Is it possible to enhance face recognition skills? The effect of transcranial direct current stimulation (tDCS) and image-variability training

A thesis submitted for the degree of Doctor of Philosophy

Kho Siew Kei
School of Psychology
University of Nottingham Malaysia
March 2023

Abstract

Face recognition ability is important for social interaction that occurs in our everyday lives. Given the importance of faces in social interactions, losing the ability to recognize faces may produce devastating consequences for an individual's social life. Improvement of face recognition ability is important not only for individuals with facial recognition deficits, but also for national security. Thus, the main aim of this thesis is to examine the effect of transcranial direct current stimulation (tDCS) and cognitive training on own- and other-race face recognition.

Chapter two focuses on examining the role of the occipital face area (OFA) and the fusiform face area (FFA) in the recognition of individual facial features and whole faces using multifocal tDCS. The results indicated that multifocal tDCS applied to the FFA led to increased efficiency for facial feature recognition while no effect of OFA stimulation on either facial feature or whole face recognition was found. Chapter three investigated how anodal and cathodal tDCS could affect the recognition of own- and other-race faces. In the course of this study, we created and evaluated a new Asian version of the Cambridge Face Memory Test (CFMT) (i.e., CFMT – Chinese Malaysian (CFMT-MY)). Our evaluation of the CFMT-MY showed high consistency and high reliability and therefore exhibits potential utility in facilitating the diagnosis of individuals with difficulty in face recognition in clinical settings, the measurement of individual differences in face recognition ability and the measurement of the other-race effect. However, we found no effect of a-tDCS and c-tDCS on either own- or other-race face recognition.

Chapter four focuses on the benefits of learning identity via multiple high variation exposure on own- and other-race faces. The findings showed enhanced own-race face learning (i.e., face recognition and face-name association) for identities learned in high variability condition compared to low variability condition. However, identities learned in high variability condition only benefited other-race face recognition, but not face-name association. Finally, chapter five aims to examine if the benefits of learning identity via high variation multiple exposure could be applied to individuals with prosopagnosia.

We found no effect of variability on face learning for either suspected developmental prosopagnosics (DP) or neurotypical participants.

Overall, our results showed that tDCS improved facial feature recognition but not own- and other-race whole face recognition. Thus, tDCS might have limited effects on improving face recognition. Additionally, our results showed enhanced own- and other-race face recognition for identities learned with multiple exposure in high variation settings. However, this effect was not found for suspected DPs and neurotypical participants. This discrepancy in results could be due to the low sample size of suspected DPs and neurotypical participants in Experiment 5.

Declarations

This thesis contains original work completed by myself under the supervision of Dr. Alejandro Estudillo, Dr. David Keeble and Dr. Wong Hoo Keat.

Chapter 2 and 3 have been submitted for publication.

Experiment 1a and 1b have been published in *Neuropsychologia.*

Kho, S. K., Keeble, D. R. T., Wong, H. K., & Estudillo, A. J. (2023). Investigating the role of the fusiform face area and occipital face area using multifocal transcranial direct current stimulation. *Neuropsychologia*, *189*(March), 108663. https://doi.org/10.1016/j.neuropsychologia.2023.108663

Experiments 2a and 2b have been published in *Behavior Research Methods*.

Kho, S. K., Leong, B. Q. Z., Keeble, D. R. T., Wong, H. K., & Estudillo, A. J. (2023). A new Asian version of the CFMT: The Cambridge Face Memory Test – Chinese Malaysian (CFMT-MY). *Behavior Research Methods*. https://doi.org/10.3758/s13428-023-02085-6

Experiment 3 has been published in *Social Neuroscience*.

Kho, S. K., Keeble, D., Wong, H. K., & Estudillo, A. J. (2023). Null effect of anodal and cathodal transcranial direct current stimulation (tDCS) on own- and other-race face recognition. *Social Neuroscience*. https://doi.org/10.1080/17470919.2023.2263924

Table of Contents

Acknowledgements

First and foremost, I would like to begin by expressing my sincere appreciation to my supervisors, Alex, David, and Hoo Keat, for their invaluable guidance, patience, and support throughout my PhD journey. Their insightful comments, constructive criticism, and unwavering encouragement have played an important role in shaping my research and helping me overcome the various challenges that I encountered along the way. Without their mentorship, I would not have achieved what I have today. I also extend my thanks to Dr. Miflah for his kind support and invaluable feedback on my annual review report.

My heartfelt gratitude also goes out to all the participants who took part in my experiments and the staff members in the School of Psychology for their support and encouragement. I would also like to thank the Fundamental Research Grant Scheme (FRGS) and the Society for Applied Research in Memory & Cognition (SARMAC) Student Caucus Research Grant for providing the necessary funding to support my research.

I am truly grateful to have met my PhD mates (in alphabetical order): Bryan, Jasmine, Kai Hao, Keith, Mei Ling, Omid and Soon Tat, for they have provided me with helpful discussions, feedback and encouragement. I cherish the memories we shared over having meals together and our occasional “part 2”. Your presence has made the journey more memorable, meaningful and enjoyable.

My family (my parents, my crazy but loving siblings and cousins, and aunty Sally and family) deserve a special mention for their unconditional love and support throughout this journey. Their encouragement, understanding, and patience have enabled me to pursue my academic dreams. I would also like to express my gratitude to my best friends since 2003 (again, in alphabetical order): Joey, Natalie and Shan Nie, for their constant support and for lending an ear to my concerns.

Lastly, and most importantly, I would like to express my deepest gratitude to my significant other for believing in me and supporting me throughout the entire PhD journey. Your encouragement, patience, and understanding have helped me achieve this milestone. I cannot thank you enough for everything you have done for me during this long journey.

List of Abbreviations

Abbreviation	Term
ANOVA	Analysis of variance
a-tDCS	Anodal transcranial direct current stimulation
CCMT	Cambridge Car Memory Task
CCTV	Closed circuit television
CFMT	Cambridge Face Memory Task
CFPT	Cambridge Face Perception Task
c-tDCS	Cathodal transcranial direct current stimulation
DLPFC	Dorsolateral prefrontal cortex
ERP	Event-related potential
FFA	Fusiform face area
fMRI	Functional magnetic resonance imaging
Gf	Fluid intelligence
HD-tDCS	High-definition transcranial direct current stimulation
OFA	Occipital face area
ORE	Other-race effect
RCS	Rate-correct score
rTMS	Repetitive transcranial magnetic stimulation
SEREC	Science and engineering research ethics committee
STS	Superior temporal sulcus
tACS	Transcranial alternating current stimulation
TBS	Theta burst transcranial magnetic stimulation
tDCS	Transcranial direct current stimulation
TES	Transcranial electrical stimulation
TMS	Transcranial magnetic stimulation
tRNS	Transcranial random noise stimulation

List of Figures

List of Tables

Chapter 1 – Introduction

Face recognition ability is vital for a wide range of social interactions and we tend to use our facial recognition skills very often in our daily lives (Jack & Schyns, 2015). Faces can provide useful information such as the emotion (Frith, 2009), gender (Reddy et al., 2004), age (Rhodes & Anastasi, 2012) and personality and health status (Jones et al., 2012) of an individual. Although face recognition ability is used extensively in our daily lives, research has shown that we are not experts in recognizing unfamiliar faces (Bruce et al., 1999; A. W. Young & Burton, 2018) and occasionally we may even have difficulties in recognizing familiar faces (A. W. Young et al., 1985). For example, some research has shown that when cashiers have to match the photograph on a credit card to the actual face of the shopper, more than half of the fraudulent cards were accepted by them (Kemp et al., 1997). Also, high error rates have been reported when matching the identity of an unfamiliar face on closed circuit television (CCTV) to photographs, even when high-quality footage and photographs were used (Henderson et al., 2001; see also Davis & Valentine, 2009).

Given the catastrophic consequences that wrong identification might have in applied scenarios, it is important to develop effective ways of improving face recognition ability for occupations related to national security that require high face recognition skills (e.g., passport and police officers) and eyewitness testimonies. Improving face recognition ability is also vital for individuals with certain developmental and neurological disorders that are associated with face recognition deficits such as acquired and developmental prosopagnosia (Rossion, 2014) and autism (Weigelt et al., 2012). Individuals with prosopagnosia may face difficulties in recognizing their family members (Busigny & Rossion, 2010) and occasionally their own face (Parketny et al., 2015). Failure in recognizing family members or friends could contribute to negative consequences such as feelings of embarrassment and guilt which may build up anxiety and fear of social interaction and a lower level of self-confidence (Dalrymple, Fletcher, et al., 2014; Yardley et al., 2008). Thus, it is important to examine the potential rehabilitation for neurological disorders that are associated with face recognition deficits.

In the following section, we will discuss some important concepts in face recognition literature, such as holistic processing and its neural underpinnings. Then, in section 1.2 we will elaborate on some potential methods of improving face recognition ability, mainly, the transcranial electrical stimulation and cognitive face training.

1.1 Face recognition

Faces are thought to be a special category of stimuli as faces are recognized differently compared to objects (McKone et al., 2007; Robbins & McKone, 2007). Human faces possess the ability to capture attention automatically (Theeuwes & Van der Stigchel, 2006) and they are more easily detected compared to animal faces or non-face objects (Hershler & Hochstein, 2005; Langton et al., 2008). Additionally, faces are processed more holistically (as a whole) compared to objects (Tanaka & Farah, 1993; Yin, 1969) and research has identified several specific brain regions specialized for face processing (Haxby et al., 2000). In this section, we will discuss how faces are processed as a whole instead of by parts (holistic processing described in the next section), face processing models, evidence for face-specific brain regions such as the fusiform face area, occipital face area and superior temporal sulcus, the other-race effect in recognizing faces and the neurological disorder associated with face recognition, specifically prosopagnosia.

1.1.1 Holistic processing of faces

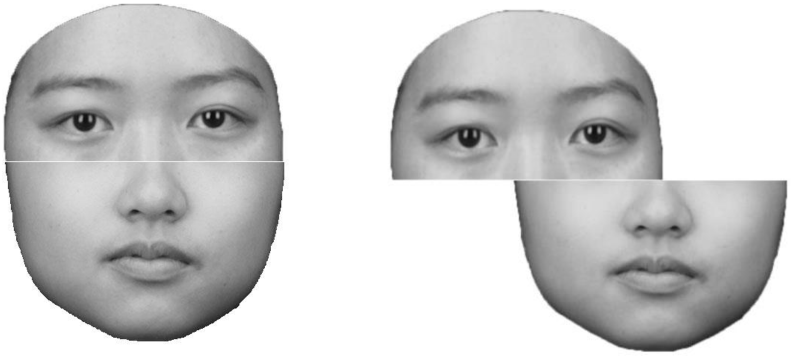
The first section on face recognition begins with an exploration of holistic processing within the realm of face processing. Upright faces are usually processed holistically or as a whole (Tanaka & Farah, 1993). Holistic processing could be defined as “the simultaneous integration of the multiple parts of a face into a single perceptual representation” (Rossion, 2013). However, the term “holistic processing” could carry a different meaning (Kimchi & Amishav, 2010; Maurer et al., 2002; Piepers & Robbins, 2012). For example, Maurer and colleagues (2002) identified three types of configural processing which include holistic processing (perceiving features of the face as a whole), first-order relations (two eyes above a nose and mouth) and second-order relations (the spacing among features of the face). The terms “holistic” and “configural” have been used interchangeably in the literature (see Rossion, 2013) and so in this thesis, these terms will be used as synonyms.

One of the measures of holistic face processing is the face inversion effect (FIE). The FIE is a phenomenon where inverted faces are more difficult to identify compared to upright faces (Yin, 1969). It is considered that inverting a face causes disruption in perceiving faces as a whole or holistically, thus the face is processed by the individual face parts (Van Belle et al., 2010). When faces are processed by the individual face parts, the process could be termed as part-based processing, featural processing, piecemeal processing or analytical processing (Collishaw & Hole, 2000). However, it is important to note that the FIE has been proposed to be an indirect measure of face holistic processing as the effect only causes disruption to holistic face processing without directly manipulating holistic or part-based processing (Tanaka & Simonyi, 2016).

Other standard measures of holistic processing are the part-whole task and the composite face task. In the part-whole task, recognition of facial features of a face is easier when they are presented in a whole face context compared to when they are presented in isolation (Tanaka & Farah, 1993). Tanaka and colleagues (1993) found that this holistic effect is specific to normal, upright faces as the effect was not found for inverted faces, scrambled faces or non-face objects. The composite face effect occurs when the top half of the face is more difficult to recognize when it is aligned with a different lower half face to form an overall face shape (Figure 1.1) (A. W. Young et al., 1987). The effect disappears when the top and bottom halves of faces are misaligned. This supports the idea that holistic processing of faces takes place as it shows that the individual parts of a face could not be perceived independently when presented in an aligned manner. These two tasks are direct measures of holistic processing that measure the second-order relations which are crucial for discriminating between faces of different identities (Maurer et al., 2002; Piepers & Robbins, 2012).

Figure 1.1

Example of face stimuli in composite face task: top half aligned with a different lower half face (left) and misaligned top and bottom half of faces (right).



A less commonly used measure of holistic processing is the Mooney face task (Figure 1.2). Mooney faces developed by Mooney (1957) are drawings of faces presented in solid black and white that show an incomplete representation of faces (Moscovitch et al., 1997). Featural processing of Mooney faces is not possible as the Mooney faces contain an incomplete representation of faces, hence viewing it as a whole is required to process Mooney faces (Latinus & Taylor, 2005). In the Mooney face task, participants are shown a series of images and asked to identify whether each image represents a face or a non-face object. Mooney face task measures the first-order relations which are crucial for the detection of faces (Piepers & Robbins, 2012).

Figure 1.2

Example of a Mooney face (image taken from Mooney (1957)).

However, it is important to note that the different measures for holistic face processing such as the face inversion task, part-whole task and the composite face task may be underpinned by different perceptual mechanisms. In fact, recent research found low to no correlation between the three holistic face processing tasks (Rezlescu et al., 2017). The three holistic measures also predicted face perception ability to different extents, as measured with the Cambridge Face Perception Test (Duchaine et al., 2007). For instance, the face inversion and the part-whole tasks predicted face perception ability, but the association was stronger in the former compared to the latter. Interestingly, the composite face task was not associated with face perception ability. This suggests that all three tasks may reflect different types of holistic processing that are modulated by different perceptual mechanisms. Additionally, mixed findings have been found for the relationship between holistic processing of the face and face identification ability (e.g., DeGutis, Wilmer, et al., 2013; Konar et al., 2010). While some studies have found that holistic processing of the face as measured by the composite face task and the part-whole task could predict face identification skills (DeGutis, Wilmer, et al., 2013; Engfors et al., 2017; Richler et al., 2011), other studies found low to no correlation between holistic processing measured by the composite face task and face identification (Konar et al., 2010; Rezlescu et al., 2017; R. Wang et al., 2012).

1.1.2 Face processing models

After examining holistic face processing, we will now proceed to elaborate on various models that are pivotal to understanding face processing. One of the most influential models in the field of face processing is the framework proposed by Bruce and Young (1986). This model describes a series of cognitive processes that occur during the processing of faces. The initial stage of the model is structural encoding. In this stage, the visual features of a face are extracted and analysed. This comprehensive evaluation includes the arrangement, shape, and size of facial features, providing descriptions of the face from both a view-centred perspective and an expression-independent perspective. The view-centred descriptions are employed for expression analysis and facial speech analysis while the expression-independent descriptions are subsequently channelled into the face recognition units (FRUs). The FRUs store and process information related to familiar faces. When we encounter a face, the corresponding FRUs are activated to varying degrees, depending on the resemblance between the processed face and the stored representations of familiar faces. The activated FRUs then establish connections with the person identity nodes (PINs), which serve as repositories for identity-specific semantic information. PINs store semantic information about a person, such as their address, occupation, and other relevant knowledge. The PINs facilitate the retrieval of the individual's name, and therefore complete the face recognition process.

Another prominent model in the field of face processing is the face-space model (Valentine, 1991; Valentine et al., 2016). This model portrays faces as unique points situated within a multidimensional space. Each dimension in this space corresponds to a specific facial feature or global feature of faces, such as the shape of the eyes or the overall structure of a face. The distances between points within this multidimensional space signify the similarity between faces. Faces that share similarities in appearance are represented by points positioned in close proximity, whereas faces with distinct appearances are positioned at greater distances from one another. According to this model, we undergo a cognitive process when encountering a novel face where we assess its resemblance to familiar faces by measuring the spatial distances between the points within the face-space. This model is often associated with the ORE, a phenomenon that will be discussed in section 1.1.4.

1.1.3 Face-selective brain regions

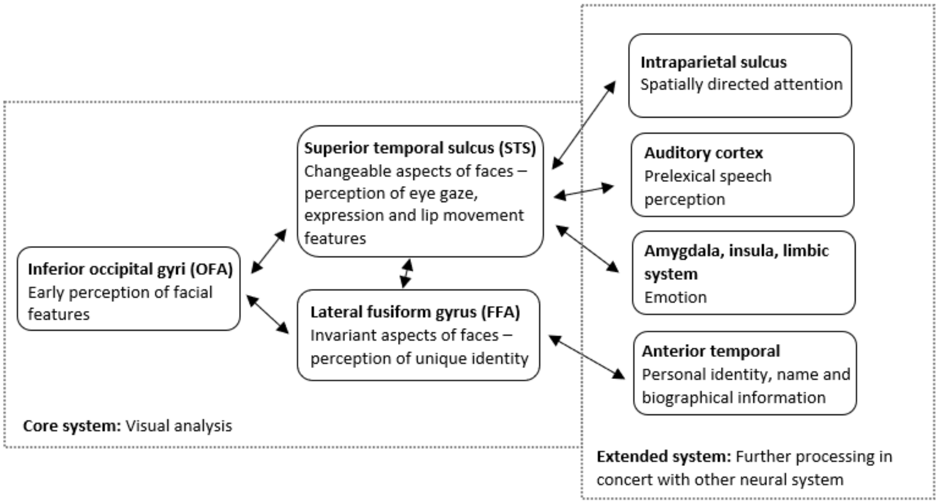
Building upon our discussion of face processing models in the previous section, we now shift our focus to the neural underpinnings of face recognition. Previous work has suggested three regions in the occipital-temporal cortex as the main neural network in face processing: the fusiform face area (FFA) located in the lateral fusiform gyrus, the occipital face area (OFA) located in the lateral inferior occipital gyri and the superior temporal sulcus (STS) (Haxby et al., 2000). The three regions can usually be located in both the left and right hemispheres but research has suggested a right hemisphere lateralization for face processing (de Heering & Rossion, 2015; Grill-Spector et al., 2018; Rangarajan et al., 2014; G. Rhodes, 1993). For instance, electrical stimulation of the fusiform gyrus in the right hemisphere led to disruption of face perception but this effect was absent during stimulation of the left hemisphere (Rangarajan et al., 2014). Also, face-selective regions in the right hemisphere are usually larger compared to the left hemisphere (Bukowski et al., 2013).

Haxby et al.'s (2000) neural model of face processing (Figure 1.3) was constructed based on the framework proposed by Bruce and Young (1986) and these two models exhibit some similarities. For instance, both models suggested a hierarchical or multi-stage processing mechanism for faces, implying that faces are processed in a series of stages. Additionally, both models highlight the significance of specific facial features or components in the process of recognizing faces, such as the eyes, nose, and mouth. According to the Haxby et al. (2000) model, face processing in the human brain is accomplished by a distributed neural system. The core system consists of three regions in the occipitotemporal visual extrastriate cortex, namely the FFA, OFA, and STS. The OFA's anatomical location suggests that it may process the early perception of facial features and provide input to both the FFA and STS regions. The FFA appears to be more involved in facial identity representation, while the STS appears to be more involved in the changeable aspects of faces. The extended system includes additional neural systems such as the intraparietal sulcus, auditory cortex, amygdala, and anterior temporal region, which are involved in further processing, such as spatial attention, speech perception, emotion, and the representation of biographical and autobiographical knowledge.

Based on the model by Haxby et al. (2000), OFA seems to be the sole entry point into the wider face network, however, contradicting evidence has been found. For instance, patients with lesions to the brain region where the OFA is usually located still showed face-selective activation in the FFA (Rossion et al., 2003; Steeves et al., 2006). Other than that, it has been shown that STS responded more to moving faces compared to static faces while OFA and FFA exhibit less response or no response at all for moving faces (Fox, Iaria, et al., 2009; Pitcher et al., 2019; Schultz & Pilz, 2009). These findings suggest that STS may be receiving input from the motion-selective brain region rather than the OFA (O'Toole et al., 2002). Also, research has found cortical connections between motion-selective brain regions and the STS (Gschwind et al., 2012). The findings discussed challenged the hypothesis that the only entry point into the extended face network is through the OFA.

Figure 1.3

Haxby et al. (2000) anatomical model of face perception (image adapted from Haxby et al., 2000).



1.1.3.1 Occipital face area (OFA) and fusiform face area (FFA)

The face-selective region located in the inferior occipital gyri was identified and named OFA by Gauthier et al. (2000). Additionally, prior fMRI studies have identified another face-selective region in the fusiform gyrus, known as the FFA, which is activated specifically by faces (Kanwisher et al., 1997; McCarthy et al., 1997). The neural model of face processing proposed by Haxby et al. (2000) considers that the OFA is involved in the early stages of face processing (i.e., structural encoding, see Bruce and Young, 1986) whereas the FFA is involved in processing facial identity. Involvement of the OFA in the early stages of face processing is evident by the fact that the response for faces in the OFA preceded the response for faces in FFA and STS by approximately 60ms, as measured by event-related potential (ERP) (Sadeh et al., 2010). Additionally, OFA has been suggested to be involved in the representation of face parts such as the eyes, nose and mouth (Pitcher, Walsh, et al., 2011). This was supported by the findings of Pitcher and colleagues (2007) who found that disruption of discrimination of face parts occurred when repetitive transcranial magnetic stimulation (rTMS) was administered to OFA, however, there was no effect on the discrimination of the spacing between the face parts.

In line with this, several studies have demonstrated the involvement of the OFA in the representation of independent facial features and the FFA in the representation of whole faces (Fox, Moon, et al., 2009; Nichols et al., 2010; Pitcher et al., 2007; Schiltz et al., 2010). For instance, transcranial magnetic stimulation (TMS) of the OFA has been shown to disrupt the discrimination of independent facial features (Pitcher et al., 2007). Additionally, a functional magnetic resonance imaging (fMRI) study has indicated that the OFA presented greater activation for a single feature of the face (e.g., eyes) over a combination of features (e.g., eyes and mouth presented together) (Dachille et al., 2012). Other fMRI studies have also shown that the OFA was responsive to independent facial features (Fox, Moon, et al., 2009; Nichols et al., 2010) irrespective of whether the features were arranged in a scrambled or normal configuration (J. Liu et al., 2010).

The FFA, in contrast, was more responsive to features that were arranged in a normal configuration compared to a scrambled configuration (J. Liu et al., 2010; Zhang et al., 2012). In terms of whole face representation, using measures of holistic face processing such as the face inversion task (Yovel & Kanwisher, 2005) and the composite face task (Schiltz et al., 2010; Schiltz & Rossion, 2006), it has been found that the FFA showed an increased response to holistically intact faces (i.e., upright faces and top-half and bottom-half aligned faces) compared to the OFA (Nichols et al., 2010). Other than the measures of holistic processing, the FFA was also found to be responsive to changes in identity or expression (Fox, Moon, et al., 2009), which involve whole face representation.

Conversely, several studies have found opposing findings such as the involvement of the OFA in holistic face processing (Bona et al., 2016; G. Rhodes, Michie, et al., 2009; Rivolta et al., 2012) and facial identity processing (Ambrus et al., 2017; Xu & Biederman, 2010) (which both involve whole face representation) and the involvement of the FFA in the perception of individual facial features (Yovel & Kanwisher, 2004). For example, an fMRI study has shown that both the OFA and the FFA support configural face processing as both regions responded more strongly to faces presented with various spacings between facial features compared to a repeated presentation of the same face (G. Rhodes, Michie, et al., 2009). Furthermore, it has been shown that TMS and anodal transcranial direct current stimulation (tDCS) to the OFA disrupt Mooney face detection (Bona et al., 2016; Renzi et al., 2015). Mooney faces are drawings of faces presented in solid black and white that show an incomplete representation of faces (Mooney, 1957; Moscovitch et al., 1997). Processing Mooney faces requires perceiving them as wholes because they only contain a partial representation of the faces (Latinus & Taylor, 2005). Hence, the disruption of Mooney face detection after TMS and tDCS to the OFA further supports the involvement of the OFA in holistic face processing. TMS over the OFA has also been shown to impair facial identification and semantic processing of facial identity which involve whole face representations (Ambrus et al., 2017, 2019; Eick et al., 2020; Kadosh et al., 2010; Solomon-Harris et al., 2013).

Additionally, an fMRI study has demonstrated that the FFA was not only involved in holistic face processing, but also in facial feature perception as it was found that the FFA responded similarly to configural (i.e., spacing among facial features) and featural (i.e., shapes of eyes and mouth in faces) changes of faces (Yovel & Kanwisher, 2004). However, as the featural changes were made in the context of a whole face, the FFA activation could reflect a change of identity, rather than featural processing itself.

In summary, the findings discussed suggest that the OFA and the FFA might have overlapping roles in the face recognition process where both regions might be involved in the representation of individual face parts and also in the representation of whole faces.

1.1.3.2 Superior temporal sulcus (STS)

Past fMRI study has also identified a face-selective region in the posterior part of the superior temporal sulcus that was referred to as the STS (T. Allison et al., 2000). The STS has been proposed to be involved in changeable aspects of faces which consist of dynamic facial information such as perception of eye gaze, expression and lip movement (Haxby et al., 2000). For example, although all three face-selective regions (OFA, FFA and STS) showed a greater response to dynamic faces compared to static faces, the response of STS to dynamic faces showed a greater increase compared to the OFA and FFA (Fox, Iaria, et al., 2009). Conversely, another study found that while the OFA and FFA did not respond differently to dynamic faces and static faces, the right posterior STS responded nearly three times more strongly to dynamic faces compared to static faces and the right anterior STS responded only to dynamic but not static faces (Pitcher, Dilks, et al., 2011). More importantly, both the right posterior and anterior STS responded more to moving faces than moving bodies, indicating that the STS was involved in processing face-specific dynamic information. Furthermore, theta burst transcranial magnetic stimulation (TBS) which caused disruption to the OFA reduced response to static but not dynamic faces, while disruption to STS reduced response to dynamic but not static faces (Pitcher et al., 2014). Taken together, the findings presented indicate that the STS plays a significant role in the processing of dynamic facial information.

1.1.4 The other-race effect

Having explored the neural foundations of face recognition in the preceding section, we shift our focus to exploring the phenomenon known as the other-race effect (ORE) to understand the variations in the recognition of different faces. The ORE (also known as the own race bias, cross race effect or cross race bias) which could be found across different races and countries is a robust psychological effect where humans tend to show superiority in the identification of same-race faces compared to other-race faces (Malpass & Kravitz, 1969; Meissner & Brigham, 2001). Faces from different races may vary in their facial morphology such as the average shape of the face, hair and skin color (Farkas et al., 2005). However, ORE has also been found among different European subpopulations that have minor differences in their facial morphology (McKone et al., 2011). The ORE seems to be present at an early age, as research has suggested that the development of the ORE started at six-months of age and was present at nine-months of age (Kelly et al., 2007). Racial group membership could affect perceptual preference whereby infants as early as three-month old attended more to same-race faces compared to other-race faces (Kelly et al., 2005).

One potential explanation for the ORE is the experience-based holistic account also known as the contact hypothesis (Rossion & Michel, 2011). Humans tend to develop a higher level of perceptual expertise for faces that are more often seen in their everyday lives, which are generally faces of their own race. This would lead to the ORE as there is a higher level of perceptual expertise for same-race faces and a lower level of perceptual expertise for other-race faces (Tanaka et al., 2013). The familiarity and experience with the faces then enhance learning of the facial physiognomy of the faces experienced which could be used in differentiating the faces experienced.

The experience-based holistic account is in line with the principles of the face-space model (Valentine, 1991; Valentine et al., 2016). According to this model, faces situated at the center or origin point of the model mainly consist of faces acquired through prolonged exposure. In this context, the faces at the center point often belong to individual’s same-race faces since they are usually exposed to and interact more frequently with people of their same race. Conversely, faces of other-race are dissimilar to these commonly seen faces and are consequently located further away from the origin point within the face-space.

Manipulation that disrupts face recognition accuracy, such as presenting faces in an inverted orientation, leads to an increase in encoding errors. However, these encoding errors tend to pose greater challenges in recognizing commonly seen faces (same-race) compared to distinctive faces (other-race). This is because commonly seen faces occupy a more densely clustered region within the face-space in comparison to distinctive faces. Therefore, an increase in encoding errors is more likely to cause confusion in identifying commonly seen faces than distinctive faces. Indeed, when faces are inverted, the impairment in the accuracy of recognition memory for distinctive faces tends to be less pronounced than for commonly seen faces (Megreya et al., 2011; Valentine, 1991). This observation highlights the distinct recognition processes for own-race and other-race faces, which arise from varying exposure durations.

Furthermore, as the experience with the facial physiognomy of same-race faces increases, the holistic representation of same-race faces is enhanced, and as a result, other-race faces are represented less holistically (Rossion & Michel, 2011). Hence, other-race faces are recognized using a more featural processing approach and this leads to greater difficulty in recognizing other-race faces as compared to same-race faces. Past work has provided compelling evidence showing that same-race faces are processed more holistically compared to other-race faces (Megreya et al., 2011; Michel et al., 2007; Tanaka et al., 2004). For example, identical face stimuli were processed more holistically when categorized as same-race compared to other-race faces suggesting that race categorization changes the holistic processing of faces (Michel et al., 2007). Additionally, greater matching performance and stronger inversion effects have been reported for same-race faces compared with other-race faces indicating that SR faces were processed more holistically as compared to other-race faces (Megreya et al., 2011). Similarly, Tanaka and colleagues (2004) in their study revealed that Caucasians processed their own race faces more holistically compared to Asian faces using a part whole task.

However, impairment in holistic processing for other-race faces has not always been found (Crookes et al., 2013; Mondloch et al., 2010; Tanaka et al., 2004; Wong et al., 2021). For instance, Asian participants demonstrated a similar extent of holistic processing for same-race faces and Caucasian faces regardless of whether the Asian participants recruited were living in predominantly other-race (Caucasian) surroundings (Tanaka et al., 2004) or same-race (Hong Kong) surroundings (Crookes et al., 2013). The absence of disruption in holistic processing for other-race faces has been replicated with African and Caucasian participants perceiving Chinese faces as well (Mondloch et al., 2010; Wong et al., 2021). These findings contradict the assumption that reduced holistic representation for other-race faces contributes to the ORE.

Moreover, it is unclear whether, and if so, which type of holistic processing is affected by the ORE. As mentioned before, holistic or configural processing could be differentiated into three types: holistic processing (perceiving features of the face as a whole), first-order relations (two eyes above a nose and mouth) and second-order relations (the spacing among features of the face) (Maurer et al., 2002). Studies have indicated that same-race and other-race faces were processed holistically to a similar extent, however, second-order relational information was processed less for other-race faces than for same-race faces suggesting that other-race faces influence the processing of second-order relational information rather than holistic processing (Lewis & Hills, 2018; Mondloch et al., 2010). These results suggest that the ORE could arise due to reduced sensitivity of spacing among facial features for other-race faces but not due to disruption of perceiving the other-race faces as a whole.

Another possible explanation for ORE is the social motivation approach (Hugenberg et al., 2007; MacLin & Malpass, 2001; Sporer, 2001). This approach suggests that other-race faces are more difficult to recognize due to the categorization of other-race faces as out-group members (Hugenberg & Corneille, 2009) and reduced motivation to recognize other-race faces (Pauker et al., 2009). For example, when white and black faces were categorized by race, participants recognized same-race faces more accurately than other-race faces, but when the same faces were categorized by university, participants recognized faces that were linked to their own university more accurately than faces that were linked to other university regardless of race (Hehman et al., 2010). This suggests that social categorization of faces could affect face recognition ability with a preference for in-group members. In line with this, same-race faces that were categorized as in-group members were recognized more accurately (Bernstein et al., 2007; Shriver et al., 2008) and more holistically (Hugenberg & Corneille, 2009) compared to same-race faces that were categorized as out-group members. These studies suggest that merely categorizing faces as in- or out-group members could affect how faces are perceived, thus supporting the idea that social categorization could contribute to the ORE.

Past work has also suggested that ORE could be modulated by motivational factors (Hugenberg et al., 2007; Pauker et al., 2009; S. G. Young & Hugenberg, 2012) and emotions (Ackerman et al., 2006; Johnson & Fredrickson, 2005). For instance, increasing motivation by creating awareness of ORE and encouraging participants to attend to individuating facial features of other-race faces eliminated the ORE (Hugenberg et al., 2007; G. Rhodes, Locke, et al., 2009; S. G. Young et al., 2010; S. G. Young & Hugenberg, 2012). Other than that, the ORE was eliminated when participants were presented with racial inclusive motivation (i.e., informing participants that prejudiced individuals tend to exclude other-race faces from their group), but not when participants were presented with accuracy motivation (i.e., instructing participants to do their best to remember the faces correctly) (Pauker et al., 2009). In line with this, inducing negative emotions such as anger to facilitate individuation of facial features (Ackerman et al., 2006; S. G. Young & Hugenberg, 2012) and positive emotions such as joy to reduce the salience of group differences (Johnson & Fredrickson, 2005) tends to diminish the ORE as well. These findings suggest that motivation could indeed contribute to the ORE where individuals tend to have reduced motivation to individuate other-race faces leading to the ORE.

When contact hypothesis and social motivation were conjointly investigated, it was reported that experience with other-race individuals improved recognition of other-race faces in the presence of motivation (i.e., instructions from the experimenter as in Hugenberg et al. (2007)), but not in the absence of motivation (S. G. Young & Hugenberg, 2012). This suggests that ORE could not be explained solely by experience with other-race individuals or social motivation alone, rather, both components are interconnected in their contribution to ORE. However, this finding is not always replicated as some studies have found no effect of motivation (as in Hugenberg et al. (2007)) on ORE, at all levels of experience with other-race individuals (Tullis et al., 2014; Wan et al., 2015). Wan and colleagues (2015) explained that the inconsistency in findings may be explained by socio-economic status, where social motivation contributed to the ORE only when the other-race faces presented were of different socio-economic status (e.g., Caucasian participants viewing Black faces (Hugenberg et al., 2007; Pauker et al., 2009; G. Rhodes, Locke, et al., 2009; S. G. Young et al., 2010; S. G. Young & Hugenberg, 2012)), but not when the other-race faces presented were of equal socio-economic status (e.g., Caucasian participants viewing Asian faces (Tullis et al., 2014; Wan et al., 2015). In other words, only experience with other-race individuals, but not social motivation contributed to ORE when the other-race faces presented were of equal socio-economic status. In sum, it could be concluded that the amount of contribution of experience with other-race individuals and social motivation to the ORE would differ depending on cultural settings.

1.1.5 Prosopagnosia

Following our exploration of disparities in recognizing faces of different races, we will explore the condition known as prosopagnosia in this final section, offering detailed insights into the potential underlying factors contributing to diminished face recognition abilities in certain individuals. Prosopagnosia, also known as face blindness, is a visual impairment that affects face recognition despite intact visual acuity and intelligence (Ellis & Young, 1988; Francis et al., 2002; McConachie, 1976; Rossion, 2014). Developmental prosopagnosia or congenital prosopagnosia is a neurodevelopmental disorder where individuals fail to develop their face recognition ability without any history of brain injury (Brunsdon et al., 2006; Cook & Biotti, 2016; Palermo et al., 2011), as opposed to acquired prosopagnosia which occurs when an individual suffers from brain injury and loses their ability to recognize faces

(Barton, 2008; Davies-Thompson et al., 2014). The prevalence of developmental prosopagnosia was estimated to be up to 5.42% for adults (DeGutis et al., 2023; Kennerknecht et al., 2006, 2008) and 5.2% for children (Bennetts et al., 2017). In addition to deficits in face recognition, some individuals with prosopagnosia also show deficits in object recognition (Geskin & Behrmann, 2018; Gray et al., 2019) while others show no such difficulty (Busigny et al., 2010; Duchaine et al., 2006).

Individuals with prosopagnosia typically use compensatory strategies such as identifying a person by their voice, gait, hairstyle or clothing; however, such strategies do not always work and could be mentally draining (Adams et al., 2020; Cook & Biotti, 2016). For example, changes in appearance such as hairstyles or situations where uniforms are required, can cause failure of the compensatory strategy. Failure in recognizing familiar identities on social occasions could contribute to devastating consequences such as feelings of embarrassment and guilt, which may lead to high levels of anxiety and fear of social interaction as well as long-term consequences such as limited employment opportunities and a lowered level of self-confidence (Dalrymple, Fletcher, et al., 2014; Yardley et al., 2008). Hence, it is important to examine the causes of face recognition deficits in prosopagnosia and its potential rehabilitation.

It was postulated that face recognition deficits in prosopagnosia may be contributed to by deficits in holistic processing of faces as described in Chapter 1 (section 1.1.1), but the findings reported are inconclusive. For instance, some research has reported that prosopagnosics showed impaired holistic processing in a face inversion task (Busigny & Rossion, 2010), part-whole task (Busigny et al., 2010; J. Towler et al., 2018) and a composite face task (Avidan et al., 2011; T. T. Liu & Behrmann, 2014; Palermo et al., 2011; Ramon et al., 2010). These findings suggest that individuals with prosopagnosia show abnormal holistic processing of faces. Contrarily, it was found that similar to neurotypical participants, participants with prosopagnosia were better at face recognition when faces were presented as a whole as opposed to when faces were presented in an aperture paradigm (face stimuli were viewed through a dynamic window obstructing holistic processing) (Tsantani et al., 2020). This suggests that individuals with prosopagnosia could process faces holistically to the same extent as neurotypical individuals. In line with this, several other studies have reported the presence of normal composite face effects in prosopagnosics (Biotti et al., 2017; Le Grand et al., 2006; Susilo et al., 2010; Ulrich et al., 2017). Thus, it is unclear whether abnormal holistic processing of faces contributes to face recognition deficits in prosopagnosia. However, a recent study has proposed that face recognition deficits in prosopagnosia could stem from two types of face processing deficits: holistic processing and featural processing (Bennetts et al., 2022). Using a two-stage cluster analysis on a widely used face perception task (i.e., the Cambridge Face Perception Task), two separate clusters of individuals with developmental prosopagnosia were identified in the study. These clusters were not distinguished by their performance on either upright face perception tasks or non-face processing tasks. However, the two clusters differed in their face inversion task performance, with one cluster showing the typical face inversion effect while the other cluster did not. This indicates that there could be multiple perceptual deficits underlying face recognition impairments in prosopagnosia.

Face recognition deficits in prosopagnosia could also be explained by differences in face viewing strategies. Neurotypical participants usually observe the eyes and mouth for successful face recognition (Tardif et al., 2019). However, individuals with prosopagnosia are impaired in processing the eyes when recognizing faces (DeGutis et al., 2012; Fisher et al., 2016). For instance, individuals with prosopagnosia demonstrated a lack of holistic advantage in a part-whole task in trials where the eyes were substituted, but exhibited a normal holistic advantage when the mouth was substituted. Furthermore, individuals with more severe prosopagnosia spend less time observing the internal region of the face (eyes, nose and mouth) (Bobak et al., 2017). Viewing the internal features is important because viewing the eyes and mouth is strongly correlated with face recognition ability (Tardif et al., 2019). Overall, these studies indicate that facial information used for face recognition differs between prosopagnosics and neurotypical individuals.

1.2 Improving face recognition ability

As discussed before, face recognition ability is important for social interactions that occur in our everyday lives (Jack & Schyns, 2015). Given the importance of faces in social interactions, losing the ability to recognize faces may produce devastating consequences in an individual’s social life such as a high level of anxiety, avoidance of social interaction and lowered levels of self-confidence (Yardley et al., 2008). Developing an effective way to enhance face recognition ability could also be important for national security as occupations such as passport officers and police officers require high facial recognition skills but these professions are not better than the general population despite having more experience and having received face recognition training (White, Kemp, Jenkins, Matheson, et al., 2014). Additionally, improvement of face recognition ability is also important for individuals with certain developmental and neurological disorders that are associated with facial recognition deficits such as individuals with prosopagnosia. In the following sections, we will discuss some potential methods that could be used to improve face recognition abilities including transcranial electrical stimulation, cognitive training and other methods available such as collaboration and oxytocin.

1.2.1 Transcranial electrical stimulation (TES)

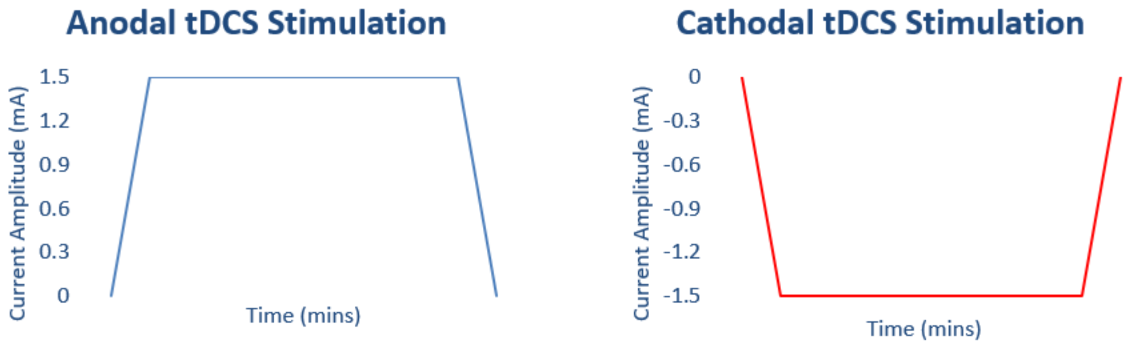
Electrical stimulation has a very long history, starting in ancient Greece, where electric fish were used as a source of electricity in an early attempt to use electrical stimulation (Sarmiento et al., 2016). Electric fish have been used to treat headaches (Kellaway, 1946) and epilepsy (Priori, 2003) by placing the fish on the human scalp and brow, but it is unclear how the effects were measured. In the present time, electrical stimulation can be applied using a non-invasive brain stimulation technique namely, transcranial electrical stimulation (TES) where a low-level intensity electrical current is delivered between two or more electrodes attached to the scalp to modulate neuronal excitability (Reed & Cohen Kadosh, 2018). Over recent years, TES has been applied to improve cognitive abilities such as numerical competence (Cohen Kadosh et al., 2010), working memory (Ke et al., 2019) and multitasking performance (Hsu et al., 2017). It has also been used to reduce symptoms of neurological and psychiatric disorders such as schizophrenia (Shiozawa et al., 2013) and depression (Loo et al., 2012 but see also Martin et al., 2018). Research has also shown that addictions such as smoking (Fregni et al., 2008), alcohol (Boggio et al., 2008) and food cravings (Goldman et al., 2011) could be reduced by the application of TES. In terms of safety issues, a review paper has shown that low intensity TES is a safe technique among healthy adults (Antal et al., 2017). In this section, the three main forms of TES: transcranial direct current stimulation (tDCS), transcranial alternating current stimulation (tACS) and transcranial random noise stimulation (tRNS) will be discussed followed by the factors that could affect the effectiveness of TES.

1.2.1.1 Transcranial direct current stimulation (tDCS)

In tDCS, a direct current between 0.5 and 2 mA is typically applied (Zaghi et al., 2010a) and cortical excitability is altered based on electrode polarity (Nitsche & Paulus, 2000; Yamada & Sumiyoshi, 2021) (Figure 1.4). Anodal tDCS (a-tDCS) is postulated to cause neuronal depolarization, where it increases neuronal excitability increasing the chances of neural firing and leading to a performance enhancement. On the other hand, cathodal tDCS (c-tDCS) is postulated to cause neuronal hyperpolarization, where it decreases neuronal excitability inhibiting the chances of neural firing and leading to performance decline. However, tDCS may not always function in such a way, as a meta-analytical review has found that while anodal stimulation often led to performance enhancement, the effects from cathodal stimulation were less clear (Jacobson et al., 2012).

Figure 1.4

An example of stimulation waveform graph for 1.5mA of a-tDCS (left) and 1.5mA c-tDCS (right).



Action potential is a phase that occurs when neurons are transmitting electrical signals (Huxley, 1972). During action potential, there is a change in voltage across the membrane due to the flow of ions such as potassium, sodium and chloride in and out of the neuron. TDCS brings the neurons closer to the firing threshold without eliciting an action potential (Bikson et al., 2004). Hence, it can be concluded that tDCS modulates the resting membrane potential of neurons by bringing the state of the neurons closer to or further away from the threshold potential (approximately -55mV) that is required to elicit an action potential. In this way, tDCS is able to increase or decrease the excitability of the neurons.

"*Montage*" refers to the number of electrodes and the arrangement of electrode positions and polarity. The traditional tDCS montage consists of two large sponge electrodes (35 cm^2), where the current flows from the anode to the cathode (Nitsche & Paulus, 2000). The target electrode will be placed over the target area and the return electrode will be placed over either the intracephalic (other regions on the head) or extracephalic region (out of the head regions such as the shoulder). As traditional montage uses large sponge electrodes, it provides low focality stimulation to the target area.

As opposed to the traditional montage, high-definition tDCS (HD-tDCS) provides increased focality by using electrodes with a smaller surface area (Nikolin et al., 2019). There are several different types of montage for HD-tDCS stimulation. One type of HD-tDCS montage consists of two small electrodes to maximize the intensity at the target region (Brunyé et al., 2017). Another type of HD-tDCS montage is the 4 × 1 ring configuration. In this montage, there is one central electrode which is the target electrode (anode or cathode) surrounded by four other return electrodes (Villamar et al., 2013). It has been hypothesized that this montage could increase the focality of the stimulation by limiting the spread of the current flow towards regions that are outside of the target region (Datta et al., 2009). Hence, the stimulation is modulating specifically the neurons in the target region only. The 4 × 1 montage also provides a longer lasting after-effect, specifically 30 minutes more compared to the traditional montage (Kuo et al., 2013).

Multifocal tDCS is a type of montage that is similar to HD-tDCS. However, it provides not only better focality of stimulation, but it is also more effective in increasing cortical excitability compared to traditional 2-electrodes tDCS montage (Fischer et al., 2017). Multifocal tDCS uses multiple electrodes to stimulate a target region. In this montage, multiple electrodes will be used as the target electrode and return electrode. The electrodes are applied with a range of different current intensities. The number of electrodes, position of each electrode and current intensity for each electrode are specified by mathematical calculation (for more information, see Ruffini et al., 2014).

Past research investigating the duration of the tDCS after-effect has shown that five minutes of 1 mA a-tDCS could generate five minutes of after-effect on cortical excitability (Nitsche & Paulus, 2000) whereas nine minutes of 1 mA c-tDCS could generate an after-effect lasting up to one hour (Nitsche et al., 2003). Additionally, it has also been reported that nine to 13 minutes of 1 mA a-tDCS could generate an after-effect on cortical excitability lasting up to a maximum duration of one hour and 30 minutes (Nitsche & Paulus, 2001). These findings suggested that the tDCS duration equal to or longer than nine minutes could generate an after-effect on the cortical excitability that lasts for a minimum of one hour. However, this after-effect on cortical excitability was not reflected in cognitive tasks, as the effect of tDCS on cognitive tasks only lasted for 30 minutes after 30 minutes of 1 mA tDCS (Ohn et al., 2008). Thus, the after-effect on cortical excitability may last longer than the after-effect of cognitive enhancement after stimulation.

Previous studies have applied tDCS to various cognitive domains. For example, it has been demonstrated that tDCS applied to the parietal lobes enhanced numerical competence and this improvement persisted six months after a six-day training programme (Cohen Kadosh et al., 2010). Additionally, tDCS applied over the left dorsolateral prefrontal cortex (DLPFC) has been shown to increase performance on working memory tasks (Ke et al., 2019). Research has also found that tDCS could produce improvement in language where tDCS to the left posterior temporal cortex generated higher scores in the test of word reading efficiency (Turkeltaub et al., 2012). This finding suggests that tDCS could potentially benefit individuals with dyslexia. TDCS has also been used to increase vigilance which could have great implications for occupations that require sustained attention (Nelson et al., 2014).

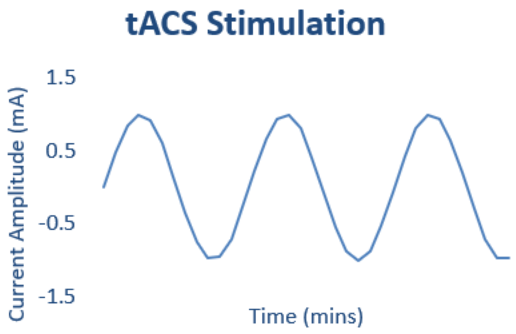
However, it is important to note that the application of tDCS could cause cognitive side effects. For instance, tDCS to the posterior parietal cortex enhanced numerical learning while automaticity for the learned material was impaired (Iuculano & Kadosh, 2013). The same study also showed an opposite pattern when tDCS was applied to the dorsolateral prefrontal cortex: automaticity for the learned material was enhanced while numerical learning was impaired. This double dissociation demonstrated that improving one cognitive area via tDCS could occur at the expense of another cognitive area.

