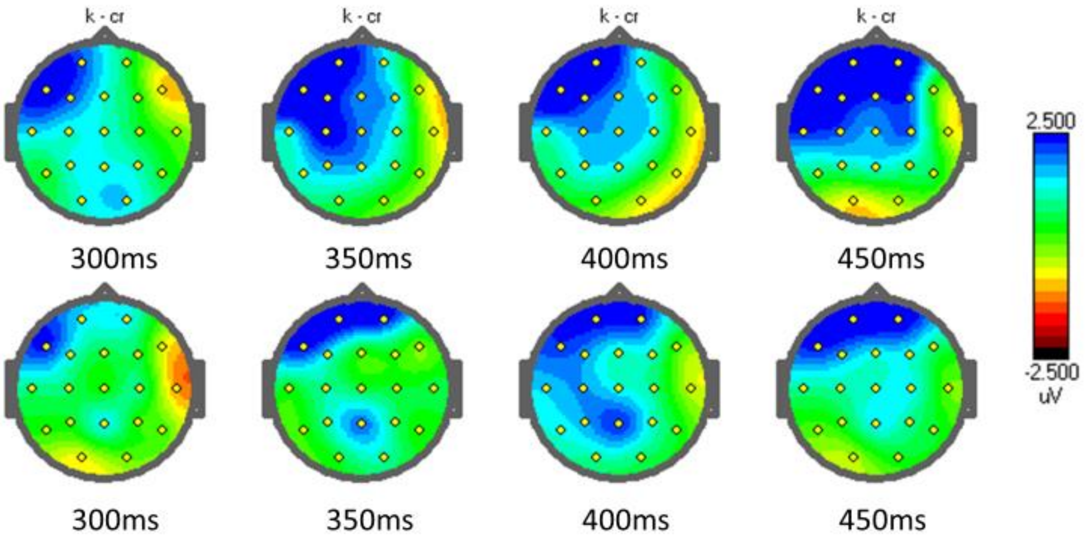

Figure A6.1.2.24. Controls' 'Know – Correct rejections' for objects at different time ranges

Appendix 7.2.1

Table A7.2.1.1. Mean performance on face and object recognition tests in high and low CFMT+ SR scorers.

	High score SRs (*n* = 123)				Low score SRs (*n* = 76)				t-tests	Significance	Effect size
	M	(SD)	95% CI		M	(SD)	95% CI		t	p	d
CFMT+	96.77	(1.72)	96.47,	97.08	93.54	(0.50)	93.42,	93.65	15.94	< .001	2.55
Adult Face Recognition Test (old/new)											
Hits	0.88	(0.08)	0.86,	0.89	0.88	(0.08)	0.86,	0.90	-0.09	.932	0.00
CR	0.90	(0.08)	0.89,	0.91	0.89	(0.08)	0.87,	0.91	1.21	.229	0.13
d'	2.64	(0.58)	2.53,	2.74	2.53	(0.51)	2.53,	2.65	1.26	.209	0.20
C	0.06	(0.31)	0.01,	0.12	0.03	(0.30)	-0.04,	0.10	0.78	.439	0.10
Object Recognition Test (old/new)											
Hits	0.78	(0.12)	0.76,	0.80	0.75	(0.11)	0.72,	0.77	2.03	.043	0.26
CR	0.70	(0.15)	0.67,	0.73	0.69	(0.12)	0.66,	0.72	0.49	.626	0.07
d'	1.41	(0.61)	1.30,	1.52	1.23	(0.55)	1.11,	1.35	2.08	.039	0.31
C	-0.14	(0.32)	-0.19,	-0.08	-0.09	(0.23)	-0.14,	-0.04	-1.17	.245	0.18
Infant face Recognition Test (old/new)											
Hits	0.81	(0.09)	0.79,	0.83	0.79	(0.10)	0.77,	0.82	1.06	.292	0.21
CR	0.77	(0.12)	0.75,	0.79	0.78	(0.09)	0.75,	0.80	-0.25	.803	0.09
d'	1.76	(0.55)	1.66,	1.86	1.69	(0.45)	1.58,	1.79	0.96	.340	0.14
C	-0.07	(0.32)	-0.12,	-0.01	-0.04	(0.30)	-0.11,	0.03	-0.63	.528	0.10