1.2.1.2 Transcranial alternating current stimulation (tACS)

As opposed to tDCS which applies a constant current, tACS oscillates a balanced sinusoidal current at a chosen frequency and amplitude to interact with the brain's natural cortical oscillations (Figure 1.5). Neural oscillations are repetitive patterns of electrical activity produced by the neurons in the brain that can be measured at different frequencies. These frequencies (number of cycles per second) are described as delta waves (less than 4Hz), theta waves (4-8Hz), alpha waves (8-12Hz), beta waves (12-30Hz) and finally gamma waves (more than 30Hz) (Moran & Hong, 2011). TACS has been shown to be able to entrain neuronal oscillations in the brain where it could modulate our brain's natural oscillation to be similar to the frequency of tACS applied (Reato et al., 2013). Past research has indicated that tACS could induce alpha brain waves, showing that tACS can induce changes in the electrical activity of the brain (Zaehle et al., 2010). This may have important implications as artificially enhanced alpha activity could improve cognitive performance (Klimesch et al., 2003; Zoefel et al., 2011).

Figure 1.5

An example of stimulation waveform graph of 1mA tACS.

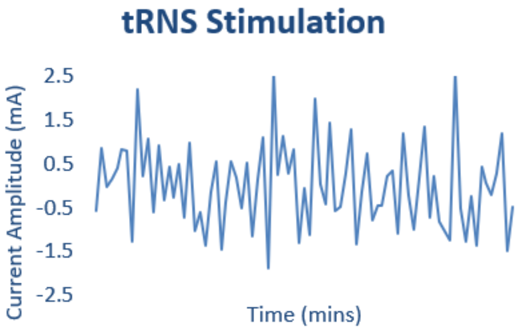


1.2.1.3 Transcranial random noise stimulation (tRNS)

Similar to tACS, tRNS applies an alternating current, but the current is applied at random amplitudes and frequencies (Figure 1.6). TRNS has been shown to be able to increase cortical excitability, possibly by inducing neuronal depolarization (Terney et al., 2008). Research has indicated that a brief duration of five minutes of tRNS can increase cortical excitability (Chaieb et al., 2011), and high-frequency tRNS (ranging from 100–640 Hz) can enhance cortical excitability at both electrode sites (Pirulli et al., 2016). This differs from tDCS where the anodal site usually enhances excitability while the cathodal site usually inhibits excitability of the cortex (Nitsche & Paulus, 2000; but see also Jacobson et al., 2012). Furthermore, high and low frequency tRNS have been shown to have an opposing effect, where high-frequency tRNS decreased visual illusions, specifically motion after-effect duration while low-frequency tRNS increased motion after-effect duration (Campana et al., 2016).

Figure 1.6

An example of stimulation waveform graph of tRNS.



1.2.1.4 Factors that modulate the effectiveness of different TES techniques

The effectiveness of different TES techniques can be modulated by different parameters, such as the TES protocol, state of the brain, hormones, age and individual differences (Krause & Cohen Kadosh, 2014). Firstly, parameters of the TES protocol such as the current and the position of electrodes are known to affect TES. For instance, it has been hypothesized that higher current intensity could lead to a stronger tDCS effect (Nitsche & Paulus, 2000), however, the relationship between current intensity and the effect of tDCS is still unclear (Esmaeilpour et al., 2018). In fact, increasing the current intensity of tDCS does not always increase the efficiency of the stimulation and, in some cases, may reverse the effect expected of the stimulation type. To illustrate, c-tDCS is expected to cause inhibition of cortical excitability (Nitsche & Paulus, 2000). However, while 1 mA of c-tDCS led to decreased cortical excitability, when the current intensity was increased to 2 mA, the effect reversed and led to increased cortical excitability instead (Batsikadze et al., 2013). Similarly, a low intensity current of 0.4 mA led to decreased cortical excitability whereas a high intensity current of 1 mA led to increased cortical excitability for both tACS and tRNS (Moliadze et al., 2012). Based on these findings, it seems that increasing the current intensity does not always increase the effectiveness of TES but could change the direction of the stimulation effect (e.g., from excitation to inhibition of cortical excitability). However, the specific current intensity threshold for each TES protocol (e.g., for a-tDCS) to change the direction of the stimulation effect is unclear. The duration of stimulation could also influence the effect of the stimulation. For example, a-tDCS resulted in increased cortical excitability when stimulation duration was less than 26 minutes, however when stimulation duration exceeded 26 minutes, a-tDCS resulted in decreased cortical excitability (Hassanzahraee et al., 2020). Similar to current intensity, the specific stimulation duration threshold for each TES protocol (e.g. c-tDCS, tRNS and tACS) to change the direction of the stimulation effect is unclear.

Other than the current intensity and duration of stimulation, the position of the electrodes could also influence the stimulation effect. For example, a reference electrode placed in the extracephalic region resulted in a larger current density compared to the intracephalic region (Noetscher et al., 2014). This suggests that the position of the reference electrode can affect the effectiveness of the stimulation as it changes the current density generated from the stimulation. The effect of stimulation is also dependent on the type of montage. For instance, HD-tDCS and multifocal montage provide better focality, a longer lasting after-effect and are also more effective in increasing cortical excitability compared to the traditional montage (Fischer et al., 2017; Kuo et al., 2013). Additionally, the frequency of stimulation could impact the stimulation effect as well. Receiving tDCS sessions daily resulted in greater increase in cortical excitability as compared to receiving the sessions every second day (Alonzo et al., 2012). This indicates that greater cortical excitability could be accumulated by increasing the number of tDCS sessions. Overall, these studies have shown that parameters of the TES protocol could greatly influence the effect of TES.

The second factor is the state of the individual brain (i.e., the level of neural activity in the brain). Although crucial, this factor is difficult to control. It is known that the state of the brain could influence the effects of TMS where less active neurons respond more strongly to TMS (Silvanto et al., 2007, 2008). Similarly, it has been shown that the initial state of the brain could also influence the effects of TES (Thirugnanasambandam et al., 2011). The effect of tDCS could be affected by the tasks performed during stimulation, including cognitive tasks and motor behaviors (Antal et al., 2007). When participants were idle during stimulation, a-tDCS was found to enhance cortical excitability while c-tDCS was found to decrease cortical excitability. Conversely, when participants engaged in a cognitive task during stimulation, a-tDCS was found to decrease cortical excitability and c-tDCS was found to enhance cortical excitability. During motor behaviors, both a-tDCS and c-tDCS were found to decrease cortical excitability. Additionally, it has been reported that c-tDCS improved performance on the Flanker task when participants were engaged with an unrelated task during the stimulation, whereas performance decreased when participants were engaged with a task using similar cognitive demands as the Flanker task (Nozari et al., 2014). Hence, these findings indicate the importance of controlling the task given during stimulation as it affects the state of the brain and, in turn, the effect of TES. The state of the brain could also be influenced by sleep patterns. Cortical excitability tends to increase with the duration of time awake and decreases with sleep (Huber et al., 2013). This suggests that differences in sleep patterns among participants could affect the stimulation effects, as the initial state of the brain during the experiment will vary according to each participant's circadian rhythm. Therefore, the reviewed findings showed that the effect of TES is dependent on the state of the brain, which could be induced by activity performed during stimulation and individual sleep patterns.

Neurotransmitter levels can also influence cortical excitability, thereby influencing the stimulation effect (McLaren et al., 2018). To illustrate, serotonin has been found to prolong the cortical excitability excitation period following the application of a-tDCS and reverse the effect of c-tDCS where the stimulation led to excitation instead of inhibition of cortical excitability (Nitsche et al., 2009). Hence, it is clear that the neurotransmitter level in the brain, such as serotonin, could modulate the effect of TES. The efficacy of TES is also dependent on the head and brain anatomy. The complex brain anatomy which consists of folds and grooves (i.e., gyri and sulci) is known to affect the electric field generated by TES (Datta et al., 2012; Miranda et al., 2013). Additionally, head anatomy, such as head size, tissue thickness and fat distribution in the head can also affect the electric field (Bikson et al., 2012; Truong et al., 2013). The conductivity of the skull, skin and grey matter in the brain also plays a crucial role in determining the electric field generated by TES (Salvador et al., 2012). Hence, the findings presented showed that the effect of TES, specifically the electric field generated by the stimulation is highly dependent on the individual head and brain anatomy.

The third factor that is known to influence the effect of TES is hormones. Hormone levels in females are mainly modulated by the menstrual cycle, which has two main stages: the follicular stage (high level of estrogen and low level of progesterone) and the luteal stage (moderate level of estrogen and high level of progesterone). Cortical excitability typically increases during the follicular stage and decreases during the luteal stage (Smith et al., 2002). During the luteal stage, inhibition of cortical excitability by TMS is enhanced as compared to the follicular phase (Smith et al., 1999). Additionally, research has shown that a-tDCS increased cortical excitability more for females compared to males, but there was no difference found for c-tDCS (Chaieb et al., 2008). However, the ongoing menstrual stage of the female participants was not recorded in the study. Hormone levels could be controlled in an experiment by recruiting females during the follicular stage of the menstrual cycle, as at that stage, the level of cortical excitability is similar to that of males (Inghilleri et al., 2004). Therefore, by recruiting female participants during the follicular stage, experimenters can ensure that female and male participants will have a similar level of cortical excitability before receiving the stimulation. Some research has also recruited only male participants for TES studies to avoid hormone level as a confounding variable (e.g., Alonzo et al., 2012).

Fourthly, the effect of TES is dependent on age. In the process of ageing, brain structures such as the cerebellum, hippocampus and white matter tend to decline (Raz et al., 2005) along with neurotransmitter levels such as gamma-aminobutyric acid (GABA) (Gao et al., 2013). As discussed previously, brain structure and neurotransmitter levels could affect the electric field generated by TES, hence age is a potential factor that could influence the effect of TES. For example, tACS, but not tRNS, improved phoneme processing among adolescents with dyslexia (10 – 16 years). In contrast, tRNS produced greater improvement in phoneme processing compared to tACS among adults with dyslexia (20 – 45 years) (Rufener et al., 2019). It was also found that tRNS decreased performance in visual perceptual learning only in adult participants and not in older adult participants (Fertonani et al., 2019). More interestingly, contrasting and hemisphere-dependent effects of TES have been found among adults and older adults. For instance, stimulation of the right anterior temporal lobe improved face naming among adults whereas stimulation of the left anterior temporal lobe stimulation improved face naming among older adults (Ross et al., 2010, 2011). These findings demonstrated that age could influence the effect of TES.

The proficiency of an individual in the task could also have an impact on the effect of TES. Individuals with lower proficiency in a task showed greater improvement after TES (Brunyé et al., 2014; Tseng et al., 2012). For example, individuals with lower working memory capacity improved on the visual short-term memory task after receiving tDCS, whereas tDCS has no effect on individuals with higher working memory capacity (Tseng et al., 2012). This finding was extended to the spatial sense of direction and navigation performance as well (Brunyé et al., 2014). Furthermore, earlier studies have found that the effect of tDCS is more apparent when the task difficulty is greater, as seen in areas such as arithmetic (Pope & Miall, 2012; Popescu et al., 2016; Rütsche et al., 2015), working memory (Gill et al., 2015; Vergallito et al., 2018) and attention (Nelson et al., 2014; Reteig et al., 2017). Similarly, performance enhancement in video games following tDCS effects was observed only when participants were multitasking but not when participants were executing a single task (Hsu et al., 2015). Interestingly, tDCS has been found to impair performance in discriminating face view in individuals who possess higher proficiency in this task, while improving performance in those who are less proficient (Wu et al., 2021). These results imply that TES might only be effective for individuals with lower task proficiency or for tasks with higher levels of difficulty.

In addition, tDCS may only enhance the performance of individuals with high anxiety levels and could potentially impede the performance of those with low anxiety levels because research has found that after tDCS, individuals with high mathematics anxiety were faster, whereas individuals with low mathematics anxiety were slower on an arithmetic task (Sarkar et al., 2014). The effect of TES also appears to be influenced by differences in education level. Older adults with a higher number of years of education improved in a working memory task after receiving tDCS, whereas tDCS had no effect on older adults with a lower number of years of education (Berryhill & Jones, 2012). The authors suggested that this was because the two groups (high education and low education) applied different working memory strategies during task completion. Therefore, the findings presented demonstrated that proficiency with tasks, task difficulty, anxiety level and education level could influence the effect of TES.

In conclusion, several factors that could potentially influence the efficacy of TES could be controlled during experimental design (e.g., hormone level and age), while other factors may be more difficult to control (e.g., head and brain anatomy). However, how some factors such as the current intensity and stimulation duration could influence the effect of TES is still unclear to date. The factors discussed in this section also showed that the effect of TES may vary across different experiments investigating the same topic (e.g., different age groups recruited in different experiments, variation in menstrual phase of female participants recruited, different parameters of TES used) or even across participants recruited in the same study (e.g., different head and brain anatomy, studies that did not account for individual differences). These factors should be carefully considered and addressed in TES experiments in order to obtain reliable and accurate data.

1.2.1.5 The effect of TES on face processing

Given the importance of face recognition in both daily interactions and security settings, the relationship between TES and face recognition has attracted increasing research interest in the past decade. Several studies have demonstrated that TES has the potential to enhance face identification abilities (Barbieri et al., 2016; Gonzalez-Perez et al., 2019; Romanska et al., 2015). For example, it has been shown that offline (stimulation applied before task execution) 1.5mA of a-tDCS administered to the right occipital cortex enhanced both face perception and face memory, while no effect of online (stimulation applied during task execution) stimulation was found (Barbieri et al., 2016). This suggests that offline stimulation may work better than online stimulation in terms of improving face identification. However, the effect of a-tDCS found in Barbieri et al. (2016) was not face-specific as it also improved object perception and object memory. This could be due to the utilization of the traditional two-electrode montage with large sponge electrodes, which could have led to low-focality stimulation of the target area. In line with this, high-focality stimulation applying 1.5mA of a-tDCS using two smaller electrodes targeting the FFA has been shown to enhance face memory but not object memory (Brunyé et al., 2017). However, it should be noted that face identification improvements following tDCS have not been consistently reported, as a recent study by Willis et al. (2019) failed to replicate the findings of Barbieri et al. (2016). Conflicting findings between Barbieri et al. (2016) and Willis et al. (2019) may be attributed to the use of the traditional two-electrode montage. Because both studies used a traditional two-electrode montage with large sponge electrodes, this may have caused low-focality stimulation of the target area. Consequently, the current flow may have spread towards non-target regions, generating noise in the data.

Research has also shown that 1.5mA of a-tDCS to the right anterior temporal lobes improved face naming but not landmark naming (Ross et al., 2010, 2011). In addition to tDCS, success in face identification improvement has also been found using tACS and tRNS. In terms of tACS, research has shown that 40Hz gamma-tACS on the right occipital cortex improved accuracy on the face perception task but not the face memory task (Gonzalez-Perez et al., 2019). High-frequency tRNS administered to the occipitotemporal cortex has been shown to improve accuracy in the Cambridge Face Perception Task (CFPT)-Identity which examined participant's abilities in perceiving the differences between facial identities presented (Romanska et al., 2015, but see Willis et al., 2019) and enhance unfamiliar face matching performance (Estudillo et al., 2023). Thus, the findings reviewed suggest that TES could potentially enhance face identification abilities.

TES could also potentially affect the holistic processing of faces. For example, it has been shown that 2mA of a-tDCS targeting the OFA could interfere with Mooney face detection (Renzi et al., 2015). Results of this study showed that although there was no difference in accuracy of the baseline score in the Mooney face task between the OFA stimulation group and the control group (i.e., sham stimulation group), after the stimulation session, participants in the OFA stimulation group had lower accuracy in the task compared to the control group. This demonstrated that a-tDCS on OFA could interfere with the detection of Mooney faces. Interestingly, they found that OFA stimulation had no effect on the composite face task. Altogether, these results suggest that a-tDCS on OFA disrupted holistic processing for face detection (i.e., Mooney face task), but not for face discrimination (i.e., composite face task). However, a different study showed that 1.5mA of tDCS on the occipitotemporal cortex was able to reduce the composite face effect compared to sham stimulation (Yang et al., 2014). In this study, the polarity of the current (i.e., anodal and cathodal) did not change the effect of the stimulation. Taken together, these studies indicated that tDCS could modulate the holistic processing of faces, and further studies are required to investigate the specific impact of tDCS on this aspect of face processing.

The N170 is an event-related potential (ERP) component that is specific for faces (Bentin et al., 1996). Past research has indicated that 1.5mA of tDCS on the occipitotemporal cortex was able to reduce the amplitude of N170 in the right hemisphere (Yang et al., 2014). Reduction of the N170 may indicate facilitation of face processing, as previous research has suggested that inverted faces led to an increment of the N170 amplitude (Sadeh & Yovel, 2010). Therefore, an increment in N170 amplitude may indicate the use of an additional neural mechanism, as processing inverted faces was more difficult. Additionally, the effect of 1.5mA of tDCS applied to the DLPFC during a face learning session has been investigated (Lafontaine et al., 2013). The findings showed that when the anode was positioned on the right DLPFC and the cathode was positioned on the left DLPFC, the stimulation led to a shorter reaction time and reduced N170 amplitude. Conversely, when the cathode was positioned on the right DLPFC and the anode was positioned on the left DLPFC, the stimulation led to a longer reaction time and increased N170 amplitude. This suggests that a-tDCS applied to the right DLPFC facilitated the learning of unfamiliar faces whereas c-tDCS applied to the right DLPFC impaired the learning of unfamiliar faces. Altogether, these findings showed that tDCS could potentially modulate the amplitude of N170.

It has also been demonstrated that TES has the potential to modulate facial emotion processing. For example, 2mA of a-tDCS to the right orbitofrontal cortex improved reaction time and the accuracy of facial expression recognition (Willis et al., 2015). Additionally, 40Hz of gamma-tACS administered to the occipital area has been shown to increase accuracy in the Cambridge Face Perception Angry Expression (CFPT-Angry) (Janik et al., 2015). This implies that modulating gamma oscillations in the occipital area could facilitate facial anger perception. Furthermore, high-frequency tRNS to the inferior frontal cortex in older adults has been shown to improve performance in CFPT-Angry but not CFPT-

Happy and CFPT-Identity, showing that tRNS to the inferior frontal cortex could facilitate face anger perception, but had no effect on face identity and happiness perception (Yang & Banissy, 2017). Thus, these findings showed that TES could enhance facial emotion perception, specifically anger perception. Overall, the majority of the research done in the area of TES and face processing has demonstrated that TES could modulate face processing ability and could potentially be used as a tool to improve face recognition abilities.

1.2.2 Cognitive training

Aside from the TES described in the previous section, cognitive training has been widely used as a method to improve face processing ability. In this section, we will explore the application of cognitive training in various settings, including national security (A. Towler et al., 2019), rehabilitation for prosopagnosia patients (DeGutis, Cohan, et al., 2013), learning new identities through multiple exposure to a face (Dowsett et al., 2016), and feedback (White, Kemp, Jenkins, & Burton, 2014). Various types of cognitive training have been investigated in previous work, including face-shape strategy (A. Towler et al., 2014), facial feature comparison (A. Towler et al., 2017), feature spacing categorization to improve holistic processing (DeGutis et al., 2014) and learning identities in high within-person variability condition (Ritchie & Burton, 2017). The effectiveness of these forms of cognitive training will be further discussed in the upcoming sections.

1.2.2.1 Professional face training

Inconsistent findings have been reported on the effectiveness of professional face training offered to occupations related to national security. It has been shown that passport control officers who have received professional training in the task and have years of experience were not better than the general population in a face matching task (White, Kemp, Jenkins, Matheson, et al., 2014) and the face-shape strategy typically used in professional face training tasks was ineffective in improving face matching ability (A. Towler et al., 2014). More recently, a study examining four types of professional face training courses provided to occupations related to national security across the world found that short courses, which consist of one hour or half a day, did not improve face identification ability, although the majority of the trainees (93%) believed that their performance had improved (A. Towler et al., 2019). However, some improvements were found after a three-day face training course involving facial feature comparison. Specifically, participants showed improvement in a face matching task and a face inversion task but not in a casework task (face matching using frontal images such as mug shots and CCTV) or a feature rating task (rating the similarity of facial features before face matching trials). This is concerning because the training course did not improve performance on the casework task that was designed to mimic the day-to-day tasks of police officers. Additionally, participants showed no improvement in the feature rating task, suggesting that there were no improvements in the examination of facial features, although the training emphasized facial feature comparison.

In Chapter 1 (section 1.1.1), we discussed how normal faces (upright) are usually recognized through holistic processing and abnormal faces (inverted) are processed by the individual face parts. We will now discuss the rationale for adopting facial feature comparison instead of holistic processing to improve normal face recognition in professional training courses. To date, two types of face experts have been identified and studied: super-recognizers and forensic facial examiners (Russell et al., 2009; White et al., 2015). Super-recognizers are individuals who are naturally talented in face recognition ability without any form of face training (Russell et al., 2009) (not to be confused with super-memorizers, see Ramon et al. 2016). Forensic facial examiners on the other hand are trained face experts who consistently outperform the normal population in face matching tasks (Phillips et al., 2018; A. Towler et al., 2017; White et al., 2015). Although both face experts possess superior face ability, super-recognizers did not receive any form of face training whereas forensic facial examiners received professional face training to develop their face recognition abilities. This suggests that face training was effective for forensic facial examiners despite being mostly ineffective for other individuals such as police officers and passport control officers (A. Towler et al., 2014, 2019). More importantly, super-recognizers and forensic facial examiners seem to employ different strategies when recognizing faces. Super-recognizers were shown to experience a larger face inversion effect (FIE) (Russell et al., 2009) whereas forensic facial examiners were shown to experience a lesser FIE when compared to the general population (White et al., 2015). Inverted faces are more difficult to recognize compared to upright faces as they cause disruption in perceiving faces holistically, thus the face is perceived by the facial features (Van Belle et al., 2010). The difference in FIE indicates that super-recognizers employ holistic processing whereas forensic facial examiners employ a feature-by-feature strategy when recognizing faces. Indeed, forensic facial examiners have been shown to use a slow, systematic, feature-based comparison strategy, which leads to higher face matching accuracy (A. Towler et al., 2017). Hence, it could be concluded that utilizing facial feature comparison in professional face training courses may be more beneficial compared to holistic processing.

In line with this, research has shown that the facial feature comparison strategy was indeed beneficial for improving face matching among the general population (Megreya & Bindemann, 2018; A. Towler et al., 2017, 2021, but see A. Towler et al., 2019). For example, accuracy in face matching improved when participants were instructed to rate the similarity of 11 facial features between two faces before deciding if the two faces depicted the same or a different person (A. Towler et al., 2017). Conversely, general verbal instructions asking the participants to compare the faces feature-by-feature in a face matching task did not improve accuracy (Megreya, 2018). Facial feature specific verbal instructions (e.g., asking participants to compare the eyebrows) however, successfully increased face matching accuracy (Megreya & Bindemann, 2018). The authors also found that only specific facial features increased face matching accuracy: for instance, while instructing the participant to compare the eyebrows increased accuracy, comparing the ears decreased accuracy and comparing the eyes did not affect accuracy. A different study however, found that instructing participants to focus on the ears and facial marks (e.g., blemishes) enhanced face matching accuracy (A. Towler et al., 2021). Consistent with this, another study has shown that participants could successfully utilize the presence and location of facial marks (i.e., moles) to enhance face matching accuracy (Fysh & Bindemann, 2022). However, it is important to note that the advantage of the facial feature comparison strategy in face matching tasks does not extend to the identification of other-race faces (Megreya & Bindemann, 2018).

In sum, it can be concluded that making facial feature comparisons is an effective strategy for improving face perception of same-race faces. Additionally, long training courses should be adopted for occupations related to national security as opposed to short training courses, as they have been shown to be ineffective in enhancing face recognition ability.

1.2.2.2 Rehabilitation of prosopagnosia

Improving face recognition ability is not only important for national security but also for individuals with prosopagnosia (see section 1.1.5). Past attempts at rehabilitation for prosopagnosia have shown varying success (e.g., Brunsdon et al., 2006; Ellis & Young, 1988; Schmalzl et al., 2008). Two main types of training have been investigated: remedial and compensatory (Bate & Bennetts, 2014). Remedial training focuses on improving the normal face recognition mechanism (i.e., holistic processing) whereas compensatory training focuses on developing a compensatory mechanism for face recognition (i.e., facial feature comparison). An earlier study using remedial training found that several training programs such as image matching of familiar, unfamiliar and computer-generated schematic faces and learning name-face association were ineffective in improving face recognition for a prosopagnosic patient (Ellis & Young, 1988). Conversely, a later study found that face matching training was effective in improving face perception, even for untrained faces (Bate et al., 2015). The patient also more often observed the internal facial features (e.g., eyes) after the training. This is important because prosopagnosics are often impaired with processing of the internal facial features (Bobak et al., 2017), especially the eyes (DeGutis et al., 2012; Fisher et al., 2016). Additionally, holistic face processing training (i.e., categorization of faces by spatial configuration, such as distance between the nose and mouth) has been shown to be successful in improving face recognition in prosopagnosic patients (DeGutis et al., 2007, 2014). After training, improvements were found in tasks related to holistic processing and front-view face matching (DeGutis et al., 2014) and the benefits of training were generalized to untrained faces (DeGutis et al., 2007). However, the patient reported that the training benefits declined after several weeks without training (DeGutis et al., 2007). Hence, the benefits of the training need to be maintained by retraining over time.

Successful attempts have also been reported using compensatory training. For example, studies that trained prosopagnosics to memorize family members using age, gender and three prominent features of the face (e.g., size of nostril, freckles and shape of eyebrow) reported improvement in recognizing trained faces (Brunsdon et al., 2006; Schmalzl et al., 2008), but not for untrained faces (Brunsdon et al., 2006). The patient also spent more time observing the internal facial features (e.g., eyes) and showed less reliance on the external features (e.g., hair) for face recognition after training, and this viewing strategy was applied for untrained faces as well (Schmalzl et al., 2008). The facial feature description training where statements about specific features of the target face were provided (e.g., “This is Casey. She has a large forehead and small eyes.”) has also been shown to improve face recognition for prosopagnosics (Powell et al., 2008). Success in improving face recognition for prosopagnosics has also been reported using the mnemonic method (i.e., name of a person is linked to a phonemically similar object in a mental image, and a prominent facial feature and semantic information are integrated into the same image) however, the patient later reported that the benefits of training were difficult to integrate into daily life as the mnemonic method requires high cognitive demands (Francis et al., 2002).

Overall, there have been some successful attempts in the rehabilitation of prosopagnosia, but with some drawbacks, such as continuous training being required to maintain improvements and high cognitive demands required for some compensatory training. Hence, when compared with the benefits from compensatory training, the benefits from remedial training may be more easily applied in real life as it enhance the normal automatic behavior of recognizing faces.

1.2.2.3 Learning new identities

Familiar faces are more easily recognized compared to unfamiliar faces (Bruce et al., 2001). We are able to recognize familiar faces in different viewing conditions (e.g., differences in lighting) but this is seemingly difficult for unfamiliar faces (Sinha et al., 2006). For example, minor differences such as viewing angle (Favelle et al., 2011), changes in lighting, viewpoint or expression (Bruce, 1982; Estudillo, 2012; Estudillo & Bindemann, 2014; Longmore et al., 2008) could deter unfamiliar face recognition. Familiar faces are thought to have a robust representation in the memory which is built up from multiple exposures to a face in different contexts (Burton et al., 2005; Jenkins & Burton, 2011; Johnston & Edmonds, 2009). Extensive research has then investigated if faces presented in multiple exposure and variation could enhance the learning of new identities (e.g., Dowsett et al., 2016; Ritchie et al., 2021; White, Burton, Jenkins, & Kemp, 2014).

Previous work has shown that multiple exposures to an identity could increase face matching accuracy (Andrews et al., 2015; Matthews & Mondloch, 2018; Menon et al., 2015). For instance, simultaneous (White, Burton, et al., 2014) and sequential (Menon et al., 2015) face matching accuracy increased when two images of an identity were available for comparison to a target image compared to when only one image was available. Face matching accuracy also improved when an average face generated from 12 images of an identity was used for comparison as opposed to single-image comparison (White, Burton, et al., 2014). Additionally, improvement in face-sorting task performance was found as additional photos of the target were presented for comparison (Dowsett et al., 2016; Matthews & Mondloch, 2018). Presenting multiple images of a target identity has also been shown to increase accuracy in identifying the target in surveillance video footage compared to when only a single image of the target was presented (Mileva & Burton, 2019). These studies demonstrate that multiple exposures to a face could enhance learning and recognition of a new identity, even when the faces are presented from different viewpoints (Hunnisett & Favelle, 2021).

Although it is clear that multiple exposures to a face could enhance identity learning, to date, the optimum number of exposures required for effective identity learning is unclear. For instance, while two-image comparison has been shown to improve face matching accuracy compared to single-image comparison, no difference in face matching accuracy was found between two-image, three-image and four-image comparisons (White, Burton, et al., 2014). This result suggests that two-image comparison may be sufficient to draw the maximum benefit of multiple exposures for face learning. In another study, it was shown that the effectiveness of presenting three target images during target search in CCTV footage was similar to when 16 target images were presented (Mileva & Burton, 2019). In contrast, one study found that presenting 96 target-images during the learning phase led to higher accuracy in a later face recognition memory task compared to when only six target-images were presented (Murphy et al., 2015). Overall, the optimum number of exposures for effective learning of new identities is still currently unclear as inconsistent results have been reported.

Apart from multiple exposures, past research has also examined if different levels of variation during multiple exposures of an identity could affect identity learning. For instance, it has been found that identification accuracy was higher when the two-image comparison presented during a sequential face matching task was in a high variability condition (i.e., photos taken on different days that are highly dissimilar) compared to a low variability condition (i.e., photos taken on the same day with high similarity) (Menon et al., 2015). In line with this study, a different study reported higher accuracy in a name verification task and a simultaneous face matching task when unfamiliar identities were learned in high variability condition compared to low variability condition (Ritchie & Burton, 2017). Another study compared identity learning when viewing a 10 minutes video footage in low variability (i.e., video filmed on the same day with the same appearance and lighting) and high variability (i.e., video filmed on different days with different appearance and lighting) in children and adults (Baker et al., 2017). Children were more accurate in an identity-sorting task after viewing the video footage in high variability condition compared to low variability condition, however, this effect was weaker in adult participants.

In summary, multiple exposures to a face, especially in high variation could improve learning of a new identity but not identification in a simultaneous face matching task. More interestingly, this benefit could be extended to other-race faces as well (Matthews & Mondloch, 2018). However, the optimum number of exposures for effective identity learning remains unclear. It is also important to note that the advantage of multiple exposures to a face in high variation in identity learning does not transfer to novel, untrained identities (Dowsett et al., 2016; Matthews & Mondloch, 2018).

1.2.2.4 Feedback

It is well known that we are superior at recognizing familiar faces compared to unfamiliar faces (Bruce et al., 2001). One possible reason for this may be that we seldom gain feedback on our recognition of unfamiliar faces in real world contexts (Jenkins et al., 2011). For example, we gain feedback immediately when we greet a familiar identity and they respond to us, or when we mistakenly recognized a stranger as a familiar person. Conversely, if we wrongly recognize an unfamiliar face, then we might assume that it is a different person, as there is no reason to inspect whether we are right or wrong in recognizing an unfamiliar identity. One study found that providing feedback did lead to higher accuracy in a face matching task (White, Kemp, Jenkins, & Burton, 2014). More interestingly, the advantage of feedback was generalized to new untrained faces where no feedback was provided. Additionally, the advantage was specific to participants with lower face recognition abilities. In contrast, another study found that providing feedback did not increase face matching accuracy (Alenezi & Bindemann, 2013). Instead, feedback only prevented the decline in face matching accuracy that was observed when no feedback was given. To conclude, research on feedback and face recognition ability has been limited and has had mixed results. Hence, further studies are required to deepen our understanding of the influence of feedback on face processing.

1.2.3 Other methods

In this section, two other methods to increase face recognition ability that have been investigated will be described: social methods such as collaboration and biochemical methods such as oxytocin. "*Wisdom of Crowds*" refers to how collaboration or the independent opinions of a group of individuals combined is superior to one expert's opinion (Savage, 2012; Surowiecki, 2004). It has been shown that group estimation is frequently more accurate than the best individual estimation (Kerr & Tindale, 2004). Two types of collaboration have been investigated in terms of face recognition: social (discussion among group members) and non-social (collective judgements from a group of individuals). In terms of social collaboration, it has been shown that participants in pairs were more accurate in a face matching task compared to individual participants (Bruce et al., 2001; Dowsett & Burton, 2015). This suggests that face identification accuracy could be enhanced by social collaboration. Similarly, non-social collaboration has also been shown to increase face recognition accuracy. For instance, combining the responses of a group of participants led to higher accuracy in a face matching task (White et al., 2013) and a face recognition task (White et al., 2015). Accuracy increased as the number of group members increased, with the advantage achieving plateau with eight group members (White et al., 2013). It is evident from these studies that the collective judgement of a group of individuals could increase face identification accuracy. Thus, it is clear that collaboration, either social or non-social, could lead to improvements in face identification.

Oxytocin is a hormone known for its role in female reproduction (Magon & Kalra, 2011), social components such as love, bonding and trust (H. J. Lee et al., 2009) and face recognition (Lopatina et al., 2018). Past research has shown that inhalation of oxytocin enhances accuracy in face memory tasks (Rimmele et al., 2009; Savaskan et al., 2008), even for other-race faces (Blandón-Gitlin et al., 2014), indicating that oxytocin could be a potential tool in increasing face recognition ability. Moreover, studies have demonstrated that oxytocin can enhance face memory and matching abilities in individuals with prosopagnosia (Bate, Cook, et al., 2014). However, this effect was not always replicated, as it has been found that oxytocin could impair face recognition ability (Herzmann et al., 2012). Additionally, it has been reported that although oxytocin enhanced the accuracy of identifying the target face in a face recognition line-up when the target was present, accuracy declined when the target was absent (Bate, Bennetts, et al., 2014). The authors conclude that oxytocin increased bias in responding that the target was present rather than increasing overall accuracy in identifying the target face. In sum, it is unclear if oxytocin could benefit recognition of faces as the current findings presented are inconsistent.

Taken together, further studies are required to resolve the mixed findings concerning the advantage of oxytocin on face recognition. However, findings on collaboration and face recognition are promising, with both social and non-social collaboration consistently producing benefits in face recognition.

1.3 General aim of the thesis

Despite the wide range of literature on TES and face recognition, relatively little is known about the use of multifocal tDCS in targeting the face-specific regions in the brain and how a-tDCS and c-tDCS could influence the recognition of other-race faces. Other than that, it is also unclear whether learning identity via high variation multiple exposure could be beneficial for prosopagnosic patients and improvement of other-race face recognition. Thus, the main aim of this thesis is to examine the effect of tDCS (i.e., multifocal, a-tDCS and c-tDCS) and cognitive training (i.e., high variation of multiple exposure) on the recognition of own- and other-race faces.

Chapter 2 focuses on examining the role of the OFA and the FFA in the recognition of individual facial features and whole faces using multifocal tDCS. In Experiment 1a, we implemented a within-subjects design where participants underwent both FFA stimulation and OFA stimulation before completing the facial features and whole faces recognition tasks. We included a control condition (i.e., sham stimulation) in Experiment 1b to closely examine the unique contributions of the OFA stimulation and the FFA stimulation towards recognition of facial features and whole faces using a between-subjects design. Chapter 3 investigates how anodal and cathodal tDCS could affect the recognition of own- and other-race faces. We created and evaluated a new Asian version of the CFMT (i.e., CFMT – Chinese Malaysian (CFMT-MY)) in Experiment 2a and Experiment 2b in order to assess the pre- and post-stimulation performance of own- and other-race face recognition using different versions of the CFMT in Experiment 2c. Chinese Malaysian participants were recruited in Experiment 2a and Caucasian participants were recruited in Experiment 2b for the evaluation of CFMT-MY. In Experiment 3, we examined the effect of a-tDCS and c-tDCS on the recognition of own- and other-race faces.

Chapter 4 focuses on the benefits of learning identity via high variation multiple exposures to own- and other-race faces. In Experiment 4a, we assessed the performance of face learning for identities learned in high variation multiple exposure compared to low variation multiple exposure using a name verification task. In Experiment 4b, we assessed the performance of face learning using an old-new recognition paradigm instead of a name verification task, which does not require precise name memorization during the testing phase. Finally, Chapter 5 aims to examine if the benefits of learning identity via high variation multiple exposure could be applied to individuals with prosopagnosia. In Experiment 5, suspected prosopagnosic participants and age-matched neurotypical participants learned identities in both high and low variation multiple exposures, and subsequently, face learning was measured using a name verification task.

Chapter 2 – Investigating the role of OFA and FFA using multifocal tDCS

In Chapter 2, we will examine how stimulation of face-specific brain regions specifically the fusiform face area (FFA) and the occipital face area (OFA) could affect face processing ability. Faces are thought to be a special category of stimuli as they are recognized differently compared to objects (McKone et al., 2007; Robbins & McKone, 2007, although see alternative reviews, Bukach et al., 2006; Burns et al., 2019; Gauthier & Bukach, 2007). Previous work has also identified several brain areas specialized for face processing which include the fusiform face area (FFA) located in the lateral fusiform gyrus (Kanwisher et al., 1997; McCarthy et al., 1997) and the occipital face area (OFA) located in the lateral inferior occipital gyri (Gauthier et al., 2000). Despite the interactive nature of the FFA and the OFA (Ishai, 2008; M. Kim et al., 2006), these areas are anatomically and functionally dissociated, as evidenced by patients with OFA lesions who still exhibit FFA activation (Rossion et al., 2003; Steeves et al., 2006). Neuropsychological models of face processing (e.g., Haxby et al., 2000) suggest that the OFA is involved in the early stages of face processing (i.e., representation of independent facial features) whereas the FFA is involved in the late stages of face processing (i.e., representation of facial identity).

Over the past years, numerous neuroimaging research studies have investigated the role of OFA and FFA in face processing (e.g., Schiltz et al., 2010; Yovel & Kanwisher, 2005; Zhang et al., 2012). For example, functional magnetic resonance imaging (fMRI) research has indicated that OFA showed greater activation for a single feature of the face (e.g., eyes) over a combination of features (e.g., eyes and mouth presented together) while FFA showed no difference in activation between a single feature and a combination of features (Dachille et al., 2012). OFA has also been shown to be involved in facial feature perception whereas FFA was involved in facial identity perception (Fox, Moon, et al., 2009). They found that the OFA responded to the structural changes in a face, even when participants did not notice a change in the faces. In contrast, FFA responded only when participants noticed a change in identity or expression.

Additionally, OFA responded more when face parts were present irrespective of the configuration (normal and scrambled) compared to when the face parts were absent (Liu et al., 2010). Similarly, FFA showed a larger response when face parts were present compared to when the face parts were absent, however, FFA produced a larger response for faces in normal as opposed to scrambled configuration. This implies that OFA was sensitive to the presence of face parts irrespective of the configuration (normal and scrambled) whereas FFA was sensitive to both the presence of face parts and the face configuration.

However, a different fMRI study suggested that OFA may be involved in holistic processing of faces, as they found that FFA and OFA, but not STS, responded more strongly to faces presented with various spacings between face parts compared to a repeated presentation of the same face (G. Rhodes et al., 2009). The spacing among features of the face reflects a second-order relation, which is one type of configural processing for faces (Maurer et al., 2002). Additionally, TMS to the right OFA disrupted the ability to discriminate Mooney faces, indicating the involvement of the OFA in the holistic processing of faces (Bona et al., 2016). This finding is in line with a TES study conducted by Renzi et al. (2015), which found that applying a-tDSC to the OFA could also disrupt Mooney face detection, suggesting that the OFA is involved in holistic processing related to face detection. However, Renzi et al. (2015) also found that a-tDSC on the OFA had no impact on the composite face task, implying that the OFA may not be involved in holistic processing related to face discrimination.

In addition, several studies have provided evidence for the involvement of OFA in facial identity processing. For example, a fMRI adaptation study conducted by Xu and Biederman (2010) showed that while the FFA was sensitive to both face identity and face expression, the OFA was only sensitive to face identity. Furthermore, rTMS applied to the right OFA has been shown to impair performance in processing face identity and face expression (Kadosh et al., 2010; Solomon-Harris et al., 2013), but had no impact on the categorization of intact and scrambled faces (Solomon-Harris et al., 2013). Past research also indicated that TMS applied to the right OFA decreased the ability to accurately learn facial identities compared to a control condition (Ambrus et al., 2017). The OFA has also been shown to be involved in the semantic processing of face identity using a priming paradigm, where the name of a famous person was presented as a prime before the presentation of the target face stimuli, which is the famous face (Ambrus et al., 2019). Participants were presented with trials consisting of congruent primes (a famous name and face, both of the same identity), incongruent primes (a famous name and a famous face, both of different identities) or no prime. The presentation of incongruent primes before the target face stimuli tends to decrease performance in recognizing faces. However, the disadvantage of incongruent primes disappeared following the application of TMS to the right OFA (Ambrus et al., 2019). This suggests that OFA is not only involved in representing facial features but is also sensitive to semantic information. Overall, the studies discussed implied that the role of the OFA in face processing extends beyond the early stages of face processing. Instead, the OFA is also involved in the later stages of face processing that are associated with whole face perception, including holistic processing and face identity processing.

Previous research has also proposed that the FFA may have a greater involvement in the later stages of face processing when compared to the OFA (Nichols et al., 2010; Schiltz et al., 2010; Yovel & Kanwisher, 2005). For instance, it has been demonstrated that the FFA, but not the OFA, showed an increased response to upright compared to inverted faces (Yovel & Kanwisher, 2005). Additionally, the magnitude of the behavioral FIE was positively correlated with the fMRI response in the FFA but not in other face-selective (OFA and STS) or object-selective regions, suggesting that the FFA may be a primary neural source of FIE. Such a finding may suggest that contributions to holistic face processing are mainly from the FFA. Moreover, neurons in the right FFA but not in the OFA responded when faces were represented holistically in the composite face task (Schiltz et al., 2010). Similarly, another study reported that the FFA responded more to whole faces compared to the OFA (Nichols et al., 2010). Furthermore, Zhang and colleagues (2012) have proposed that if the spatial patterns of activation in FFA are relevant to the administered face processing task, then these patterns of activation should be more similar in correct trials as compared to incorrect trials. Supporting this hypothesis, it was found that the spatial pattern of activation in FFA was more similar in correct trials as compared to incorrect trials, but only when the facial features were arranged in a normal configuration and not for scrambled faces. This suggests that FFA represents faces holistically, and the representation of faces in FFA is not on the basis of individual face components. Other than that, larger holistic effects were found in the FFA compared to the OFA, suggesting that the FFA may be more involved in holistic processing and the OFA may represent face parts more independently (Schiltz and Rossion, 2006). These studies suggest that the FFA may play a larger role in the later stages of face processing that involve whole face perception such as holistic processing compared to the OFA.

However, findings from an earlier fMRI study conducted by Yovel and Kanwisher (2004) suggested that the FFA was not only involved in representing faces holistically but was also involved in the representation of individual face parts. They found that the FFA responded similarly to configural (i.e., spacing among facial features) and featural (i.e., shapes of eyes and mouth in faces) changes in faces. However, as the featural changes were made in the context of a whole face, the FFA activation could reflect a change of identity rather than featural processing itself. Overall, it is unclear if the FFA only contains representations of faces that are more holistically integrated or if it includes representations of individual face parts as well. These findings suggest that the OFA and the FFA may have overlapping roles in face processing, where both regions are involved in the representation of facial features together with whole faces.

The present study aims to further explore the functional role of the OFA and the FFA in face recognition using multifocal tDCS. TDCS is a non-invasive brain stimulation technique where a low-intensity electrical current is delivered between two or more electrodes attached to the scalp in order to modulate neuronal excitability (Reed & Cohen Kadosh, 2018). Previous work has suggested that anodal tDCS could cause neuronal depolarization and lead to an increase in the neurons' firing rate and excitability (Nitsche & Paulus, 2000; Yamada & Sumiyoshi, 2021). Such an increment in the neurons' excitability induced by the application of anodal tDCS usually results in cognitive enhancement (Jacobson et al., 2012). Previous studies have shown that applying tDCS to the occipital region could enhance face processing, including face memory (Barbieri et al., 2016; Brunyé et al., 2017) and holistic face processing (L. Z. Yang et al., 2014). For example, it has been found that 1.5mA anodal tDCS administered to the right occipital cortex improved face memory (Barbieri et al., 2016). However, it should be noted that face processing improvements following tDCS have not been consistently reported, as a recent study by Willis et al. (2019) failed to replicate the findings of Barbieri et al. (2016).

Conflicting findings between Barbieri et al. (2016) and Willis et al. (2019) may be attributed to two possible reasons. Firstly, both studies used a traditional two-electrode montage with large sponge electrodes, which could have led to low-focality stimulation of the target area. This may have resulted in the current flow spreading towards non-target regions, generating noise in the data. For instance, Barbieri et al. (2016) found that the stimulation effect using the traditional two-electrode montage with large sponge electrodes was not face-specific as it improved both face memory and object memory. Conversely, high-focality stimulation targeting the FFA has been shown to enhance face memory but not object memory (Brunyé et al., 2017). Hence, both Barbieri et al. (2016) and Willis et al. (2019) may have found conflicting findings due to low-focality stimulation of the target area.

Secondly, the effects of tDCS are not always consistent across different measures of performance. For example, a meta-analysis study showed that working memory enhancement was solely shown in reaction time (Brunoni & Vanderhasselt, 2014), whereas another meta-analysis study concluded that working memory enhancement was primarily seen in accuracy (Hill et al., 2016). This discrepancy in results is not unique to working memory research, as similar inconsistencies have been observed in face processing studies: while some research found face processing improvements only in terms of accuracy (Barbieri et al., 2016; Brunyé et al., 2017; Costantino et al., 2017; Renzi et al., 2015), other research found improvements only in reaction times (Willis et al., 2015). These inconclusive findings might reflect potential speed-accuracy trade-offs (Heitz, 2014; Wickelgren, 1977), which can vary within and between participants (Gueugneau et al., 2017; Liesefeld et al., 2015). Such trade-offs could lead to confounding effects and are not uncommon in tDCS research (e.g., Ankri et al., 2020).

In the current study, we use multifocal tDCS to stimulate our target regions (i.e., the OFA and the FFA) as it provides high focal stimulation and is more effective in increasing cortical excitability compared to the traditional two-electrode tDCS montage (Fischer et al., 2017). The stimulation will be delivered in an offline manner (i.e., stimulation applied before task execution) as previous work has found that offline tDCS improved recognition and memory of faces while online tDCS did not affect task performance (Barbieri et al., 2016). This advantage of applying offline stimulation was also found for working memory (Friehs & Frings, 2019). The effect of applying multifocal tDCS to the OFA and the FFA will be explored at a behavioral level where the accuracy and reaction times for the recognition of whole faces and facial features (eyes, nose and mouth) will be measured.

2.1 Experiment 1a

Experiment 1a investigated the functional role of the OFA and the FFA on whole face and facial feature recognition using multifocal tDCS. Based on previous work that showed the involvement of the OFA in the representation of independent facial features and the FFA in the representation of whole faces (Fox, Moon, et al., 2009; Nichols et al., 2010; Pitcher et al., 2007; Schiltz et al., 2010), we expect enhanced performance for whole face recognition following the FFA stimulation compared to the OFA stimulation if tDCS could successfully enhance performance in the recognition tasks. Conversely, enhanced performance is expected for facial feature recognition following the OFA stimulation compared to FFA stimulation. Alternatively, if both regions (i.e., FFA and OFA) have overlapping roles in facial feature and whole face representation as suggested by the mixed findings in the literature (e.g., Bona et al., 2016; Nichols et al., 2010; Yovel & Kanwisher, 2004), there might be no difference in performance for facial feature and whole face recognition between the FFA stimulation and the OFA stimulation.

2.1.1 Methods

Design

As previous research revealed that variations in biological factors such as head size and scalp thickness could affect the electric field produced by tDCS, a within-subjects design was implemented (Krause & Cohen Kadosh, 2014). The within-subject factors were stimulation type (OFA and FFA) and task type (features and whole face). The order of the stimulation type was counterbalanced, where half of the participants received stimulation targeting the OFA for the first session and the other half received stimulation targeting the FFA for the first session. The presentation order of task type was also counterbalanced within each kind of stimulation. The dependent variables were accuracy, reaction time and efficiency. Reaction times and accuracy were used to calculate the rate-correct score (RCS) (Woltz & Was, 2006), a measure of efficiency. RCS is calculated by the number of correct trials divided by the sum of reaction times for correct and incorrect trials, thus providing a measure that combines accuracy and reaction times. The value of RCS indicates the number of correct trials per second, where a higher value of RCS denotes higher efficiency. RCS has been shown to be more efficient in effect detection and accounting for a larger proportion of the variance compared to other integrative measures of speed and accuracy (Vandierendonck, 2017). In addition to efficiency measurements, signal detection measurements were included to evaluate participants' ability to distinguish between signals (stimuli) and noise (absence of stimuli) (Macmillan & Creelman, 2005; Stanislaw & Todorov, 1999). Sensitivity was calculated using the hit rate (proportion of responding yes on signal trials) and the false-alarm rate (proportion of responding yes on noise trials) to calculate d-prime.

Participants

The sample size was based on past studies (Brunyé et al., 2017; Renzi et al., 2015) that used a similar procedure where participants (24 and 16 participants, respectively) were recruited to attend two experimental sessions for a within-subjects tDCS study. Additionally, an a priori power analysis was conducted using G*Power 3.1 (Faul et al., 2009) for a repeated-measures analysis of variance (ANOVA) comparing between two stimulation types (FFA and OFA) and two task types (features and whole faces). The effect size was estimated as a medium effect size, $\eta_p^2 = .06$. The effect size estimate was entered into the power analysis with the following parameters: alpha = .05, power = .95. The power analysis suggested that $N = 35$ was required to detect an interaction effect of stimulation type and task type with 95% probability.

Thirty-seven Malaysian Chinese male participants were recruited. Only male participants were recruited, as it has been indicated that hormone levels, which fluctuate more in females compared to males due to the menstrual cycle, could be a potential confounding variable as it could affect cortical excitability (Smith et al., 2002). Prior to the experiment, participants completed a screening form regarding the inclusion and exclusion criteria concerning the application of transcranial electrical stimulation (TES) and provided informed consent. Participants were instructed to sleep for at least six hours at night and avoid consuming alcohol the day before the experiment session. They were also asked to refrain from caffeine for one hour before the session and to avoid applying any hair products before each session.

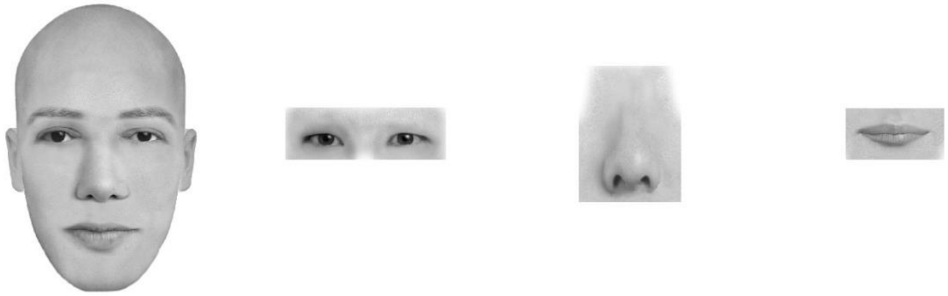
Two participants were excluded from the analysis due to their absence from the second session of the experiment. Participants' ages ranged from 18 to 29 years (*M* = 20.89 years, *SD* = 2.27 years) and they were students at the University of Nottingham Malaysia. A remuneration of RM20 or course credits was given for participation. The study has been reviewed and approved by the Science and Engineering Research Ethics Committee (SEREC) at the University of Nottingham Malaysia (approval code: KSK050319).

Apparatus & Materials

PsychoPy was used for stimuli presentation and data collection (Peirce et al., 2019). The transcranial electrical stimulator used was a Starstim 8 (Neuroelectrics, Spain). The stimuli used in the facial recognition task were created using facial composite software, Faces 4.0 (IQ Biometrics, US). Facial composite software was used as it contains a large variety of facial features (i.e., eyes, nose and mouth) whose appearances are distinct from each other. In total, 80 whole faces, 80 eyes, 80 noses and 80 mouths were used as stimuli. The whole faces had no piercings, glasses or hair. The eyes images were edited to a size of 212 × 69 pixels, nose images were edited to 100 × 133 pixels, mouth images were edited to 130 × 68 pixels and whole face images were edited to 250 × 382 pixels. Whole faces and features were then placed on a 350 × 450 pixels white canvas using Adobe Photoshop CS6. Examples of stimuli are shown below in Figure 2.1. The task was administered with an Acer XF240H 24-inch monitor with a resolution of 1920 × 1080 pixels.

Figure 2.1

Examples of stimuli used in the experiment. From right to left: whole face, eyes, nose, mouth (not to scale).



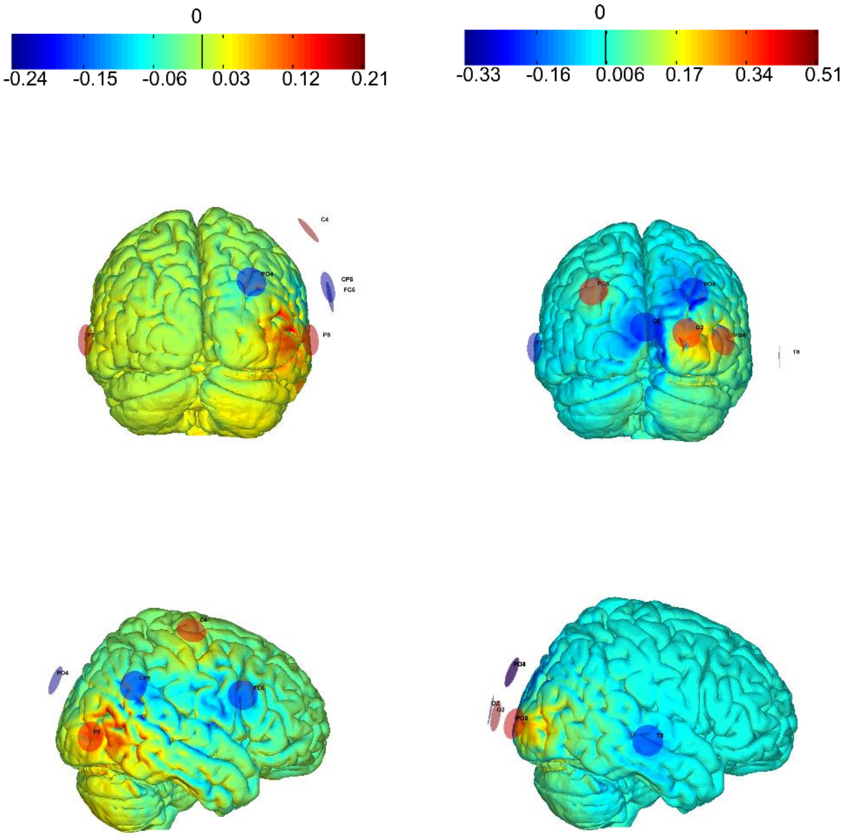
TDCS

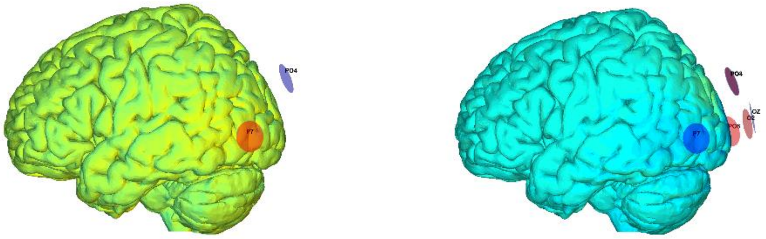
TDCS was delivered through Ag/AgCl electrodes with a $3.14cm^2$ contact area coated with conductive electrode gel (SignaGel, Parker Laboratories) to ensure good conductivity with the scalp. The electrodes were inserted into a neoprene cap (Starstim, Neuroelectrics, Barcelona, Spain) in accordance with the international 10-10 EEG system. The optimal montages for stimulation of the FFA and the OFA were produced using the Neuroelectrics Stimweaver optimization technique on a realistic head model template (Ruffini et al., 2014). The montage allowed excitation in the target area while limiting the effects in other non-target cortical locations. Only the right FFA and right OFA were selected as target areas as a large body of research has suggested a right hemisphere advantage for face processing (de Heering & Rossion, 2015; Grill-Spector et al., 2018; Rangarajan et al., 2014; G. Rhodes, 1993).

The standard safety constraint was applied to both parameters, where the maximum total injected current was 4mA and the maximum current allowed for each electrode was 2mA. During OFA stimulation, seven electrodes were mounted: PO4 (-1455 µA), OZ (-1635 µA), T8 (-317 µA), PO3 (771 µA), P7 (-338 µA), PO8 (1690 µA) and O2 (1284 µA). Seven electrodes were mounted during the FFA stimulation: PO4 (-655 µA), CP6 (-1467 µA), C4 (839 µA), FC6 (-1083 µA), P7 (366 µA), P8 (2000 µA) and CP1 (0 µA). This extra electrode (CP1) was attached during the FFA stimulation with no injected current to ensure that both stimulations had seven electrodes. The model predicted a field intensity of 0.13 V/m at the OFA region and 0.032 V/m at the FFA region (Figure 2.2). Both stimulations lasted for 20 minutes and the current was ramped up and down for the first and last 30s of stimulation respectively.

Figure 2.2

Visualisation of the normal component of the E-field (V/m) for the FFA stimulation (left) and the OFA stimulation (right) modelled using the Stimweaver algorithm on a standard brain.





Note. From top to bottom: back view, right view and left view of the brain. The red circles correspond to the anode and blue circles correspond to the cathode.

Procedure

FFA and OFA stimulation were performed in two sessions separated by at least one week to avoid any carry-over effects from the first session (see Mulquiney et al., 2011; Röhner et al., 2018; Rufener et al., 2019 for a similar procedure). As circadian rhythms could potentially influence cortical excitability (Krause & Cohen Kadosh, 2014), participants received the two sessions of stimulation at the same time of the day (± 1 hour). The order of stimulation type was counterbalanced among the participants.

At the beginning of the experiment, the participant's head circumference was measured to determine the suitable neoprene cap size. The electrode sites were then cleaned with alcohol prior to stimulation. Next, the gel-filled electrodes were fitted onto the neoprene cap and the electrical reference ear clip was clipped onto the participant's ear lobe. The cables were connected to the electrodes and the impedance level was checked. A cartoon video was presented concurrently with the stimulation. The cartoon video was introduced to reduce inter-participant variability in visual experience during the stimulation period (e.g., Renzi et al., 2015, for a similar procedure). Participants were monitored for any signs of distress at all times for safety purposes.

Participants were seated 80cm from the screen. After the stimulation, participants completed the face recognition tasks in a counterbalanced order. Whole face images were presented at a visual angle of

13.54° (height) and 9.65° (width), eyes images at 3.58° (height) and 12.84° (width), nose images at 7.15° (height) and 6.08° (width) and mouth images at 3.94° (height) and 8.93° (width). In total, there were 160 trials: 40 trials for whole faces, 40 trials for eyes, 40 trials for nose and 40 trials for mouth. Each stimulus type was presented in different blocks. For each block, participants were instructed to memorize 20 images and 40 images were presented during the test stage. Each block was separated into four sections, and in each section, participants had to memorize five images and were tested with ten images.

During the first session, participants were given a brief set of six practice trials with feedback before the actual task. There were two phases in each task: the study phase and the test phase. The use of stimuli in the study and test phases was counterbalanced among the participants. A fixation cross was presented at the center of the screen for 0.5s before the presentation of stimuli in each phase. In the study phase, each image was presented for 1s followed by a blank screen for 1s. Participants were instructed to memorize the images. In the test phase, the images that were presented in the study phase were presented along with novel images. Participants were instructed to distinguish which of the images were and were not presented in the study phase. If the image had been presented in the study phase, participants pressed the ‘x’ key and if the image was novel, the ‘m’ key was pressed. The images were presented until the participant responded. A different set of images was used for the face recognition tasks in the next session. At the end of each session, participants were asked to complete a questionnaire of sensations related to TES in order to check if there was any difference between the sensation perceived from FFA and OFA stimulation. The experimental session lasted for approximately one hour for each session.

2.1.2 Results[1]

All data were analyzed using JASP version 0.16.3 (JASP Team, 2022). An alpha level of .05 was used for all statistical tests.

---

[1] Perceived sensation after the FFA and the OFA stimulation can be found in Appendix A.

Accuracy

A 2 (stimulation type: OFA vs. FFA) × 2 (task type: features vs. whole face) repeated-measures ANOVA was conducted on accuracy calculated by proportion correct (Figure 2.3). Analysis showed no effect of stimulation type, $F(1, 34) = .611$, $p = .440$, $\eta_p^2 = .018$, or task type, $F(1, 34) = .065$, $p = .801$, $\eta_p^2 = .002$. No interaction effect of stimulation type and task type was found, $F(1, 34) = .823$, $p = .371$, $\eta_p^2 = .024$.

Reaction time

For the reaction time analysis, median reaction times were used instead of mean reaction times as medians are less influenced by extreme scores. A 2 (stimulation type: OFA vs. FFA) × 2 (task type: features vs. whole face) repeated-measures ANOVA was conducted on the median reaction times for correct responses (Figure 2.3). Analysis showed no effect of stimulation type, $F(1, 34) = .098$, $p = .756$, $\eta_p^2 = .003$. However, a significant effect of task type was found, $F(1, 34) = 11.548$, $p = .002$, $\eta_p^2 = .254$, where reaction time for features ($M = 1.141$s, $SD = .268$s) was faster compared to whole faces ($M = 1.260$s, $SD = .437$s). No interaction effect of stimulation type and task type was found, $F(1, 34) = 1.576$, $p = .218$, $\eta_p^2 = .044$.

Efficiency

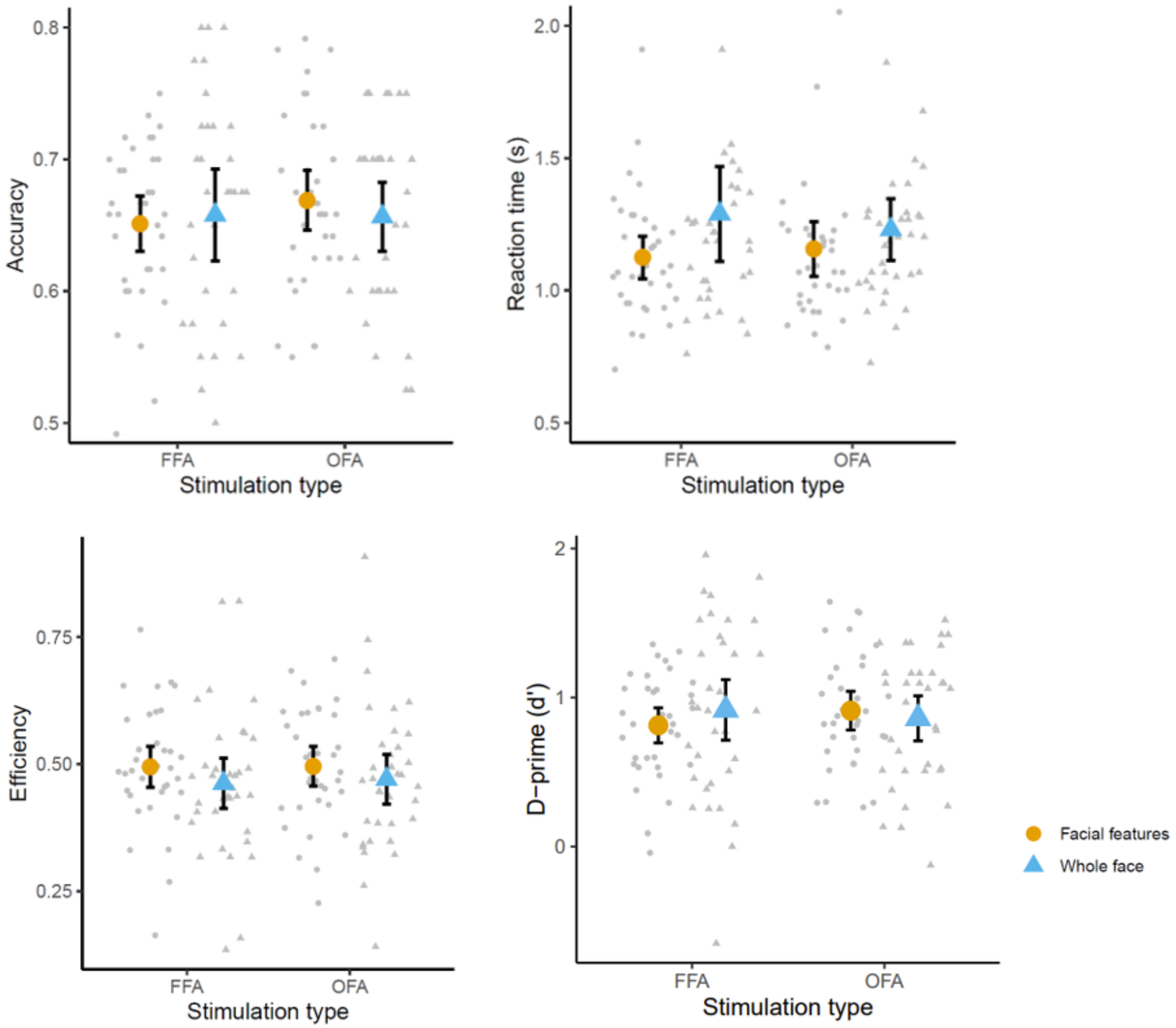
A 2 (stimulation type: OFA vs. FFA) × 2 (task type: features vs. whole face) repeated-measures ANOVA was conducted on RCS (Figure 2.3). Analysis showed no effect of stimulation type, $F(1, 34) = .076$, $p = .785$, $\eta_p^2 = .002$. A significant effect of task type was found, $F(1, 34) = 7.608$, $p = .009$, $\eta_p^2 = .183$, where efficiency for features ($M = .495$, $SD = .115$) was higher than whole face ($M = .466$, $SD = .142$). No interaction effect of stimulation type and task type was found, $F(1, 34) = .058$, $p = .811$, $\eta_p^2 = .002$.

D-prime

A 2 (stimulation type: OFA vs. FFA) × 2 (task type: features vs. whole face) repeated-measures ANOVA was conducted on d-prime (d') (Figure 2.3). Analysis showed no effect of stimulation type, $F(1, 34) = .132$, $p = .719$, $\eta_p^2 = .004$, or task type, $F(1, 34) = .150$, $p = .701$, $\eta_p^2 = .004$. No interaction effect of stimulation type and task type was found, $F(1, 34) = 1.623$, $p = .211$, $\eta_p^2 = .046$.

Figure 2.3

Measure of accuracy, reaction time, efficiency and d' for whole faces and features recognition tasks for OFA and FFA stimulation.



Note. Error bars represent 95% confidence interval. The grey circles and triangles represent the individual data, while the orange circle and blue triangles represent the summary statistics.

2.1.3 Discussion

Our results showed no difference in performance (accuracy, reaction time, efficiency and d') in the face recognition tasks between the FFA and the OFA stimulation. The OFA stimulation did not specifically enhance the performance of facial feature recognition compared to the FFA stimulation. Similarly, the FFA stimulation did not specifically enhance whole face recognition compared to the OFA stimulation. Two potential reasons could explain our results. First, it is possible that neither type of stimulation had an effect on the face recognition tasks as previous work has shown that tDCS may not always lead to an enhancement of face recognition ability (Willis et al., 2019). However, it is also possible that the stimulation was successfully delivered but due to the potential overlapping roles of the FFA and the OFA in facial feature and whole face representation, we found no differences across stimulation conditions. However, as the current experiment lacked a control condition (sham stimulation), it is unclear if the FFA stimulation and the OFA stimulation influenced the performance in the face recognition tasks to a similar extent or if neither stimulation type affected face recognition performance.

Additionally, as the stimuli used in this experiment were generated from facial composite software, they may not be processed in the same way as real human faces (Kätsyri, 2018). Artificial faces are more difficult to remember and less discriminable compared to real human faces as they are treated as out-group members (Balas & Pacella, 2015). This is problematic as in-group members are usually recognized more easily compared to out-group members (Meissner & Brigham, 2001). Moreover, the whole face stimuli in this experiment were made to have the same global shape (jawline and forehead size) and external features (ears). However, past research has shown that the presence of face shape is important to enhance holistic face processing (Retter & Rossion, 2015). Hence, in Experiment 1b, we included a control no-stimulation condition (i.e., sham stimulation) and used real faces as stimuli.

2.2 Experiment 1b

Similar to Experiment 1a, Experiment 1b aims to examine the contributions of OFA and FFA stimulation towards performance in the recognition of whole faces and facial features. In Experiment 1b, we introduced several changes. First, we used stimuli cropped from real face images as they more accurately reflect the faces, eyes, noses, and mouths encountered in real life. Additionally, the face shape was preserved as it provides relevant cues for holistic face processing (Retter & Rossion, 2015). Second, stimulation was provided following a between-subject design and included a control no-stimulation condition (i.e., sham stimulation condition). We decided to follow a between-subject design for two main reasons. From a practical point of view, a within-subject design including the three stimulation conditions (FFA, OFA, and sham) would require a minimum of 14 days, assuming the recommended minimum gap of seven days between stimulation sessions (see Mulquiney et al., 2011; Röhner et al., 2018; Rufener et al., 2019 for a similar procedure). This could lead to an increase in dropouts, making data collection more difficult. In addition, recent research showed that transcranial electrical stimulation enhances face identification following a between-subject, but not a within-subject design (Penton et al., 2018). However, to avoid the effect of differences across groups, in Experiment 1b, participants were tested before and after the stimulation. Finally, in this experiment we also included female participants to improve the representativeness of the sample. To prevent any potential confounding effects resulting from fluctuations in hormone levels caused by the menstrual cycle (Smith et al., 2002), female participants were only recruited during the follicular phase. This phase was chosen as hormone levels during this time are the most comparable to those of males (for a similar procedure, see Barbieri et al., 2016).

If the OFA is involved in facial feature representation while the FFA is involved in whole face representation (Nichols, 2010; Fox, Moon, et al., 2009; Pitcher et al., 2007; Schiltz et al., 2010), we would expect enhanced performance for whole face recognition following FFA stimulation compared to OFA stimulation and sham stimulation. Conversely, we expect enhanced performance for facial feature recognition following OFA stimulation compared to FFA stimulation and sham stimulation.

Alternatively, if both regions (i.e., FFA and OFA) have overlapping roles in facial feature and whole face representation as suggested by the mixed findings in the literature (e.g., Bona et al., 2016; Nichols et al., 2010; Yovel & Kanwisher, 2004), performance for facial feature and whole face recognition should be improved to the same extent after the application of FFA stimulation and OFA stimulation compared to sham stimulation.

2.2.1 Methods

Design

A mixed design was used. The within-subject factors were task type (whole face and features) and session (pre-stimulation and post-stimulation). The between-subject factor was the stimulation type (OFA, FFA and sham). Similar to Experiment 1a, the dependent variables were accuracy, reaction time and efficiency. The presentation order of task type was counterbalanced for all participants.

Participants

The sample size for this study was based on Barbieri et al. (2016) who used a similar procedure where 48 participants were recruited for a between-subjects tDCS study with three conditions (online a-tDCS, offline a-tDCS and sham stimulation). Additionally, an a priori power analysis was conducted using G*Power 3.1 (Faul et al., 2009) for a mixed ANOVA comparing between three stimulation types (FFA, OFA and sham stimulation), two task types (whole faces and facial features) and two session types (pre-stimulation and post-stimulation). The effect size was estimated as a medium effect size, $\eta_p^2 = .06$. The effect size estimate was entered into the power analysis with the following parameters: alpha = .05, power = .95. The power analysis suggested that $N = 24$ was required to detect an interaction effect of stimulation type, task type and session with 95% probability.

Sixty Malaysian Chinese (38 females) participants were recruited. To address the potential influence of ORE in face recognition (Estudillo, 2021; Estudillo et al., 2020; Hayward et al., 2008; Wong et al., 2020), only Malaysian Chinese participants were recruited as the stimuli presented in the experiment were created using only Chinese faces. Past work has also indicated that hormone levels which fluctuate among females due to the menstrual cycle could affect cortical excitability (Smith et al., 2002). Hence, female participants were recruited during the follicular phase of the menstrual cycle as in this phase, the hormone levels are most similar to those of males (for a similar procedure, see Barbieri et al., 2016). Female participants were requested to provide the start date of their most recent menstrual cycle to determine if they are currently in the follicular phase.

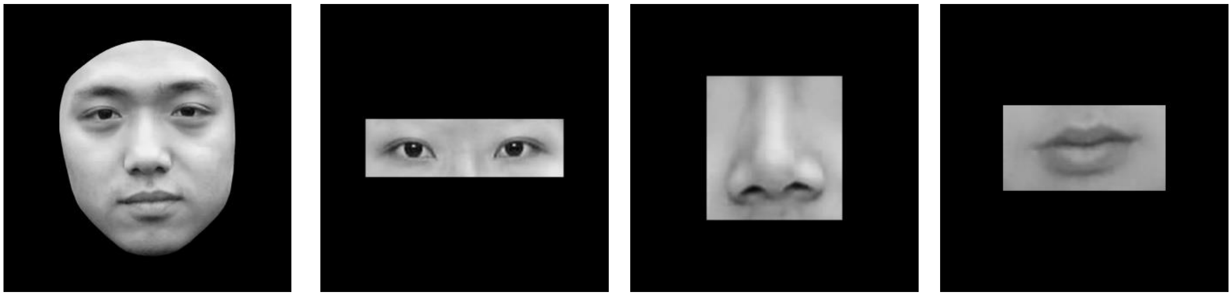
Prior to the experiment, participants completed a screening form for the inclusion and exclusion criteria concerning the application of TES and provided informed consent. Participants were instructed to sleep for at least six hours at night and avoid consuming alcohol the day before the experiment session. They were also asked to refrain from caffeine for one hour before the session and to avoid applying any hair products before each session. Participants' ages ranged between 18 and 29 years (*M* = 21.38 years, *SD* = 2.2 years) and were students at the University of Nottingham Malaysia. Remuneration of RM10 or course credits was given for participation. The study has been reviewed and approved by the Science and Engineering Research Ethics Committee (SEREC) in the University of Nottingham Malaysia (approval code: KSK050319).

Apparatus and Materials

Similar to Experiment 1a, PsychoPy (Peirce et al., 2019) and Starstim 8 (Neuroelectrics, Spain) were used. The stimuli used in the recognition tasks were created using the CAS-PEAL face database (Gao et al., 2008). In total, 180 whole faces (90 females and 90 males), 60 eyes (30 females and 30 males), 60 noses (30 females and 30 males) and 60 mouths (30 females and 30 males) were used as stimuli. The whole faces had no piercings, glasses, external hair or facial hair. The stimuli for the features task were cropped from whole faces available in the CAS-PEAL face database. The eyes images were cropped to a size of 550 × 162 pixels, nose images were cropped to 377 × 400 pixels and mouth images were cropped to 450 × 237 pixels. The whole face images were resized to 600 pixels in height and the width was resized according to the original proportion of the whole face. Whole faces and features were then placed on a 800 × 800 pixels black canvas using Adobe Photoshop CS6. Examples of stimuli are shown below in Figure 2.4.

Figure 2.4

Examples of stimuli used in the experiment, from right to left: whole face, eyes, nose, mouth (not to scale).



TDCS

Three types of stimulation were used in this experiment: FFA stimulation, OFA stimulation and sham stimulation. The montage used for stimulation of the right FFA and the right OFA was as in Experiment 1a. Sham stimulation used the same montage as either FFA stimulation or OFA stimulation but the current was only delivered during the first and last 30s to evoke the sensation of stimulation, without affecting neuronal excitability (Thair et al., 2017). Half of the participants received sham stimulation using the FFA stimulation montage and the other half using the OFA stimulation montage.

Procedure

Participants first completed baseline whole face and feature recognition tasks. The baseline task was used to control potential differences across groups. Participants completed the baseline whole face and feature recognition tasks in a counterbalanced order and were seated 80cm from the screen. Whole face images were presented at a visual angle of 10.36° (height) and 7.87°-8.58° (width), eyes images at 3.08° (height) and 10.21° (width), nose images at 6.94° (height) and 6.58° (width) and mouth images at 4.44° (height) and 8.36° (width). Participants were given a brief six practice trials session with feedback before the actual trial began. In total, there were 180 trials: 90 trials for whole faces and 90 trials for features (30 trials each for eyes, nose and mouth stimuli). In each recognition task, participants were instructed to memorize 45 images and 90 images were presented during the test stage. Each task was separated into nine blocks where participants had to memorize five images in each block and were then tested with ten images. A self-paced break of at least 20 seconds was given after every three blocks.

There were two phases in each task: the study phase and the test phase. The use of stimuli in the study and test phases was counterbalanced among the participants. A fixation cross was presented at the center of the screen for 0.5s before the presentation of stimuli in the study and test phases. In the study phase, each image was presented for 1s followed by a blank screen for 1s. Participants were instructed to memorize the images presented in the study phase. After the study phase, participants had a self-paced rest of at least 10 seconds before moving on to the test phase. In the test phase, the images that were presented in the study phase were presented intermixed with novel images. The images were presented until the participant responded. Participants were instructed to distinguish which of the images were presented and which were not presented in the study phase. If the image was presented in the study phase, participants pressed the ‘x’ key and if the image was novel, the ‘m’ key was pressed.

The procedure for the stimulation session was as in Experiment 1a. After the stimulation session, participants were asked to complete new versions of the whole face and features recognition tasks that were identical in procedure to the baseline tasks. The versions of the tasks were counterbalanced for pre- and post-stimulation sessions. At the end of the session, participants were asked to complete a questionnaire of sensations related to TES to check if there was any difference between the sensations perceived from FFA, OFA and sham stimulation. The experimental session lasted for approximately one hour for each session.

2.2.2 Results[2]

All data were analyzed using JASP version 0.16.3 (JASP Team, 2022).

Accuracy

A mixed 2 (task type: features vs. whole faces) × 2 (session: pre vs. post) × 3 (simulation type: FFA vs. OFA vs. sham) ANOVA was conducted on accuracy calculated by proportion correct (Figure 2.5). Analysis revealed no main effect of stimulation type, $F(2, 57) = .173$, $p = .842$, $\eta_p^2 = .006$, or session, $F(1, 57) = 2.432$, $p = .124$, $\eta_p^2 = .041$. A main effect of task type was found, $F(1, 57) = 75.496$, $p < .001$, $\eta_p^2 = .570$, where features task ($M = .658$, $SD = .083$) had lower accuracy compared to whole faces task ($M = .722$, $SD = .082$). The analysis revealed no interaction effect of stimulation type and task type, $F(2, 57) = 1.189$, $p = .312$, $\eta_p^2 = .040$, no interaction effect of stimulation type and session, $F(2, 57) = .111$, $p = .895$, $\eta_p^2 = .004$, no interaction effect of task type and session, $F(1, 57) = 1.988$, $p = .164$, $\eta_p^2 = .034$, and no three-way interaction effect of stimulation type, task type and session, $F(2, 57) = .153$, $p = .858$, $\eta_p^2 = .005$.

Reaction time

A mixed 2 (task type: features vs. whole faces) × 2 (session: pre vs. post) × 3 (simulation type: FFA vs. OFA vs. sham) ANOVA was conducted on median reaction time for correct trials (Figure 2.5). No main effect of stimulation type was found, $F(2, 57) = .256$, $p = .775$, $\eta_p^2 = .009$. A significant main effect of session was found, $F(1, 57) = 23.764$, $p < .001$, $\eta_p^2 = .294$, where pre-stimulation trials ($M = 1.095$s, $SD = .238$s) had longer reaction time compared to post-stimulation trials ($M = 1$s, $SD = .210$s). Analysis revealed a significant main effect of task type, $F(1, 57) = 30.555$, $p < .001$, $\eta_p^2 = .349$, where features task ($M = 1.085$s, $SD = .247$s) had longer reaction time compared to whole faces task ($M = 1.011$s, $SD = .203$s). Analysis also revealed no interaction effect of stimulation type and task type, $F(2,$

---

[2] Analysis of the perceived sensation after the FFA, OFA and sham stimulation and an analysis on baseline scores to compare face recognition ability and age between stimulation groups could be found in Appendix B.

57) = 2.346, p = .105, η_p^2 = .076, no interaction effect of stimulation type and session, F(2, 57) = .280, p = .757, η_p^2 = .010, and no interaction effect of task type and session, F(1, 57) = 2.289, p = .136, η_p^2 = .039.

A three-way interaction effect of stimulation type, task type and session was found, F(2, 57) = 3.406, p = .04, η_p^2 = .107. To further explore this three-way interaction, we ran a 2 (task type: features vs. whole faces) × 3 (simulation type: FFA vs. OFA vs. sham) ANOVA for pre-stimulation and post-stimulation sessions separately. For pre-stimulation session, no main effect of stimulation type was found, F(2, 57) = .389, p = .679, η_p^2 = .013. A significant main effect of task type was found, F(1, 57) = 20.909, p < .001, η_p^2 = .268, where features (M = 1.140s, SD = .253s) had longer reaction time compared to whole faces (M = 1.050s, SD = .214s). No interaction effect between task type and stimulation type was found in pre-stimulation session, F(2, 57) = 2.403, p = .100, η_p^2 = .078.

In terms of post-stimulation session, no main effect of stimulation type was found, F(2, 57) = .103, p = .902, η_p^2 = .004. A significant main effect of task type was found, F(1, 57) = 16.312, p < .001, η_p^2 = .222, where features (M = 1.029s, SD = .229s) had longer reaction time compared to whole faces (M = .971s, SD = .186s). A significant interaction effect between task type and stimulation type was found in post-stimulation session, F(2, 57) = 3.466, p = .038, η_p^2 = .108. Simple main effect analysis showed that for FFA stimulation, no difference was found between features (M = .986s, SD = .281s) and whole face (M = .981s, SD = .247s), F(1, 19) = .025, p = .877, η^2 = .001. Features (M = 1.047s, SD = .214s) had longer reaction time compared to whole faces (M = .965s, SD = .149s) for OFA stimulation, F(1, 19) = 17.501, p < .001, η^2 = .479 and sham stimulation, F(1, 19) = 12.545, p = .002, η^2 = .398 (features: M = 1.055s, SD = .187s; whole faces: M = .968s, SD = .155s). Additionally, no difference were found between the three stimulation types (FFA, OFA and sham) in features task, F(2, 57) = .528, p = .593, η^2 = .018, and whole face task, F(2, 57) = .043, p = .958, η^2 = .002, post-stimulation.

We also ran a 2 (session: pre vs. post) × 3 (simulation type: FFA vs. OFA vs. sham) ANOVA for features and whole faces separately. In the features task, no main effect of stimulation type was found, F(2, 57) = .591, p = .557, η_p^2 = .020. A significant main effect of session was found, F(1, 57) = 26.346, p < .001, η_p^2 = .316, where pre-stimulation (M = 1.140s, SD = .253s) had longer reaction time compared to post-stimulation (*M* = 1.029s, *SD* = .229s). No interaction effect between session and stimulation type was found in features task, *F*(2, 57) = 1.087, *p* = .344, η_p^2 = .037.

In whole faces task, no main effect of stimulation type was found, *F*(2, 57) = .071, *p* = .931, η_p^2 = .002. A significant main effect of session was found, *F*(1, 57) = 11.704, *p* = .001, η_p^2 = .170, where pre-stimulation (*M* = 1.050s, *SD* = .214s) had longer reaction time compared to post-stimulation (*M* = .971s, *SD* = .186s). No interaction effect between session and stimulation type was found in whole faces task, *F*(2, 57) = .974, *p* = .384, η_p^2 = .033.

We also ran a 2 (session: pre vs. post) × 2 (task type: features vs. whole faces) ANOVA for FFA, OFA and sham stimulation separately. For FFA stimulation, no main effect of task type was found, *F*(1, 19) = 3.825, *p* = .065, η_p^2 = .168. A significant main effect of session was found, *F*(1, 19) = 4.975, *p* = .038, η_p^2 = .208, where pre-stimulation (*M* = 1.063s, *SD* = .188s) had longer reaction time compared to post-stimulation (*M* = .984s, *SD* = .261s). A significant interaction effect between session and task type was found after FFA stimulation, *F*(1, 19) = 6.350, *p* = .021, η_p^2 = .250.

Simple main effect analysis showed that for pre-stimulation session, features (*M* = 1.109s, *SD* = .206s) had longer reaction time compared to whole faces (*M* = 1.017s, *SD* = .160s), *F*(1, 19) = 8.677, *p* = .008, η^2 = .314. For post-stimulation session, no difference was found between features (*M* = .986s, *SD* = .281s) and whole faces (*M* = .981s, *SD* = .247s), *F*(1, 19) = .025, *p* = .877, η^2 = .001. Additionally, pre-stimulation (*M* = 1.109s, *SD* = .206s) had longer reaction time compared to post-stimulation (*M* = .986s, *SD* = .281s) for features task, *F*(1, 19) = 10.943, *p* = .004, η^2 = .365. No difference between pre-stimulation (*M* = 1.017s, *SD* = .160s) and post-stimulation was found for whole face task (*M* = .981s, *SD* = .247s), *F*(1, 19) = .723, *p* = .406, η^2 = .037.

For OFA stimulation, a significant main effect of task type was found, *F*(1, 19) = 11.692, *p* = .003, η_p^2 = .381, where features (*M* = 1.080s, *SD* = .222s) had longer reaction time compared to whole faces (*M* = 1.021s, *SD* = .223s). A significant main effect of session was found, *F*(1, 19) = 7.551, *p* = .013, η_p^2 = .284, where pre-stimulation (*M* = 1.095s, *SD* = .249s) had longer reaction time compared to post-stimulation (*M* = 1.006s, *SD* = .187s). No interaction effect between session and task type was found after OFA stimulation, *F*(1, 19) = 1.267, *p* = .274, η_p^2 = .063.

For sham stimulation, a significant main effect of task type was found, *F*(1, 19) = 18.702, *p* < .001, η_p^2 = .496, where features (*M* = 1.126s, *SD* = .271s) had longer reaction time compared to whole faces (*M* = 1.011s, *SD* = .184s). A significant main effect of session was found, *F*(1, 19) = 12.504, *p* = .002, η_p^2 = .397, where pre-stimulation (*M* = 1.126s, *SD* = .271s) had longer reaction time compared to post-stimulation (*M* = 1.011s, *SD* = .176s). No interaction effect between session and task type was found after sham stimulation, *F*(1, 19) = 2.207, *p* = .154, η_p^2 = .104.

Efficiency

A mixed 2 (task type: features vs. whole faces) × 2 (session: pre vs. post) × 3 (simulation type: FFA vs. OFA vs. sham) ANOVA was conducted on efficiency measured by RCS (Figure 2.5). No main effect of stimulation type was found, *F*(2, 57) = .133, *p* = .876, η_p^2 = .005. A main effect of session was found, *F*(1, 57) = 19.694, *p* < .001, η_p^2 = .257, where pre-stimulation trials (*M* = .57, *SD* = .152) had lower efficiency compared to post-stimulation trials (*M* = .617, *SD* = .16). Analysis revealed a main effect of task type, *F*(1, 57) = 45.985, *p* < .001, η_p^2 = .447, where features task (*M* = .553, *SD* = .149) had lower efficiency compared to whole faces task (*M* = .633, *SD* = .156).

Analysis also revealed a significant interaction effect of stimulation type and task type, *F*(2, 57) = 3.534, *p* = .036, η_p^2 = .11. Simple main effect analysis revealed that no difference was found between FFA, OFA and sham stimulation for features task, *F*(2, 57) = .845, *p* = .435, η^2 = .029, and whole faces task, *F*(2, 57) = .187, *p* = .830, η^2 = .007. Features task (*M* = .570, *SD* = .139) had lower efficiency compared to whole face task *(M* = .617, *SD* = .125) for FFA stimulation, *F*(1, 19) = 5.374, *p* = .032, η^2 = .220, OFA stimulation, *F*(1, 19) = 18.165, *p* < .001, η^2 = .489 (features: *M* = .569, *SD* = .132; whole faces: *M* = .640, *SD* = .155) and sham stimulation, *F*(1, 19) = 26.384, *p* < .001, η^2 = .581 (features: *M* = .522, *SD* = .133; whole faces: *M* = .643, *SD* = .169).

A significant interaction effect of task type and session was found, *F*(1, 57) = 4.865, $p = .031$, $\eta_p^2 = .079$. Simple main effect analysis revealed that features task (*M* = .521, *SD* = .131) had lower efficiency compared to whole faces (*M* = .619, *SD* = .156) for pre-stimulation session, *F*(1, 59) = 43.216, $p < .001$, $\eta^2 = .423$, and post-stimulation session, *F*(1, 59) = 16.236, $p < .001$, $\eta^2 = .216$ (features: *M* = .586, *SD* = .160; whole faces: *M* = .647, *SD* = .155). Additionally, pre-stimulation (*M* = .521, *SD* = .131) had lower efficiency compared to post-stimulation (*M* = .586, *SD* = .160) for features task, *F*(1, 59) = 18.966, $p < .001$, $\eta^2 = .243$, and whole faces task, *F*(1, 59) = 5.307, $p = .025$, $\eta^2 = .083$ (pre-stimulation: *M* = .619, *SD* = .156; post-stimulation: *M* = .647, *SD* = .155).

No interaction effect of stimulation type and session was found, *F*(2, 57) = .379, $p = .687$, $\eta_p^2 = .013$. A three-way interaction effect of stimulation type, task type and session was found, *F*(2, 57) = 3.817, $p = .028$, $\eta_p^2 = .118$. To further explore this three-way interaction, we ran a 2 (task type: features vs. whole faces) × 3 (simulation type: FFA vs. OFA vs. sham) ANOVA for pre-stimulation and post-stimulation sessions separately. For pre-stimulation session, no main effect of stimulation type was found, *F*(2, 57) = .178, $p = .837$, $\eta_p^2 = .006$. A significant main effect of task type was found, *F*(1, 57) = 45.544, $p < .001$, $\eta_p^2 = .444$, where features (*M* = .521, *SD* = .131) had lower efficiency compared to whole faces (*M* = .619, *SD* = .156). No interaction effect between task type and stimulation type was found in pre-stimulation session, *F*(2, 57) = 2.589, $p = .084$, $\eta_p^2 = .083$.

For post-stimulation session, no main effect of stimulation type was found, *F*(2, 57) = .132, $p = .876$, $\eta_p^2 = .005$. A significant main effect of task type was found, *F*(1, 57) = 18.274, $p < .001$, $\eta_p^2 = .243$, where features (*M* = .586, *SD* = .160) had lower efficiency compared to whole faces (*M* = .647, *SD* = .155). A significant interaction effect between task type and stimulation type was found in post-stimulation session, *F*(2, 57) = 4.703, $p = .013$, $\eta_p^2 = .142$. Simple main effect analysis showed that for FFA stimulation, no difference was found between features (*M* = .623, *SD* = .187) and whole face (*M* = .623, *SD* = .153), *F*(1, 19) = 1.795e - 4, $p = .989$, $\eta^2 = 9.448\text{e} - 6$. Features (*M* = .584, *SD* = .136) had lower efficiency compared to whole faces (*M* = .665, *SD* = .161) for OFA stimulation, *F*(1, 19) = 15.589, $p < .001$, $\eta^2 = .451$ and sham stimulation, *F*(1, 19) = 14.841, $p = .001$, $\eta^2 = .439$ (features: *M* = .551, *SD*

= .151; whole faces: *M* = .654, *SD* = .156). Additionally, no differences were found between the three stimulation types (FFA, OFA and sham) in features task (FFA: *M* = .623, *SD* = .187; OFA: *M* = .584, *SD* = .136; sham: *M* = .551, *SD* = .151), *F*(2, 57) = .998, *p* = .375, η^2 = .034, and whole face task (FFA: *M* = .623, *SD* = .153; OFA: *M* = .665, *SD* = .161; sham: *M* = .654, *SD* = .156), *F*(2, 57) = .382, *p* = .684, η^2 = .013, post-stimulation.

We also ran a 2 (session: pre vs. post) × 3 (simulation type: FFA vs. OFA vs. sham) ANOVA for features and whole faces separately. In features task, no main effect of stimulation type was found, *F*(2, 57) = .845, *p* = .435, η_p^2 = .029. A significant main effect of session was found, *F*(1, 57) = 19.821, *p* < .001, η_p^2 = .258, where pre-stimulation (*M* = .521, *SD* = .131) had lower efficiency compared to post-stimulation (*M* = .586, *SD* = .160). No interaction effect between session and stimulation type was found in features task, *F*(2, 57) = 2.330, *p* = .107, η_p^2 = .076.

In whole faces task, no main effect of stimulation type was found, *F*(2, 57) = .187, *p* = .830, η_p^2 = .007. A significant main effect of session was found, *F*(1, 57) = 5.281, *p* = .025, η_p^2 = .085, where pre-stimulation (*M* = .619, *SD* = .156) had lower efficiency compared to post-stimulation (*M* = .647, *SD* = .155). No interaction effect between session and stimulation type was found in whole faces task, *F*(2, 57) = .856, *p* = .430, η_p^2 = .029.

We also ran a 2 (session: pre vs. post) × 2 (task type: features vs. whole faces) ANOVA for FFA, OFA and sham stimulation separately. For FFA stimulation, a significant main effect of task type was found, *F*(1, 19) = 5.374, *p* = .032, η_p^2 = .220, where features task (*M* = .570, *SD* = .139) had lower efficiency compared to whole face task (*M* = .617, *SD* = .125). A significant main effect of session was found, *F*(1, 19) = 5.410, *p* = .031, η_p^2 = .222, where pre-stimulation (*M* = .564, *SD* = .130) had lower efficiency compared to post-stimulation (*M* = .623, *SD* = .169). A significant interaction effect between session and task type was found after FFA stimulation, *F*(1, 19) = 7.928, *p* = .011, η_p^2 = .294. Simple main effect analysis showed that for pre-stimulation session, features (*M* = .517, *SD* = .119) had lower efficiency compared to whole faces (*M* = .610, *SD* = .126), *F*(1, 19) = 13.593, *p* = .002, η^2 = .417. For post-stimulation session, no difference was found between features (*M* = .623, *SD* = .187) and whole faces (*M* = .623, *SD* = .153), *F*(1, 19) = 1.795e - 4, *p* = .989, η^2 = 9.448e - 6. Additionally, pre-stimulation (*M* = .517, *SD* = .119) had lower efficiency compared to post-stimulation (*M* = .623, *SD* = .187) for features task, *F*(1, 19) = 10.572, *p* = .004, η^2 = .358. No difference between pre-stimulation (*M* = .610, *SD* = .126) and post-stimulation (*M* = .623, *SD* = .153) was found for whole face task, *F*(1, 19) = .206, *p* = .655, η^2 = .011.

For OFA stimulation, a significant main effect of task type was found, *F*(1, 19) = 18.165, *p* < .001, η_p^2 = .489, where features task (*M* = .569, *SD* = .132) had lower efficiency compared to whole face task (*M* = .640, *SD* = .155). A significant main effect of session was found, *F*(1, 19) = 12.633, *p* = .002, η_p^2 = .399, where pre-stimulation (*M* = .585, *SD* = .149) had lower efficiency compared to post-stimulation (*M* = .624, *SD* = .153). No interaction effect between session and task type was found after OFA stimulation, *F*(1, 19) = .716, *p* = .408, η_p^2 = .036.

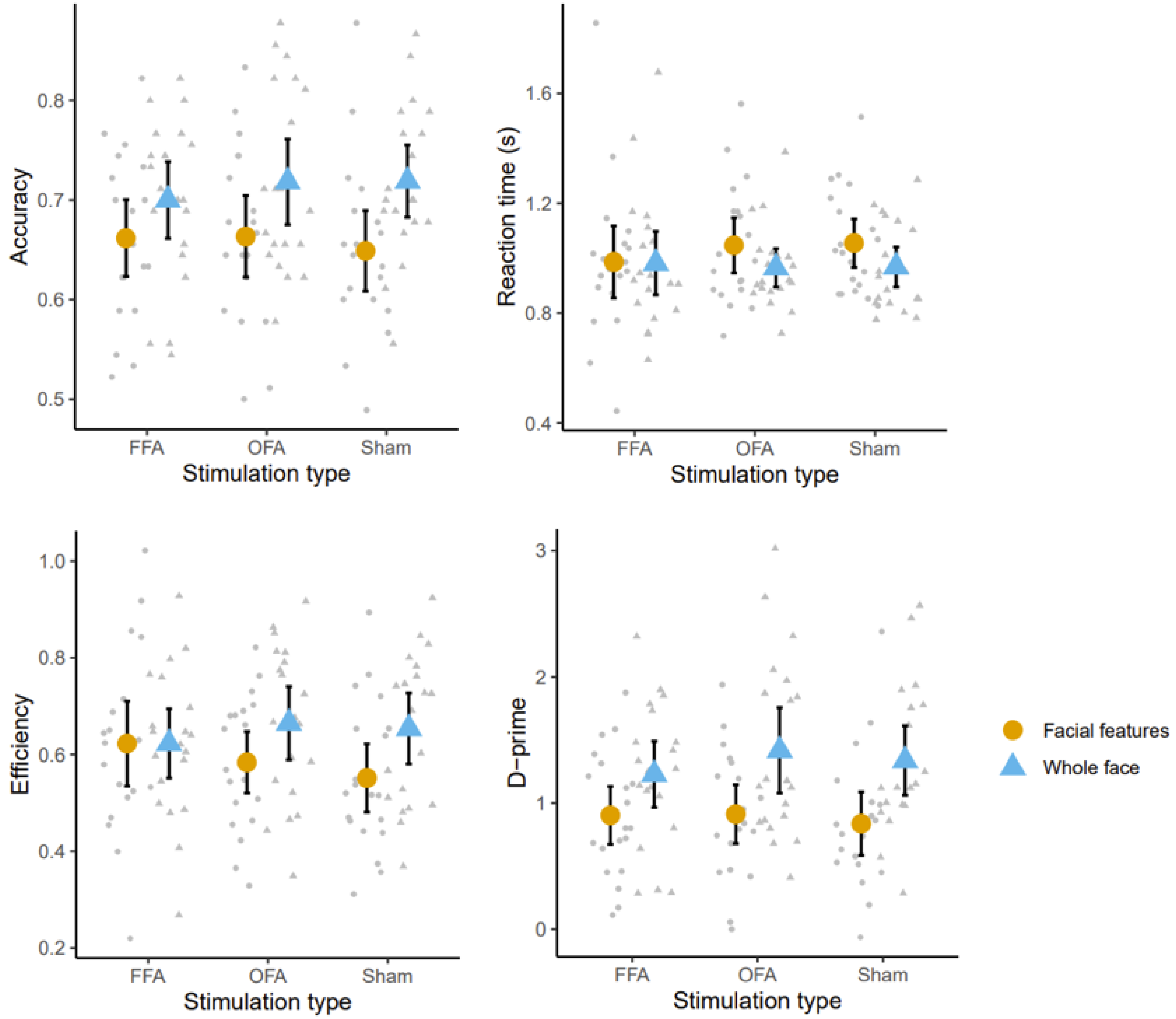
For sham stimulation, a significant main effect of task type was found, *F*(1, 19) = 26.384, *p* < .001, η_p^2 = .581, where features task (*M* = .522, *SD* = .133) had lower efficiency compared to whole face task (*M* = .643, *SD* = .169). A significant main effect of session was found, *F*(1, 19) = 7.741, *p* = .012, η_p^2 = .289, where pre-stimulation (*M* = .562, *SD* = .177) had lower efficiency compared to post-stimulation (*M* = .603, *SD* = .160). No interaction effect between session and task type was found after sham stimulation, *F*(1, 19) = 1.749, *p* = .202, η_p^2 = .084.

D-prime

A mixed 2 (task type: features vs. whole faces) × 2 (session: pre vs. post) × 3 (simulation type: FFA vs. OFA vs. sham) ANOVA was conducted on d’ (Figure 2.5). Analysis revealed no main effect of stimulation type, *F*(2, 57) = .225, *p* = .799, η_p^2 = .008, or session, *F*(1, 57) = .926, *p* = .340, η_p^2 = .016. A main effect of task type was found, *F*(1, 57) = 77.533, *p* < .001, η_p^2 = .576, where features task (*M* = .873, *SD* = .484) had lower d’ compared to whole faces task (*M* = 1.374, *SD* = .620). The analysis revealed no interaction effect of stimulation type and task type, *F*(2, 57) = .587, *p* = .559, η_p^2 = .020, no interaction effect of stimulation type and session, *F*(2, 57) = .107, *p* = .899, η_p^2 = .004, no interaction effect of task type and session, $F(1, 57) = 1.672$, $p = .201$, $\eta_p^2 = .028$, and no three-way interaction effect of stimulation type, task type and session, $F(2, 57) = .374$, $p = .689$, $\eta_p^2 = .013$.

Figure 2.5

Post-stimulation accuracy, reaction time, efficiency and d' for features and whole face recognition tasks for OFA, FFA and sham stimulation.



Note. Error bars represent 95% confidence interval. The grey circles and triangles represent the individual data, while the orange circle and blue triangles represent the summary statistics.

2.2.3 Discussion

Our results showed that there was no difference in reaction times between feature recognition and whole face recognition following FFA stimulation. However, participants showed longer reaction times for feature recognition compared to whole face recognition after OFA and sham stimulation. The analysis also revealed that prior to the FFA stimulation, participants indeed took more time for feature recognition compared to whole face recognition, but after the FFA stimulation the difference between feature and whole face recognition was absent, indicating an enhancement in feature recognition facilitated by FFA stimulation. Similarly, the efficiency results mirrored this pattern. Before FFA stimulation, participants exhibited lower efficiency in feature recognition compared to whole face recognition. However, post-FFA stimulation, this discrepancy disappeared, further supporting the notion of enhanced feature recognition resulting from FFA stimulation. No differences in terms of accuracy and d’ were found across stimulation conditions. Given the absence of any significant differences in accuracy across stimulation conditions and considering the potential confounding effects of the speed-accuracy trade-offs, we will discuss and prioritize efficiency (which combines both accuracy and reaction time into a single measure) over reaction time measure in this experiment. Contrary to previous work that showed the involvement of the OFA in the representation of facial features and the FFA in the representation of whole faces (Fox, Moon, et al., 2009; Nichols et al., 2010; Pitcher et al., 2007; Schiltz et al., 2010), our results showed that the FFA stimulation enhanced facial feature recognition whereas the OFA stimulation had no effect on both facial feature and whole face recognition. Additionally, no effect of the FFA stimulation was found on whole face recognition. Overall, our findings support the involvement of the FFA in featural recognition.

2.3 General discussion

This study aimed to investigate the functional role of the FFA and the OFA using multifocal tDCS. In Experiment 1a, tDCS over the OFA and the FFA did not produce any change in the performance to recognize whole faces and facial features. However, past work has shown that artificial faces may not be processed in the same way as real human faces as they are more difficult to remember and less discriminable compared to real human faces as they are treated as out-group members (Balas & Pacella, 2015; Kätsyri, 2018). Furthermore, in Experiment 1a, the whole face stimuli were created with identical global shape (forehead size and jawline). However, previous studies have demonstrated that the presence of face shape is crucial for holistic face processing (Retter & Rossion, 2015).

To avoid these problems, in Experiment 1b, we used real faces and found that the FFA stimulation increased efficiency for feature recognition. Similarly, the reaction time results mirrored this pattern. Although we used a between-subject design, this result could not be attributed to individual differences in face recognition abilities (i.e., participants in the FFA stimulation group having higher facial feature recognition ability compared to the OFA stimulation group and sham stimulation group) as we measured baseline performance before the stimulation session and improvements in Experiment 1b were calculated by comparing pre- and post-stimulation scores. Additionally, analysis of pre-stimulation scores showed no difference in face recognition ability between the stimulation groups (Appendix B). This finding of enhanced feature recognition following the FFA stimulation is in line with past fMRI studies showing the involvement of the FFA in feature recognition (Dachille et al., 2012; J. Liu et al., 2010). For example, the FFA responded similarly to facial features presented individually and facial features presented in a face-like combination (Dachille et al., 2012). Although a different study found that the FFA was more responsive to features that were arranged in a normal configuration compared to a scrambled configuration, this finding showed that the FFA responded to the presence of facial features even in a scrambled configuration (J. Liu et al., 2010). These studies suggest that the FFA is involved in facial feature representation which contradicts the neural model by Haxby et al. (2000) which suggests that the FFA is mainly involved in the representation of whole faces.

However, it is important to note that the accuracy and d’ results indicate that the stimulation of the FFA does not improve the ability to discriminate between learned and novel stimuli, irrespective of whether they are whole faces or features. This may suggest that the improvements are mainly in terms of reaction time. Additionally, enhanced facial feature recognition following FFA stimulation might also be associated with improved object recognition. Previous research has indicated that facial features are perceived as objects when faces are not processed holistically (Moscovitch et al., 1997), and there is evidence of FFA involvement in object recognition (McGugin et al., 2016). Hence, it is advisable for future studies to incorporate an object-related task to investigate whether the effects of tDCS were face-specific.

Despite using real faces, our results in Experiment 1b showed no effect of the FFA stimulation on whole face recognition. One possible explanation for the lack of FFA stimulation effect on whole face recognition in Experiment 1b is the difference in task difficulty between facial features and whole face recognition. Our findings showed that the features task was more difficult (e.g., lower efficiency) compared to the whole face task in Experiment 1b. Earlier studies have found that the effect of tDCS is more apparent when the task difficulty is greater, as seen in areas such as arithmetic (Pope & Miall, 2012; Popescu et al., 2016; Rütsche et al., 2015), working memory (Gill et al., 2015; Vergallito et al., 2018) and attention (Nelson et al., 2014; Reteig et al., 2017). Similarly, performance enhancement in video games following tDCS effects was observed only when participants were multitasking but not when participants were executing a single task (Hsu et al., 2015). Since the feature recognition task was more difficult than the whole face recognition task, the effect of tDCS may only be apparent for facial feature recognition and not whole face recognition.

In contrast to our expectations, we found no difference in efficiency for facial features and whole face recognition after OFA stimulation. One possible reason for this may be that the montage used for the OFA stimulation in this experiment was not effective in eliciting an advantage in the recognition tasks. In other words, our results may not rule out the involvement of OFA in the representation of facial features and whole faces, but the montage used for OFA stimulation in this experiment was not effective in enhancing performance in the recognition tasks. In fact, based on the Neuroelectrics Stimweaver report, the predicted field intensity for OFA stimulation (0.13 V/m) was much higher compared to the predicted field intensity for FFA stimulation (0.032 V/m), hence, the effect of OFA stimulation should be larger than that of FFA stimulation. In contrast to this, participants reported in Experiment 1a that they felt more itching for FFA stimulation compared to OFA stimulation (see Appendix A). Since there is no direct way of measuring the effect of the stimulation in our experiment, it could be that the real stimulation effect did not replicate the predicted stimulation effect as other factors such as biological differences could affect the application of tDCS (Krause & Cohen Kadosh, 2014). Differences in the biological substrates such as the pre-existing neurotransmitter levels, head size and scalp thickness could contribute to inter-individual differences in the electric field in the brain generated by tDCS causing the stimulation effect to vary across participants (Krause & Cohen Kadosh, 2014; Laakso et al., 2019). As a result, the efficiency of the OFA stimulation might have varied depending on whether the participants received the stimulation in an optimum manner.

In sum, our results from Experiment 1a showed no significant change in performance to recognize whole faces and facial features after tDCS application over the OFA and FFA, which may have been influenced by the use of artificial faces. Experiment 1b, using real faces, revealed that FFA stimulation increased efficiency for facial feature recognition. However, no effect of FFA stimulation was observed for whole face recognition, possibly due to a lower level of task difficulty. OFA stimulation did not show any effect on either whole face or feature recognition, which may be attributed to the ineffectiveness of the stimulation montage. Overall, our findings suggest that the FFA is involved in facial feature representation, with implications for understanding the neural mechanisms underlying face processing.

Chapter 3 – Investigating the other-race effect using anodal and cathodal tDCS

In addition to multifocal tDCS (Chapter 2), we also examined the potential benefits of the traditional 2 electrode montage on own- and other-race face recognition in Chapter 3 (Experiment 3). To gain insights into how we can improve face recognition, a reliable face recognition measure is crucial. Currently, there are two Caucasian versions of the CFMT but only one version of the Asian CFMT. This led us to the development of a new Asian Cambridge Face Memory Test (Experiment 2a and 2b). The introduction of the CFMT-MY enables us to effectively assess participants before and after stimulation using the CFMT in Experiment 3.

Faces are one of the most critical stimuli for successful social interaction. However, despite its importance, face recognition abilities present substantial inter-individual variability (Bowles et al., 2009; Bruce et al., 2018; R. Wang et al., 2012; Wilmer, 2017) with some people showing superior face recognition (i.e., super-recognizers) (Russell et al., 2009) while others present difficulties in recognizing even highly familiar faces (i.e., prosopagnosics) (Rossion, 2014). Prosopagnosia, also known as face blindness, is a visual impairment that affects face recognition despite intact visual acuity and intelligence and can result from brain injury (i.e., acquired prosopagnosia) or abnormal development (i.e., developmental or congenital prosopagnosia). Remarkably, these difficulties in face recognition could contribute to negative social consequences (e.g., high anxiety in social situations) not only for adults (Yardley et al., 2008), but also for children (Dalrymple, Fletcher, et al., 2014). Although the estimated prevalence of developmental prosopagnosia in the general population is around 2.5% (Bowles et al., 2009; Kennerknecht et al., 2006, 2008), many cases remain undiagnosed (Duchaine, 2000). Given the limited insights that people have into their own face recognition skills (Bate & Dudfield, 2019; Bobak et al., 2019; Estudillo, 2021; Estudillo & Wong, 2021; Palermo et al., 2017), objective measures of face identification are crucial for the study of individual differences in face recognition skills and the diagnosis of prosopagnosia.

One of the most prominent objective measures of face recognition abilities is the Cambridge Face Memory Test (CFMT) (Duchaine & Nakayama, 2006). This test, which can be completed in about 15 minutes, provides a valid measure of face recognition, as it requires the identification of faces across different views (Bruce, 1982; Estudillo & Bindemann, 2014). The CFMT is poorly correlated with general intelligence (Shakeshaft & Plomin, 2015) and object recognition ability (Dennett et al., 2012; Shakeshaft & Plomin, 2015), which suggests that this test taps into face identification specific processes. The original version of the CFMT consists of a three-alternative forced choice paradigm subdivided into three stages of increasing difficulty. Participants are first asked to study six Caucasian target faces. Subsequently, during the recognition trials, the target faces are presented without any variation in the image (learning stage) with different lighting and viewpoints (novel stage) and with the addition of visual noise (novel-with-noise stage). The CFMT has been widely used to investigate different aspects of face recognition, including its heritability (Wilmer et al., 2010), development (Germine et al., 2011), relationship with holistic processing (DeGutis, Wilmer, et al., 2013) and other group effects (Childs et al., 2021; Estudillo et al., 2020; McKone et al., 2012; Wan et al., 2017). Importantly, because it has high reliability (Cronbach's alpha (α) ≈ .90), the CFMT is also used to aid the diagnosis of prosopagnosia (e.g., Bowles et al., 2009; Duchaine & Nakayama, 2006; Estudillo et al., 2020; McKone et al., 2017). Specifically, individuals scoring two standard deviations below the mean CFMT performance are considered possible prosopagnosia cases (Duchaine & Nakayama, 2006).

Despite the remarkable psychometric properties of the CFMT, several factors (i.e., problems understanding the instructions and inattentiveness) could influence the final test scores irrespective of actual face recognition skills (see e.g., Gamaldo & Allaire, 2016). Although repeating the same test could provide a more reliable score, this practice is not exempt from problems (McCaffrey & Westervelt, 1995). For example, due to face familiarity effects as a consequence of using the same face stimuli, an individual who scored below the cut-off value during the first assessment may score above the cut-off value in the next reassessment test (Murray & Bate, 2020). This familiarity effect could be easily avoided by using a complementary version of the CFMT containing a different set of face stimuli (Murray & Bate, 2020). In addition, with the increasing interest in face training protocols (Bate et al., 2020; Corrow et al., 2019; Davies-Thompson et al., 2017), having complementary versions of the CFMT is also highly useful for rigorous pre-post training comparisons. For Caucasian participants, such a complementary version does exist, the CFMT-Australian (CFMT-Aus) (McKone et al., 2011). Importantly, the psychometric properties of the CFMT-Aus are comparable to those of the original CFMT, making this test not only an alternative to the original CFMT, but also a complementary assessment tool in the aforementioned situations.

People tend to be better recognizing faces of their own-race compared to other-race faces, the so-called other-race effect (Meissner & Brigham, 2001). Both the CFMT-original and the CFMT-Aus consist of Caucasian face stimuli and have shown strong other-race effects (see e.g., Estudillo et al., 2020; McKone et al., 2012; Wan et al., 2017), limiting their use to Caucasian populations. The CFMT-Chinese (McKone et al., 2012) was introduced to study individual differences in face recognition and aid in the diagnosis of prosopagnosia in Asian populations. This test follows an identical format compared to the original version of the test and has comparable psychometric properties (McKone et al., 2017). However, at present, the CFMT-Chinese is the only Asian version of the CFMT which, as previously discussed, might present difficulties for the study of individual differences, the diagnosis of borderline cases of prosopagnosia and pre-post face training comparisons.

Although the CFMT-Chinese aims to explore individual differences in face recognition and aid the diagnosis of prosopagnosia in the Asian population, the other-race effect has also been found within the Asian population (Wong et al., 2020). However, other studies using the CFMT-Chinese found that the scores of the CFMT-Chinese were still higher than the CFMT-original where the Asian participants recruited comprised of a variety of Asian origins, some of which were not Chinese, such as Indonesian (McKone et al., 2012), Malay and Filipino participants (Bate, Bennetts, Hasshim, et al., 2019). Similarly, Estudillo et al. (2020) found that although Malaysian Malay and Malaysian Indian showed a clear other-race effect for Caucasian faces, they presented identical performance for Chinese faces compared to Malaysian Chinese participants in the CFMT-Chinese. Altogether, these findings suggest that non-Chinese Asians may perform better for Chinese faces as compared to Caucasian faces. Despite the fact that using the CFMT with Chinese faces for the diagnosis of prosopagnosia among the non-Chinese Asian population may not be ideal, currently, the CFMT-Chinese may still be a superior face recognition measure compared to the Caucasian CFMT versions for the diagnosis of prosopagnosia among the non-Chinese Asian population.

In the current study, we presented a novel Asian version of the CFMT, the CFMT-Chinese Malaysian (CFMT-MY). In Experiment 2a, we determined the psychometric properties of the CFMT-MY using a Chinese Malaysian sample. Specifically, in Experiment 2a we explored the internal reliability, convergent validity and divergent validity of the CFMT-MY. Experiment 2a also tested whether the three stages of the CFMT-MY represent increasing levels of difficulty. The increasing levels of difficulty across stages is an important property of the CFMT-original (Duchaine & Nakayama, 2006) that has been overlooked in the CFMT-Chinese (e.g., Estudillo et al., 2020; McKone et al., 2012, 2017). After checking the psychometric properties of the CFMT-MY, Experiment 2b used a sample of Caucasian participants to explore whether the CFMT-MY captures an other-race effect of similar magnitude compared to that of the CFMT-Chinese.

3.1 Experiment 2a

Experiment 2a aimed to investigate the psychometric properties of the CFMT-MY. In addition to measures of reliability (Cronbach's α) and internal consistency across stages, we explored the convergent and divergent validities of the test. Convergent validity was explored by correlating participants' performance in the CMFT-MY with their performance in the CFMT-Chinese. Divergent validity was explored by correlating participants' performance in the CFMT-MY and their performance in a general object recognition task that follows the same format as the CFMT: the Cambridge Car Memory Test (CCMT) (Dennett et al., 2012). If the CFMT-MY had appropriate convergent and divergent validity we would expect a stronger correlation between the CFMT-MY and the CFMT-Chinese than between the CFMT-MY and the CCMT. Additionally, we examined the increasing level of difficulty across the three stages of the CFMT-Chinese and the CFMT-MY. Differences in accuracy between the different stages of the CFMT-MY and CFMT-Chinese were assessed using repeated-measures ANOVA.

3.1.1 Methods

Design

A within-subjects design was implemented. The within-subject factors were task type (CFMT-MY, CFMT-Chinese and CCMT) and task stage (learning, novel and novel-with-noise). The order of the tasks was randomised and the accuracy of the tasks were recorded.

Participants

One hundred and thirty-nine participants took part in this experiment, but the final sample included 134 Chinese Malaysians (92 females and 42 males) with an age range of 18 to 66 years (*M* = 22.81 years, *SD* = 5.53 years). The age range for female participants was between 18 and 66 years (*M* = 22.50 years, *SD* = 6.24 years) while for male participants, the age range was from 18 to 35 years (*M* = 23.48 years, *SD* = 3.47 years). Data from participants of other-ethnicity (e.g., Malay, Indian, Eurasian, mixed) (four participants) and that had median reaction times less than 500ms (one participant) were removed from further analysis. Eight additional participants were excluded from the data analysis (except for internal reliability and internal consistency analyses) as their performance on the face memory tasks was indicative of possible prosopagnosia (Appendix C). The remaining participants were 126 Chinese Malaysians (87 females and 39 males) with an age range from 18 to 66 years (*M* = 22.92 years, *SD* = 5.64 years). The age range for female participants was between 18 and 66 years (*M* = 22.58 years, *SD* = 6.38 years) while for male participants, the age range was between 18 and 35 years (*M* = 23.69 years, *SD* = 3.40 years).

An a priori power analysis was conducted using G*Power 3.1 (Faul et al., 2009) for a repeated-measures ANOVA comparing the stages of the two Asian CFMT versions (CFMT-MY and CFMT-Chinese). The effect size for the task stage was based on Murray and Bate (2020) where $\eta_p^2 = .824$, a large effect size. A large effect size estimate ($\eta_p^2 = .14$) was entered into the power analysis with the following parameters: $\alpha = .05$, power = .95. The power analysis implied that $N = 50$ would be required to detect a difference between the CFMT versions with 95% probability. A priori power analysis was also conducted for correlation tests comparing two versions of face memory test (CFMT-Chinese and CFMT-MY). The correlations between two different versions of the CFMT reported in past studies were higher than .5 (e.g., $r = .71$ in Arrington et al., 2022; $r = .61$ in McKone et al., 2011). A medium correlation ($r = .5$) was entered into the power analysis with the following parameters: $\alpha = .05$, power = .95. The power analysis suggested that $N = 46$ would be required to detect a correlation between the two CFMT versions with 95% probability.

All participants provided informed consent to participate in the study. Upon recruiting every 10 participants, a lucky draw was held with each participant given a chance to win RM20 or alternatively course credits were given for participation. The study has been reviewed and approved by the Science and Engineering Research Ethics Committee (SEREC) at the University of Nottingham Malaysia (approval code: KSK050320).

Cambridge Face Memory Test – Chinese (CFMT-Chinese)

The CFMT-Chinese was obtained from McKone et al. (2012). Fifty-two male identities were used in the task. The CFMT consists of three stages with increasing difficulty: learning stage (i.e., faces are presented in the same lighting and viewpoint condition), novel stage (i.e., faces are presented in different lighting and viewpoint condition) and novel-with-noise stage (i.e., faces are presented in different lighting and viewpoint condition with Gaussian noise applied). In total, there were 72 trials and six target faces to be memorized throughout the whole task.

Three practice trials with feedback were given before the experimental trials to familiarize participants with the procedure. The practice trials were identical to the procedure in the learning stage, but using cartoon images of Bart Simpson. In the learning stage, three study images (left 1/3 profile, frontal view and right 1/3 profile) of the same identity were presented sequentially for three seconds each with inter-trial interval of 500ms (Figure 3.1a). The target face was then presented with two distractor faces and participants were required to select the target face shown using the “1”, “2” or “3” key with no time limit (Figure 3.1b). In total, there were 18 trials in the learning stage (six target faces × three trials).

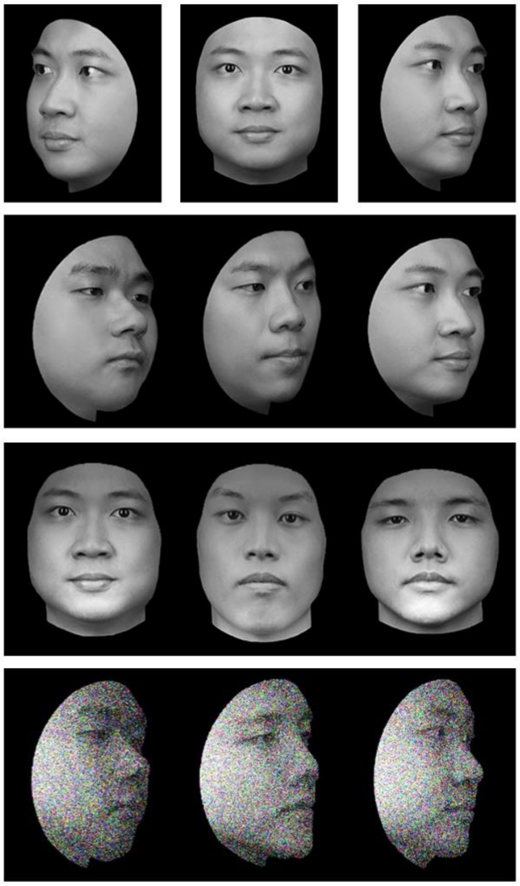
In the novel stage, participants were required to memorize the same six target faces in the learning stage which were presented simultaneously in frontal view for 20 seconds. Similar to the test phase of the previous stage, participants were required to select the target face presented with two distractor faces with no time limit. The images presented in this stage were different from the learning stage in terms of lighting and/or viewing angle (Figure 3.1c). In total, there were 30 trials in the novel stage (six target faces × five trials). The novel-with-noise stage was identical to the novel stage, except that noise was added to the test images to increase the difficulty level (Figure 3.1d). In total, there were 24 trials in the novel-with-noise stage (six target faces × four trials).

Cambridge Face Memory Test – Chinese Malaysian (CFMT-MY)

The stimuli used in the CFMT-MY were created using the University of Nottingham Malaysia face database, where photographs of students from the University of Nottingham Malaysia were obtained with informed consent before photographing. In total, 52 male Chinese Malaysian identities were used as stimuli. The faces had no piercings or glasses. Editing of images was conducted using Adobe Photoshop CS6. Blemishes, moles and facial hair were removed. Five different viewing angles of each identity were used (frontal, 45 degrees left, 45 degrees right, 90 degrees left and 90 degrees right). The face images were cropped to a size of 210 pixels in height while the width of the face images was resized according to the original proportion of the face. Each image was then placed onto a 200 × 250 pixels black canvas. Examples of the CFMT stimuli similar to the actual test stimuli used are shown below in Figure 3.1.

Figure 3.1

Sample CFMT-MY stimuli.



Three study images in learning stage presented in different views

Test trials in learning stage (faces are presented with same light and viewpoint condition as in study image)

Test trials in novel stage (faces are presented with different lighting and cropping template)

Test trials in novel-with-noise stage (faces are presented with different light and viewpoint condition with Gaussian noise applied)

Note. None of the faces shown in the sample figure were used in the actual task to avoid familiarity with the actual target faces used in the task.

The CFMT-MY was designed to replicate the original CFMT but using Chinese Malaysian faces. For the learning stage, the same cropping template was used for all targets and distractors. Frontal viewpoint, 45 degrees right and 45 degrees left were used. The distractors were matched to the target faces in the testing phase based on their similarity in appearance. Replicating the original CFMT, target faces were never used as distractors and the distractors were presented repeatedly to ensure that participants could not use familiarity to decide if the faces were previously memorized or not.

In the novel stage of the original CFMT, images of the same identity were captured with different poses and physical lighting (i.e., the frontal view of the same identity was captured with lighting from the bottom or a slightly different frontal pose). However, such images did not exist in our face database. Thus, we used frontal viewpoint, 45 degrees right, 90 degrees right and 90 degrees left for the novel stage. We followed the procedure of CFMT-Aus (McKone et al., 2011) where instead of poses, different templates were used and lighting was added to the images using Adobe Photoshop CS6. For the frontal view and the 45 degrees right view, the images from the learning stage were used with modifications (i.e., the use of different external template shape and/or the addition of lighting). The external templates used were replicated based on CFMT-Aus. Point light was added using the function *Lighting effects*. The lighting was directed from the right for the 45 degrees right images, from the left for half of the frontal view images and from the bottom for the other half of the frontal view images. As the 90 degrees right and left images were not shown in the learning stage, only a template was used with no lighting changes made.

In the novel-with-noise stage, the viewpoints used were frontal, 45 degrees left and 90 degrees right. The lighting was directed from the right for half of the frontal view images and the 45 degrees left images. For the 90 degrees right images, the lighting was directed from the left. The other half of the front-facing images were made to appear lightly shadowed by adjusting the brightness and contrast (-30 brightness and +30 contrast). Different templates were applied to the frontal view and the 45 degrees left images. Next, 30% coloured Gaussian noise was added using the function *Add noise*. The CFMT-MY materials (stimuli and trial order) are available in the Open Science Framework repository, https://osf.io/gu4fy/.

Cambridge Car Memory Test (CCMT)

CCMT was obtained from the authors of the task (Dennett et al., 2012). Fifty-two different cars were used in the CCMT. The CCMT follows the same procedure as CFMT, except the images presented were cars instead of faces.

Procedure

Testable (https://www.testable.org/) was used to run the online experiment (Rezlescu et al., 2020). To ensure that the stimuli size remained the same for different screen sizes, calibration was included before the start of the task where participants had to match the length of a line on the screen to the length of a bank card. The average vertical height of the face stimuli in the CFMT-Chinese and CFMT-MY was 4 cm while the average vertical height of the car stimuli in the CCMT was 3.5 cm. Participants completed all three tasks: Asian CFMT (Chinese and Malaysia) and CCMT in random order. The experiment took about 45 minutes to complete.

3.1.2 Results

All data analysis was conducted using JASP (JASP Team, 2022), except for the internal reliability analysis which was carried out using R software and R Studio (R Core Team, 2021; RStudio Team, 2021) including several R packages: dplyr (Wickham et al., 2021), tidyr (Wickham, 2021), data.table (Dowle & Srinivasan, 2021), psy (Falissard, 2012) and reshape (Wickham, 2007).

Normal distribution

The skewness (skew = -.397, *SE* = .216) and kurtosis (kurtosis = -.485, *SE* = .428) values for the CFMT-MY score were between ± 1 which indicates normal distribution (George & Mallery, 2019). Additionally, no significant skew was found for the scores of CFMT-MY (z = -1.838, p = .07). The mean score for CFMT-MY was 59.94/72, *SD* = 6.93. The CFMT-Chinese score also exhibited a normal distribution where skewness (skew = -.252, *SE* = .216) and kurtosis (kurtosis = -.767, *SE* = .428) values were between ± 1. No significant skew was found for the scores of CFMT-Chinese (*z* = -1.167, *p* = .24). The mean score for CFMT-Chinese was 56.98/72, *SD* = 8.37.

Internal reliability

The internal reliability of the test was measured using Cronbach's α. For all trials, internal reliability was α = .86 for CFMT-MY. Results showed high internal reliability for CFMT-MY which was in line with previous work such as CFMT-Chinese, α = .86 (McKone et al., 2017) and CFMT-Aus, α = .88 (McKone et al., 2011). The internal reliability was α = .89 for CFMT-Chinese.

Internal consistency

The internal consistency of the CFMT-MY at stage level (i.e., learning, novel and novel-with-noise) was measured using Pearson correlation (*r*). Results showed positive correlation between the learning and novel stage, *r*(134) = .55, *p* < .001, learning and novel-with-noise stage, *r*(134) = .40, *p* < .001 and novel and novel-with-noise stage, *r*(134) = .68, *p* < .001 showing that the scores were highly consistent across the different stages of CFMT-MY. Additionally, the CFMT-Chinese scores also showed a positive correlation between the learning and novel stage, *r*(134) = .41, *p* < .001, learning and novel-with-noise stage, *r*(134) = .41, *p* < .001 and the novel and novel-with-noise stage, *r*(134) = .79, *p* < .001 showing that the scores were highly consistent across the different stages of CFMT-Chinese.

Validity

Convergent and divergent validity were measured using Pearson correlation (*r*). Convergent validity was measured by examining the correlation between the CFMT-Chinese and the CFMT-MY whereas divergent validity was measured by examining the correlation between the CCMT and the CFMT-MY. Results showed positive correlation between the scores of the CFMT-MY and the CFMT-Chinese, *r*(124) = .59, *p* < .001. A weak positive correlation was found between the scores of the CCMT and the CFMT-MY, $r(124) = .26$, $p = .004$. The difference between the two correlation was further analyzed by comparing the dependent overlapping correlations (Diedenhofen & Musch, 2015; Hittner et al., 2003). The test showed that the correlation between the CFMT-MY and the CFMT-Chinese (i.e., convergent validity) was larger than the correlation between the CCMT and the CFMT-MY (i.e., divergent validity), $z = 3.62$, $p < .001$.

Repeated-measures ANOVA

A repeated-measures ANOVA was conducted to explore (1) potential differences between the CFMT-Chinese and the CFMT-MY and (2) the increasing levels of difficulty across the test stages. A 3 (stage: learning vs. novel vs. novel-with-noise) × 2 (test version: CFMT-MY vs. CFMT-Chinese) repeated-measures ANOVA was conducted on the accuracy (calculated by proportion correct scores). When the Mauchly's test indicated that the assumption of sphericity was violated, the degrees of freedom were corrected using the Greenhouse-Geisser method.

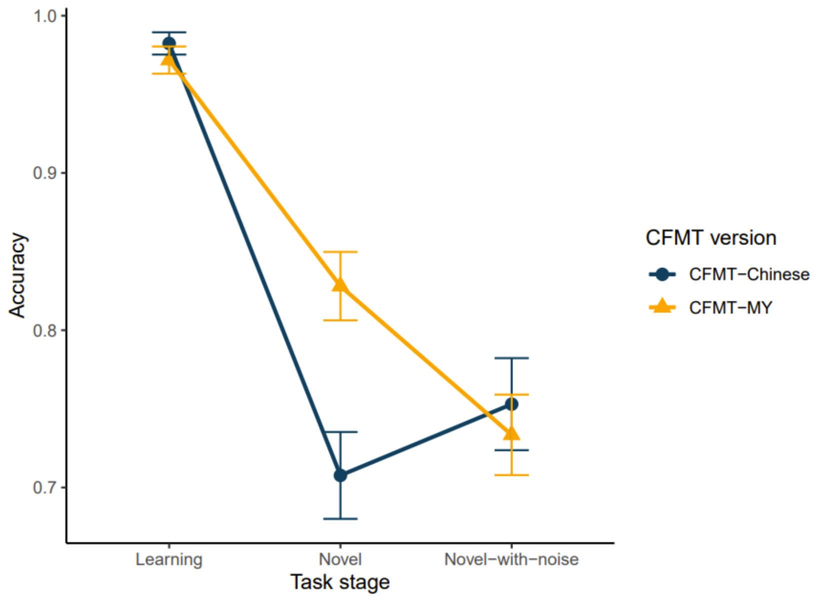
Analysis revealed a significant main effect of stage on accuracy, $F(1.70, 212.05) = 357.49$, $p < .001$, $\eta_p^2 = .74$. A post hoc Holm-Bonferroni test demonstrate that the accuracy of the learning stage ($M = 0.98$, $SD = 0.05$) was higher than the novel stage ($M = 0.77$, $SD = 0.15$), $p < .001$, $d = 1.94$. Similarly, the accuracy of the learning stage was higher than the novel-with-noise stage ($M = 0.74$, $SD = 0.16$), $p < .001$, $d = 2.17$. Accuracy was found to be higher in the novel stage compared to the novel-with-noise stage, $p = .01$, $d = 0.23$.

Results showed a significant main effect of test version on accuracy, $F(1, 125) = 14.03$, $p < .001$, $\eta_p^2 = .10$, where the accuracy of CFMT-MY ($M = 0.83$, $SD = 0.10$) was higher than CFMT-Chinese ($M = 0.79$, $SD = 0.12$). A significant interaction effect between stage and test version on accuracy was found, $F(2, 250) = 65.68$, $p < .001$, $\eta_p^2 = .34$ (Figure 3.2). Simple main effects analysis showed no differences between the test versions in the learning stage, $F(1, 125) = 3.497$, $p = .064$, $\eta^2 = .027$, and novel-with-noise stage, $F(1, 125) = 2.042$, $p = .156$, $\eta^2 = .016$. However, a significant effect was found in the novel stage, *F*(1, 125) = 89.45, *p* < .001, η^2 = .417, where the novel stage score for CFMT-MY (*M* = 0.83, *SD* = 0.12) was higher than CFMT-Chinese (*M* = 0.71, *SD* = 0.16).

Additional simple main effects analysis showed a significant main effect of stage on accuracy in the CFMT-MY, *F*(1.86, 231.82) = 245.16, *p* < .001, η^2 = .66. A post hoc Holm-Bonferroni test showed that the accuracy of the learning stage (*M* = 0.97, *SD* = 0.05) was higher than the novel stage (*M* = 0.83, *SD* = 0.12), *p* < .001, *d* = 1.18. Similarly, the accuracy of the learning stage was higher than the novel-with-noise stage (*M* = 0.73, *SD* = 0.15), *p* < .001, *d* = 1.96. Accuracy for the novel stage was found to be higher than the novel-with-noise stage, *p* < .001, *d* = 0.78. Results also showed a significant main effect of stage on accuracy in the CFMT-Chinese, *F*(1.81, 226.17) = 270.01, *p* < .001, η^2 = .68. A post hoc Holm-Bonferroni test demonstrated that the accuracy of the learning stage (*M* = 0.98, *SD* = 0.04) was higher than the novel stage (*M* = 0.71, *SD* = 0.16), *p* < .001, *d* = 1.93. Similarly, the accuracy of the learning stage was higher than the novel-with-noise stage (*M* = 0.75, *SD* = 0.17), *p* < .001, *d* = 1.61. Interestingly, the accuracy for the novel stage was found to be lower than the novel-with-noise stage, *p* < .001, *d* = -0.318.

Figure 3.2

Proportion correct scores of Chinese Malaysian participants in the three stages of CFMT.



Note. Error bars represent 95% confidence intervals.

3.1.3 Discussion

Overall, the results showed that the CFMT-MY seems to be suitable to study individual differences in face recognition and exhibits potential utility in facilitating the diagnosis of individuals with face recognition impairments. The scores of CFMT-MY were normally distributed when all trials were included in the analysis (72 trials). Hence, the standard method used to calculate the cut-off score, *M* – 2*SD* seems to be a suitable option for the diagnosis of face recognition impairments in the CFMT-MY. Additionally, the CFMT-MY was highly consistent and exhibited high internal reliability (α = .86) which was in line with those reported in previous work on CFMT-Chinese and CFMT-Aus (α = .86, .88; McKone et al., 2011, 2017). This high reliability further supports the suitability of the test to be used for diagnosis in clinical settings and for the measurement of individual differences in face recognition.

The findings also demonstrated convergent validity where the CFMT-MY was moderately correlated with the CFMT-Chinese. This suggest that both tests tap very similar cognitive processes. Results also demonstrated divergent validity where the CFMT-MY was weakly correlated with the CCMT which measures object recognition, despite both tests having similar procedures and formats.

Additionally, the correlation between the Asian CFMT versions was larger compared to the correlation between CCMT and CFMT-MY. Hence, there is strong evidence that the CFMT-MY taps face-recognition-specific processes rather than general visual memory.

Our results showed that the difficulty of the CFMT-MY increases across stages. Specifically, the learning stage achieved the highest accuracy followed by the novel and finally the novel-with-noise stage. The CFMT-Chinese showed a similar pattern of results where the learning stage achieved higher accuracy compared to the novel and novel-with-noise stages. However, the novel stage had lower accuracy compared to the novel-with-noise stage. This finding is surprising and contradicted the intended higher level of difficulty for the novel-with-noise stage (Duchaine & Nakayama, 2006).

In summary, the analysis revealed that the CFMT-MY exhibits potential utility in facilitating the diagnosis of face recognition difficulties in clinical settings and the measurement of individual differences in face recognition ability with high consistency and high internal reliability scores. The CFMT-MY also shows appropriate convergent and divergent validity. In addition, the CFMT-MY scores show an increasing level of difficulty stages which is important for the assessment of a wide range of face recognition abilities.

3.2 Experiment 2b

In Experiment 2b, we aim to investigate if the CFMT-MY would be sensitive to a classical effect in face recognition literature: the other-race effect. We also aim to explore if Caucasian participants would present similar levels of other-race effect for the CFMT-MY and the CFMT-Chinese. Differences in accuracy between the CFMT-MY, CFMT-Chinese and CFMT-original would be assessed using a repeated-measures ANOVA. Additionally, the CFMT-MY scores of Chinese Malaysian participants in Experiment 2a and the Caucasian participants in Experiment 2b would be compared using an independent samples t-test to determine if the CFMT-MY is sensitive to the other-race effect.

3.2.1 Methods

Design

A within-subjects design was implemented. The within-subject factors were task type (CFMT-MY, CFMT-Chinese and CFMT-original) and task stage (learning, novel and novel-with-noise). The order of the tasks was randomised and the accuracy of the tasks were recorded.

Participants

One hundred and fifty participants took part in this experiment, but the final sample included 135 Caucasians (108 females, 25 males and 2 non-binary) with ages ranging between 18 to 52 years (*M* = 22.04 years, *SD* = 6.62 years). The age range for female participants was between 18 and 52 years (*M* = 21.64 years, *SD* = 6.54 years) while for male participants, the age range was between 18 and 49 years (*M* = 23.32 years, *SD* = 6.58 years). The age range for non-binary participants was between 19 and 36 years (*M* = 27.50 years, *SD* = 12.02 years). Data from participants who had a median reaction time of less than 500ms (nine participants) or scored below chance level (24/72) (one participant) for any one of the CFMT versions were removed from further analysis. Five participants of other ethnicities (e.g., Asian, Other) other than White/Caucasian were also excluded. Ten participants were excluded from the data analysis (except for internal reliability and internal consistency analysis) as their performance on the face memory tasks was indicative of possible prosopagnosia (Appendix D). The remaining participants were 125 Caucasians (100 females, 24 males and 1 non-binary) with ages ranging between 18 and 52 years (*M* = 21.53 years, *SD* = 5.66 years). The age range for female participants was between 18 and 52 years (*M* = 21.38 years, *SD* = 6.03 years) while for male participants, the age range was between 18 and 34 years (*M* = 22.25 years, *SD* = 3.92 years). The age for the non-binary participant was 19 years.

An a priori power analysis was conducted using G*Power 3.1 (Faul et al., 2009) for a repeated-measures ANOVA comparing the three CFMT versions (CFMT-MY, CFMT-Chinese and CFMT-original). The effect size for the other-race effect was estimated from two studies which had used CFMT in measuring the other-race effect (McKone et al., 2012; Wan et al., 2017) where the average $\eta_p^2 = .44$, large effect size (effect size (η_p^2) in the papers was calculated using formula 13 in Lakens (2013)). Additionally, a meta-analysis study has reported a large effect size for the other-race effect, Hedge's g = .82. Therefore, a large effect size estimate ($\eta_p^2 = .14$) was entered into the power analysis with the following parameters: $\alpha = .05$, power = .95. The power analysis implied that 50 participants would be required to detect a difference between the CFMT versions with 95% probability.

All participants provided informed consent to participate in the study. Course credits were given for participation. The study has been reviewed and approved by the Science and Engineering Research Ethics Committee (SEREC) at the University of Nottingham Malaysia (approval code: KSK050320).

Apparatus and Materials

Three versions of CFMT were used: the CFMT-original, the CFMT-Chinese and the CFMT-MY. The CFMT-original was obtained from the authors of the task (Duchaine & Nakayama, 2006). Fifty-two male identities were used in the task. The CFMT-original follows the same procedure as the CFMT-Chinese and the CFMT-MY (refer to Experiment 2a for full procedure).

Procedure

Testable (https://www.testable.org/) was used to run the online experiment (Rezlescu et al., 2020). The average vertical height of the face stimuli in the CFMT was 4 cm. Participants completed all three CFMT versions in random order. The experiment took about 45 minutes to complete.

3.2.2 Results

The analysis of internal reliability, internal consistency and validity were consistent with Experiment 2a and are available in Appendix E. A repeated-measures ANOVA was conducted to examine if there were any differences between the scores of the different test versions and the different stages of the test. A 3 (test version: CFMT-MY vs. CFMT-Chinese vs. CFMT-original) × 3 (stage: learning vs. novel vs. novel-with-noise) repeated-measures ANOVA was conducted on the accuracy (calculated by proportion correct scores). When the Mauchly's test indicated that the assumption of sphericity was violated, the degrees of freedom were corrected using the Greenhouse-Geisser method.

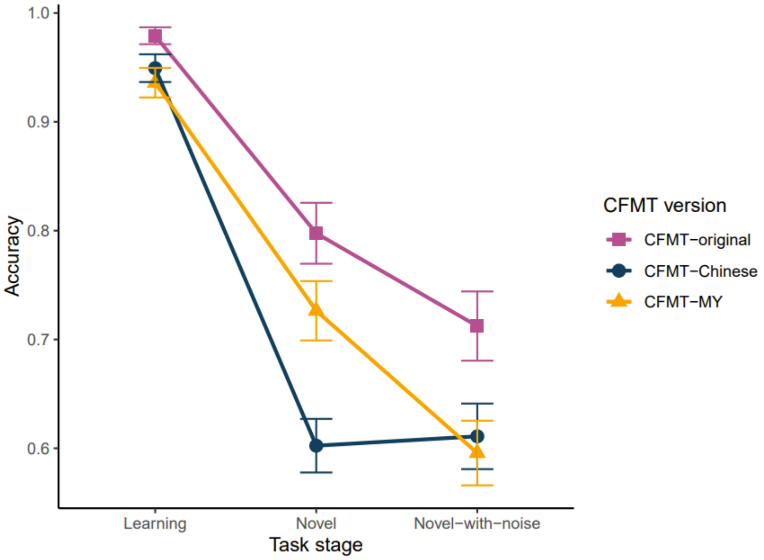
Results showed a significant main effect of test version on accuracy, $F(2, 248) = 70.49$, $p < .001$, $\eta_p^2 = .36$. A post hoc Holm-Bonferroni test demonstrated that the accuracy of CFMT-original ($M = 0.82$, $SD = 0.12$) was higher than CFMT-MY ($M = 0.74$, $SD = 0.12$), $p < .001$, $d = .73$. Similarly, the accuracy of CFMT-original was higher than CFMT-Chinese ($M = 0.69$, $SD = 0.11$), $p < .001$, $d = 1.03$. Accuracy for CFMT-MY was also found to be higher than CFMT-Chinese, $p < .001$, $d = -0.30$. To further demonstrate the other-race effect, we ran an additional analysis comparing the CFMT-MY scores of Chinese Malaysian participants in Experiment 2a and the Caucasian participants in Experiment 2b. Independent samples t-test revealed that Chinese Malaysian participants ($M = 0.83$, $SD = 0.10$) scored higher than the Caucasian participants ($M = 0.74$, $SD = 0.12$) on the CFMT-MY, $t(249) = -7.20$, $p < .001$, $d = -.91$.

Analysis revealed a significant main effect of stage on accuracy, $F(1.64, 203.00) = 628.13$, $p < .001$, $\eta_p^2 = .84$. A post hoc Holm-Bonferroni test demonstrate that the accuracy of the learning stage ($M = 0.96$, $SD = 0.05$) was higher than the novel stage ($M = 0.71$, $SD = 0.12$), $p < .001$, $d = 2.35$. Similarly, the accuracy of the learning stage was higher than the novel-with-noise stage ($M = 0.64$, $SD = 0.14$), $p < .001$, $d = 3.02$. Accuracy was found to be higher for the novel compared to the novel-with-noise stage, $p < .001$, $d = .66$.

A significant interaction effect between test version and stage was found, $F(4, 496) = 38.47$, $p < .001$, $\eta_p^2 = .24$ (Figure 3.3). Results showed a significant main effect of test version on accuracy in the learning stage, $F(2, 248) = 17.48$, $p < .001$, $\eta^2 = .12$. A post hoc Holm-Bonferroni test demonstrated that the accuracy of CFMT-original ($M = 0.98$, $SD = 0.04$) was higher than CFMT-MY ($M = 0.94$, $SD = 0.07$) in the learning stage, $p < .001$, $d = .52$. Similarly, the accuracy of the CFMT-original was higher than the accuracy in the CFMT-Chinese ($M = 0.95$, $SD = 0.07$) in the learning stage, $p < .001$, $d = .36$. No difference was found between the accuracy for the CFMT-MY and the CFMT-Chinese in the learning stage, $p = .08$, $d = .16$. Analysis also revealed a significant main effect of test version on accuracy in the novel stage, *F*(2, 248) = 96.96, $p < .001$, $\eta^2 = .44$. A post hoc Holm-Bonferroni test demonstrate that the accuracy of the CFMT-original (*M* = 0.80, *SD* = 0.16) was higher than the CFMT-MY (*M* = 0.73, *SD* = 0.15) in the novel stage, $p < .001$, *d* = .45. Similarly, the accuracy of the CFMT-original was higher than the CFMT-Chinese (*M* = 0.60, *SD* = 0.14) in the novel stage, $p < .001$, *d* = 1.23. Accuracy for the CFMT-MY was also found to be higher than the accuracy in the CFMT-Chinese in the novel stage, $p < .001$, *d* = -0.78. A significant main effect of test version on accuracy in the novel-with-noise stage was found, *F*(2, 248) = 30.57, $p < .001$, $\eta^2 = .20$. A post hoc Holm-Bonferroni test demonstrated that the accuracy of the CFMT-original (*M* = 0.71, *SD* = 0.18) was higher than the accuracy in the CFMT-MY (*M* = 0.60, *SD* = 0.17) in the novel-with-noise stage, $p < .001$, *d* = .64. Similarly, the accuracy of the CFMT-original was higher than the accuracy in the CFMT-Chinese (*M* = 0.61, *SD* = 0.17) in the novel-with-noise stage, $p < .001$, *d* = .56. No difference was found for the accuracy in the CFMT-MY and the CFMT-Chinese in the novel-with-noise stage, *p* = .35, *d* = .09.

Figure 3.3

Proportion correct scores of Caucasian participants in the three stages of CFMT.



Note. Error bars represent 95% confidence intervals.

Simple main effects analysis also revealed differences on accuracy across stages in the CFMT-MY, $F(2, 248) = 330.81$, $p < .001$, $\eta^2 = .73$. A post hoc Holm-Bonferroni test demonstrated that the accuracy of the learning stage ($M = 0.94$, $SD = 0.08$) was higher than accuracy in the novel stage ($M = 0.73$, $SD = 0.15$), $p < .001$, $d = 1.4$. Similarly, the accuracy of learning stage was higher than the accuracy of the novel-with-noise stage ($M = 0.6$, $SD = 0.17$), $p < .001$, $d = 2.28$. Accuracy for the novel stage was found to be higher than the novel-with-noise stage, $p < .001$, $d = .88$. Analysis revealed a significant main effect of stage on accuracy in the CFMT-Chinese, $F(1.85, 228.85) = 480.27$, $p < .001$, $\eta^2 = .8$. A post hoc Holm-Bonferroni test demonstrate that the accuracy of the learning stage ($M = 0.95$, $SD = 0.07$) was higher than the novel stage ($M = 0.6$, $SD = 0.14$), $p < .001$, $d = 2.43$. Similarly, the accuracy of the learning stage was higher than the novel-with-noise stage ($M = 0.61$, $SD = 0.17$), $p < .001$, $d = 2.37$. No difference was found for the accuracy of the novel stage and novel-with-noise stage, $p = .5$, $d = -.06$. A significant main effect of stage on accuracy in the CFMT-original was found, $F(1.65, 205.15) = 212.68$, $p < .001$, $\eta^2 = .63$. A post hoc Holm-Bonferroni test demonstrated that the accuracy of the learning stage ($M = 0.98$, $SD = 0.04$) was higher than the novel stage ($M = 0.8$, $SD = 0.16$), $p < .001$, $d = 1.23$. Similarly, the accuracy of the learning stage was higher than the accuracy in the novel-with-noise stage ($M = 0.71$, $SD = 0.18$), $p < .001$, $d = 1.81$. Accuracy for the novel stage was found to be higher than the accuracy in the novel-with-noise stage, $p < .001$, $d = .58$.

3.2.3 Discussion

Our findings revealed that the CFMT-MY was sensitive to the other-race effect. Although the accuracy of the CFMT-original was higher than the CFMT-MY and CFMT-Chinese in all three stages, this could not adequately demonstrate the other-race effect since the other-race CFMT (i.e., CFMT-Chinese and CFMT-MY) may be more difficult compared to the own-race CFMT (i.e., CFMT-original). Hence, we ran an additional analysis which showed that Caucasian participants scored lower compared to the Chinese Malaysian participants from Experiment 2a on the CFMT-MY. This indicated that Chinese Malaysian participants had superior recognition of own-race faces (i.e., Chinese Malaysian faces) as compared to Caucasian participants, replicating the other-race effect in face recognition (Meissner & Brigham, 2001).

Furthermore, while it is worth noting that Caucasian participants exhibited poorer performance in the CFMT-MY when compared to the CFMT-original, there was no observed crossover effect in this experiment, as there was no evidence of Chinese Malaysian participants performing worse in the CFMT-original than in the CFMT-MY. However, in Experiment 3 (see Appendix G), a distinct group of Chinese Malaysian participants consistently performed better in own-race CFMT (CFMT-MY and CFMT-Chinese) when compared to other-race CFMT (CFMT-original and CFMT-Aus) across various performance measures, including accuracy, reaction time, and efficiency. This finding provides further support for the CFMT-MY's sensitivity to the ORE.

Our results also showed that the scores of CFMT-MY and CFMT-original clearly represent the increasing difficulty of the three stages, with the learning stage achieving close-to-ceiling scores, followed by the novel stage and the novel-with-noise stage with the highest difficulty. Interestingly, while the learning stage had higher accuracy compared to the novel and novel-with-noise stage in the CFMT-Chinese, accuracies for the novel and novel-with-noise stages were similar. Additionally, higher accuracy was found for the CFMT-MY compared to CFMT-Chinese in our Caucasian sample, replicating our findings from Experiment 2a in a different race.

To summarize, our results show that the CFMT-MY is sensitive to the other-race effect as Caucasian participants scored lower on the CFMT-MY compared to the Chinese Malaysian participants from Experiment 2a. Interestingly, with a Caucasian sample, we have shown that the difficulty of the CFMT-MY increases across stages. This result was, however, not found in the CFMT-Chinese.

3.3 General discussion

The current study aimed to develop a new version of the Asian CFMT using Chinese Malaysian faces, the CFMT-MY, as a standardized test of face recognition ability. Overall, results indicated that the CFMT-MY has high consistency and high reliability thus exhibiting potential utility in facilitating the diagnosis of individuals with difficulty in face recognition in clinical settings and also for research measuring individual differences in face recognition ability. The CFMT-MY also showed convergent validity with the CFMT-Chinese and divergent validity with the CCMT. Scores for the CFMT-MY corresponded to the increasing level of difficulty intended for the CFMT stages (see Duchaine & Nakayama, 2006), where the learning stage achieved the highest accuracy followed by the novel and finally the novel-with-noise stage. The CFMT-MY scores were also normally distributed when all trials were included in the analysis (72 trials). Thus, the standard method used to calculate the cut-off score, *M* – 2*SD* can be used for the diagnosis of impairments related to face recognition. The CFMT-MY was also sensitive to the other-race effect. Our results revealed that Caucasian participants scored lower on the CFMT-MY compared to the Chinese Malaysian participants from Experiment 2a. Chinese Malaysian participants showed superior recognition of own-race faces compared to Caucasian participants, supporting the other-race effect in face recognition (Meissner & Brigham, 2001; Wong et al., 2020, 2021).

The results of both experiments also revealed an interesting pattern: Chinese Malaysian and Caucasian participants showed higher accuracy in the CFMT-MY compared to the CFMT-Chinese. This result seems to be explained by a surprisingly low performance in the novel stage of the CFMT-Chinese. In fact, performance on this stage was lower (Experiment 2a) or identical (Experiment 2b) to that of the novel-with-noise stage. This pattern of results, which was only found in the CFMT-Chinese, is problematic as it shows no linear increment of difficulty across stages. The increment of difficulty across stages is important for the assessment of a wide range of face recognition abilities (Duchaine & Nakayama, 2006). Because in our first experiment we used a sample of Chinese Malaysian participants, it could be argued that these results could be explained by the other-ethnicity effect (McKone et al., 2012). However, this hypothesis cannot explain why in Experiment 2b, with a Caucasian sample, we found no differences between the novel and the novel-with-noise stages in the CFMT-Chinese, but clear differences across these stages in the CFMT-MY. More importantly, previous studies have also revealed a similar percentage of correct responses across the novel and the novel-with-noise stage in the CFMT-Chinese (i.e., 72.13% and 71.58%, see McKone et al. 2017, table 3 and 79.24% and 80.11%, see McKone et al. 2012, table 1). Past research has suggested that the CFMT could be shortened by including only the first two stages (i.e., learning and novel stage) for diagnosis of prosopagnosia (Corrow et al., 2018; Murray & Bate, 2020). In this case, including only the first two stages of the CFMT-Chinese may be problematic, as in this test the novel stage seems to be identical or even more difficult than the novel-with-noise stage, which could potentially result in more individuals scoring below the cut-off.

It is important to note here that, compared to the CFMT-Chinese and CFMT-original, we used a different method to create the novel stage. Images of the same identity that were captured with different poses and physical lighting were used for the CFMT-Chinese novel stage, but such images did not exist in our face database, and hence we followed the procedure of CFMT-Aus (McKone et al., 2011) where instead of poses, different cropping templates were used and lighting was added into the images using photo editing software. Despite these differences, the CFMT-MY showed a clear increment in difficulty across stages. In addition, these differences in the stimuli cannot explain the discrepancy in difficulty levels between the novel stage of the CFMT-Chinese and CFMT-MY as both the CFMT-original and the CFMT-Chinese use the same method in the novel stage. In this sense, higher accuracy for the novel stage compared to the novel-with-noise stage was found in the CFMT-original while these differences were not found in the CFMT-Chinese. Thus, we conclude that the lower accuracy for CFMT-Chinese compared to CFMT-MY among Chinese Malaysian and Caucasian participants was due to differences in test difficulty, specifically in the novel stage.

Malaysia is a multiracial country with Malays constituting 57.93% of the population; followed by Chinese at 22.58%; Indians at 6.7%; indigenous people (i.e., Orang Asli) at 3.95%; others at 0.64%; and non-citizen at 8.2% (Department of Statistics Malaysia, 2011). In this case, the use of CFMT-MY in Malaysia may be limited to Chinese Malaysian participants due to the presence of the other-race effect in face recognition (Meissner & Brigham, 2001; Wong et al., 2020). However, recent research showed no differences in the recognition of Chinese faces between Chinese Malaysian and non-Chinese Malaysian (i.e., Malays and Indians) (Estudillo et al., 2020) suggesting that the CFMT-MY may also be suitable to use for diagnosis of face recognition difficulties in the non-Chinese population. Because Chinese is Malaysia's second most populous race, non-Chinese Malaysian may have developed greater expertise with Chinese faces due to extensive experience with the Chinese Malaysian population (Tanaka et al., 2013; Wan et al., 2015). However, some of the states in Malaysia have majority Malay populations (e.g., Kelantan, Terengganu and Perlis) (Saravanamuttu, 2010) and hence, the population in those states may not be as familiar with Chinese faces, hindering the use of CFMT-MY for diagnosis of face recognition difficulties in those regions.

In summary, we report that the CFMT-MY is a highly consistent and reliable test for diagnosing individuals with difficulty in face recognition in clinical settings, measurement of individual differences in face recognition ability and measurement of the other-race effect. The standard method to calculate the cut-off score ($M - 2SD$) seems to be appropriate for the diagnosis of impairments related to face recognition. Additionally, the lower end of the norm scores was far from the chance level (24/72 trials) which permits a range of scores for the diagnosis of impairments related to face recognition such as prosopagnosia. Although the psychometric properties of the CFMT-MY have been shown to be appropriate for the diagnosis of face recognition impairments, future research involving Asian prosopagnosics participants would be required to further validate the use of the CFMT-MY for the diagnosis of prosopagnosia. The CFMT-MY scores corresponded to the increasing level of difficulty intended for the CFMT stages where the learning stage achieved the highest accuracy followed by the novel and finally the novel-with-noise stage. Finally, the current availability of two Asian CFMT versions could lead to improvement of diagnosis for face recognition difficulties and is beneficial for use in pre-post face recognition ability assessments.

3.4 Experiment 3

Face recognition is important for many social interactions that occur in our everyday life (Jack & Schyns, 2015). Although face recognition is used extensively, research has shown that we are not experts in recognizing unfamiliar faces (Bruce et al., 1999; Davis & Valentine, 2009; Kemp et al., 1997; White, Kemp, Jenkins, Matheson, et al., 2014; A. W. Young & Burton, 2018). For example, passport control officers present high error rates (14%) in face matching despite having years of experience and having received specific training in the task (White, Kemp, Jenkins, Matheson, et al., 2014). Additionally, more than half of the fraudulent credit cards are accepted by cashiers when they have to match the photograph on a credit card to the actual face of the shopper (Kemp et al., 1997). High error rates have also been reported when matching the identity of an unfamiliar face on closed circuit television (CCTV) to photographs, even when high-quality footage and photographs were used (Davis & Valentine, 2009; Henderson et al., 2001). This is alarming as police officers are constantly required to match the face of a suspect to CCTV as a part of their duty. In fact, errors in the identification of unfamiliar faces in public security could lead to serious personal and societal consequences such as wrongful conviction of an innocent person while the actual criminal remains unrestrained.

Difficulties in face identification are even more prominent with other-race faces (Meissner & Brigham, 2001). The other-race effect (ORE) in face recognition shows that humans tend to be better at recognizing own-race faces compared to other-race faces (Estudillo et al., 2020; Malpass & Kravitz, 1969; Wong et al., 2021). The ORE has been found across different tasks and countries, and even when the morphological differences across the faces are minor (McKone et al., 2011), pointing to a very robust phenomenon. Own and other race faces are recognized differently and potentially involve different neural mechanisms (e.g., Feng et al., 2011; Serafini & Pesciarelli, 2022). For example, prior research has reported greater activation to own-race compared to other-race faces in different brain areas such as the occipital face area, the fusiform gyrus, the right inferior frontal gyrus, and the right medial frontal cortex (Feng et al., 2011; Golby et al., 2001; J. S. Kim et al., 2006). Interestingly, although the activation in the fusiform face area is initially stronger for own-race faces, the activation for other-race faces increases over time, eventually surpassing the response to own-race faces (Natu et al., 2011). This suggests that own-race faces are processed more automatically compared to other-race faces. Furthermore, event-related potential (ERP) research has generally found larger N170 amplitudes in response to other- compared to own- race faces (Anzures & Mildort, 2021; Giménez-Fernández et al., 2020; Yao & Zhao, 2019, but see Cassidy et al., 2014; Senholzi & Ito, 2013; Wiese, 2013, for a reversed pattern). This finding has been associated with a disruption of configural face processing (Jacques & Rossion, 2010), as it is comparable to the N170 face inversion effect, where larger N170 amplitudes are observed for inverted faces as opposed to upright faces (Eimer, 2000; Goffaux et al., 2003; Rossion et al., 1999). Other ERP components, such as the P100 (Anzures & Mildort, 2021; Giménez-Fernández et al., 2020) and P200 (Anzures & Mildort, 2021; Wiese, 2013) have also shown differences between own- and other-race faces (for a review, see Serafini & Pesciarelli, 2022).

The ORE can have negative consequences in those applied scenarios where the identification of other-race faces is required, such as eyewitness identification and passport control. In fact, other-race eyewitness misidentifications have long posed problems for the criminal justice system (Davies & Griffiths, 2008; Estudillo, 2021), as over the years, a great amount of eyewitness misidentifications has been made affecting the life of numerous innocent suspects. For example, Cornelius Dupree, an African American was wrongly convicted of robbery and rape on the basis of mistaken identification and sentenced to prison for 75 years. After serving 30 years of his sentence, he was released on parole after DNA test results proved his innocence (BBC News, 2011). In addition, it may also be more difficult for police officers to accurately identify a criminal in a multiracial country due to the ORE. The ORE could also greatly influence passport officers as they encounter faces of different nationality, race and ethnicity very regularly in their daily job.

Improvement of face recognition is also important for individuals with developmental and neurological disorders that are associated with face recognition deficits such as prosopagnosia (Rossion, 2014), autism (Weigelt et al., 2012) and schizophrenia (Marwick & Hall, 2008; but see Bortolon et al., 2015). Prosopagnosia, also known as face blindness, is a visual impairment that affects face recognition despite intact visual acuity and intelligence (Bate & Tree, 2017). Individuals with prosopagnosia may face difficulties in recognizing unfamiliar faces (Duchaine et al., 2006), familiar faces (Busigny & Rossion, 2010) and occasionally their own face (Parketny et al., 2015). Failure in recognizing familiar identities (e.g., family members and friends) could contribute to negative consequences such as feeling of embarrassment and guilt which may build up anxiety, increase fear of social interaction and lower levels of self-confidence (Dalrymple, Fletcher, et al., 2014; Yardley et al., 2008).

Given the catastrophic consequences of inaccurate face recognition in terms of public security and for individuals with developmental and neurological disorders associated with face recognition deficits, it is important to develop effective ways of improving face recognition skills. One possible method of improving face recognition is by using transcranial direct current stimulation (tDCS). TDCS is a form of non-invasive brain stimulation technique where a low-level intensity electrical current is delivered between two or more electrodes attached to the scalp to modulate neuronal excitability (Reed & Cohen Kadosh, 2018). TDCS produces opposing effects on neuronal excitability depending on electrode polarity. Anodal tDCS (a-tDCS) is thought to cause neuronal depolarization which leads to an increase in neurons firing rate and excitability while cathodal tDCS (c-tDCS) is thought to cause neuronal hyperpolarization which leads to a decrease in neurons firing rate and excitability (Nitsche & Paulus, 2000; Yamada & Sumiyoshi, 2021). Although anodal stimulation often led to performance enhancement, the effects from cathodal stimulation were relatively inconsistent (Jacobson et al., 2012).

Improvement in own-race face processing has been found following the application of a-tDCS to the occipital area (Barbieri et al., 2016) and, more specifically, to the fusiform face area (Brunyé et al., 2017). For example, participants who received online (i.e., stimulation applied during task execution) 1.5mA of a-tDCS to the right fusiform gyrus showed improvement in face memory accuracy compared to participants who received 0.5mA of a-tDCS and participants who received no stimulation (Brunyé et al., 2017). Another study found that offline (i.e., stimulation applied before task execution) 1.5mA of a-tDCS to the right occipital cortex improved face perception and face memory while no effect of online a-tDCS was found (Barbieri et al., 2016). This showed that offline stimulation may work better compared to online stimulation in terms of improving face processing. However, the positive effects of a-tDCS on face identification are not always replicated (Willis et al., 2019).

In comparison to a-tDCS, research on the effects of c-tDCS on face identification is scarce (Costantino et al., 2017; L. Z. Yang et al., 2014). One early study found that, compared to sham stimulation, both anodal and cathodal 1.5mA tDCS over occipitotemporal cortex reduced the N170 face-specific event-related potential component (L. Z. Yang et al., 2014). The findings of this study showed that the polarity of the current did not alter the effect of the stimulation, suggesting that anodal and cathodal tDCS elicit similar effects, at least in the face domain. A more recent study found that 1.5mA of c-tDCS over the right occipital cortex could decrease recognition performance for other-race faces (Costantino et al., 2017). Specifically, this study tested a group of non-Caucasian participants who lived in a Caucasian-majority country and had extensive experience with Caucasian faces. Interestingly, after c-tDCS, performance to identify Caucasian faces decreased in the non-Caucasian group, suggesting that c-tDCS elicited an ORE-like behaviour.

However, Costantino et al's. (2017) study presents three important methodological drawbacks, which might confound their conclusions. First, an own-race face recognition measure for the non-Caucasian participants was not included. In fact, the pre-stimulation comparison across the c-tDCS and sham non-Caucasian groups was based on the perception of Caucasian faces. Therefore, general differences in face identification skills between the c-tDCS and the sham non-Caucasian groups could potentially explain any poststimulation differences. In addition, while the pre-stimulation task comprised a face perception test (i.e., Cambridge Face Perception Test, Duchaine et al. (2007)), the post-stimulation task comprised a face memory test (i.e., the Cambridge Face memory Test, Duchaine and Nakayama (2006)). Interestingly, research has shown that face perception and face memory are only moderately correlated (e.g., Bate et al., 2019; Verhallen et al., 2017) and dissociations between these two skills have been previously reported (Barton, 2008; Behrmann et al., 2005; Dalrymple, Garrido, et al., 2014; Estudillo & Bindemann, 2014; Weigelt et al., 2014). Thus, in Costantino et al. (2017) study, the sham non-Caucasian groups might not be equivalent in face memory performance. Finally, Costantino et al., (2017) only used c-tDCS, so it is unknown whether anodal stimulation would produce similar effects in other-race faces.

The current study aims to closely replicate Costantino et al.'s (2017) study to further investigate the effect of anodal and cathodal tDCS on the recognition of own- and other-race faces. The stimulation will be applied in an offline manner since previous research using transcranial electrical stimulation has shown that offline stimulation is more effective compared to online stimulation (Barbieri et al., 2016; Estudillo et al., 2023; Friehs & Frings, 2019), at least in the neurotypical population (Hill et al., 2016). The effects of a-tDCS and c-tDCS to the right occipital cortex will be measured using the Cambridge Face Memory Test (CFMT). As previous work examining the tDCS effects on face processing showed inconsistent findings (Barbieri et al., 2016; Costantino et al., 2017; Willis et al., 2019; L. Z. Yang et al., 2014), we based our hypothesis on the neurophysiological mechanism of tDCS (Nitsche & Paulus, 2000) where a-tDCS should improve the recognition of own- and other-race faces while c-tDCS should impair the recognition of own- and other-race faces.

3.4.1 Methods

The experiment was pre-registered via the Open Science Framework (OSF) before data collection (https://osf.io/6cf7w).

Design

A mixed design was implemented. The within-subject factor was task type (own-race and other-race CFMT) and the between-subject factor was stimulation type (a-tDCS, c-tDCS and sham stimulation). The order of the tasks was counterbalanced. The dependent variables were accuracy, reaction time and efficiency. We include an efficiency measure to avoid any potential speed-accuracy trade-offs (Gueugneau et al., 2017; Heitz, 2014; Liesefeld et al., 2015; Wickelgren, 1977) and because the effects of tDCS are not always consistent across different measures of performance (Barbieri et al., 2016; Brunoni & Vanderhasselt, 2014; Hill et al., 2016; Willis et al., 2015). Reaction times and accuracy were used to calculate the rate-correct score (RCS), a measure of efficiency (Woltz & Was, 2006). RCS is calculated by the number of correct trials divided by the sum of reaction time for correct and incorrect trials, providing thus a measure that combines accuracy and reaction times. The value of RCS indicates the number of correct trials per second, where a higher value of RCS denotes higher efficiency. We use RCS as it has been shown to be more efficient in effect detection and accounting for a larger proportion of the variance compared to other integrative measures of speed and accuracy (Vandierendonck, 2017).

Participants

An a priori power analysis was conducted using G*Power 3.1 (Faul et al., 2009) for a mixed ANOVA comparing a-tDCS, c-tDCS and sham stimulation in the own- and other-race CFMT scores. The effect size for this analysis was estimated from a recent study (Costantino et al., 2017) where partial $\eta^2 = .037$, $f = .196$. The effect size estimate was entered into the power analysis with the following parameters: alpha = .05, power = .8. The power analysis suggested that $N = 90$ is required to detect a difference between the stimulation type with 80% probability.

Ninety Chinese Malaysian (67 females) were recruited. Participants' age ranged between 18 and 28 years ($M = 21.11$ years, $SD = 1.97$ years) and were students at the University of Nottingham Malaysia. The participants were assigned randomly to one of three stimulation conditions: a-tDCS, c-tDCS or sham stimulation, with 30 participants in each condition. One-way ANOVA revealed no age difference between stimulation groups, $F(2, 87) = 1.896$, $p = .156$, $\eta^2 = .042$. Prior to the experimental session, all participants completed a screening form regarding the inclusion and exclusion criteria concerning the application of transcranial electrical stimulation and provided informed consent. Participants were asked to sleep for a minimum of six hours and refrain from consuming alcohol (one day before the experimental session) and caffeine (one hour before the experimental session). Participants were also asked to avoid using any hair products (i.e., hair cream, hair gel) on the day of the experimental session. Since hormone levels which fluctuate among females due to the menstrual cycle could affect cortical excitability (Smith et al., 2002), female participants were only recruited during the follicular phase of the menstrual cycle, as in this phase the hormone levels are most similar to males (for a similar procedure, see Barbieri et al., 2016). Female participants were requested to provide the start date of their most recent menstrual cycle to determine if they are currently in the follicular phase.

A remuneration of RM20 was given for participation. The study has been reviewed and approved by the Science and Engineering Research Ethics Committee (SEREC) at the University of Nottingham Malaysia (approval code: KSK050320).

CFMT

Two versions of the own-race CFMT (i.e., CFMT-Chinese (McKone et al., 2017) and CFMT-Chinese Malaysian (Kho et al., 2023)) and two versions of the other-race CFMT (i.e., CFMT-original (Duchaine & Nakayama, 2006) and CFMT-Australian (McKone et al., 2011)) were used in the experiment. Details on the complete procedure for the CFMT could be found in section 3.1.1 Methods, Cambridge Face Memory Test – Chinese (CFMT-Chinese).

TDCS

The stimulation was delivered using Starstim 8 (Starstim, Neuroelectrics, Barcelona, Spain). The electrodes were inserted into a neoprene cap in accordance with the international 10-10 EEG system. For the cathodal condition, 1.5mA was applied to PO8 (cathode) and FP1 (anode) by using a pair of surface sponge electrodes (25cm^2) soaked in saline solution (0.9% NaCl). Conversely, 1.5mA was applied to PO8 (anode) and FP1 (cathode) for anodal condition. The current was ramped up and down for the first and last 30 seconds for anodal and cathodal stimulation. In the sham condition, the stimulation was only delivered for the first and last 30 seconds to evoke the sensation of stimulation, without affecting neuronal excitability (Thair et al., 2017). The parameters of the stimulations were in accordance with the standard safety constraints (i.e., maximum total injected current: 4mA; maximum current for each electrode: 2mA). All stimulation conditions lasted for 20 minutes. Participants were monitored for any signs of distress at all times for safety purposes.

Procedure

The CFMT was presented using PsychoPy (Peirce et al., 2019). Own and other-race versions of the CFMT were counterbalanced across participants. Participants first completed one own- and one other-race CFMT as baseline tasks. The baseline tasks were included to ensure that there was no difference in individual face recognition ability between the stimulation groups prior to the stimulation.

At the beginning of the stimulation session, a suitable neoprene cap size was selected based on the participant’s head circumference measurement. Next, the location of stimulation was cleaned with alcohol solution using a cotton swab. The sponge electrodes were then fitted onto the neoprene cap and the electrical reference ear clip was fixed onto the participant’s ear lobe. The impedance level was checked prior to the stimulation and monitored throughout the stimulation session. Participants received either sham stimulation, a-tDCS or c-tDCS for 20 minutes. A cartoon video was presented during the stimulation session to reduce inter-participant variability in visual sensation during the session (e.g., Renzi et al., 2015, for a similar procedure).

After the stimulation, participants completed the alternate versions of the own- and other-race CFMT. At the end of the experiment, participants were asked to complete a questionnaire related to tDCS sensations to check if there was any difference between the sensation perceived from a-tDCS, c-tDCS and sham stimulation. The experimental session lasted for approximately one and a half hours for each session.

3.4.2 Results

All data were analyzed using JASP version 0.16.3 (JASP Team, 2022).

Perceived sensation

Kruskal-Wallis test was conducted on the rating score (0 = none, 1 = mild, 2 = moderate and 3 = strong) of perceived sensation (itching, pain, burning, warmth/heat, and fatigue/decreased alertness) from the stimulation (a-tDCS vs. c-tDCS vs. sham stimulation). A difference in rating score of itching between stimulation type was found ($H(2) = 13.918$, $p < .001$). Post-hoc Dunn test showed that itching sensation for a-tDCS (*M* = 1.633, *SD* = .890) was higher than c-tDCS (*M* = 1.233, *SD* = .774), $p = .046$. Itching sensation for a-tDCS was also higher than sham stimulation (*M* = .833, *SD* = .592), $p < .001$. The post-hoc also showed that the itching sensation for c-tDCS was higher than sham stimulation, $p = .046$. No difference was found for rating score of pain ($H(2) = 1.233$, $p = .540$), burning ($H(2) = 1.851$, $p = .396$), warmth/heat ($H(2) = 4.791$, $p = .091$) and fatigue/decreased alertness ($H(2) = 1.002$, $p = .606$) between stimulation type. Kruskal-Wallis test also revealed no difference between stimulation type on the rating score for change in general state after stimulation (0 = not at all, 1 = slightly, 2 = considerably, 3 = much and 4 = very much), $H(2) = .744$, $p = .689$. For additional remarks on the sensation of stimulation and participants' beliefs about whether they had received real or sham stimulation, refer to Appendix F.

Baseline (pre-stimulation)

Accuracy is reported in proportion correct. No accuracy difference was found for own-race recognition between stimulation groups, $F(2, 87) = 1.532$, $p = .222$, $\eta^2 = .034$. A significant effect of stimulation group was found for other-race recognition accuracy, $F(2, 87) = 3.417$, $p = .037$, $\eta^2 = .073$. However, Holm's post hoc test reveal no difference between a-tDCS and c-tDCS ($p = .915$), a-tDCS and sham ($p = .069$), c-tDCS and sham ($p = .069$). Altogether, the results showed no difference in recognition ability for own- and other-race faces between stimulation groups prior to receiving stimulation.

Post-stimulation performance[3]

A mixed 2 (CFMT type: own-race vs. other-race) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA was conducted to examine if there was any difference in accuracy between stimulation groups (Figure 3.4). Accuracy reported is in proportion correct. Analysis revealed no main effect of stimulation group on accuracy, $F(2, 87) = 1.093$, $p = .34$, $\eta_p^2 = .025$. A main effect of CFMT type was

---

[3] Results of 2 (CFMT type: own-race vs. other-race) × 2 (session: pre vs. post) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA and 2 (CFMT type: own-race vs. other-race) × 3 (task stage: learn vs. novel vs. novel-with-noise) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA for CFMT performance on accuracy, reaction time and efficiency are included in Appendix G.

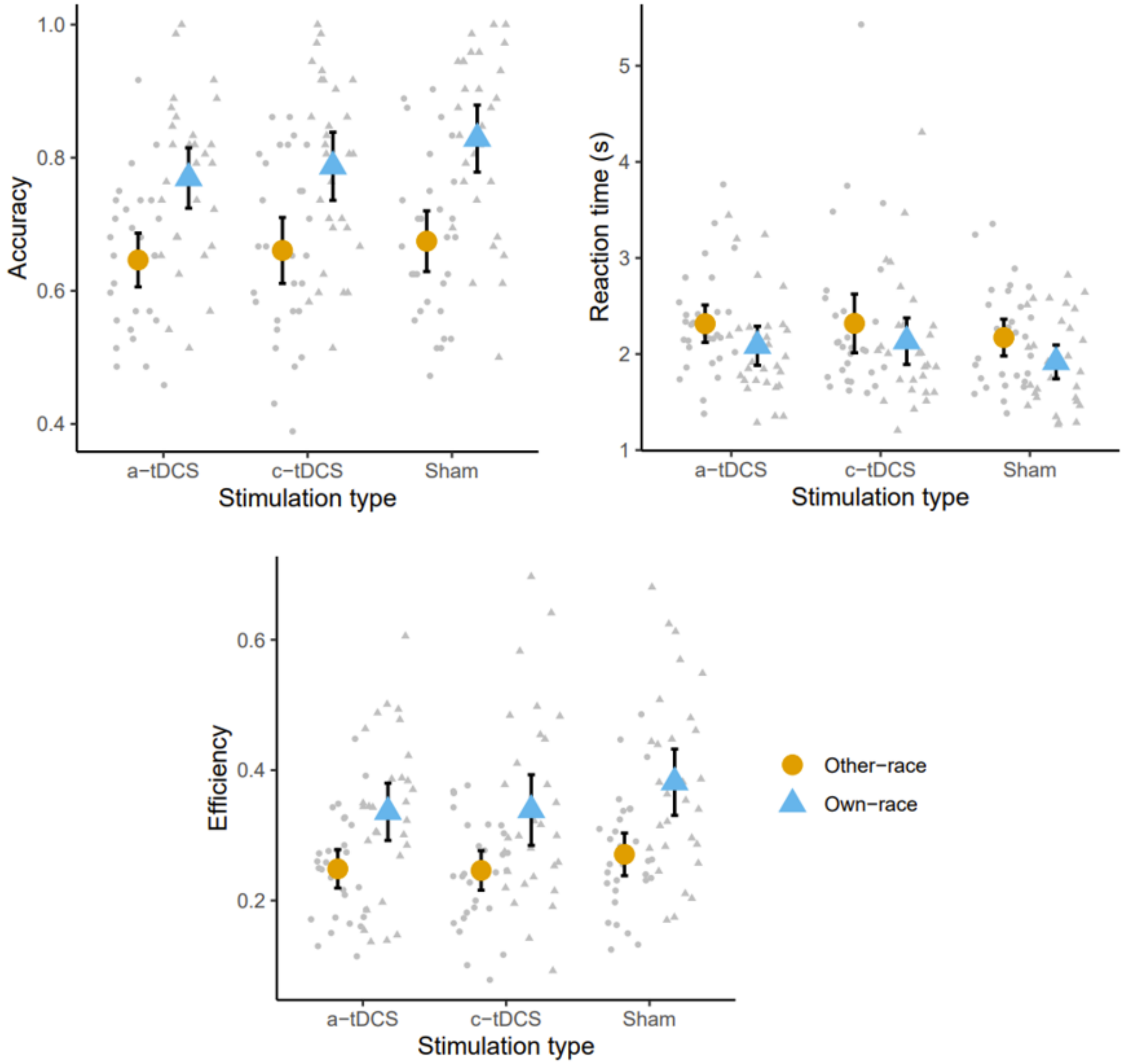
found, *F*(1, 87) = 160.809, $p < .001$, $\eta_p^2 = .649$, where own-race face recognition (*M* = .795, *SD* = .132) had higher accuracy compared to other-race face recognition (*M* = .660, *SD* = .121). No significant interaction effect was found between stimulation group and CFMT type on accuracy, *F*(2, 87) = .861, *p* = .427, $\eta_p^2 = .019$.

A mixed 2 (CFMT type: own-race vs. other-race) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA was also conducted on correct median reaction times (Figure 3.4). Analysis revealed no main effect of stimulation group on reaction time, *F*(2, 87) = .892, *p* = .414, $\eta_p^2 = .02$. A main effect of CFMT type was found, *F*(1, 87) = 32.247, $p < .001$, $\eta_p^2 = .27$, where own-race face recognition (*M* = 2.046s, *SD* = .561s) had shorter reaction time compared to other-race face recognition (*M* = 2.269s, *SD* = .630s). No significant interaction effect was found between stimulation group and CFMT type on reaction time, *F*(2, 87) = .265, *p* = .768, $\eta_p^2 = .006$.

A mixed 2 (CFMT type: own-race vs. other-race) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA was also conducted on RCS (Figure 3.4). Analysis revealed no main effect of stimulation group on efficiency, *F*(2, 87) = 1.128, *p* = .328, $\eta_p^2 = .025$. A main effect of CFMT type was found, *F*(1, 87) = 93.887, $p < .001$, $\eta_p^2 = .519$, where own-race face recognition (*M* = .352, *SD* = .134) had higher efficiency compared to other-race face recognition (*M* = .255, *SD* = .083). No significant interaction effect was found between stimulation group and CFMT type on efficiency, *F*(2, 87) = .494, *p* = .612, $\eta_p^2 = .011$.

Figure 3.4

Accuracy (proportion correct), median reaction time for correct trials and efficiency in the stimulation groups, separated by own- and other-race CFMT versions.



Note. Error bar represents 95% confidence interval. The grey circles and triangles represent the individual data, while the orange circle and blue triangles represent the summary statistics.

To explore the change in performance as a consequence of stimulation type, we also calculated the difference in accuracy between post- and pre-stimulation for each stimulation group and CFMT type ($ACC_{Post} - ACC_{Pre}$). A higher value would indicate higher improvement in accuracy after stimulation. We analyzed these scores using a 2 (CFMT type: own-race vs. other-race) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA (Figure 3.5). Analysis revealed no main effect of stimulation group, *F*(2,

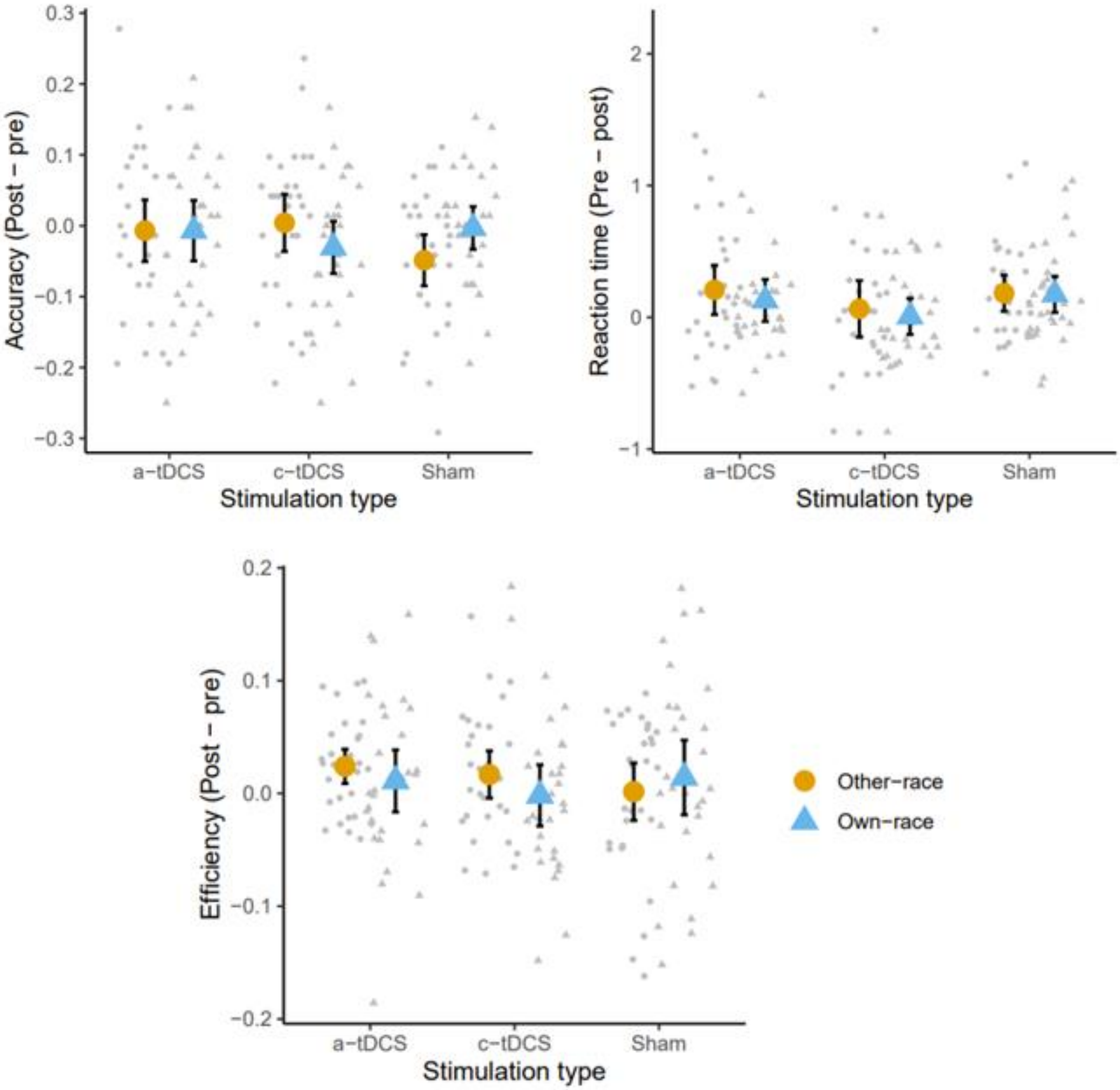
87) = .458, p = .634, η_p^2 = .01, nor a main effect of CFMT type, F(1, 87) = .063, p = .802, η_p^2 = .0007, on accuracy improvement. No significant interaction effect was found between stimulation group and CFMT type on accuracy improvement, F(2, 87) = 2.688, p = .074, η_p^2 = .058.

We also calculated the difference in correct median reaction time between post- and pre-stimulation for each stimulation group and CFMT type ($RT_{Pre} - RT_{Post}$). A higher value would indicate higher improvement in reaction times after stimulation. We analyzed these scores using a 2 (CFMT type: own-race vs. other-race) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA (Figure 3.5). Analysis revealed no main effect of stimulation group, F(2, 87) = 1.782, p = .174, η_p^2 = .039, nor a main effect of CFMT type, F(1, 87) = .613, p = .436, η_p^2 = .007, on reaction time improvement. No significant interaction effect was found between stimulation group and CFMT type on reaction time improvement, F(2, 87) = .114, p = .893, η_p^2 = .003.

We also calculated the difference in efficiency between post- and pre-stimulation for each stimulation group and CFMT type ($RCS_{Post} - RCS_{Pre}$). A higher value would indicate higher improvement in efficiency after stimulation. We analyzed these scores using a 2 (CFMT type: own-race vs. other-race) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA (Figure 3.5). Analysis revealed no main effect of stimulation group, F(2, 87) = .354, p = .703, η_p^2 = .008, nor a main effect of CFMT type, F(1, 87) = .475, p = .493, η_p^2 = .005, on efficiency improvement. No significant interaction effect was found between stimulation group and CFMT type on efficiency improvement, F(2, 87) = 1.094, p = .339, η_p^2 = .025.

Figure 3.5

Change in accuracy (post- minus pre-stimulation), median reaction time for correct trials (pre- minus post-stimulation) and efficiency (post- minus pre-stimulation) after stimulation, separated by stimulation group and own- and other-race CFMT versions.



Note. Error bar represents 95% confidence interval. The grey circles and triangles represent the individual data, while the orange circle and blue triangles represent the summary statistics.

3.4.3 Discussion

This study aimed to investigate the effect of anodal and cathodal tDCS on the recognition of own- and other-race faces. Based on the neurophysiological mechanism of tDCS (Nitsche & Paulus, 2000), we expected to find an enhanced performance for own- and other-race face recognition following a-tDCS and a reduced performance for own- and other-race face recognition following c-tDCS. Our findings demonstrated that participants' post-stimulation performance was similar across all stimulation conditions (i.e., a-tDCS, c-tDCS and sham stimulation). In addition, there were no differences in the performance change (calculated using baseline and post-stimulation scores) between the different stimulation conditions. Thus, overall, our results showed no difference in accuracy, reaction time and efficiency for own- and other-race face recognition after either a-tDCS, c-tDCS or sham stimulation.

Contrary to our expectation, a-tDCS did not improve own- or other-race face recognition. Our findings are in line with past work which have reported null effects of a-tDCS on the occipital region involved in face processing (Willis et al., 2019). Interestingly, although the same stimulation protocol (i.e., 20 minutes of offline 1.5mA of tDCS to the occipital region delivered using a 25cm^2 sponge electrode) and face recognition measure (i.e., CFMT) were used in the current experiment and Barbieri et al. (2016), we failed to replicate the face memory improvement effect found in their experiment. We also found no impairment of own- or other-race face recognition after c-tDCS. This is in line with previous work suggesting that the effects from cathodal stimulation are relatively inconsistent (Jacobson et al., 2012). However, this contradicted findings by Costantino et al. (2017) where they suggested that c-tDCS impaired the recognition of other-race faces. In this study, we used the same stimulation protocol and face recognition measure as Costantino et al. (2017). In addition, we also used more comparable measures across baseline and post-stimulation tasks (i.e., different versions of the CFMT). However, we failed to replicate the impairment of other-race recognition reported by Costantino et al. (2017). Our findings are in line with past studies showing that cathodal stimulation does not always lead to a decrease in neuronal excitability and performance (Horvath et al., 2015; Wiethoff et al., 2014), and that its effects on cognition can be inconsistent (Jacobson et al., 2012).

Overall, our findings support past research showing that the effect of a-tDCS and c-tDCS may not always be reliable (López-Alonso et al., 2014; Strube et al., 2015; Wiethoff et al., 2014). For example, it has been reported that more than half of the participants (55%) did not show the expected excitatory effect on neuronal excitability after a-tDCS whereas the remaining 45% showed the expected excitatory effect (López-Alonso et al., 2014). In line with this, a different study reported that 50% of the participants showed little or no response to tDCS whereas the remaining participants responded similarly to both c-tDCS and a-tDCS (Wiethoff et al., 2014). Thus, it could be that the participants in our experiment were less responsive to tDCS leading to the null effects of both a-tDCS and c-tDCS on the face recognition tasks.

In fact, the inter-individual differences in the tDCS effects is a known limitation of tDCS studies. The lack of stimulation effect could be attributed to differences in the biological substrate such as the pre-existing neurotransmitter levels and differences in head size and scalp thickness (Krause & Cohen Kadosh, 2014; Laakso et al., 2019). Therefore, some participants might have received more or less stimulation effect than others, leading to variability in the effectiveness of tDCS. This issue, however, could not be resolved by implementing a within-subjects design as past work has also shown intra-individual differences in the effect of tDCS where the effect of tDCS varies across different test sessions (Dyke et al., 2016). Hence, intra- and inter-individual differences may have contributed to the inconsistent findings of tDCS studies.

In addition, the lack of stimulation effect observed in our study may be due to the low focality of stimulation to the target area, which is a common limitation of tDCS studies that use a traditional two-electrode montage. Research by Barbieri et al. (2016) found that this type of stimulation did not produce face-specific effects, as it improved both face and object memory. In contrast, research targeting the FFA with high-focality stimulation have shown selective enhancement of face memory (Brunyé et al., 2017). The low focality stimulation used in our study may have resulted in current spreading to non-target regions, leading to noise in the data. To address this limitation, future studies could use high focality stimulation techniques such as high-definition tDCS (Datta et al., 2009; Kuo et al., 2013; Villamar et al., 2013) or multifocal tDCS (Fischer et al., 2017), which rely on smaller electrodes to increase focality and reduce current spread to non-target regions.

To conclude, we found no effect of a-tDCS and c-tDCS in the recognition of own- and other-race faces. Our findings showed that the effects of anodal and cathodal tDCS may not always be reliable and support the inconsistency of tDCS effects in face processing (Willis et al., 2019). This is consistent with the increasing number of studies that have failed to replicate the positive effects of transcranial electrical stimulation on mood and emotion (Koenigs et al., 2009), working memory (Nilsson et al., 2015, 2017; Westwood & Romani, 2018), verbal fluency (Vannorsdall et al., 2016; Westwood & Romani, 2018), reading (Cummine et al., 2020), sustained attention (Jacoby & Lavidor, 2018) and spatial attention (Learmonth et al., 2017).

Chapter 4 – Own- and other-race face learning in high and low variability

Other than tDCS, we also examined if different variation during multiple exposure of an identity could affect own- and other-race face learning. Familiar faces are more easily recognized compared to unfamiliar faces (Bruce et al., 2001). We are able to recognize familiar faces in different viewing conditions (e.g., difference in lighting) but this is seemingly difficult for unfamiliar faces (Sinha et al., 2006). For example, minor differences such as viewing angle (Favelle et al., 2011), changes in lighting, viewpoint or expression (Bruce, 1982; Estudillo, 2012; Estudillo & Bindemann, 2014; Longmore et al., 2008) could impair unfamiliar face recognition. Familiar faces are thought to have a robust representation in the memory which is built up from multiple exposure of a face in different context (Burton et al., 2005; Jenkins & Burton, 2011; Johnston & Edmonds, 2009). Extensive research has since investigated if faces presented in multiple exposure and variation could enhance the learning of new identities (e.g., Dowsett et al., 2016; Ritchie et al., 2021; White et al., 2014).

In face matching tasks, observers have to determine if two images of a face, presented either simultaneously or sequentially depict the same or a different identity (Burton et al., 2010). Strong evidence has been found that multiple exposures to a face could enhance identity learning using a face matching task. For instance, face matching accuracy increased when two images of an identity were available for comparison to a target image compared to when only one image was available (Menon et al., 2015; White, Burton, et al., 2014). Furthermore, face matching accuracy was better when an average face generated from 12 images of an identity was used for comparison as opposed to a single-image comparison. In line with these results, it has been found that performance for the face-sorting task improved as additional photos of the target were presented for comparison (Dowsett et al., 2016; Matthews & Mondloch, 2018). Additionally, viewing multiple images of an identity in a face-sorting task later improved face matching accuracy for faces that were previously viewed in the face-sorting task

(Andrews et al., 2015). Presenting multiple images of a target identity has also been shown to increase accuracy in identifying the target in surveillance video footage (Mileva & Burton, 2019). Accuracy improved when three different images of the target were presented during target search in surveillance video footage, as compared to when only a single image of the target was presented. To summarize, these studies demonstrate that multiple exposures to a face do enhance learning and recognition of a new identity in terms of photos and videos.

Apart from that, past research has also examined if different levels of variation during multiple exposures to an identity could affect identity learning. Variability plays an important role in developing a robust face representation (Burton et al., 2005). Faces exhibit a remarkable degree of natural variability, encompassing features like expressions, lighting conditions, angles, and identity-specific characteristics. By encountering faces in diverse contexts and under varying conditions, individuals develop a more durable and flexible face recognition system (Corpuz & Oriet, 2022). Exposure to variability facilitates the refinement of face-processing mechanisms, enhancing the ability to extract invariant facial information while accommodating the nuances of change (Jenkins & Burton, 2011). For instance, it has been found that accuracy was higher when the two-image comparison presented during a face matching task was in a high variability condition (i.e., photos taken on different days that are highly dissimilar) compared to a low variability condition (i.e., photos taken on the same day with high similarity) (Menon et al., 2015). In line with this, a different study reported higher accuracy in a name verification task and a face matching task when unfamiliar identities were learned in a high variability condition compared to a low variability condition (Ritchie & Burton, 2017). The benefit of high variability in identity learning was observed in terms of videos as well. For example, one study compared identity learning when viewing a 10 minutes video footage in low variability (video filmed on the same day with the same appearance and lighting) and high variability (video filmed on different days with different appearance and lighting) (Baker et al., 2017). Children were more accurate in an identity-sorting task after viewing the video footage in the high variability condition compared to the low variability condition, however, this effect was weaker in adult participants. Taken together, these studies indicate that multiple exposures to a face with high within-person variability are more advantageous for identity learning as compared to low within-person variability. It is, however, important to note that only natural variability is important for identity learning, as uncommon variability such as inversion and contrast-reversed could deter identity learning (Kramer et al., 2017).

Since multiple exposures to a face in high variation have been shown to be effective in enhancing identity learning, this could have potential applied consequences for forensic settings (i.e., ID control). For example, it has been suggested that photo IDs could be redesigned to incorporate multiple photos instead of a single photo to improve identity verification procedures (White, Burton, et al., 2014). However, when multiple exposures (four images of an identity for comparison to the target) and an average face (generated from 12 images of an identity) were tested in a real-life matching task, it was found that the accuracy level for multiple exposures and average faces did not differ from single-image comparison (Ritchie et al., 2020). In line with this, one study has shown that accuracy in a simultaneous face matching task did not differ between two-image comparison (frontal and profile views) and single-image comparison (frontal or profile view) (Kramer & Reynolds, 2018). Findings from these studies contradict previous work discussed in this section, which demonstrated that multiple exposures to a face could improve identity learning. One possible explanation for this is that the advantage of multiple exposures in high variation only applies to tasks with high memory demands (but see Bindemann & Sandford, 2011). For instance, it has been found that the advantage of multiple exposures in identity learning is present in a name verification task and sequential face matching task (involves memory), but not in a simultaneous face matching task (does not involve memory) (Ritchie et al., 2021; Ritchie & Burton, 2017; Sandford & Ritchie, 2021). Taken together, these studies indicate that multiple exposures of a face with high within-person variability are more advantageous for learning a new identity but not identification in a simultaneous face matching task as compared to low within-person variability.

Recognition of other-race faces is usually more difficult compared to own-race faces and this is known as the other-race effect (ORE) (Meissner & Brigham, 2001). Consistent with this, research has shown that other-race faces are indeed more difficult to be learned compared to own-race faces

(Tüttenberg & Wiese, 2019). In fact, single image repetition of faces seems to improve recognition accuracy for own-race faces (Y. Wang et al., 2017), but impair recognition accuracy for other-race faces (Palma & Garcia-Marques, 2021). However, other research has shown that exposure to within-person variability of an identity could enhance other-race face recognition compared to the presentation of a single image of an identity in old-new recognition paradigm (Cavazos et al., 2019) and in a line-up task (Matthews & Mondloch, 2018). These findings suggest that whereas repeating a single image could deter other-race face recognition, exposure to within-person variability across images could enhance other-race face recognition. However, it is still unclear how different levels of within-person variability during face exposure would affect identity learning for other-race faces.

This question is important from a theorical point of view. Recently, a cost-effective mechanism for face learning have been proposed (Devue et al., 2021; Reedy & Devue, 2019), which suggests that external features are prioritized when presented with stable face appearance, while detailed encoding of internal features occurs when there is variability in face appearance. Previous research has shown that other-race face recognition usually relies more on external features (e.g., hairstyle) compared to internal features (e.g., shape of eyes) (Havard, 2021; Sporer & Horry, 2011; Wong et al., 2020). For instance, Wong et al. (2020) found that the ORE was observed only when internal features were presented independently, and this effect was eliminated when faces were shown with both internal and external features as a unified whole, demonstrating the importance of external features for other-race face recognition. In line with this, other research has indicated that the omission of external features leads to a decline in accuracy for recognizing other-race faces, as observed in both memory-based tasks (i.e., old-new recognition paradigm) (Sporer & Horry, 2011) and tasks without a memory component (i.e., face matching tasks) (Havard, 2021). Since other-race face recognition relies more on external features, it is possible that low within-person variability (i.e., stable face appearance) may be more beneficial for other-race face learning than high within-person variability, because the latter involves consistent changes in external features that may hinder other-race face learning.

Thus, we aim to examine the effect of high and low within-person variability exposure for both own- and other-race face learning. Own- and other-race identities will be learned in high and low variability conditions and identity recognition will first be tested by using a name verification task in Experiment 4a and then by an old-new recognition paradigm in Experiment 4b. Through a name verification task, we can examine the potential impact of variability on the person identity nodes (PINs) as outlined in Bruce and Young (1986). Conversely, the old-new verification task will allow us to evaluate whether variability has an effect on the face recognition units (FRUs) described in the same model by Bruce and Young (1986).

Based on the findings discussed earlier which showed that multiple exposures with high within-person variability are more advantageous for own-race identity learning compared to low within-person variability (Baker et al., 2017; Menon et al., 2015; Ritchie & Burton, 2017), we expect enhanced face learning for own-race identities learned in high variability condition compared to low variability condition. For other-race faces, we expect that enhanced face learning would occur for identities learned in low variability condition than high variability condition if other-race faces are predominantly processed using external features. Conversely, if participants could successfully focus on the internal features when exposed to high within-person variability images with consistent changes in external features, we expect that enhanced learning of other-race faces would occur for identities learned in high variability condition than low variability condition, as high variation in face appearance leads to detailed encoding of internal features.

4.1 Experiment 4a

The current study aimed to investigate own- and other-race face learning in high and low within-person variability exposure. Experiment 4a partially replicates Ritchie and Burton's experiment (2017) where participants learned identities in high and low variability condition and were tested with a name verification task. However, the current experiment included both own- and other-race identities in the task (i.e., Caucasian and Chinese) and we recruited both Chinese Malaysian and Caucasian participants for this experiment.

4.1.1 Methods

Design

A mixed design was implemented. The within-subject factors were variability (high and low) and stimuli (Chinese and Caucasian) and the between-subject factor was participants' race (Chinese Malaysian and Caucasian). The presentation order of stimuli was counterbalanced. The dependent variables were accuracy, reaction time and efficiency. We include an efficiency measure to avoid any potential speed-accuracy trade-offs (Gueugneau et al., 2017; Heitz, 2014; Liesefeld et al., 2015; Wickelgren, 1977). Reaction times and accuracy were used to calculate the rate-correct score (RCS), a measure of efficiency (Woltz & Was, 2006). RCS is calculated by the number of correct trials divided by the sum of reaction time for correct and incorrect trials, providing thus a measure that combines accuracy and reaction times. The value of RCS indicates the number of correct trials per second, where a higher value of RCS denotes higher efficiency. We use RCS as it has been shown to be more efficient in effect detection and accounting for a larger proportion of the variance compared to other integrative measures of speed and accuracy (Vandierendonck, 2017).

Participants

In total, 125 Chinese Malaysian and 156 Caucasian participants took part in this experiment, but the final sample included 103 Chinese Malaysian (79 females, 2 others) and 91 Caucasian (76 females, 2 others) age ranged between 18 to 67 years (M = 22.32 years, SD = 5.42 years). Data from participants of other-race (12), median reaction time that was less than 500ms or accuracy below chance level (50%) (32), inaccurate responses for the learning stage (41), which accidentally did the experiment for the second time (1) and were familiar with more than 50% of the identities shown in the task (i.e., eight identities) (1) were removed from further analysis.

An a priori power analysis was conducted using G*Power 3.1 (Faul et al., 2009) for a mixed ANOVA comparing the own- and other-race identities learned in high and low variability condition of Chinese Malaysian and Caucasian participants. The effect size for variability was based on Ritchie and Burton (2017) where $\eta_p^2 = .28$ and Ritchie et al. (2021) where $\eta_p^2 = .52$ and .20, large effect size. A large effect size estimate ($\eta_p^2 = .14$) was entered into the power analysis with the following parameters: alpha = .05, power = .95. The power analysis suggested that *N* = 40 is required to detect a difference between the variability condition with 95% probability.

All participants provided informed consent to participate in the study. Participants were compensated with either course credits or RM5 for participation. The study was reviewed and approved by the Science and Engineering Research Ethics Committee (SEREC) at the University of Nottingham Malaysia (approval code: KSK270521).

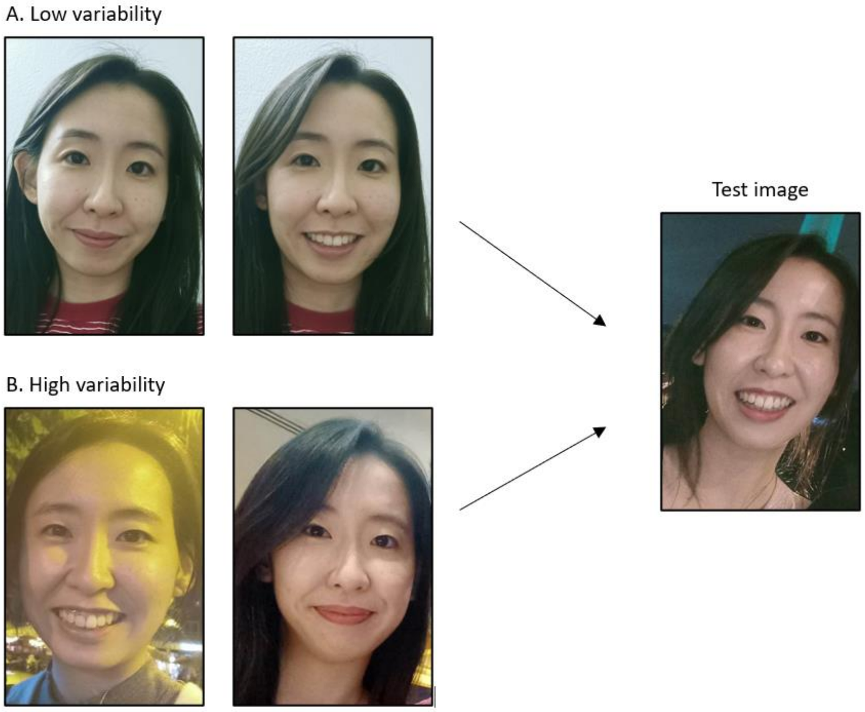
Apparatus and Materials

The Caucasian stimuli used in the face learning task were identical to Ritchie and Burton (2017) which were kindly provided by the authors. Ten identities (five males and five females) were included for each race, totalling up to 20 identities. Identities used in the Caucasian stimuli consist of Australian celebrities (radio host, comedian, etc.) and identities used in the Chinese stimuli consist of Chinese celebrities (athlete, Esports player, etc.), so participants recruited in this experiment should not be familiar with any of the identities shown in the task. In total, there were 20 high variability images and 10 low variability images for each identity (i.e., 10 high variability and 10 low variability images for study phase, and 10 high variability images for test phase). The high variability images differed in terms of person (hairstyle, age, clothing, facial expression, etc.) and conditions (background, lighting, quality of image, etc.) whereas the low variability images differed in terms facial expression and head angle but not in terms of hairstyle, age, clothing and conditions (background, lighting, quality of image, etc.). For the Chinese stimuli, the high variability images were obtained by searching the name of the celebrity on Google Image whereas the low variability images were screenshots of interview videos found on

YouTube by searching the name of the celebrity. The images (260 × 390 pixels) were presented on a grey background. Sample low and high variability images could be found in Figure 4.1.

Figure 4.1

Sample stimuli for low variability (A) and high variability (B) condition, featuring an identity that did not appear in the experiment. Test images comprised of high variability images that were not used during the study phase. Actual stimuli used in experiment are not presented due to copyright restriction on the images.



Procedure

Testable (https://www.testable.org/) was used to run the online experiment (Rezlescu et al., 2020). The task was presented in two blocks, Chinese and Caucasian. Each block consists of two phases: learning and test. In the learning phase, 10 identities (10 images for each identity) were presented with their actual names above the image to be memorized. Each image was presented for 5000ms with inter-trial interval of 500ms. Five identities were presented in low variability condition and five were presented in high variability condition. The identities used for high and low within-person variability condition were counterbalanced. The name of the identity remained on screen throughout the presentation of images of each identity. At the end of the presentation of each identity, participants were asked to type the name of the identity that they had viewed. This was done to ensure that participants were attentive during the learning phase. Participants were allowed to take breaks in between the presentation of identities if required. The learning phase took approximately 10 minutes.

The test phase of the task consists of a name verification task which consisted of 100 trials (10 identities × 10 trials). Images presented in the test phase were novel high variability images. In each trial, the name was presented for 1500ms followed by the test images which were presented until response. There was an inter-trial interval of 500ms. Half of the trials were matched with the correct name and the other half were mismatched (five matched trials and five mismatched trials for each identity). The names presented were only of the 10 identity's name, no novel name was introduced. Female names were only used for female identities and male names were only used for male identities in the mismatched trials. Participants were asked to indicate if the name matched the image presented as quickly and as accurately as possible. The keys used for response was "z" and "m". The keys used for "match" or "does not match" response, either right hand ("m") or left hand ("z") were counterbalanced. The test phase took about 5 minutes to complete. At the end of each block, participants were asked if they were familiar with any of the identities shown in the task. The whole experiment lasted approximately 30 minutes.

4.1.2 Results

All data analysis was conducted using JASP (JASP Team, 2022). Participants who had typed the name of the identity with one incorrect letter during the learning phase had their data included in the analysis (e.g., typing Fiffi when the actual name is Fifi). For participants (two Chinese Malaysian) who reported familiarity with less than half of the identities shown in the task (i.e., one identity), test trials involving the familiar identity were removed prior to the analysis. Mixed ANOVAs were conducted to explore potential differences between own- and other-race identities learned in high and low variability condition.

Accuracy

A 2 (variability: high vs. low) × 2 (face race: Chinese vs. Caucasian) × 2 (participant race: Chinese Malaysian vs. Caucasian) mixed ANOVA was conducted on the accuracy (calculated by proportion correct scores including hits and correct rejections) (Figure 4.2). The analysis revealed a significant main effect of variability on accuracy, $F(1, 192) = 11.494$, $p < .001$, $\eta_p^2 = .056$. Accuracy for high variability condition ($M = .770$, $SD = .146$) was higher compared to the low variability condition ($M = .752$, $SD = .140$). The analysis also revealed a significant main effect of face race, $F(1, 192) = 118.122$, $p < .001$, $\eta_p^2 = .381$ where Caucasian stimuli ($M = .802$, $SD = .122$) had higher accuracy compared to Chinese stimuli ($M = .720$, $SD = .151$). A significant main effect of participant race was found, $F(1, 192) = 20.981$, $p < .001$, $\eta_p^2 = .099$ where Caucasian participants ($M = .727$, $SD = .143$) had lower accuracy compared to Chinese Malaysian participants ($M = .792$, $SD = .137$).

A significant interaction effect of face race and participant race was found, $F(1, 192) = 104.859$, $p < .001$, $\eta_p^2 = .353$. Chinese Malaysian participants showed similar accuracy for both Chinese and Caucasian stimuli, $F(1, 102) = .200$, $p = .656$, $\eta^2 = .002$, while Caucasian participants showed higher accuracy for Caucasian stimuli ($M = .811$, $SD = .110$) than Chinese stimuli ($M = .642$, $SD = .091$), $F(1, 90) = 222.742$, $p < .001$, $\eta^2 = .712$. Additionally, for Chinese stimuli, Chinese Malaysian participants ($M = .789$, $SD = .134$) showed higher accuracy compared to Caucasian participants ($M = .642$, $SD = .091$), $F(1, 192) = 77.553$, $p < .001$, $\eta^2 = .288$. No difference between Chinese Malaysian participants and Caucasian participants were found for Caucasian stimuli, $F(1, 192) = 1.113$, $p = .293$, $\eta^2 = .006$.

No significant interaction was found between variability and participant race, $F(1, 192) = 2.593$, $p = .109$, $\eta_p^2 = .013$, variability and face race, $F(1, 192) = 1.055$, $p = .306$, $\eta_p^2 = .005$ and variability, face race and participant race, $F(1, 192) = 3.517$, $p = .062$, $\eta_p^2 = .018$.

Reaction time

A 2 (variability: high vs. low) × 2 (face race: Chinese vs. Caucasian) × 2 (participant race: Chinese Malaysian vs. Caucasian) mixed ANOVA was conducted on the median reaction time for correct trials (Figure 4.2). The analysis revealed a significant main effect of variability on reaction time, $F(1, 192) = 5.752$, $p = .017$, $\eta_p^2 = .029$. Reaction time for high variability condition ($M = 1323.091$ms, $SD = 736.341$ms) was shorter compared to the low variability condition ($M = 1367.768$ms, $SD = 727.758$ms). The analysis also revealed a significant main effect of face race, $F(1, 192) = 20.479$, $p < .001$, $\eta_p^2 = .096$ where Caucasian stimuli ($M = 1246.548$ms, $SD = 577.935$ms) had shorter reaction times compared to Chinese stimuli ($M = 1444.312$ms, $SD = 848.066$ms). No main effect of participant race was found, $F(1, 192) = 2.749$, $p = .099$, $\eta_p^2 = .014$.

A significant interaction of face race and participant race was found, $F(1, 192) = 18.888$, $p < .001$, $\eta_p^2 = .090$. Chinese Malaysian participants showed no difference in reaction time for both Chinese and Caucasian stimuli, $F(1, 102) = .026$, $p = .873$, $\eta^2 = .0003$, while Caucasian participants showed shorter reaction time for Caucasian stimuli ($M = 1061.492$ms, $SD = 309.735$ms) than Chinese stimuli ($M = 1473.670$ms, $SD = 930.629$ms), $F(1, 90) = 26.871$, $p < .001$, $\eta^2 = .023$. Additionally, for Caucasian stimuli, Chinese Malaysian participants ($M = 1410.044$ms, $SD = 665.369$ms) showed longer reaction time compared to Caucasian participants ($M = 1061.492$ms, $SD = 309.735$ms), $F(1, 192) = 20.951$, $p < .001$, $\eta^2 = .098$. No difference between Chinese Malaysian participants and Caucasian participants were found for Chinese stimuli, $F(1, 192) = .216$, $p = .643$, $\eta^2 = .001$.

A significant interaction effect of variability and participant race was found, $F(1, 192) = 3.953$, $p = .048$, $\eta_p^2 = .020$. Chinese Malaysian participants showed shorter reaction time for high variability condition ($M = 1375.345$ms, $SD = 620.281$ms) than low variability condition ($M = 1453.073$ms, $SD = 692.830$ms), $F(1, 102) = 8.368$, $p = .005$, $\eta^2 = .076$, while Caucasian participants showed no difference in reaction time for high and low variability condition, $F(1, 90) = .106$, $p = .745$, $\eta^2 = .001$. In terms of low variability condition, Chinese Malaysian participants ($M = 1453.073$ms, $SD = 692.830$ms) showed longer reaction time compared to Caucasian participants ($M = 1271.214$ms, $SD = 569.739$ms), $F(1, 192) = 3.924$, *p* = .049, η^2 = .020. No difference between Chinese Malaysian participants and Caucasian participants were found in high variability condition, *F*(1, 192) = 1.582, *p* = .210, η^2 = .008.

No interaction effect between variability and face race, *F*(1, 192) = 1.018, *p* = .314, η_p^2 = .005, and variability, face race and participant race, *F*(1, 192) = .012, *p* = .914, η_p^2 = 6.044e - 5, were found.

Efficiency

A 2 (variability: high vs. low) × 2 (face race: Chinese vs. Caucasian) × 2 (participant race: Chinese Malaysian vs. Caucasian) mixed ANOVA was conducted on efficiency calculated by RCS (Figure 4.2). The analysis revealed a significant main effect of variability on efficiency, *F*(1, 192) = 25.010, *p* < .001, η_p^2 = .115. Efficiency for high variability condition (*M* = .529, *SD* = .241) was higher compared to the low variability condition (*M* = .495, *SD* = .221). The analysis also revealed a significant main effect of face race, *F*(1, 192) = 78.159, *p* < .001, η_p^2 = .289, where Caucasian stimuli (*M* = .562, *SD* = .245) had higher efficiency compared to Chinese stimuli (*M* = .462, *SD* = .206). No main effect of participant race was found, *F*(1, 192) = 2.609, *p* = .108, η_p^2 = .013.

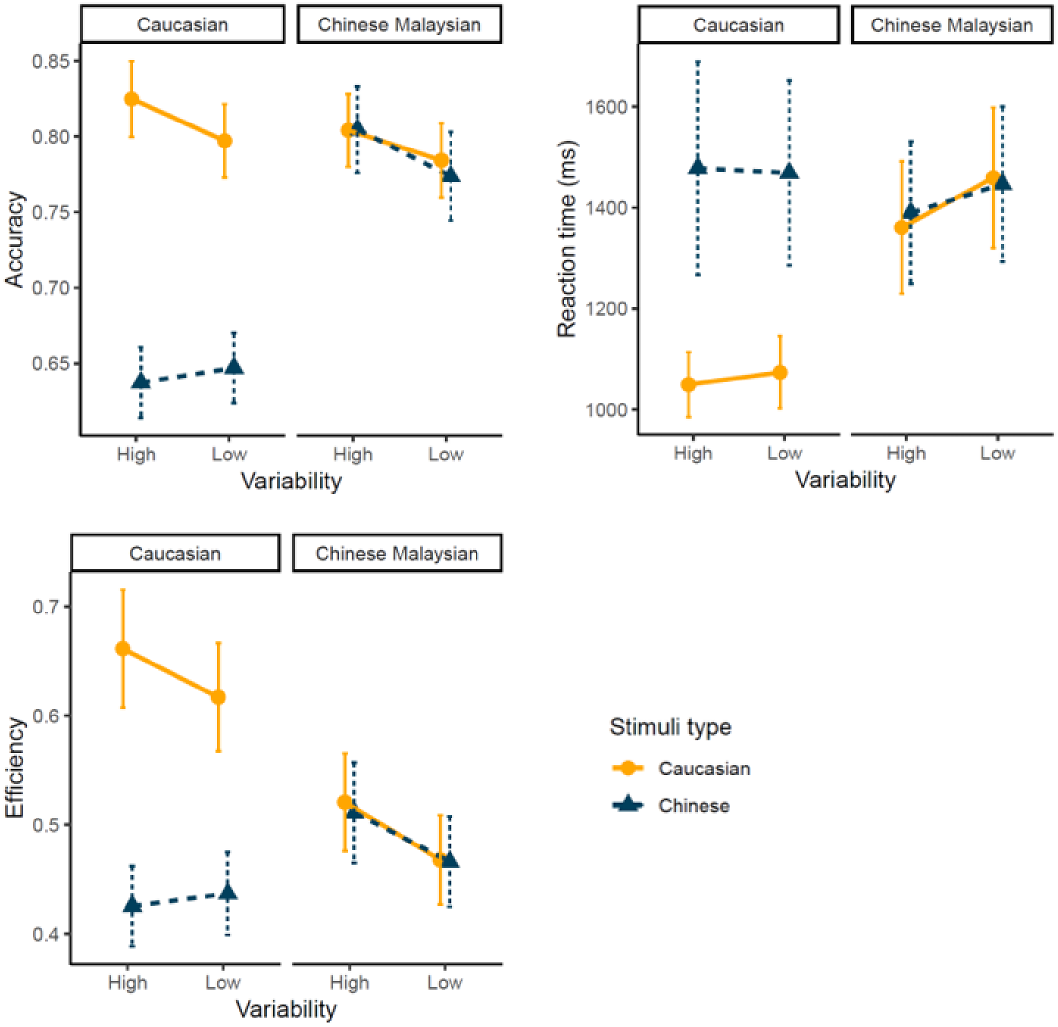
A significant interaction effect of face race and participant race was found, *F*(1, 192) = 70.254, *p* < .001, η_p^2 = .268. Chinese Malaysian participants showed no difference in efficiency for both Chinese and Caucasian stimuli, *F*(1, 102) = .120, *p* = .730, η^2 = .001, while Caucasian participants showed higher efficiency for Caucasian stimuli (*M* = .639, *SD* = .233) than Chinese stimuli (*M* = .431, *SD* = .169), *F*(1, 90) = 130.637, *p* < .001, η^2 = .592. Additionally, Chinese Malaysian participants (*M* = .489, *SD* = .208) showed higher efficiency compared to Caucasian participants (*M* = .431, *SD* = .169) for Chinese stimuli, *F*(1, 192) = 4.40, *p* = .037, η^2 = .022. Contrastingly, Chinese Malaysian participants (*M* = .494, *SD* = .208) showed lower efficiency compared to Caucasian participants (*M* = .639, *SD* = .233) for Caucasian stimuli, *F*(1, 192) = 20.966, *p* < .001, η^2 = .098.

A significant interaction effect of variability and participant race was found, *F*(1, 192) = 6.181, *p* = .014, η_p^2 = .031. Chinese Malaysian participants showed higher efficiency for high variability condition (*M* = .516, *SD* = .202) than low variability condition (*M* = .467, *SD* = .190), *F*(1, 102) = 33.440, *p* < .001,

η^2 = .247, while Caucasian participants showed no difference in efficiency for high and low variability condition, $F(1, 90) = 2.657$, $p = .107$, $\eta^2 = .029$. In terms of the low variability condition, Chinese Malaysian participants ($M = .467$, $SD = .190$) showed lower efficiency compared to Caucasian participants ($M = .527$, $SD = .189$), $F(1, 192) = 4.827$, $p = .029$, $\eta^2 = .025$. No difference between Chinese Malaysian participants and Caucasian participants was found in the high variability condition, $F(1, 192) = .937$, $p = .334$, $\eta^2 = .005$. Analysis showed no interaction effect of variability and face race, $F(1, 192) = 3.376$, $p = .068$, $\eta_p^2 = .017$, and variability, face race and participant race, $F(1, 192) = 1.923$, $p = .167$, $\eta_p^2 = .010$.

Figure 4.2

Accuracy, median reaction time for correct trials and efficiency plotted separately for Caucasian and Chinese Malaysian participants in Experiment 4a.



Note. Error bars represent 95% confidence intervals.

4.1.3 Discussion

Overall, our results showed that participants performed better in terms of accuracy, reaction time and efficiency for identities learned in high variability condition compared to the identities learned in low variability condition. Additionally, Caucasian participants performed better in terms of accuracy, reaction time and efficiency for Caucasian stimuli compared to Chinese stimuli. However, Chinese Malaysian participants performed equally well for Caucasian stimuli and Chinese stimuli. Although Caucasian participants presented the expected ORE for Chinese faces which is in line with past work (Meissner &

Brigham, 2001; Wong et al., 2020), Chinese Malaysians did not present an ORE for Caucasian faces. This finding is in line with Tan et al. (2012) who found that Chinese Malaysian participants recognized East Asian and Western faces equally well. The absence of ORE for Caucasian faces may be due to high exposure to Western culture in Malaysia as evident from the preference of Hollywood films over local films in Malaysia (Kit & Chuan, 2012; Sriganeshvarun & Abdul Aziz, 2019). Additionally, previous research has suggested that bilinguals may display reduced ORE (Burns, Tree, et al., 2019; Kandel et al., 2016). Malaysia is a multilingual country featuring multiple prominent languages such as Malay, English, Mandarin and Tamil (David et al., 2017). Therefore, the lack of ORE observed for Caucasian faces among Chinese Malaysian may be attributed to the high rate of bilingualism or multilingualism in the country, which could potentially reduce the ORE.

Since Chinese Malaysians did not show an ORE for Caucasian faces, only Caucasian participants could be used to examine if other-race identities (i.e., Chinese) learned in high variability condition had better recognition compared to the other-race identities learned in low variability condition. Based on the graphs in Figure 4.2 for Caucasian participants, there seem to be no differences in terms of accuracy, reaction time or efficiency for other-race identities learned in high variability condition and low variability condition.

One limitation of this experiment is that the name verification task requires participants to memorize the name and the face to perform accurately during the testing phase. However, Caucasian participants may be unfamiliar with Chinese names which could deter face and name matching accuracy for the Chinese identities. This is demonstrated by the high percentage of Caucasian participants who entered names inaccurately during the learning stage: 33 of the 41 participants who did so were Caucasian participants, whereas the remaining eight were Chinese Malaysian participants. Therefore, In Experiment 4b, we employed an old-new recognition paradigm which does not require precise name memorization during the testing phase.

4.2 Experiment 4b

In Experiment 4b, participants learned own- and other-race identities in high and low variability conditions as in Experiment 4a, but they were tested with an old-new face recognition paradigm as opposed to a name verification task. Similar to Experiment 4a, we recruited Chinese Malaysian and Caucasian participants for this experiment.

4.2.1 Methods

Design

A mixed design was implemented. The within-subject factors were variability (high and low) and stimuli (Chinese and Caucasian) and the between-subject factor was participant race (Chinese Malaysian and Caucasian). The presentation order of stimuli was counterbalanced. Similar to Experiment 4a, the dependent variables were accuracy, reaction time, and efficiency. In addition to efficiency measurements, signal detection measurements were included to evaluate participants' ability to distinguish between signals (stimuli) and noise (absence of stimuli) (Macmillan & Creelman, 2005; Stanislaw & Todorov, 1999). Sensitivity was calculated using the hit rate (proportion of responding yes on signal trials) and the false-alarm rate (proportion of responding yes on noise trials) to calculate d-prime.

Participants

In total, 129 Chinese Malaysian and 135 Caucasian participants took part in this experiment, but the final sample included 95 Chinese Malaysian (63 females, 1 others) and 96 Caucasian (84 females, 2 others) aged between 18 to 67 years (*M* = 21.59 years, *SD* = 4.78 years). Data from participants of other-race (1), median reaction time that was less than 500ms or accuracy below chance level (50%) (31), inaccurate responses for the learning stage (40) and which accidentally did the experiment for the second time (1) were removed from further analysis.

The results of an a priori power analysis conducted using G*Power 3.1 (Faul et al., 2009) was as in Experiment 4a. A large effect size was estimated and the power analysis suggested that *N* = 40 is required to detect a difference between the variability condition with 95% probability. All participants have provided informed consent to participate in the study. Participants were compensated with either course credits or RM5 for participation. The study has been reviewed and approved by the Science and Engineering Research Ethics Committee (SEREC) at the University of Nottingham Malaysia (approval code: KSK270521).

Apparatus and Materials

For both Caucasian and Chinese stimuli, the high variability images were obtained by searching the name of the celebrity on Google Image whereas the low variability images were screenshots of interview videos found on YouTube by searching the name of the celebrity. We employed a new set of Caucasian and Chinese stimuli in this study to prevent familiarity with the stimuli used in Experiment 4a. Twenty identities (ten males and ten females) were included for each race, totalling up to 20 identities. Identities used in the Caucasian stimuli consist of American and Australian celebrities (athletes, model, television presenter, etc.) and identities used in the Chinese stimuli consist of China celebrities (athletes, etc.), so participants recruited in this experiment should not be familiar with any of the identities shown in the task. In total, there were 15 high variability images and 10 low variability (i.e., 10 high variability and 10 low variability images for study phase, and five high variability images for test phase) images for each identity. The images (260 × 390 pixels) were presented on a grey background.

Procedure

Testable was used to run the online experiment (Rezlescu et al., 2020). The task was presented in two blocks, Chinese and Caucasian. Each block consists of two phases: learning and test. The learning phase was as in Experiment 4a. In this study, six Chinese names were modified to facilitate name memorization in the learning phase (e.g., MoSheung to MoShen). The names were included in the experiment to aid participants in differentiating the faces and to ensure that participants were attentive during the learning phase. However, it was not required for participants to recognize the names during the test phase.

The test phase of the task consists of a recognition memory task which consisted of 100 trials (10 identities × 10 trials). Images presented in the test phase were novel high variability images. In each trial, the test images without names were presented until response. There was an inter-trial interval of 500ms. Half of the trials were images of identities which have been presented in the learning stage and the other half were novel identities. Participants were asked to indicate if the identity shown has been presented in the learning stage or not as quickly and as accurately as possible. The keys used for response was “z” and “m”. The keys used for “have seen the identity in the learning stage” or “have not seen the identity before” response, either right hand (“m”) or left hand (“z”) were counterbalanced. The test phase took about 5 minutes to complete. Identities used in the learning phase and novel identities in the test phase were counterbalanced. At the end of each block, participants were asked if they were familiar with any of the identities shown in the task. The whole experiment lasted approximately 30 minutes.

4.2.2 Results

Participants who had typed the name of the identity with just one incorrect letter during the learning phase were included in the analysis. For participants (four Chinese Malaysian) who reported familiarity with less than half of the identities shown in the task (i.e., one identity), test trials involving the familiar identity were removed prior to the analysis. We conducted our analysis using only the trials featuring identities that were presented during the learning stage (i.e., hit trials) (for a similar procedure, see Longmore et al., 2008). This was because the identities presented during the learning stage varied on two factors (high and low variability), while the distractors only varied on one factor (novel identities). Consequently, we excluded trials with novel identities from our analysis. Mixed ANOVAs were conducted to explore potential differences between own- and other-race identities learned in high and low variability condition. D’ was calculated based on the same false alarm rate for high variability and low variability conditions.

Accuracy

A 2 (variability: high vs. low) × 2 (face race: Chinese vs. Caucasian) × 2 (participant race: Chinese Malaysian vs. Caucasian) mixed ANOVA was conducted on the accuracy (calculated by proportion correct scores) (Figure 4.3). The analysis revealed a significant main effect of variability on accuracy, $F(1, 189) = 635.647$, $p < .001$, $\eta_p^2 = .771$. Accuracy for high variability condition ($M = .699$, $SD = .177$) was higher compared to the low variability condition ($M = .441$, $SD = .182$). The analysis also revealed a significant main effect of face race, $F(1, 189) = 10.223$, $p = .002$, $\eta_p^2 = .051$, where Caucasian stimuli ($M = .586$, $SD = .215$) had higher accuracy compared to Chinese stimuli ($M = .554$, $SD = .226$). No effect of participant race was found, $F(1, 189) = .242$, $p = .623$, $\eta_p^2 = .001$.

Results showed a significant interaction effect between variability and participant race, $F(1, 189) = 7.577$, $p = .006$, $\eta_p^2 = .039$. High variability condition ($M = .681$, $SD = .143$) had higher accuracy compared to low variability condition ($M = .450$, $SD = .152$) for Caucasian participants, $F(1, 95) = 287.509$, $p < .001$, $\eta^2 = .752$ and Chinese Malaysian participants (high variability condition: $M = .718$, $SD = .156$; low variability condition: $M = .431$, $SD = .150$), $F(1, 94) = 347.484$, $p < .001$, $\eta^2 = .787$. Chinese Malaysian participants and Caucasian participants showed no difference in accuracy in the high variability condition, $F(1, 189) = 3.049$, $p = .082$, $\eta^2 = .016$, and the low variability condition, $F(1, 189) = .741$, $p = .390$, $\eta^2 = .004$.

A significant interaction effect between face race and participant race was found, $F(1, 189) = 6.351$, $p = .013$, $\eta_p^2 = .033$. Chinese Malaysian participants showed similar accuracy for both Chinese and Caucasian stimuli, $F(1, 94) = .211$, $p = .647$, $\eta^2 = .002$, while Caucasian participants showed higher accuracy for Caucasian stimuli ($M = .594$, $SD = .145$) than Chinese stimuli ($M = .537$, $SD = .149$), $F(1, 95) = 17.820$, $p < .001$, $\eta^2 = .158$. Chinese Malaysian participants and Caucasian participants showed no difference in accuracy for Chinese stimuli, $F(1, 189) = 2.418$, $p = .122$, $\eta^2 = .013$, and Caucasian stimuli, $F(1, 189) = .557$, $p = .457$, $\eta^2 = .003$.

No interaction effect of variability and face race was found, *F*(1, 189) = .835, $p = .362$, $\eta_p^2 = .004$. A significant interaction was found between variability, face race and participant race, *F*(1, 189) = 4.986, $p = .027$, $\eta_p^2 = .026$. To further explore this three-way interaction, we ran a 2 (variability: high vs. low) × 2 (face race: Chinese vs. Caucasian) ANOVA for Chinese Malaysian participants and Caucasian participants separately. For Caucasian participants, we found a significant main effect of variability, *F*(1, 95) = 287.509, $p < .001$, $\eta_p^2 = .752$, where high variability condition (*M* = .681, *SD* = .172) had higher accuracy compared to low variability condition (*M* = .45, *SD* = .18). Analysis also revealed a significant main effect of face race, *F*(1, 95) = 17.82, $p < .001$, $\eta_p^2 = .158$, where Caucasian stimuli (*M* = .594, *SD* = .208) had higher accuracy compared to Chinese stimuli (*M* = .537, *SD* = .21). No interaction effect of variability and face race was found, *F*(1, 95) = .902, $p = .345$, $\eta_p^2 = .009$.

For Chinese Malaysian participants, we found a significant main effect of variability, *F*(1, 94) = 347.484, $p < .001$, $\eta_p^2 = .787$, where high variability condition (*M* = .718, *SD* = .181) had higher accuracy compared to low variability condition (*M* = .431, *SD* = .183). No main effect of face race was found, *F*(1, 94) = .211, $p = .647$, $\eta_p^2 = .002$. Analysis reveal a significant interaction effect of variability and face race, *F*(1, 94) = 4.776, $p = .031$, $\eta_p^2 = .048$. Simple main effects analysis revealed that Chinese Malaysian participants showed no difference between Chinese stimuli (*M* = .730, *SD* = .170) and Caucasian stimuli (*M* = .707, *SD* = .191) in high variability condition, *F*(1, 94) = 1.548, $p = .217$, $\eta^2 = .016$, and in low variability condition, *F*(1, 94) = 3.019, $p = .086$, $\eta^2 = .031$ (Chinese stimuli: *M* = .413, *SD* = .192; Caucasian stimuli: *M* = .450, *SD* = .173). Additionally, Chinese Malaysian participants showed higher accuracy for the high variability condition (*M* = .730, *SD* = .170) compared to the low variability condition (*M* = .413, *SD* = .192) for Chinese stimuli, *F*(1, 94) = 292.434, $p < .001$, $\eta^2 = .757$, and Caucasian stimuli (high variability: *M* = .707, *SD* = .450; low variability: *M* = .450, *SD* = .173), *F*(1, 94) = 128.146, $p < .001$, $\eta^2 = .577$.

We also ran a 2 (variability: high vs. low) × 2 (participant race: Chinese vs. Caucasian) ANOVA for Chinese stimuli and Caucasian stimuli separately. In terms of Chinese stimuli, we found a significant main effect of variability, *F*(1, 190) = 379.043, $p < .001$, $\eta_p^2 = .667$, where the high variability condition

(*M* = .688, *SD* = .178) had higher accuracy compared to the low variability condition (*M* = .420, *SD* = .186). Analysis also revealed no significant main effect of participant race, *F*(1, 189) = 2.418, $p = .122$, $\eta_p^2 = .013$. A significant interaction effect of variability and participant race was found, *F*(1, 189) = 13.107, $p < .001$, $\eta_p^2 = .065$.

Simple main effects analysis revealed that in terms of Chinese stimuli, Chinese Malaysian participants showed higher accuracy (*M* = .730, *SD* = .170) compared to Caucasian participants (*M* = .646, *SD* = .177) in the high variability condition, *F*(1, 189) = 11.246, $p < .001$, $\eta^2 = .056$. No difference was found between Chinese Malaysian participants and Caucasian participants in the low variability condition, *F*(1, 189) = .320, $p = .572$, $\eta^2 = .002$. Additionally, higher accuracy was found for the high variability condition (*M* = .730, *SD* = .170) compared to the low variability condition (*M* = .413, *SD* = .192) for Chinese Malaysian participants, *F*(1, 94) = 292.434, $p < .001$, $\eta^2 = .757$, and Caucasian participants, *F*(1, 95) = 115.589, $p < .001$, $\eta^2 = .549$ (high variability: *M* = .646, *SD* = .177; low variability: *M* = .428, *SD* = .182) in terms of Chinese stimuli.

In terms of Caucasian stimuli, we found a significant main effect of variability, *F*(1, 189) = 301.479, $p < .001$, $\eta_p^2 = .615$, where the high variability condition (*M* = .711, *SD* = .176) had higher accuracy compared to the low variability condition (*M* = .461, *SD* = .175). Analysis revealed no significant main effect of participant race, *F*(1, 189) = .557, $p = .457$, $\eta_p^2 = .003$. No significant interaction effect of variability and participant race was found, *F*(1, 189) = .220, $p = .640$, $\eta_p^2 = 001$.

We also ran a 2 (face race: Chinese vs. Caucasian) × 2 (participant race: Chinese vs. Caucasian) ANOVA for high variability and low variability conditions separately. In terms of the high variability condition, we found no significant main effect of face race, *F*(1, 189) = 3.016, $p = .084$, $\eta_p^2 = .016$, and participant race, *F*(1, 189) = 3.049, $p = .082$, $\eta_p^2 = .016$. A significant interaction effect of face race and participant race was found, *F*(1, 189) = 12.370, $p < .001$, $\eta_p^2 = .061$.

Simple main effects analysis revealed that in the high variability condition, Chinese Malaysian participants showed higher accuracy (*M* = .730, *SD* = .170) compared to Caucasian participants (*M* = 646, *SD* = .177) for Chinese stimuli, *F*(1, 189) = 11.246, $p < .001$, $\eta^2 = .056$. In terms of Caucasian stimuli, no difference in accuracy was found between Chinese Malaysian participants and Caucasian participants, $F(1, 189) = .121$, $p = .728$, $\eta^2 = 6.418\text{e} - 4$. Additionally, no difference in accuracy was found between Chinese stimuli and Caucasian stimuli for Chinese Malaysian participants, $F(1, 94) = 1.548$, $p = .217$, $\eta^2 = .016$. For Caucasian participants, it was found that Chinese stimuli ($M = .646$, $SD = .177$) had lower accuracy compared to Caucasian stimuli ($M = .715$, $SD = .160$), $F(1, 95) = 14.135$, $p < .001$, $\eta^2 = .130$, in the high variability condition.

In terms of the low variability condition, we found a significant main effect of face race, $F(1, 189) = 7.924$, $p = .005$, $\eta_p^2 = .040$, where Chinese stimuli ($M = .420$, $SD = .186$) had lower accuracy compared to Caucasian stimuli ($M = .461$, $SD = .175$). Analysis revealed no significant main effect of participant race, $F(1, 189) = .741$, $p = .390$, $\eta_p^2 = .004$, and no significant interaction effect of face race and participant race, $F(1, 189) = .061$, $p = .806$, $\eta_p^2 = 3.216\text{e} - 4$.

Reaction time

A 2 (variability: high vs. low) × 2 (face race: Chinese vs. Caucasian) × 2 (participant race: Chinese Malaysian vs. Caucasian) mixed ANOVA was conducted on the median reaction time for correct trials (Figure 4.3). The analysis revealed a significant main effect of variability on reaction time, $F(1, 188) = 60.569$, $p < .001$, $\eta_p^2 = .244$. Reaction time for high variability condition ($M = 931.804$ms, $SD = 321.632$ms) was shorter compared to the low variability condition ($M = 1120.741$ms, $SD = 604.628$ms). No main effect of face race, $F(1, 188) = .051$, $p = .822$, $\eta_p^2 = 2.694\text{e} - 4$, and participant race, $F(1, 188) = .395$, $p = .530$, $\eta_p^2 = .002$, was found.

Results showed a significant interaction effect of variability and participant race, $F(1, 188) = 5.721$, $p = .018$, $\eta_p^2 = .030$. High variability condition ($M = 942.414$ms, $SD = 369.404$ms) had shorter reaction time compared to low variability condition ($M = 1074.099$ms, $SD = 543.513$ms) for Caucasian participants, $F(1, 95) = 26.460$, $p < .001$, $\eta^2 = .218$, and Chinese Malaysian participants (high variability condition: $M = 921.082$ms, $SD = 223.311$ms; low variability condition: $M = 1167.513$ms, $SD = 507.503$ms), $F(1, 94) = 35.269$, $p < .001$, $\eta^2 = .273$. Chinese Malaysian participants and Caucasian participants showed no difference in reaction time in the high variability condition, *F*(1, 189) = .233, *p* = .630, η^2 = .001, and the low variability condition, *F*(1, 189) = 1.506, *p* = .221, η^2 = .008.

Analysis revealed no interaction effect of face race and participant race, *F*(1, 188) = 8.122e - 4, *p* = .977, η_p^2 = 4.320e - 6. No interaction effect was found between variability and face race, *F*(1, 188) = .001, *p* = .974, η_p^2 = 5.631e - 6, and between variability, face race and participant race, *F*(1, 188) = .079, *p* = .779, η_p^2 = 4.216e - 4.

Efficiency

A 2 (variability: high vs. low) × 2 (face race: Chinese vs. Caucasian) × 2 (participant race: Chinese Malaysian vs. Caucasian) mixed ANOVA was conducted on efficiency calculated by RCS (Figure 4.3). The analysis revealed a significant main effect of variability, *F*(1, 189) = 524.991, *p* < .001, η_p^2 = .735. Efficiency for high variability condition (*M* = .668, *SD* = .248) was higher compared to the low variability condition (*M* = .381, *SD* = .188). No main effect of face race, *F*(1, 189) = 3.862, *p* = .051, η_p^2 = .020, and participant race, *F*(1, 189) = 1.080, *p* = .300, η_p^2 = .006, was found.

Results showed a significant interaction effect of variability and participant race, *F*(1, 189) = 5.420, *p* = .021, η_p^2 = .028. High variability condition (*M* = .666, *SD* = .209) had higher efficiency compared to low variability condition (*M* = .408, *SD* = .163) for Caucasian participants, *F*(1, 95) = 248.565, *p* < .001, η^2 = .723, and Chinese Malaysian participants (high variability condition: *M* = .670, *SD* = .221; low variability condition: *M* = .353, *SD* = .152), *F*(1, 94) = 276.833, *p* < .001, η^2 = .747. Chinese Malaysian participants and Caucasian participants showed no difference in efficiency in the high variability condition, *F*(1, 189) = .017, *p* = .897, η^2 = 8.923e – 5. In the low variability condition, Caucasian participants (*M* = .408, *SD* = .163) showed higher efficiency compared to Chinese Malaysian participants (*M* = .353, *SD* = .152), *F*(1, 189) = 5.692, *p* = .018, η^2 = .029.

Analysis revealed no interaction effect of face race and participant race, *F*(1, 189) = 2.128, *p* = .146, η_p^2 = .011. No interaction effect was found between variability and face race, *F*(1, 189) = 1.547, *p*

= .215, η_p^2 = .008, and between variability, face race and participant race, *F*(1, 189) = 3.359, *p* = .068, η_p^2 = .017.

D-prime

A 2 (variability: high vs. low) × 2 (face race: Chinese vs. Caucasian) × 2 (participant race: Chinese Malaysian vs. Caucasian) mixed ANOVA was conducted on d-prime (d') (Figure 4.3). The analysis revealed a significant main effect of variability on d', *F*(1, 189) = 540.223, *p* < .001, η_p^2 = .741. D' for the high variability condition (*M* = 1.470, *SD* = .761) was higher compared to the low variability condition (*M* = .731, *SD* = .605). The analysis also revealed a significant main effect of face race, *F*(1, 189) = 17.028, *p* = < .001, η_p^2 = .083, where Caucasian stimuli (*M* = 1.191, *SD* = .791) had higher d' compared to Chinese stimuli (*M* = 1.011, *SD* = .760). No effect of participant race was found, *F*(1, 189) = 1.353, *p* = .246, η_p^2 = .007.

Results showed a significant interaction effect between variability and participant race, *F*(1, 189) = 7.976, *p* = .005, η_p^2 = .040. High variability condition (*M* = 1.384, *SD* = .607) had higher d' compared to low variability condition (*M* = .734, *SD* = .502) for Caucasian participants, *F*(1, 95) = 253.052, *p* < .001, η^2 = .727 and Chinese Malaysian participants (high variability condition: *M* = 1.558, *SD* = .613; low variability condition: *M* = .728, *SD* = .436), *F*(1, 94) = 287.950, *p* < .001, η^2 = .754. Chinese Malaysian participants and Caucasian participants showed no difference in d' in the high variability condition, *F*(1, 189) = 3.872, *p* = .051, η^2 = .020, and the low variability condition *F*(1, 189) = .008, *p* = .930, η^2 = 4.10e - 5.

A significant interaction effect between face race and participant race was found, *F*(1, 189) = 83.901, *p* < .001, η_p^2 = .307. Chinese Malaysian participants showed higher d' for Chinese stimuli (*M* = 1.252, *SD* = .582) than Caucasian stimuli (*M* = 1.034, *SD* = .531), *F*(1, 94) = 13.313, *p* < .001, η^2 = .124. In contrast, Caucasian participants showed higher d' for Caucasian stimuli (*M* = 1.346, *SD* = .695) than Chinese stimuli (*M* = .772, *SD* = .494), *F*(1, 95) = 84.264, *p* < .001, η^2 = .470. Chinese Malaysian participants (*M* = 1.252, *SD* = .582) showed higher d' compared to Caucasian participants (*M* = .772, *SD*

= .494) in terms of Chinese stimuli, *F*(1, 189) = 37.734, $p < .001$, $\eta^2 = .166$. In contrast, Caucasian participants (*M* = 1.346, *SD* = .695) showed higher d' compared to Chinese Malaysian participants (*M* = 1.034, *SD* = .531) in terms of Caucasian stimuli, *F*(1, 189) = 12.121, $p < .001$, $\eta^2 = .060$. No interaction effect of variability and face race was found, *F*(1, 189) = .608, $p = .436$, $\eta_p^2 = .003$.

A significant interaction was found between variability, face race and participant race, *F*(1, 189) = 7.108, $p = .008$, $\eta_p^2 = .036$. To further explore this three-way interaction, we ran a 2 (variability: high vs. low) × 2 (face race: Chinese vs. Caucasian) ANOVA for Chinese Malaysian participants and Caucasian participants separately. For Caucasian participants, we found a significant main effect of variability, *F*(1, 95) = 253.052, $p < .001$, $\eta_p^2 = .727$, where the high variability condition (*M* = 1.384, *SD* = .607) had a higher d' compared to the low variability condition (*M* = .734, *SD* = .502). Analysis also revealed a significant main effect of face race, *F*(1, 95) = 84.264, $p < .001$, $\eta_p^2 = .470$, where Caucasian stimuli (*M* = 1.346, *SD* = .695) had higher d' compared to Chinese stimuli (*M* = .772, *SD* = .494). No interaction effect of variability and face race was found, *F*(1, 95) = 1.870, $p = .175$, $\eta_p^2 = .019$.

For Chinese Malaysian participants, we found a significant main effect of variability, *F*(1, 94) = 287.950, $p < .001$, $\eta_p^2 = .754$, where the high variability condition (*M* = 1.558, *SD* = .613) had a higher d' compared to the low variability condition (*M* = .728, *SD* = .436). A main effect of face race was found, *F*(1, 94) = 13.313, $p < .001$, $\eta_p^2 = .124$, where Chinese stimuli (*M* = 1.252, *SD* = .582) had higher d' compared to Caucasian stimuli (*M* = 1.034, *SD* = .531). Analysis revealed a significant interaction effect of variability and face race, *F*(1, 94) = 5.656, $p = .019$, $\eta_p^2 = .057$.

Simple main effects analysis revealed that Chinese Malaysian participants showed higher d' for Chinese stimuli (*M* = 1.715, *SD* = .708) compared to Caucasian stimuli (*M* = 1.401, *SD* = .730) in the high variability condition, *F*(1, 94) = 16.601, $p < .001$, $\eta^2 = .150$, while no difference was found in the low variability condition, *F*(1, 94) = 3.301, $p = .072$, $\eta^2 = .034$. Additionally, Chinese Malaysian participants showed higher d' for the high variability condition (*M* = 1.715, *SD* = .708) compared to the low variability condition (*M* = .789, *SD* = .582) for Chinese stimuli, *F*(1, 94) = 250.078, $p < .001$, η^2

= .727, and Caucasian stimuli, $F(1, 94) = 116.099$, $p < .001$, $\eta^2 = .553$ (high variability: $M = 1.401$, $SD = .730$; low variability: $M = .668$, $SD = .502$).

We also ran a 2 (variability: high vs. low) × 2 (participant race: Chinese vs. Caucasian) ANOVA for Chinese stimuli and Caucasian stimuli separately. In terms of Chinese stimuli, we found a significant main effect of variability, $F(1, 189) = 347.864$, $p < .001$, $\eta_p^2 = .648$, where the high variability condition ($M = 1.391$, $SD = .738$) had a higher d' compared to the low variability condition ($M = .630$, $SD = .567$). Analysis also revealed a significant main effect of participant race, $F(1, 189) = 37.734$, $p < .001$, $\eta_p^2 = .166$, where Caucasian participants ($M = .772$, $SD = .494$) had a lower d' compared to Chinese Malaysian participants ($M = 1.252$, $SD = .582$). A significant interaction effect of variability and participant race was found, $F(1, 189) = 16.212$, $p < .001$, $\eta_p^2 = .079$.

Simple main effects analysis revealed that in terms of Chinese stimuli, Chinese Malaysian participants showed higher d' ($M = 1.715$, $SD = .708$) compared to Caucasian participants ($M = 1.071$, $SD = .621$) in the high variability condition, $F(1, 189) = 44.676$, $p < .001$, $\eta^2 = .191$, and the low variability condition, $F(1, 189) = 15.930$, $p < .001$, $\eta^2 = .078$ (Chinese Malaysian participants: $M = .789$, $SD = .582$; Caucasian participant: $M = .474$, $SD = .508$). Additionally, higher d' was found for the high variability condition ($M = 1.715$, $SD = .708$) compared to the low variability condition ($M = .789$, $SD = .582$) for Chinese Malaysian participants, $F(1, 94) = 250.078$, $p < .001$, $\eta^2 = .727$, and Caucasian participants, $F(1, 95) = 109.992$, $p < .001$, $\eta^2 = .537$ (high variability: $M = 1.071$, $SD = .621$; low variability: $M = .474$, $SD = .508$) in terms of Chinese stimuli.

In terms of Caucasian stimuli, we found a significant main effect of variability, $F(1, 189) = 268.310$, $p < .001$, $\eta_p^2 = .587$, where the high variability condition ($M = 1.550$, $SD = .776$) had a higher d' compared to the low variability condition ($M = .832$, $SD = .627$). Analysis also revealed a significant main effect of participant race, $F(1, 189) = 12.121$, $p < .001$, $\eta_p^2 = .060$, where Caucasian participants ($M = 1.346$, $SD = .695$) had a higher d' compared to Chinese Malaysian participants ($M = 1.034$, $SD = .531$). No significant interaction effect of variability and participant race was found, $F(1, 189) = .123$, $p = .726$, $\eta_p^2 = 6.502e - 4$.

We also ran a 2 (face race: Chinese vs. Caucasian) × 2 (participant race: Chinese vs. Caucasian) ANOVA for the high variability and the low variability conditions separately. In terms of the high variability condition, we found a significant main effect of face race, *F*(1, 189) = 8.306, *p* = .004, η_p^2 = .042, where Chinese stimuli (*M* = 1.391, *SD* = .738) had lower d' compared to Caucasian stimuli (*M* = 1.550, *SD* = .776). Analysis revealed no significant main effect of participant race, *F*(1, 189) = 3.872, *p* = .051, η_p^2 = .020. A significant interaction effect of face race and participant race was found, *F*(1, 189) = 74.979, *p* < .001, η_p^2 = .284.

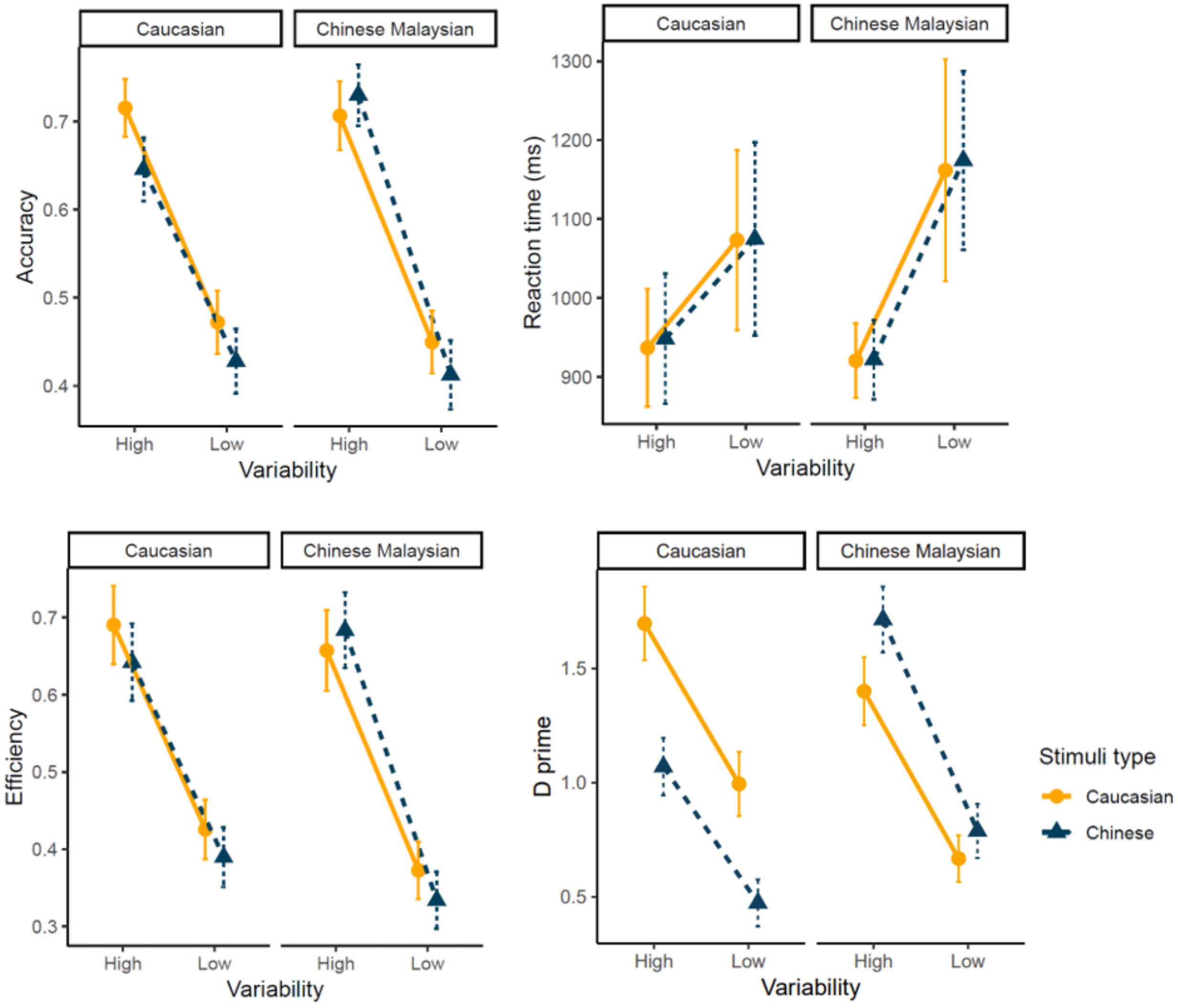
Simple main effects analysis revealed that in the high variability condition, Chinese Malaysian participants showed a higher d' (*M* = 1.715, *SD* = .708) compared to Caucasian participants (*M* = 1.071, *SD* = .621) for Chinese stimuli, *F*(1, 189) = 44.676, *p* < .001, η^2 = .191. In terms of Caucasian stimuli, a lower d' was found for Chinese Malaysian participants (*M* = 1.401, *SD* = .730) compared to Caucasian participants (*M* = 1.697, *SD* = .795), *F*(1, 189) = 7.211, *p* = .008, η^2 = .037. Additionally, higher d' was found for Chinese stimuli (*M* = 1.715, *SD* = .708) compared to Caucasian stimuli (*M* = 1.401, *SD* = .730) for Chinese Malaysian participants, *F*(1, 94) = 16.601, *p* < .001, η^2 = .150. For Caucasian participants, it was found that Chinese stimuli (*M* = 1.071, *SD* = .621) had lower d' compared to Caucasian stimuli (*M* = 1.697, *SD* = .795), *F*(1, 95) = 66.944, *p* < .001, η^2 = .413, in the high variability condition.

In terms of the low variability condition, we found a significant main effect of face race, *F*(1, 189) = 17.071, *p* < .001, η_p^2 = .083, where Chinese stimuli (*M* = .630, *SD* = .567) had lower d' compared to Caucasian stimuli (*M* = .832, *SD* = .627). Analysis revealed no significant main effect of participant race, *F*(1, 189) = .008, *p* = .930, η_p^2 = 4.10e - 5. A significant interaction effect of face race and participant race was found, *F*(1, 189) = 44.023, *p* < .001, η_p^2 = .189.

Simple main effects analysis revealed that in the low variability condition, Chinese Malaysian participants showed higher d' (*M* = .789, *SD* = .582) compared to Caucasian participants (*M* = .474, *SD* = .508) for Chinese stimuli, *F*(1, 189) = 15.930, *p* < .001, η^2 = .078. In terms of Caucasian stimuli, lower d' was found for Chinese Malaysian participants (*M* = .668, *SD* = .502) compared to Caucasian participants (*M* = .995, *SD* = .694), *F*(1, 189) = 13.923, *p* < .001, η^2 = .069. Additionally, no difference in d' was found between Chinese stimuli and Caucasian stimuli for Chinese Malaysian participants, *F*(1, 94) = 3.301, *p* = .072, η^2 = .034. For Caucasian participants, it was found that Chinese stimuli (*M* = .474, *SD* = .508) had lower d' compared to Caucasian stimuli (*M* = .995, *SD* = .694), *F*(1, 95) = 55.219, *p* < .001, η^2 = .368, in the low variability condition.

Figure 4.3

Accuracy, median reaction time for correct trials, efficiency and d prime plotted separately for Caucasian and Chinese Malaysian participants in Experiment 4b.



Note. Error bars represent 95% confidence intervals.

4.2.3 Discussion

Similar to Experiment 4a, our results showed that participants performed better in terms of accuracy, reaction time, efficiency and d’ for identities learned in the high variability condition compared to the identities learned in low variability condition. Our results also showed that while Caucasian participants showed the expected ORE for Chinese faces (i.e., higher accuracy for Caucasian stimuli compared to Chinese stimuli), Chinese Malaysian participants showed no ORE for Caucasian faces in terms of accuracy scores (i.e., similar accuracy for Caucasian stimuli and Chinese stimuli). However, Chinese Malaysian participants exhibited an ORE for Caucasian faces in the d’ measure (i.e., higher d’ for Chinese stimuli compared to Caucasian stimuli). Interestingly, this ORE was only observed in the high variability condition and was not evident in the low variability condition. The contrasting results between accuracy and d’ measure could potentially be attributed to the fact that accuracy solely encompasses old trials (faces that were previously learned), whereas d' encompasses both old and new trials (faces that were novel). This suggests that the ORE in Chinese Malaysian participants may be more pronounced when they are making decisions to reject faces (i.e., indicating that a face was not seen before) as opposed to confirming familiarity (i.e., acknowledging that a face was previously learnt). In line with this, a comparison of hit rates (in the high variability condition) and correct rejections for Chinese and Caucasian stimuli among Chinese Malaysian participants revealed similar hit rates for both stimulus types. However, higher correct rejections were observed for Chinese stimuli compared to Caucasian stimuli (see Appendix H). Despite these findings, the precise reasons behind the presence of the ORE in Chinese Malaysian participants exclusively in the high variability condition and its absence in the low variability condition remain unclear.

In contrast to Caucasian participants, who consistently demonstrated the ORE across various measures (accuracy and d') and conditions (high and low variability), Chinese Malaysian participants exhibited inconsistent ORE patterns across different measures and conditions. This may be due to the high exposure of Western culture in Malaysia as evident from the preference of Hollywood films over local films in Malaysia (Kit & Chuan, 2012; Sriganeshvarun & Abdul Aziz, 2019). This is in line with the contact hypothesis, where we tend to develop a higher level of perceptual expertise for faces that are more often seen in our everyday lives (Rossion & Michel, 2011). Viewing Hollywood films may have increased Chinese Malaysian participants' perceptual expertise for Caucasian faces, which in turn reduced the ORE for Caucasian faces. However, it is important to note that while some studies propose that exposure and the magnitude of the ORE are not associated (Wong et al., 2020), others have identified a reduction in the ORE with increased exposure (Estudillo et al., 2020). Furthermore, the high rate of bilinguals and multilinguals in Malaysia could also potentially reduce the ORE (Burns, Tree, et al., 2019; Kandel et al., 2016).

Hence, we mainly focus on the Caucasian participants to examine if other-race identities (i.e., Chinese) learned in high variability condition had better recognition compared to the identities learned in low variability condition. Based on our results for Caucasian participants, other-race identities learned in high variability condition had higher accuracy compared to low variability condition. This demonstrates that identities learned in high variability conditions benefitted both own- and other-race face learning.

4.3 General discussion

We aimed to examine the effect of high and low within-person variability exposure for own- and other-race face learning. Own- and other-race identities were learned in high and low variability conditions and identity recognition were tested using a name verification task in Experiment 4a and an old-new recognition paradigm in Experiment 4b.

We found enhanced own-race face learning for identities learned in high variability condition compared to low variability condition across Experiment 4a and Experiment 4b. This finding is in line with previous work which found that multiple exposure to own-race faces in high within-person variability stimuli sets is more advantageous for identity learning as compared to low within-person variability, as demonstrated in a face matching task (Menon et al., 2015; Ritchie & Burton, 2017), name verification task (Ritchie & Burton, 2017) and identity-sorting task (Baker et al., 2017).

To examine if identities learned in a high variability condition enhanced other-race face learning compared to the identities learned in a low variability condition, we mainly examined Caucasian participants as Chinese Malaysian participants exhibited inconsistent ORE patterns for Caucasian faces across different measures and conditions across Experiment 4a and Experiment 4b. In Experiment 4a, we found no difference in performance of other-race face learning for identities learned in the high variability condition and low variability condition. However, we implemented a name verification task in Experiment 4a, which required participants to precisely memorize the name and the face in order to perform accurately during the testing phase. While Chinese participants may be familiar with Caucasian names (Kit & Chuan, 2012; Sriganeshvarun & Abdul Aziz, 2019), Caucasian participants may be unfamiliar with Chinese names which could deter face and name matching accuracy for the Chinese identities. This is demonstrated by the high percentage of Caucasian participants who entered the names inaccurately during the learning stage: 33 of the 41 participants who did so were Caucasian participants, whereas the remaining eight were Chinese Malaysian participants.

In Experiment 4b, the face-name association was removed in the testing phase by employing an old-new recognition paradigm. Experiment 4b revealed that identities learned in the high variability condition benefitted other-race face learning in comparison to low variability condition. While it has been demonstrated that exposures to identities with within-person variability can improve other-race face recognition compared to a single image of identities (Cavazos et al., 2019; Matthews & Mondloch, 2018), our findings indicate that identities learned in high variability condition could further improve other-race face recognition compared to identities learned in low variability condition. This suggests that different levels of variation during multiple exposure to other-race faces could affect identity learning, where higher variation of faces would lead to improved other-race face learning.

Our findings revealed that even though there were consistent changes in external features in the high variability condition, and previous research suggests that external features are typically prioritized when processing other-race faces (Havard, 2021; Sporer & Horry, 2011; Wong et al., 2020), participants in our study were able to focus on internal features of other-race faces in the high variability condition.

This resulted in detailed encoding of internal features and enhanced learning of other-race faces. While previous research has suggested that external features are prioritized when presented with stable face appearances (Devue et al., 2021; Reedy & Devue, 2019), this did not benefit other-race face learning in the low variability condition compared to the high variability condition. Altogether, this suggests that the identities learned in high variability condition may only benefit other-race face recognition but not the association of other-race faces and names.

However, our study is subject to several limitations. First, we did not incorporate an eye-tracking task to validate participants' attention to specific facial features, whether internal or external. Second, the stimuli comprising Caucasian faces requested from Ritchie and Burton (2017) and additional stimuli generated for this experiment were not controlled for levels of variability across faces. Thus, it is possible that the identities employed in our experiment exhibit varying degrees of variability in the high variability condition. These limitations underscore the need for future research to address these factors and enhance the robustness of our findings.

In sum, we found enhanced own-race face learning for identities learned in a high variability condition compared to a low variability condition. Our results revealed that identities learned in high variability condition benefit only other-race face recognition, but not face-name association of other-race face as compared to identities learned in low variability condition. This suggests that high within-person variation during multiple exposure to faces could lead to detailed encoding of internal features which refined the resolution of the representation not only for own-race faces but also for other-race faces.

Chapter 5 – Face learning in high and low variability for prosopagnosia

Having observed the positive effects of the image variability training on both own- and other-race face learning, we then proceed to examine the potential application of this training for prosopagnosia rehabilitation in Chapter 5. Prosopagnosia, also known as face blindness, is a condition characterized by severe deficits in face recognition despite intact visual acuity and intelligence (McConachie, 1976; Rossion, 2014). Acquired prosopagnosia is defined as individuals that experience loss of face recognition ability following brain injury (Barton, 2008; Davies-Thompson et al., 2014) whereas developmental prosopagnosia, also known as congenital prosopagnosia is defined as individuals that experience failure in development of face recognition ability despite having no apparent brain injury (Brunsdon et al., 2006; Cook & Biotti, 2016; Palermo et al., 2011). The prevalence of developmental prosopagnosia was estimated to be up to 5.42% for adults (DeGutis et al., 2023; Kennerknecht et al., 2006, 2008) and 5.2% for children (Bennetts et al., 2017). Individuals with prosopagnosia typically recognize someone based on their hairstyle, clothing, voice or gait which could be mentally draining (Adams et al., 2020; Cook & Biotti, 2016). In addition, this identification method does not always work, for instance, changes in appearances (e.g., hairstyle) could lead to failure in recognizing a familiar face. Failure in face recognition could lead to devastating social consequences such as high anxiety and fear of social situation, limited employment opportunities and lowered levels of self-confidence (Dalrymple, Fletcher, et al., 2014; Yardley et al., 2008). Thus, it is crucial to investigate potential rehabilitation methods for prosopagnosia.

Neuropsychological rehabilitation can be classified into two main types: remedial and compensatory (Wilson, 2003). In the rehabilitation of prosopagnosia, both of these approaches have been applied (Bate & Bennetts, 2014). Remedial strategy focuses on improving the normal face recognition mechanisms (i.e., holistic processing) whereas compensatory strategy focuses on developing a compensatory mechanism for face recognition (i.e., facial feature comparison).

In an earlier work, remedial training was given to a prosopagnosic child patient, KD, over a period of 18 months such as photograph matching of familiar and unfamiliar faces and paired discrimination of computer generated schematic faces and images of real faces (Ellis & Young, 1988). The training was ineffective as none of the training tasks improved KD’s face recognition ability. Conversely, another study found that face matching training was effective in improving face perception, even for untrained faces (Bate et al., 2015). The patient also observed the internal facial features (e.g., eyes) more often after the training. This is important because prosopagnosics are often impaired with processing of the internal facial features (Bobak et al., 2017), especially the eyes (DeGutis et al., 2012; Fisher et al., 2016). Additionally, training that involves discrimination of faces that vary in terms of feature size or spacing has been shown to enhance face memory but not face perception, and this enhancement persisted for a duration of two weeks (Bate et al., 2022) and one month (Bate et al., 2020) following the training session. Successful attempts have also been reported using training that involves discriminating variations in whole faces across multiple expressions and viewpoints, with difficulty levels gradually adjusted for subsequent trials (Corrow et al., 2019; Davies-Thompson et al., 2017). The training resulted in improved perceptual sensitivity towards faces, which extended to novel expressions and viewpoints of the trained faces. Additionally, the effect of the training was generalized to novel faces, and the enhancement persisted for three months.

Furthermore, holistic face processing training which involves categorization of faces by spatial configuration (i.e., distance between the nose and mouth) over a period of 14 months was successful in improving the prosopagnosic patient MZ’s face recognition ability (DeGutis et al., 2007). MZ self-reported being better at face recognition, and the benefits of the training were generalized to other face recognition tests as well, such as the Cambridge Face Memory Test (CFMT) and the Benton Facial Recognition Test. However, MZ later reported that improvement from the training declined after several weeks without training, but the retraining process took fewer trials when compared to the original training. In a later study, a similar training method involving face spatial configuration was used in an eight-hour face training (spanned over three weeks) for 24 prosopagnosic patients (DeGutis et al., 2014). Improvements in tasks related to holistic processing and front-view face matching were found, but not for tasks that present faces at different viewing angles. This suggests that the benefit of the training was not extended to recognizing faces when presented from different angles. Although both studies mentioned administered similar methods in their training, the duration of training was evidently different (14 months vs. 3 weeks) which could explain why patient MZ in the 14-month study was able to generalize the benefits to CFMT, which presents faces with different viewing angles, but not the prosopagnosics in the three-week study.

Successful attempts have also been made for the rehabilitation of prosopagnosia using compensatory strategies (Brunsdon et al., 2006; Schmalzl et al., 2008). In one study, prosopagnosic child AL was trained to memorize family members by using age, gender and three prominent features of the face such as size of nostril, freckles and shape of eyebrow (Brunsdon et al., 2006). AL showed and reported improvements in recognizing the trained faces, but the improvement did not extend to faces that were untrained. Using the same training method as Brunsdon et al. (2006), improvement was found in recognizing trained faces in a prosopagnosic child, K (Schmalzl et al., 2008). More importantly, K spent more time observing the internal features of the face after training and this viewing strategy was applied to untrained faces as well. This suggested that after training, K more often utilized internal facial features (e.g., eyes) and showed less reliance on external features (e.g., hair) for face recognition similar to neurotypicals. In a different study, prosopagnosic patient WJ showed improvement in face recognition with facial feature description training where statements about specific features of the target face were provided (e.g., “This is Tracy. She has a large forehead and small eyes.”). (Powell et al., 2008). Overall, these studies demonstrated that compensatory strategies, specifically feature-by-feature recognition training, were beneficial for rehabilitation for prosopagnosia.

However, there may be some limitations to using a compensatory strategy. For instance, a prosopagnosic patient, NE, was trained to recognize faces using a mnemonic method where the name of the person was linked to an object that was phonemically similar in an image, and a prominent facial feature and semantic information were integrated into the same image (e.g., “Carol the doctor” would be memorized as a snowman with large lips (the selected prominent facial feature) singing carols (name of face) with a stethoscope around the neck (semantic information)) (Francis et al., 2002). Although NE showed improvement in the face recognition tasks after training, the deficits in face recognition remained in her daily life. She reported this as a case of competing demands, where she is trying to use the mnemonic method which is a highly contrived method for recognizing and identifying new faces while coping with her more general memory issues such as remembering new routes. Hence, when compared with the benefits from compensatory strategy, the benefits from remedial strategy may be more easily applied in real life as it enhance the normal automatic behavior of recognizing faces.

In sum, there have been successful attempts to use training for the rehabilitation of prosopagnosia, although there were some drawbacks to the training, such as the long duration of the training period. However, it is important to note that the effectiveness of training could differ for every prosopagnosic patient. Factors such as the type of prosopagnosia (i.e., acquired vs. developmental), age, severity (size and location) and impact of the lesion could affect the success rate of the types of face training administered (Bate & Bennetts, 2014). For instance, while patient RJ showed improvement after semantic association (presenting face along with a name and fictitious information) training but not facial feature comparison training (Polster & Rapcsak, 1996), patient WJ demonstrated the opposite effect where improvements were found after facial feature comparison training but not semantic association training (Powell et al., 2008). Based on these findings, it could be concluded that prosopagnosia is a heterogeneous condition and that cognitive training should be individually tailored for each prosopagnosic patient to address their specific area of deficit.

Previous research have shown that face learning could be enhanced by presenting multiple exposures of an identity (Andrews et al., 2015; Dowsett et al., 2016; Matthews & Mondloch, 2018; Menon et al., 2015; Mileva & Burton, 2019; White, Burton, et al., 2014). For example, presenting two images of an identity has been shown to increase face matching accuracy compared to when only one image was available (Menon et al., 2015; White, Burton, et al., 2014). Presenting multiple images of a target identity has also been shown to increase accuracy in recognition of the target in a surveillance video footage (Mileva & Burton, 2019). These studies demonstrate that multiple exposures of a face could enhance learning and recognition of a new identity. Apart from that, different levels of variation during multiple exposure of an identity could affect identity learning (Baker et al., 2017; Menon et al., 2015; Ritchie & Burton, 2017). For instance, face matching accuracy was higher when multiple exposure of a face was in high variability condition (i.e., photos taken on different days which were highly dissimilar) compared to low variability condition (i.e., photos taken on the same day which were highly similar) (Menon et al., 2015). In line with this, a different study has reported higher accuracy in a name verification task and a face matching task when unfamiliar identities were learned in high variability condition compared to low variability condition (Ritchie & Burton, 2017). Taken together, it could be concluded that multiple exposures of a face, especially in high variation could improve learning of a new identity.

Recently, a cost-effective mechanism for face learning have been proposed (Devue et al., 2021; Reedy & Devue, 2019), suggesting that external features are prioritized when presented with stable face appearance (i.e., low variability), while detailed encoding of internal features occurs when there is variability in face appearance (i.e., high variability). Previous studies have shown that individuals with prosopagnosia tend to adopt a different face viewing strategies than neurotypical individuals (Bobak et al., 2017; DeGutis et al., 2012; Fisher et al., 2016). While neurotypical individuals tend to focus on the eyes and mouth regions for successful face recognition (Tardif et al., 2019), prosopagnosics spend less time observing these internal regions (i.e., eyes, nose, and mouth) (Bobak et al., 2017) and exhibit impairments in processing the eyes (DeGutis et al., 2012; Fisher et al., 2016). Individuals with prosopagnosia also often rely on non-facial cues such as voice, gait, clothing, or external features (e.g., hairstyle) for person identification (Adams et al., 2020; Cook & Biotti, 2016). Hence, it is plausible that individuals with prosopagnosia may benefit more from low within-person variability exposure (i.e., stable face appearance) in face learning compared to high within-person variability, as the latter involves consistent changes in external features, which may hinder face learning for individuals with prosopagnosia if they rely mainly on external features of the face.

5.1 Experiment 5

In the current study, we aim to explore if multiple high variability face exposure could enhance face identification compared to low variability face exposure for individuals with suspected developmental prosopagnosia (DP). Suspected DPs and neurotypical participants will be presented with faces with names during the learning stage and tested using a name verification task. Based on previous studies (Baker et al., 2017; Menon et al., 2015; Ritchie & Burton, 2017), we expect enhanced face learning for identities learned in high variability condition compared to low variability condition for neurotypical participants. For suspected DPs, we expect that enhanced face learning would occur for identities learned in low variability condition than high variability condition if they focus mainly on external features for face recognition. In contrast, if suspected DPs could successfully focus on internal features when presented with high within-person variability, we expect enhanced learning would occur for identities learned in high variability condition than low variability condition, as detailed encoding of internal features occurs when there is variability in face appearance.

5.1.1 Methods

Design

A mixed design was used. The within-subject factor was within-person variability (high and low). The between-subject factor was participant diagnosis (suspected DPs and neurotypical). The dependent variables were the accuracy, reaction times and efficiency in the tasks. Reaction times and accuracy were used to calculate the rate-correct score (RCS) (Woltz & Was, 2006), a measure of efficiency. RCS is calculated by the number of correct trials divided by the sum of reaction time for correct and incorrect trials, providing thus a measure that combines accuracy and reaction times. The value of RCS indicates the number of correct trials per second, where a higher value of RCS denotes higher efficiency. RCS has been shown to be more efficient in effect detection and accounting for a larger proportion of the variance compared to other integrative measures of speed and accuracy (Vandierendonck, 2017).

Participants

Purposive sampling method was used to recruit participants. Suspected DPs were recruited by posting the study advertisement on Prosopagnosia/Face blindness support/discussion Facebook groups. We specified in the study advertisement that we were recruiting individuals with difficulties in face recognition or prosopagnosic participants for a face learning study. In total, 23 participants completed four neuropsychological tests which consist of the CFMT, CCMT, Cambridge Face Perception Task (CFPT) and the Autism Spectrum Quotient - 10 items (AQ-10). Eighteen participants were removed due to other-race (one participant), eye condition (i.e., amblyopia) (one participant), high scores on AQ-10 (≥ six) indicative of autism spectrum disorder (seven participants), scored above cut-off calculated by 1.7 standard deviations below the mean on the CFMT (based on mean and standard deviation reported in Duchaine and Nakayama (2006)) (nine participants). We used 1.7 standard deviations below the mean instead of the usual 2.0 standard deviation below the mean as cut-off as in previous works (DeGutis et al., 2012, 2014; Palermo et al., 2017; Tardif et al., 2019) to be more inclusive as some people report severe prosopagnosia symptoms while scoring close to the normal range on the CFMT. Additionally, given that other researchers have often advertised their study that recruits prosopagnosics in the Facebook groups, participants may have completed the CFMT more than once. In total, five Caucasian (four females and one male) suspected DPs were recruited. Suspected DPs' ages ranged from 49 to 64 years (*M* = 55.2 years, *SD* = 6.54 years). The details of the participants are in Table 5.1. Although CFPT scores were not lower than 1.7 standard deviations below the mean for four participants, prosopagnosics who are unable to recognize faces only on memory tests seem to be relatively common (DeGutis et al., 2012, 2014; Y. Lee et al., 2010; McKone et al., 2011; Palermo et al., 2011, 2017).

We also recruited 16 age-matched neurotypical participants. One participant was removed as his CFMT score was below cut-off (calculated by 1.7 standard deviations below the mean), one participant was removed due to high scores on AQ-10 (≥ six) indicative of autism spectrum disorder, two participants were removed due to below chance accuracy level on the experimental task (less than 50%). The ages were matched based on Germine et al. (2011) where ages were grouped as 35-59 years and 60 years and above. Five female participants aged between 35-59 years and seven participants (six female and one male) aged 60 years and above were recruited. Neurotypical participants age ranged between 37 to 68 years (*M* = 56.08 years, *SD* = 11.12 years). Independent samples t-test revealed no difference between neurotypical participants and suspected DPs in age, $t(15) = .164$, $p = .872$. The study has been reviewed and approved by the Science and Engineering Research Ethics Committee (SEREC) in the University of Nottingham Malaysia (approval code: KSK040321).

Table 5.1

Demographic information and raw scores for the suspected developmental prosopagnosics for CFMT, CFPT and CCMT with z scores in parentheses.

Age (years)	Gender	CFMT	CFPT (upright)	CCMT
49	F	44 (−1.76)	42 (−0.43)	59 (0.70)
50	F	35 (−2.90)	44 (−0.60)	44 (−1.10)
53	F	44 (−1.76)	52 (−1.25)	44 (−1.10)
60	F	36 (−2.77)	38 (−0.11)	45 (−0.98)
64	M	39 (−2.39)	76 (−3.22)	54 (0.10)

Note. CFMT = Cambridge Face Memory Test, CFPT = Cambridge Face Perception Test and CCMT = Cambridge Car Memory Test. M = male and F = female.

Apparatus and Materials

The stimuli used in the face learning task were identical to those in Ritchie and Burton (2017) which were kindly provided by the authors. Ten identities (five males and five females) which consisted of Australian celebrities (radio host, comedian, etc.) were used, so participants recruited in this experiment should not be familiar with any of the identities shown in the task. In total, there were 20 high variability images and 10 low variability images for each identity. The high variability images differed in terms of person (hairstyle, age, clothing, facial expression, etc.) and conditions (background, lighting, quality of image, etc.) whereas the low variability images differed in terms facial expression and head angle but not in terms of hairstyle, age, clothing and conditions (background, lighting, quality of image, etc.). The coloured images (260 × 390 pixels) were presented on a grey background. For sample stimuli, please refer to Figure 4.1.

Neuropsychological test

a. Cambridge Face Memory Test (CFMT)

The CFMT measures short-term memory for novel face recognition (Duchaine & Nakayama, 2006). For a detailed description of the procedure for the CFMT, please see Chapter 3, section 3.1.1 Methods, Cambridge Face Memory Test - Chinese (CFMT-Chinese).

b. Cambridge Car Memory Test (CCMT)

The CCMT measures short-term memory for object recognition (Dennett et al., 2012). The procedure for CCMT replicates the CFMT using images of cars instead of faces.

c. Cambridge Face Perception Test (CFPT)

The CFPT (Duchaine et al., 2007) measures perception of faces in the absence of working memory demands. Participants were shown a target face (3/4 profile view) above six frontal-view morphed faces with varying similarity to the target face shown. In total there were 16 trials, half of the trials was presented in an upright manner and the other half was presented in an inverted manner. Participants were given a maximum of one minute to rearrange the faces according to their similarity to the target face shown.

d. Autism Spectrum Quotient - 10 items (AQ-10)

The AQ-10 (C. Allison et al., 2012) is a short form of the Autism Spectrum Quotient (Baron-Cohen et al., 2001) used for assessment of autistic traits. Ten statements were included and participants were required to indicate how much the statement applies to them in a scale (i.e., Definitely agree; Slightly agree; Slightly disagree; Definitely disagree). The statements are listed in Appendix I.

Experimental Task

The face learning task consists of two phases: learning and test. The full procedure for the task is outlined in Chapter 4, section 4.1.1 Methods, Procedure. Only own-race faces (i.e., Caucasian faces) were included in the task. The task took about 15 minutes to complete.

Procedure

Testable was used to run the online experiment (Rezlescu et al., 2020). Participants completed the experiment in two parts. The first part (45 minutes) consists of the neuropsychological tests where participants first complete the CFMT, followed by the CCMT, CFPT and finally the AQ-10. Part two (15 minutes) consists of the name verification task. Following the completion of part 1, participants were given the flexibility to complete part 2 at their convenience. The whole experiment took about one hour to complete.

5.1.2 Results

All data analysis was conducted using JASP (JASP Team, 2022). Participants who had typed the name of the identity with only one incorrect character during the learning phase were included in the analysis (e.g., typing Merrik when the actual name is Merrick). For two participants who had reported familiarity with some of the identities shown in the task (i.e., one and three identities), test trials of the familiar identity were removed prior to analysis.

Neuropsychological test

An independent samples t-test revealed no difference between neurotypical participants and suspected DPs in CCMT scores, $t(15) = -.48$, $p = .64$, $d = -.26$, and CFPT scores, $t(15) = -1.62$, $p = .13$, $d = -.86$. Neurotypical participants scored higher in the CFMT ($M = 62.25$, $SD = 7.09$) compared to suspected DPs ($M = 39.60$, $SD = 4.28$), $t(15) = 6.59$, $p < .001$, $d = 3.51$.

Several modified t-tests were conducted using SINGLIMS software (Crawford et al., 2010; Crawford & Garthwaite, 2002; Crawford & Howell, 1998) to compare each suspected DP to their age-matched control group. All t-tests were one-tailed and p-values were compared to $\alpha = 0.05$. The results for the modified t-tests are presented in Table 5.2. All five suspected DPs scored significantly lower compared to the control group ($M = 62.250$, $SD = 7.086$) in the CFMT. Only one suspected DP (M64) showed a significantly higher error in the CFPT compared to the control group ($M = 37.833$, $SD = 14.409$). No suspected DPs scored differently than controls ($M = 46.833$, $SD = 9.953$) in the CCMT.

Table 5.2

Modified t-statistics results for suspected developmental prosopagnosia on CFMT, CFPT and CCMT.

	Suspected DPs				
Test	F49	F50	F53	F60	M64
CFMT	44	35	44	36	39
	$t(11) = -2.474$	$t(11) = -3.695$	$t(11) = -2.474$	$t(11) = -3.559$	$t(11) = -3.152$
	$p = .015$*	**$p = .002$***	**$p = .015$***	**$p = .002$***	**$p = .005$***
	$z\text{-}cc = -2.576$	$z\text{-}cc = -3.846$	$z\text{-}cc = -2.576$	$z\text{-}cc = -3.704$	$z\text{-}cc = -2.576$
CFPT	42	44	52	38	76
	$t(11) = .278$	$t(11) = .411$	$t(11) = .945$	$t(11) = .011$	$t(11) = 2.545$
	$p = .393$	$p = .344$	$p = .183$	$p = .496$	**$p = .014$***
	$z\text{-}cc = .286$	$z\text{-}cc = .428$	$z\text{-}cc = .983$	$z\text{-}cc = .012$	$z\text{-}cc = 2.649$
CCMT	59	44	44	45	54
	$t(11) = 1.174$	$t(11) = -.273$	$t(11) = -.273$	$t(11) = -.177$	$t(11) = .692$
	$p = .133$	$p = .395$	$p = .395$	$p = .431$	$p = .252$

	$z\text{-}cc$ = 1.222	$z\text{-}cc$ = -.285	$z\text{-}cc$ = -.285	$z\text{-}cc$ = -.184	$z\text{-}cc$ = .720

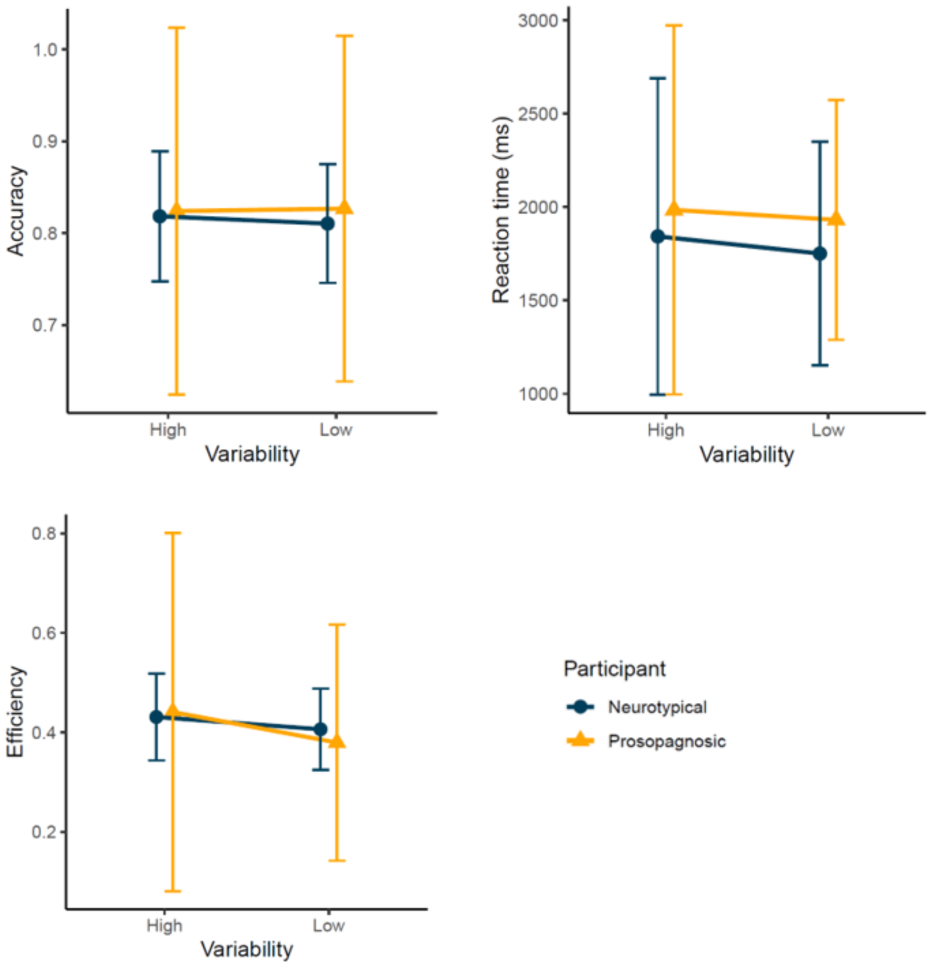
*Note. DP = Developmental prosopagnosia; CFMT = Cambridge Face Memory Test; CFPT = Cambridge Face Perception Test; CCMT = Cambridge Car Memory Test. *indicates scores significantly different than age-matched control group based on modified t-tests (one-tailed t-test, α=0.05).

Name verification task

A 2 (variability: high vs. low) × 2 (participant: neurotypical vs. suspected DPs) mixed ANOVA was conducted on the accuracy (calculated by proportion correct scores) (Figure 5.1). The analysis revealed no main effect of variability, $F(1, 15) = 009$, $p = .924$, $\eta_p^2 = .0006$, or participant, $F(1, 15) = .035$, $p = .855$, $\eta_p^2 = .002$. No interaction effect of variability and participant was found, $F(1, 15) = .038$, $p = .847$, $\eta_p^2 = .003$. A mixed ANOVA was conducted on the median reaction time correct (Figure 5.1). The analysis revealed no main effect of variability, $F(1, 15) = 287$, $p = .600$, $\eta_p^2 = .019$, or participant, $F(1, 15) = .089$, $p = .770$, $\eta_p^2 = .006$. No interaction effect of variability and participant was found, $F(1, 15) = .021$, $p = .888$, $\eta_p^2 = .001$. A mixed ANOVA was also conducted on efficiency calculated by RCS (Figure 5.1). The analysis revealed no main effect of variability, $F(1, 15) = 1.996$, $p = .178$, $\eta_p^2 = .117$, or participant, $F(1, 15) = .010$, $p = .923$, $\eta_p^2 = .0006$. No interaction effect of variability and participant was found, $F(1, 15) = .361$, $p = .557$, $\eta_p^2 = .024$.

Figure 5.1

Accuracy, median reaction time for correct trials and efficiency separated by neurotypical and suspected developmental prosopagnosics.



Note. Error bars represent 95% confidence intervals.

We also ran several modified t-tests comparing the accuracy levels of each suspected DP in high variability and low variability conditions to age-matched controls by using SINGLIMS software (Crawford et al., 2010; Crawford & Garthwaite, 2002; Crawford & Howell, 1998). The results for the modified t-tests are presented in Table 5.3. All five suspected DPs scored similarly to the control group (*M* = .818, *SD* = .111) in the high variability condition. Only one suspected DP (F60) scored significantly lower in the low variability condition compared to the control group (*M* = .810, *SD* = .101).

Table 5.3

Modified t-statistics results for suspected developmental prosopagnosia on accuracy levels of name verification task.

	Suspected DPs				
Name verification task	F49	F50	F53	F60	M64
High variability	.98 $t(11) = 1.402$ $p = .09$ $z\text{-}cc = 1.459$	1 $t(11) = 1.575$ $p = .07$ $z\text{-}cc = 1.640$	.66 $t(11) = -1.368$ $p = .10$ $z\text{-}cc = -1.423$	.80 $t(11) = -.156$ $p = .440$ $z\text{-}cc = -.162$	.68 $t(11) = -1.194$ $p = .129$ $z\text{-}cc = -1.243$
Low variability	.96 $t(11) = 1.427$ $p = .09$ $z\text{-}cc = 1.485$	.93 $t(11) = 1.170$ $p = .133$ $z\text{-}cc = 1.218$	.80 $t(11) = -.095$ $p = .463$ $z\text{-}cc = -.099$	**.58** $\boldsymbol{t(11) = -2.188}$ $\boldsymbol{p = .026}$***** $\boldsymbol{z\text{-}cc = -2.277}$	.86 $t(11) = .476$ $p = .322$ $z\text{-}cc = .495$

*Note. DP = Developmental prosopagnosia, *indicates scores significantly different than age-matched control group based on modified t-tests (one-tailed t-test, α=0.05).

We also ran several modified t-tests comparing reaction time of each suspected DP in the high variability and the low variability condition to age-matched controls by using SINGLIMS software (Crawford et al., 2010; Crawford & Garthwaite, 2002; Crawford & Howell, 1998). The results for the modified t-tests are presented in Table 5.4. All five suspected DPs scored similarly to the control group in the high variability condition (*M* = 1842.625ms, *SD* = 1334.369ms) and the low variability condition (*M* = 1750.583ms, *SD* = 941.501ms).

Table 5.4

Modified t-statistics results for suspected developmental prosopagnosia on reaction time of name verification task.

	Suspected DPs				
Name verification task	F49	F50	F53	F60	M64
<u>High variability</u>	926 $t(11) = -.660$ $p = .261$ $z\text{-}cc = -.687$	1784.5 $t(11) = -.042$ $p = .484$ $z\text{-}cc = -.044$	1691 $t(11) = -.109$ $p = .458$ $z\text{-}cc = -.114$	2554.5 $t(11) = .513$ $p = .309$ $z\text{-}cc = .533$	2965.5 $t(11) = .808$ $p = .218$ $z\text{-}cc = .842$
<u>Low variability</u>	1226 $t(11) = -.535$ $p = .302$ $z\text{-}cc = -.557$	2333.5 $t(11) = .595$ $p = .282$ $z\text{-}cc = .619$	1557.5 $t(11) = -.197$ $p = .424$ $z\text{-}cc = -.205$	2414 $t(11) = .677$ $p = .256$ $z\text{-}cc = .705$	2125 $t(11) = .382$ $p = .355$ $z\text{-}cc = .398$

*Note. DP = Developmental prosopagnosia

5.1.3 Discussion

We aimed to explore in the current study whether multiple high variability face exposure could enhance face identification compared to low variability face exposure for suspected DPs. Our results showed no difference in name verification task performance for identities learned in high variability condition and low variability condition. This showed that there was no effect of variability on face learning for either suspected DPs or neurotypical participants. Interestingly, no difference was found in performance of the name verification task between suspected DPs and neurotypical participants indicating that suspected DPs' face learning ability was comparable to neurotypical participants. Furthermore, in the single case analysis, it was observed that only one suspected DP obtained a significantly lower score under the low variability condition. This implies that suspected DPs were performing similarly to the age-matched control group.

We found no effect of variability on face learning for both prosopagnosic participants and neurotypical participants which contradicts past studies indicating that identities learned in high variability condition were recognized better compared to identities learned in low variability condition

(Baker et al., 2017; Menon et al., 2015; Ritchie & Burton, 2017). Furthermore, our results did not provide evidence to suggest that individuals with prosopagnosia experience greater benefits in face learning from exposure to low variability faces as opposed to high variability faces, despite the latter involving consistent changes in external features that may hinder learning for individuals with prosopagnosia who rely predominantly on such features for face recognition.

One possible reason for this may be the age difference in participants recruited. In previous work, participants recruited were children (aged 6-13 years) (Baker et al., 2017) and adults (i.e., *M* = 20.23 years and *M* = 37.65 years in Baker et al. (2017); *M* = 19.4 in Menon et al. (2015); *M* = 22 years and *M* = 23 years in Ritchie & Burton (2017)). However, the mean age for the participants in the current study was 55.2 years for prosopagnosic participants and 56.08 years for neurotypical participants. Past work has shown that face recognition will continue to improve and peaks around age 30 (Germine et al., 2011) and sensitivity to faces will gradually reduce after age 50 (Logan et al., 2022). Indeed, it has been shown that face memory (Boutet & Meinhardt-Injac, 2021) and face perception (Boutet & Meinhardt-Injac, 2021; Megreya & Bindemann, 2015; Shah, Sowden, et al., 2015) deteriorates with age. Additionally, age-related changes in face viewing strategies including holistic processing (Konar et al., 2013; Schwarzer et al., 2010), dependence on external and internal facial cues (Meinhardt-Injac et al., 2014; Schwarzer et al., 2010) and neural changes in face processing brain regions (Goh et al., 2010; Grady et al., 2000; Jaworska et al., 2020; Thomas et al., 2008) are common. Thus, the middle-aged participants in our sample and adult participants in other studies (Baker et al., 2017; Menon et al., 2015; Ritchie & Burton, 2017) may not show the same effect of learning identities in high variability exposure.

However, the current study has several limitations. One of the limitations was that the sample size for suspected DPs was extremely limited, resulting in low statistical power. Furthermore, suspected DPs were recruited based only on their CFMT scores. It has been suggested that assessment of everyday face recognition difficulties should be included as a part of prosopagnosia diagnosis (Dalrymple & Palermo, 2016). Thus, future studies should include self-report questionnaires assessing face recognition difficulties experienced in daily life, such as the 15-item questionnaire by Kennerknecht et al. (2008) or the 20-item prosopagnosia index (PI20) (Shah, Gaule, et al., 2015) along with objective measures of face recognition ability for prosopagnosia diagnosis (Estudillo & Wong, 2021; Palermo et al., 2017).

Additionally, a recent study has proposed that face recognition deficits in prosopagnosia could stem from two types of face processing deficits: holistic processing and featural processing (Bennetts et al., 2022). Two separate clusters of individuals with developmental prosopagnosia were identified in the study, and the clusters differed in their face inversion task performance, with one cluster showing the typical face inversion effect while the other cluster did not. However, we did not evaluate the specific perceptual deficit within our suspected DP sample in this study, despite the potential impact of such a deficit on the training outcomes.

In sum, we found no effect of variability on face learning for both suspected DPs and neurotypical participants which may be due to the low sample size in the current study.

Chapter 6 – General discussion and conclusion

6.1 Summary of findings

The main aim of the thesis was to explore whether it is possible to improve face recognition skills. To achieve this, we used tDCS (Chapter 2 and Chapter 3) and cognitive training based on face variability (Chapter 4 and Chapter 5). The results from Chapter 2 indicated that multifocal tDCS applied to the FFA led to increased efficiency for facial feature recognition while no effect of OFA stimulation on facial feature and whole face recognition was found. In Chapter 3, our new version of the CFMT, the CFMT-MY, showed high consistency and high reliability and so it is suitable for diagnosing individuals having difficulty in face recognition in clinical settings, measurement of individual differences in face recognition ability and measurement of the other-race effect. Additionally, we found no effect of a-tDCS and c-tDCS on own- and other-race face recognition. The findings from Chapter 4 showed enhanced own-race face learning (i.e., face recognition and face-name association) for identities learned in high variability condition compared to low variability condition. However, identities learned in high variability condition only benefited other-race face recognition, but not face-name association of other-race. We also found no effect of variability on face learning for both prosopagnosic participants and neurotypical participants in Chapter 5.

Effect of tDCS on face recognition

Chapter 2 consisted of two experiments. Experiment 1a required participants to complete whole face and facial features (i.e., eyes, nose, mouth) recognition tasks after OFA and FFA stimulation in a within-subject design. The whole face and facial features presented in the task were computer-generated. In Experiment 1b, we used real faces in the task, provided stimulation following a between-subjects design and included a sham control group. We found no effect of the FFA and the OFA stimulation in recognition of features and whole faces in Experiment 1a. In Experiment 1b, we found that the FFA stimulation increased efficiency for feature recognition while no difference in facial features and whole face recognition was found after the OFA stimulation. The discrepancy in results for Experiment 1a and 1b may be due to the difference in stimuli. Artificial faces and features were used in Experiment 1a while real faces and features were used in Experiment 1b. Artificial faces may not be processed the same as real human faces as they are more difficult to remember and less discriminable compared to real human faces (Balas & Pacella, 2015; Kätsyri, 2018). In addition, recent research showed that transcranial electrical stimulation enhances face identification following a between-subject, but not a within-subject design (Penton et al., 2018). We tested participants before and after the stimulation in Experiment 1b to avoid the effect of differences across groups. Although our findings showed effects of a-tDCS in improving facial feature recognition in Chapter 2, no effect of a-tDCS and c-tDCS was found on recognition of own- and other-face recognition in Experiment 3, Chapter 3. In Experiment 3, participants completed own- and other-race CFMT before and after receiving either anodal tDCS, cathodal tDCS or sham stimulation. Our findings did not replicate previous research suggesting that c-tDCS impair recognition of other-race faces although the same stimulation protocol and face recognition measure were used (Costantino et al., 2017).

The parameters of the tDCS protocols used in Experiment 1 and Experiment 3 differed, which may have contributed to the discrepancy in results between the two experiments. Firstly, the tDCS montage used in the two experiment was different. While the montage used in Experiment 3 was the traditional 2-electrodes tDCS montage using large sponge electrodes which provides low focality stimulation to the target area, Experiment 1 used a multifocal tDCS montage which uses multiple small electrodes to provide better focality of stimulation and a more effective increase in cortical excitability than the traditional tDCS montage (Fischer et al., 2017). Thus, effect of tDCS may be present in Experiment 1 but not Experiment 3 as the multifocal tDCS montage was more effective in increasing cortical excitability compared to the traditional tDCS montage. Next, the current intensity used in Experiment 1 (3.21 mA for FFA stimulation and 3.75 mA for OFA stimulation) was much higher compared to Experiment 3 (1.5 mA for a-tDCS and c-tDCS). Hence, the higher current intensity in Experiment 1 may have led to a more effective tDCS effect in Experiment 1 but not Experiment 3 as past work has suggested that higher current intensity could lead to stronger tDCS effects (Nitsche & Paulus, 2000). However, another study has indicated that the relationship between current intensity and the effect of tDCS is unclear (Esmaeilpour et al., 2018).

While tDCS montage and current intensity may explain the differences in tDCS effects between the two experiments, an absence of effect was also found for the OFA stimulation in Experiment 1, which uses the same tDCS montage and similar current intensity (i.e., ≥ 3 mA) as the FFA stimulation. Even though both OFA and FFA stimulation used multifocal tDCS montage, the number of electrodes, position of each electrode, and current intensity for each electrode differed which may have contributed to the discrepancy in tDCS effects generated by the FFA stimulation and the OFA stimulation. For example, the brain anatomy (i.e., gyri and sulci of the brain) (Datta et al., 2012; Miranda et al., 2013) and the head anatomy (i.e., head size, tissue thickness, head fat, conductivity of the skull, skin and grey matter in the brain) (Bikson et al., 2012; Salvador et al., 2012; Truong et al., 2013) are known to affect the electric field generated by tDCS. Therefore, it seems plausible that these biological factors influenced how the participant received the OFA stimulation, making it less effective. Additionally, previous studies have reported that some participants showed no response to tDCS (López-Alonso et al., 2014; Strube et al., 2015; Wiethoff et al., 2014) and the positive effects of tDCS in face perception is not always found (Willis et al., 2019) indicating that the effect of tDCS may not always be reliable.

Overall, our results indicated that the FFA stimulation improved facial feature recognition and high focality tDCS montage may lead to a more effective tDCS effect as compared to low focality tDCS montage. However, there are some limitations to tDCS studies. While some factors that may affect tDCS effects, including age and hormone levels, are controllable, others, like biological substrate, are more difficult to control and may cause inconsistency in tDCS effects. Furthermore, the exact relationship between current intensity and tDCS effects is still unclear.

Effect of high variation multiple exposure of an identity on face learning

In Chapter 4, participants learned own- and other-race identities in high and low variability condition and were tested with a name verification task (Experiment 4a) and an old-new recognition task

(Experiment 4b). Our results for Experiment 4a showed that identities learned in high variability conditions enhanced own-race face-name association, but not other-race face-name association compared to the identities learned in low variability condition.

The advantage for identities learned in high variability condition may be absent for other-race face-name association due to unfamiliarity of Caucasian participants with Chinese names which deterred face and name matching accuracy for the Chinese identities. In Experiment 4b, our results showed that identities learned in high variability condition enhanced own- and other-race face recognition compared to the identities learned in low variability condition. In sum, the results for Experiment 4a and 4b showed that identities learned in the high variability condition enhanced own-race face learning (i.e., face recognition and face-name association) and other-race face recognition, but not other-race face-name association compared to identities learned in low variability condition. In Chapter 5, suspected DPs and neurotypical participants learned identities in high and low variability condition and were tested with a name verification task (Experiment 5). Contrastingly, we found no effect of variability on face learning for either suspected DPs or neurotypical participants.

The discrepancy in results between Experiment 4 and Experiment 5 may be due to the age difference in participants recruited. Participants' mean age was 22.32 years in Experiment 4a and 21.59 years in Experiment 4b while in Experiment 5 the mean age for suspected DPs were 55.2 years and 56.08 years for neurotypical participants. Previous work has shown that face recognition will continue to improve and peaks around age 30 (Germine et al., 2011) and sensitivity to faces will gradually reduce after age 50 (Logan et al., 2022). Additionally, face memory (Boutet & Meinhardt-Injac, 2021) and face perception (Boutet & Meinhardt-Injac, 2021; Megreya & Bindemann, 2015; Shah, Sowden, et al., 2015) tend to deteriorate with age. Age-related declines in face processing ability are also linked to neural changes in the face processing brain regions (Goh et al., 2010; Grady et al., 2000; Jaworska et al., 2020; Thomas et al., 2008). Face viewing strategies such as holistic processing (Konar et al., 2013; Schwarzer et al., 2010) and dependence on external and internal facial cues (Meinhardt-Injac et al., 2014; Schwarzer et al., 2010) have also been found to change with age.

However, the results from Experiment 5 should be taken with caution, as the study has several limitations. Firstly, the sample size for suspected DPs was extremely limited, resulting in low statistical power. Furthermore, the diagnostic assessment was insufficient, as the suspected DPs were recruited based only on their CFMT scores. Additionally, a recent study has proposed that face recognition deficits in prosopagnosia could stem from two types of face processing deficits: holistic processing and featural processing (Bennetts et al., 2022). However, we did not evaluate the specific perceptual deficit within our suspected DP sample in this study, despite the potential impact of such a deficit on the training outcomes.

Thus, although it is possible that the younger participants recruited in Experiment 4a and 4b may not show the same effect of learning identities in high variability exposure as the older participants recruited in Experiment 5 due to age differences, drawing this conclusion is difficult due to the constraints posed by the limitations in Experiment 5.

The ORE for Caucasian faces among Chinese Malaysian participants

In Chapter 3, our results for Experiment 3 revealed that Chinese Malaysians presented an ORE for Caucasian faces where participants performed better (i.e., higher accuracy) in own-race CFMT (i.e., CFMT-Chinese and CFMT-MY) compared to other-race CFMT (i.e., CFMT-original and CFMT-Aus). Contrastingly, in Chapter 4, our results for Experiment 4a and 4b revealed that Chinese Malaysian did not present an ORE for Caucasian faces where participants performed equally well (i.e., similar accuracy) in recognizing Chinese and Caucasian faces.

The task used to measure face recognition ability in Experiment 3 and Experiment 4a and 4b differed, which may have contributed to the discrepancy in results between the two experiments. Firstly, the stimuli in both experiments were different where greyscale faces with no hair and neutral emotion were presented in Experiment 3 whereas naturalistic face images with hair and varying facial emotions were presented in Experiment 4. Because past studies have shown that natural variability (i.e., difference in appearances (e.g., hair and makeup), lighting and facial emotion) could improve face processing ability (Baker et al., 2017; Menon et al., 2015; Ritchie & Burton, 2017), it is possible that the presentation of naturalistic face images reduced the ORE for Caucasian faces. Furthermore, other-race face recognition usually relies more on external features (e.g., hairstyle) compared to internal features (e.g., shape of eyes) (Havard, 2021; Sporer & Horry, 2011; Wong et al., 2020) suggesting that presence of external features in Experiment 4 may have also contributed to the reduce ORE for Caucasian faces. In line with this, Tan et al. (2012) found that Chinese Malaysian participants recognized East Asian and Western faces equally well with the use of colored face images with hair as stimuli.

Second, the difference in findings between the two experiments may be explained by variation in the learning phase of the task employed in Experiment 3 and Experiments 4. In Experiment 3, the CFMT was employed where each target face was exposed in three different viewing angles (i.e., frontal, left 1/3 profile and right 1/3 profile) whereas in Experiment 4, ten images of high or low variability were presented for each target face. The increased exposure of target faces in Experiment 4 may have contributed to the reduced ORE for Caucasian faces, as previous studies have demonstrated that multiple exposure to faces can improve face processing abilities (Andrews et al., 2015; Dowsett et al., 2016; Matthews & Mondloch, 2018; Menon et al., 2015; Mileva & Burton, 2019; White, Burton, et al., 2014). Moreover, recent research has indicated that face familiarity has a greater impact on face recognition than race (Zhou et al., 2021). As there were more exposure in Experiment 4, participants maybe more familiar with the identities presented, therefore improving recognition Caucasian faces. Additionally, semantic information (i.e., the name) was presented together with the target faces during the learning phase in Experiment 4 but not Experiment 3. Presentation of names with faces could lead to deep encoding of faces which is associated with enhanced face recognition ability (Schwartz & Yovel, 2019). Thus, deep encoding of the target faces may have contributed to the reduced ORE of Caucasian faces among Chinese Malaysian participants.

Although these factors (i.e., stimuli, exposure and name presentation in learning phase) may have reduced the ORE for Caucasian faces among Chinese Malaysian participants, it is important to note that the ORE for Chinese faces still persisted among Caucasian participants in Experiment 4 despite the presence of these factors. Therefore, it could be that in addition to these factors, Chinese Malaysian participants may have reduced ORE for Caucasian faces due to the high exposure of Western culture in Malaysia as evident from the preference of Hollywood films over local films in Malaysia (Kit & Chuan, 2012; Sriganeshvarun & Abdul Aziz, 2019). This is in line with the contact hypothesis where we tend to develop higher level of perceptual expertise for faces that were more often seen in their everyday life (Rossion & Michel, 2011). Viewing Hollywood films may have increased Chinese Malaysian participants' perceptual expertise for Caucasian faces which in turn, reduce the ORE for Caucasian faces. Thus, future studies should include the social contact questionnaire as in Wong et al. (2020) to assess the quality and quantity of contact between Malaysian participants and Caucasian people. However, it is important to note that while some studies propose that exposure and the magnitude of the ORE are not associated (Wong et al., 2020), others have identified a reduction in the ORE with increased exposure (Estudillo et al., 2020).

Additionally, it is possible that Chinese Malaysian participants may show reduced ORE for Caucasian faces as past research have indicated that bilinguals tend to exhibit reduced ORE (Burns, Tree, et al., 2019; Kandel et al., 2016). Given that Malaysia is a multilingual country where several languages including Malay, English, Mandarin and Tamil are widely spoken (David et al., 2017), the lack of ORE observed in Chinese Malaysian participants for Caucasian faces may be attributed to the high prevalence of bilingualism or multilingualism in the country, which could potentially reduce the ORE.

Although Chinese Malaysian participants did not show an ORE for Caucasian faces in terms of accuracy in Experiment 4b, they exhibited an ORE for Caucasian participants in the d’ measure (i.e., higher d’ for Chinese stimuli compared to Caucasian stimuli). The contrasting results between accuracy and d’ measure could potentially be attributed to the fact that in Experiment 4b, accuracy solely encompasses old trials (faces that were previously learned), whereas d' encompasses both old and new trials (faces that were novel). This suggests that the ORE in Chinese Malaysian participants may be more pronounced when they are making decisions to reject faces (i.e., indicating that a face was not seen before) as opposed to confirming familiarity (i.e., acknowledging that a face was previously learnt). Additionally, this ORE was only observed in the high variability condition and was not evident in the low variability condition. However, the precise reasons behind the presence of the ORE in Chinese Malaysian participants exclusively in the high variability condition and its absence in the low variability condition remain unclear. Altogether, this suggests that Chinese Malaysian participants may exhibit inconsistent ORE patterns across different measures and conditions.

6.2 Theoretical and practical implications

Developing an effective way to enhance face recognition ability is not only theoretically relevant, but it is also important for national security and for individuals with certain developmental and neurological disorders that are associated with facial recognition deficit. Occupations such as passport officers and police officers require high facial recognition skills but these individuals are not better than the general population despite having more experience and having received face recognition training (White, Kemp, Jenkins, Matheson, et al., 2014). Additionally, difficulties in face recognition could lead to devastating consequences in an individual's social life such as a high level of anxiety, avoidance of social interaction and lowered level of self-confidence (Yardley et al., 2008). Recognition of other-race faces presents additional challenges for face recognition (Meissner & Brigham, 2001). In situations when it is necessary to identify other-race faces such as passport control and eyewitness identification, the ORE will presumably have detrimental consequences (Davies & Griffiths, 2008; Estudillo, 2021). The ORE may also contribute to difficulties in everyday social interaction (McKone et al., 2021). Hence, we investigated two different methods of improving face recognition ability: tDCS and cognitive training based on face variability.

In terms of tDCS, our findings suggest that multifocal a-tDCS targeting the FFA improved recognition of facial features (i.e., eyes, nose and mouth) presented individually but not whole faces (Experiment 1). Our results also revealed no effect of multifocal a-tDCS targeting the OFA on recognition of facial features and whole faces (Experiment 1). Additionally, we found that a-tDCS and c-tDCS applied to the occipital region had no influence on recognition of both own- and other-race faces (Experiment 3). Taken together, our results indicate a potential benefit of tDCS in improving facial features recognition. However, it is important to acknowledge that improved recognition of facial features may not necessarily translate into enhanced overall face recognition ability, as faces are usually processed holistically or as a whole (Tanaka & Farah, 1993). Despite this, it is possible that the tDCS protocol (e.g., current intensity and montage) used in Experiment 1 and 3 may not have been optimal for face recognition ability enhancement. Therefore, our findings indicated that tDCS could improve facial features recognition, although further research is needed to determine its effectiveness for improving overall face recognition ability.

Our findings in Experiment 1 also indicated the involvement of the FFA in facial feature processing. In line with this, past fMRI studies have shown involvement of the FFA in feature recognition (Dachille et al., 2012; J. Liu et al., 2010). For example, the FFA responded similarly to facial features presented individually and facial features presented in face-like combination (Dachille et al., 2012). Although a different study found that the FFA was more responsive to features that were arranged in a normal configuration compared to a scrambled configuration, this finding showed that the FFA responded to the presence of facial features, even in a scrambled configuration (J. Liu et al., 2010). The involvement of the FFA in feature representation challenged the neuropsychological model of face processing by Haxby et al. (2000) which suggests that the FFA is only involved in the late stages of face processing (i.e., representation of facial identity). Although we did not found involvement of the FFA in whole face processing, this may be due to the lower difficulty of the whole face recognition task in Experiment 1b, causing the effect of tDCS to be present only for facial feature recognition and not whole face recognition (Popescu et al., 2016; Reteig et al., 2017; Vergallito et al., 2018). Thus, our results showed involvement of the FFA in facial feature representation, and that FFA may have overlapping roles in face processing, where it is involved in the representation of facial features together with whole faces.

In terms of cognitive training based on face variability, our results revealed that identities learned in high variability condition enhanced own-race face learning (i.e., face recognition and face-name association) and other-race face recognition, but not face-name association of other-race (Experiment 4), however, this benefit did not extend to older adults (Experiment 5). Although this benefit could not be applied during simultaneous face matching as in identity verification procedures (Ritchie et al., 2021; Sandford & Ritchie, 2021) and is not transferable to novel untrained identities (Dowsett et al., 2016; Matthews & Mondloch, 2018), the ability to swiftly familiarise individuals with new identities by exposing them to high within-person variation may still be valuable in certain applied situations. For instance, this method of learning new identities could be employed when searching for a specific own- or other-race criminal in a large crowd. Additionally, this method could be used by individuals with face recognition deficits when searching for a friend or family member in a large crowd. However, we found no effect of variability in face learning for suspected DPs in Experiment 5 which may be due to the low sample size of suspected DPs. Therefore, further studies are required to examine the effect of multiple exposure of identity in high variation among prosopagnosic participants.

Furthermore, in line with previous studies suggesting that familiar faces with strong representation in the memory are built up from multiple exposure of a face in different context (Burton et al., 2005; Jenkins & Burton, 2011; Johnston & Edmonds, 2009), our findings from Experiment 4b showed that high variability presentation of an identity produced stronger representations of own- and other-race faces. Although past research has suggested that external features are prioritized when presented with stable face appearances (i.e., low variability) (Devue et al., 2021; Reedy & Devue, 2019) and when processing other-race faces (Havard, 2021; Sporer & Horry, 2011; Wong et al., 2020), low variability presentation of an identity did not benefit other-race face learning. Instead, participants in our study were able to focus on the internal features of other-race faces in the high variability condition, resulting in detailed encoding of internal features (Devue et al., 2021; Reedy & Devue, 2019) and enhanced learning of other-race faces.

In Experiment 2a and 2b, we created and evaluated a new version of an Asian CFMT, the CFMT-MY. Our evaluation across two experiments showed that the CFMT-MY had high consistency and high reliability, and so is suitable for diagnosing individuals with difficulty in face recognition in clinical settings, measurement of individual differences in face recognition ability and measurement of the other-race effect. Although two versions of the Caucasian CFMT are available (Duchaine & Nakayama, 2006;

McKone et al., 2011), currently there is only one Asian CFMT version available for use (McKone et al., 2012). Hence, the availability of CFMT-MY is important in aiding the diagnosis of borderline cases of prosopagnosia in Asia. For example, although repeating the same test could provide a more reliable score, this could lead to some issues (McCaffrey & Westervelt, 1995) such as increased familiarity with the target faces in the test which could lead to higher scores the second time the test is taken (Murray & Bate, 2020). In this case, the familiarity effect could be eliminated by using a complementary version of the CFMT which present a different set of face stimuli (Murray & Bate, 2020). The availability of a complementary version of the CFMT is also valuable for pre-post training comparison to assess the effectiveness of face training protocols (e.g., Bate et al., 2019; Corrow et al., 2019; Davies-Thompson et al., 2017).

6.3 Limitations and future research

As discussed in Chapter 1 (section 1.2.1: Factors that modulate the effectiveness of different TES techniques), the effectiveness of TES can be modulated by several factors such as the TES protocol, state of brain, hormones, age and individual differences, which is a common limitation for TES studies. While some factors that may affect the stimulation including age and hormone levels, are controllable, other factors, such as biological substrate (e.g., head size and skull thickness), are more difficult to control and may cause inconsistency in tDCS effects. Ideally, factors such as biological substrate should be controlled using a within-subjects design, however there is also the presence of intra-individual differences in tDCS effects across different testing sessions (Dyke et al., 2016). The current ideal strategy to increase the validity of TES studies is to increase the power of the study which will increase the chances of detecting a true effect (Minarik et al., 2016). One limitation in Experiment 3 is the lack of Caucasian participants for a cross-cultural comparison tDCS study. Previous research has demonstrated that cultural variations may result in differential face processing strategies (Blais et al., 2008; Jack et al., 2009; Kelly et al., 2011). Hence, it would be valuable for future research to examine if the absence of tDCS effects found in our experiment with Chinese Malaysian participants is due to cultural differences (i.e., Eastern vs. Western) in face processing strategies as previous work reporting successes in improvement of face processing ability using tDCS mostly recruited Caucasian participants (e.g., Barbieri et al., 2016; Brunyé et al., 2017).

In this thesis, we have investigated one form of TES which is the tDCS applied to the occipital cortex. Future studies could further investigate the effect of other forms of TES in face recognition as some successes in improving face perception and facial emotions have been reported using tACS (Gonzalez-Perez et al., 2019; Janik et al., 2015) and tRNS (Estudillo et al., 2023; Romanska et al., 2015; T. Yang & Banissy, 2017). Additionally, further investigations on the target stimulation region other than the occipital cortex could be conducted such as the anterior temporal lobes (Ross et al., 2010, 2011), orbitofrontal cortex (Willis et al., 2015) and dorsolateral prefrontal cortex (Civile et al., 2021) for face processing improvement. Previous research has also reported long-term (i.e., three to six months) cognitive enhancements when TES was applied over several training sessions such as improvement of motor skill (Reis et al., 2009) and numerical skills (Cohen Kadosh et al., 2010; Snowball et al., 2013). Thus, subsequent studies could also investigate the effects of TES coupled with face training sessions in long-term improvement of face processing abilities.

Replicability of studies has been a critical issue in the area of psychological research over the past years (Pashler & Wagenmakers, 2012). This issue can be observed in TES research as well as the number of failures to replicate the positive effects of TES is increasing. For instance, failures in replicating the positive effects of TES were found in terms of mood and emotion (Koenigs et al., 2009), working memory (Nilsson et al., 2015, 2017), verbal fluency (Vannorsdall et al., 2016), spatial attention (Learmonth et al., 2017) and face perception (Willis et al., 2019). These studies demonstrated the inconsistency in TES literature. The TES literature may also be subjected to publication bias and underpowered studies (Medina & Cason, 2017; Minarik et al., 2016). Additionally, the effect of tDCS may not always be reliable as some participants showed no response to TES (Horvath et al., 2015; López-Alonso et al., 2014; Strube et al., 2015; Wiethoff et al., 2014). Hence, subsequent research will need to increase the evidential value of future TES studies.

Next, the suspected DPs sample in Experiment 5 was extremely limited and the sample were selected solely on the basis of their CFMT results. It has been proposed that prosopagnosia diagnosis should include an evaluation of daily facial recognition challenges as well (Dalrymple & Palermo, 2016). Therefore, along with objective measures of face recognition ability for prosopagnosia diagnosis (Estudillo & Wong, 2021; Palermo et al., 2017), future studies should include self-report questionnaires assessing face recognition difficulties experiences in daily life, such as the 15-item questionnaire by Kennerknecht et al. (2008) or the 20-item prosopagnosia index (PI20) (Shah, Gaule, et al., 2015). Additionally, a recent study has proposed that face recognition deficits in prosopagnosia could stem from two types of face processing deficits: holistic processing and featural processing (Bennetts et al., 2022). However, we did not evaluate the specific perceptual deficit within our suspected DP sample in this study, despite the potential impact of such a deficit on the training outcomes. Future study should assess the specific perceptual deficit of the prosopagnosic sample when evaluating face training outcomes.

6.4 Conclusion

The main aim of the thesis was to examine the effect of tDCS and cognitive training based on face variability on the improvement of face recognition skills. Overall, our results showed that FFA stimulation improved facial feature recognition while no effect of the OFA stimulation was found. Additionally, we found no effect of a-tDCS and c-tDCS on own- and other-race face recognition. This suggest that high focality tDCS montage may lead to a more effective tDCS effect as compared to low focality tDCS montage. However, it is important to acknowledge that improved recognition of facial features may not necessarily translate into enhanced overall face recognition ability, as faces are usually processed holistically or as a whole (Tanaka & Farah, 1993). Therefore, further research is needed to determine the optimal TES protocol for improving overall face recognition ability. Next, our results showed enhanced own-race face learning (i.e., face recognition and face-name association) for identities learned in high variability condition compared to low variability condition. However, identities learned in high variability condition only benefited other-race face recognition, but not face-name association of other-race. We also found no advantage of identities learned in high variability on face learning for both suspected DPs and neurotypical participants. However, this discrepancy in results could be due to the low sample size in suspected DPs and neurotypical participants in Experiment 5. Finally, we created a new Asian CFMT version (CFMT-MY) the evaluation of which showed high consistency and high reliability and which is therefore exhibit potential utility in facilitating diagnosis of individuals with difficulty in face recognition in clinical settings, measurement of individual differences in face recognition ability and measurement of the other-race effect.

References

Ackerman, J. M., Shapiro, J. R., Neuberg, S. L., Kenrick, D. T., Becker, D. V., Griskevicius, V., Maner, J. K., & Schaller, M. (2006). They all look the same to me (unless they're angry): From out-group homogeneity to out-group heterogeneity. *Psychological Science*, *17*(10), 836–840. https://doi.org/10.1111/j.1467-9280.2006.01790.x

Adams, A., Hills, P. J., Bennetts, R. J., & Bate, S. (2020). Coping strategies for developmental prosopagnosia. *Neuropsychological Rehabilitation*, *30*(10), 1996–2015. https://doi.org/10.1080/09602011.2019.1623824

Alenezi, H. M., & Bindemann, M. (2013). The Effect of Feedback on Face-Matching Accuracy. *Applied Cognitive Psychology*, *27*(6), 735–753. https://doi.org/10.1002/acp.2968

Allison, C., Auyeung, B., & Baron-Cohen, S. (2012). Toward brief "red flags" for autism screening: The short Autism Spectrum Quotient and the short Quantitative Checklist in 1,000 cases and 3,000 controls. *Journal of the American Academy of Child and Adolescent Psychiatry*, *51*(2), 202–212. https://doi.org/10.1016/j.jaac.2011.11.003

Allison, T., Puce, A., & McCarthy, G. (2000). Social perception from visual cues: role of the STS region. *Trends in Cognitive Sciences*, *4*(7), 267–278.

Alonzo, A., Brassil, J., Taylor, J. L., Martin, D., & Loo, C. K. (2012). Daily transcranial direct current stimulation (tDCS) leads to greater increases in cortical excitability than second daily transcranial direct current stimulation. *Brain Stimulation*, *5*(3), 208–213. https://doi.org/10.1016/j.brs.2011.04.006

Ambrus, G. G., Amado, C., Krohn, L., & Kovács, G. (2019). TMS of the occipital face area modulates cross-domain identity priming. *Brain Structure and Function*, *224*(1), 149–157. https://doi.org/10.1007/s00429-018-1768-0

Ambrus, G. G., Windel, F., Burton, A. M., & Kovács, G. (2017). Causal evidence of the involvement of the right occipital face area in face-identity acquisition. *NeuroImage*, *148*, 212–218.

https://doi.org/10.1016/j.neuroimage.2017.01.043

Andrews, S., Jenkins, R., Cursiter, H., & Burton, A. M. (2015). Telling faces together: Learning new faces through exposure to multiple instances. *Quarterly Journal of Experimental Psychology*, *68*(10), 2041–2050. https://doi.org/10.1080/17470218.2014.1003949

Ankri, Y. L. E., Braw, Y., Luboshits, G., & Meiron, O. (2020). The effects of stress and transcranial direct current stimulation (tDCS) on working memory: A randomized controlled trial. *Cognitive, Affective and Behavioral Neuroscience*, *20*(1), 103–114. https://doi.org/10.3758/s13415-019-00755-7

Antal, A., Alekseichuk, I., Bikson, M., Brockmöller, J., Brunoni, A. R., Chen, R., Cohen, L. G., Dowthwaite, G., Ellrich, J., Flöel, A., Fregni, F., George, M. S., Hamilton, R., Haueisen, J., Herrmann, C. S., Hummel, F. C., Lefaucheur, J. P., Liebetanz, D., Loo, C. K., … Paulus, W. (2017). Low intensity transcranial electric stimulation: Safety, ethical, legal regulatory and application guidelines. *Clinical Neurophysiology*, *128*(9), 1774–1809. https://doi.org/10.1016/j.clinph.2017.06.001

Antal, A., Terney, D., Poreisz, C., & Paulus, W. (2007). Towards unravelling task-related modulations of neuroplastic changes induced in the human motor cortex. *European Journal of Neuroscience*, *26*(9), 2687–2691. https://doi.org/10.1111/j.1460-9568.2007.05896.x

Anzures, G., & Mildort, M. (2021). Do perceptual expertise and implicit racial bias predict early face-sensitive ERP responses? *Brain and Cognition*, *147*(December 2020), 105671. https://doi.org/10.1016/j.bandc.2020.105671

Arrington, M., Elbich, D., Dai, J., Duchaine, B., & Scherf, K. S. (2022). Introducing the female Cambridge face memory test – long form (F-CFMT+). *Behavior Research Methods*, *17*(10), 841. https://doi.org/10.3758/s13428-022-01805-8

Avidan, G., Tanzer, M., & Behrmann, M. (2011). Impaired holistic processing in congenital prosopagnosia. *Neuropsychologia*, *49*(9), 2541–2552. https://doi.org/10.1016/j.neuropsychologia.2011.05.002

Baker, K. A., Laurence, S., & Mondloch, C. J. (2017). How does a newly encountered face become familiar? The effect of within-person variability on adults' and children's perception of identity. *Cognition*, *161*, 19–30. https://doi.org/10.1016/j.cognition.2016.12.012

Balas, B., & Pacella, J. (2015). Artificial faces are harder to remember. *Computers in Human Behavior*, *52*, 331–337. https://doi.org/10.1016/j.chb.2015.06.018

Barbieri, M., Negrini, M., Nitsche, M. A., & Rivolta, D. (2016). Anodal-tDCS over the human right occipital cortex enhances the perception and memory of both faces and objects. *Neuropsychologia*, *81*, 238–244. https://doi.org/10.1016/j.neuropsychologia.2015.12.030

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism-Spectrum Quotient (AQ): Evidence from Asperger Syndrome/High-Functioning Autism, Males and Females, Scientists and Mathematicians. *Journal of Autism and Developmental Disorders*, *31*(1), 5–17. https://doi.org/10.1023/A:1005653411471

Barton, J. J. S. (2008). Structure and function in acquired prosopagnosia: Lessons from a series of 10 patients with brain damage. *Journal of Neuropsychology*, *2*(1), 197–225. https://doi.org/10.1348/174866407X214172

Bate, S., Adams, A., & Bennetts, R. J. (2020). Guess who? Facial identity discrimination training improves face memory in typically developing children. *Journal of Experimental Psychology: General*, *149*(5), 901–913. https://doi.org/10.1037/xge0000689

Bate, S., Bennetts, R., Hasshim, N., Portch, E., Murray, E., Burns, E., & Dudfield, G. (2019). The limits of super recognition: An other-ethnicity effect in individuals with extraordinary face recognition skills. *Journal of Experimental Psychology: Human Perception and Performance*, *45*(3), 363–377. https://doi.org/10.1037/xhp0000607

Bate, S., & Bennetts, R. J. (2014). The rehabilitation of face recognition impairments: a critical review and future directions. *Frontiers in Human Neuroscience*, *8*. https://doi.org/10.3389/fnhum.2014.00491

Bate, S., Bennetts, R. J., Gregory, N., Tree, J. J., Murray, E., Adams, A., Bobak, A. K., Penton, T., Yang, T., & Banissy, M. J. (2019). Objective patterns of face recognition deficits in 165 adults with self-reported developmental prosopagnosia. *Brain Sciences*, *9*(6), 133. https://doi.org/10.3390/brainsci9060133

Bate, S., Bennetts, R., Mole, J. A., Ainge, J. A., Gregory, N. J., Bobak, A. K., & Bussunt, A. (2015). Rehabilitation of face-processing skills in an adolescent with prosopagnosia: Evaluation of an online perceptual training programme. *Neuropsychological Rehabilitation*, *25*(5), 733–762. https://doi.org/10.1080/09602011.2014.973886

Bate, S., Bennetts, R., Parris, B. A., Bindemann, M., Udale, R., & Bussunt, A. (2014). Oxytocin increases bias, but not accuracy, in face recognition line-ups. *Social Cognitive and Affective Neuroscience*, *10*(7), 1010–1014. https://doi.org/10.1093/scan/nsu150

Bate, S., Cook, S. J., Duchaine, B., Tree, J. J., Burns, E. J., & Hodgson, T. L. (2014). Intranasal inhalation of oxytocin improves face processing in developmental prosopagnosia. *Cortex*, *50*, 55–63. https://doi.org/10.1016/j.cortex.2013.08.006

Bate, S., Dalrymple, K., & Bennetts, R. J. (2022). Face recognition improvements in adults and children with face recognition difficulties. *Brain Communications*, *4*(2). https://doi.org/10.1093/braincomms/fcac068

Bate, S., & Dudfield, G. (2019). Subjective assessment for super recognition: an evaluation of self-report methods in civilian and police participants. *PeerJ*, *7*, e6330. https://doi.org/10.7717/peerj.6330

Bate, S., & Tree, J. J. (2017). The definition and diagnosis of developmental prosopagnosia. *Quarterly Journal of Experimental Psychology*, *70*(2), 193–200. https://doi.org/10.1080/17470218.2016.1195414

Batsikadze, G., Moliadze, V., Paulus, W., Kuo, M. F., & Nitsche, M. A. (2013). Partially non-linear stimulation intensity-dependent effects of direct current stimulation on motor cortex excitability in humans. *Journal of Physiology*, *591*(7), 1987–2000. https://doi.org/10.1113/jphysiol.2012.249730

BBC News. (2011). *DNA clears Cornelius Dupree from 30 years in Texas jail*. https://www.bbc.com/news/world-us-canada-12115208

Behrmann, M., Avidan, G., Marotta, J. J., & Kimchi, R. (2005). Detailed exploration of face-related processing in congenital prosopagnosia: 1. Behavioral findings. *Journal of Cognitive Neuroscience*, *17*(7), 1130–1149. https://doi.org/10.1162/0898929054475154

Bennetts, R. J., Gregory, N. J., Tree, J., Di Bernardi Luft, C., Banissy, M. J., Murray, E., Penton, T., & Bate, S. (2022). Face specific inversion effects provide evidence for two subtypes of developmental prosopagnosia. *Neuropsychologia*, *174*, 108332. https://doi.org/10.1016/j.neuropsychologia.2022.108332

Bennetts, R. J., Murray, E., Boyce, T., & Bate, S. (2017). Prevalence of face recognition deficits in middle childhood. *Quarterly Journal of Experimental Psychology*, *70*(2), 234–258. https://doi.org/10.1080/17470218.2016.1167924

Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience*, *8*(6), 551–565. https://doi.org/10.1162/jocn.1996.8.6.551

Bernstein, M. J., Young, S. G., & Hugenberg, K. (2007). The Cross-Category Effect: Mere Social Categorization Is Sufficient to Elicit an Own-Group Bias in Face Recognition. *Psychological Science*, *18*(8), 706–712. https://doi.org/10.1111/j.1467-9280.2007.01964.x

Berryhill, M. E., & Jones, K. T. (2012). tDCS selectively improves working memory in older adults with more education. *Neuroscience Letters*, *521*(2), 148–151. https://doi.org/10.1016/j.neulet.2012.05.074

Bikson, M., Inoue, M., Akiyama, H., Deans, J. K., Fox, J. E., Miyakawa, H., & Jefferys, J. G. R. (2004). Effect of uniform extracellular DC electric fields on excitability in rat hippocampal slices in vitro. *Journal of Physiology*, *557*(1), 175–190. https://doi.org/10.1113/jphysiol.2003.055772

Bikson, M., Rahman, A., & Datta, A. (2012). Computational models of transcranial direct current stimulation. *Clinical EEG and Neuroscience*, *43*(3), 176–183. https://doi.org/10.1177/1550059412445138

Bindemann, M., & Sandford, A. (2011). Me, myself, and I: Different recognition rates for three photo-IDs of the same person. *Perception*, *40*(5), 625–627. https://doi.org/10.1068/p7008

Biotti, F., Wu, E., Yang, H., Jiahui, G., Duchaine, B., & Cook, R. (2017). Normal composite face effects in developmental prosopagnosia. *Cortex*, *95*(6), 63–76. https://doi.org/10.1016/j.cortex.2017.07.018

Blais, C., Jack, R. E., Scheepers, C., Fiset, D., & Caldara, R. (2008). Culture Shapes How We Look at Faces. *PLoS ONE*, *3*(8), e3022. https://doi.org/10.1371/journal.pone.0003022

Blandón-Gitlin, I., Pezdek, K., Saldivar, S., & Steelman, E. (2014). Oxytocin eliminates the own-race bias in face recognition memory. *Brain Research*, *1580*, 180–187. https://doi.org/10.1016/j.brainres.2013.07.015

Bobak, A. K., Mileva, V. R., & Hancock, P. J. B. (2019). Facing the facts: Naive participants have only moderate insight into their face recognition and face perception abilities. *Quarterly Journal of Experimental Psychology*, *72*(4), 872–881. https://doi.org/10.1177/1747021818776145

Bobak, A. K., Parris, B. A., Gregory, N. J., Bennetts, R. J., & Bate, S. (2017). Eye-movement strategies in developmental prosopagnosia and “super” face recognition. *Quarterly Journal of Experimental Psychology*, *70*(2), 201–217. https://doi.org/10.1080/17470218.2016.1161059

Boggio, P. S., Sultani, N., Fecteau, S., Merabet, L., Mecca, T., Pascual-Leone, A., Basaglia, A., & Fregni, F. (2008). Prefrontal cortex modulation using transcranial DC stimulation reduces alcohol craving: A double-blind, sham-controlled study. *Drug and Alcohol Dependence*, *92*(1–3), 55–60. https://doi.org/10.1016/j.drugalcdep.2007.06.011

Bona, S., Cattaneo, Z., & Silvanto, J. (2016). Investigating the Causal Role of rOFA in Holistic Detection of Mooney Faces and Objects: An fMRI-guided TMS Study. *Brain Stimulation*, *9*(4), 594–600. https://doi.org/10.1016/j.brs.2016.04.003

Bortolon, C., Capdevielle, D., & Raffard, S. (2015). Face recognition in schizophrenia disorder: A comprehensive review of behavioral, neuroimaging and neurophysiological studies. *Neuroscience and Biobehavioral Reviews*, *53*, 79–107. https://doi.org/10.1016/j.neubiorev.2015.03.006

Boutet, I., & Meinhardt-Injac, B. (2021). Measurement of individual differences in face-identity processing abilities in older adults. *Cognitive Research: Principles and Implications*, *6*, 48.

https://doi.org/10.1186/s41235-021-00310-4

Bowles, D. C., McKone, E., Dawel, A., Duchaine, B., Palermo, R., Schmalzl, L., Rivolta, D., Wilson, C. E., & Yovel, G. (2009). Diagnosing prosopagnosia: Effects of ageing, sex, and participant–stimulus ethnic match on the Cambridge Face Memory Test and Cambridge Face Perception Test. *Cognitive Neuropsychology*, *26*(5), 423–455. https://doi.org/10.1080/02643290903343149

Bruce, V. (1982). Changing faces: Visual and non-visual coding processes in face recognition. *British Journal of Psychology*, *73*(1), 105–116. https://doi.org/10.1111/j.2044-8295.1982.tb01795.x

Bruce, V., Bindemann, M., & Lander, K. (2018). Individual differences in face perception and person recognition. *Cognitive Research: Principles and Implications*, *3*, 18. https://doi.org/10.1186/s41235-018-0109-4

Bruce, V., Henderson, Z., Greenwood, K., Hancock, P. J. B., Burton, A. M., & Miller, P. (1999). Verification of face identities from images captured on video. *Journal of Experimental Psychology: Applied*, *5*(4), 339–360. https://doi.org/10.1037/1076-898X.5.4.339

Bruce, V., Henderson, Z., Newman, C., & Burton, A. M. (2001). Matching identities of familiar and unfamiliar faces caught on CCTV images. *Journal of Experimental Psychology: Applied*, *7*(3), 207–218. https://doi.org/10.1037/1076-898X.7.3.207

Bruce, V., & Young, A. (1986). Understanding face recognition. *British Journal of Psychology*, *77*(3), 305–327. https://doi.org/10.1111/j.2044-8295.1986.tb02199.x

Brunoni, A. R., & Vanderhasselt, M. A. (2014). Working memory improvement with non-invasive brain stimulation of the dorsolateral prefrontal cortex: A systematic review and meta-analysis. *Brain and Cognition*, *86*, 1–9. https://doi.org/10.1016/j.bandc.2014.01.008

Brunsdon, R., Coltheart, M., Nickels, L., & Joy, P. (2006). Developmental prosopagnosia: A case analysis and treatment study. *Cognitive Neuropsychology*, *23*(6), 822–840. https://doi.org/10.1080/02643290500441841

Brunyé, T. T., Holmes, A., Cantelon, J., Eddy, M. D., Gardony, A. L., Mahoney, C. R., & Taylor, H. A. (2014). Direct current brain stimulation enhances navigation efficiency in individuals with low spatial sense of direction. *NeuroReport*, *25*(15), 1175–1179. https://doi.org/10.1097/WNR.0000000000000214

Brunyé, T. T., Moran, J. M., Holmes, A., Mahoney, C. R., & Taylor, H. A. (2017). Non-invasive brain stimulation targeting the right fusiform gyrus selectively increases working memory for faces. *Brain and Cognition*, *113*, 32–39. https://doi.org/10.1016/j.bandc.2017.01.006

Bukach, C. M., Bub, D. N., Gauthier, I., & Tarr, M. J. (2006). Perceptual expertise effects are not all or none: Spatially limited perceptual expertise for faces in a case of prosopagnosia. *Journal of Cognitive Neuroscience*, *18*(1), 48–63. https://doi.org/10.1162/089892906775250094

Bukowski, H., Dricot, L., Hanseeuw, B., & Rossion, B. (2013). Cerebral lateralization of face-sensitive areas in left-handers: Only the FFA does not get it right. *Cortex*, *49*(9), 2583–2589. https://doi.org/10.1016/j.cortex.2013.05.002

Burns, E. J., Arnold, T., & Bukach, C. M. (2019). P-curving the fusiform face area: Meta-analyses support the expertise hypothesis. *Neuroscience and Biobehavioral Reviews*, *104*(July), 209–221. https://doi.org/10.1016/j.neubiorev.2019.07.003

Burns, E. J., Tree, J., Chan, A. H. D., & Xu, H. (2019). Bilingualism shapes the other race effect. *Vision Research*, *157*, 192–201. https://doi.org/10.1016/j.visres.2018.07.004

Burton, A. M., Jenkins, R., Hancock, P. J. B., & White, D. (2005). Robust representations for face recognition: The power of averages. *Cognitive Psychology*, *51*(3), 256–284. https://doi.org/10.1016/j.cogpsych.2005.06.003

Burton, A. M., White, D., & McNeill, A. (2010). The glasgow face matching test. *Behavior Research Methods*, *42*(1), 286–291. https://doi.org/10.3758/BRM.42.1.286

Busigny, T., Joubert, S., Felician, O., Ceccaldi, M., & Rossion, B. (2010). Holistic perception of the individual face is specific and necessary: Evidence from an extensive case study of acquired prosopagnosia. *Neuropsychologia*, *48*(14), 4057–4092. https://doi.org/10.1016/j.neuropsychologia.2010.09.017

Busigny, T., & Rossion, B. (2010). Acquired prosopagnosia abolishes the face inversion effect. *Cortex*, *46*(8), 965–981. https://doi.org/10.1016/j.cortex.2009.07.004

Campana, G., Camilleri, R., Moret, B., Ghin, F., & Pavan, A. (2016). Opposite effects of high- and low-frequency transcranial random noise stimulation probed with visual motion adaptation. *Scientific Reports*, *6*, 38919. https://doi.org/10.1038/srep38919

Cassidy, K. D., Boutsen, L., Humphreys, G. W., & Quinn, K. A. (2014). Ingroup categorization affects the structural encoding of other-race faces: Evidence from the N170 event-related potential. *Social Neuroscience*, *9*(3), 235–248. https://doi.org/10.1080/17470919.2014.884981

Cavazos, J. G., Noyes, E., & O'Toole, A. J. (2019). Learning context and the other-race effect: Strategies for improving face recognition. *Vision Research*, *157*, 169–183. https://doi.org/10.1016/j.visres.2018.03.003

Chaieb, L., Antal, A., & Paulus, W. (2008). Gender-specific modulation of short-term neuroplasticity in the visual cortex induced by transcranial direct current stimulation. *Visual Neuroscience*, *25*(1), 77–81. https://doi.org/10.1017/S0952523808080097

Chaieb, L., Paulus, W., & Antal, A. (2011). Evaluating Aftereffects of Short-Duration Transcranial Random Noise Stimulation on Cortical Excitability. *Neural Plasticity*, *2011*, 105927. https://doi.org/10.1155/2011/105927

Childs, M. J., Jones, A., Thwaites, P., Zdravković, S., Thorley, C., Suzuki, A., Shen, R., Ding, Q., Burns, E., Xu, H., & Tree, J. J. (2021). Do individual differences in face recognition ability moderate the other ethnicity effect? *Journal of Experimental Psychology: Human Perception and Performance*, *47*(7), 893–907. https://doi.org/10.1037/xhp0000762

Civile, C., McLaren, R., Milton, F., & McLaren, I. P. L. (2021). The effects of transcranial direct current stimulation on perceptual learning for upright faces and its role in the composite face effect. *Journal of Experimental Psychology: Animal Learning and Cognition*, *47*(1), 74–90. https://doi.org/10.1037/xan0000274

Cohen Kadosh, R., Soskic, S., Iuculano, T., Kanai, R., & Walsh, V. (2010). Modulating neuronal activity produces specific and long-lasting changes in numerical competence. *Current Biology*, *20*(22), 2016–2020. https://doi.org/10.1016/j.cub.2010.10.007

Collishaw, S. M., & Hole, G. J. (2000). Featural and configurational processes in the recognition of faces of different familiarity. *Perception*, *29*(8), 893–909. https://doi.org/10.1068/p2949

Cook, R., & Biotti, F. (2016). Developmental prosopagnosia. *Current Biology*, *26*(8), R312–R313. https://doi.org/10.1016/j.cub.2016.01.008

Corpuz, R. L., & Oriet, C. (2022). Within-Person Variability Contributes to More Durable Learning of Faces. *Canadian Journal of Experimental Psychology*, *76*(4), 270–282. https://doi.org/10.1037/cep0000282

Corrow, S. L., Albonico, A., & Barton, J. J. S. (2018). Diagnosing Prosopagnosia: The Utility of Visual Noise in the Cambridge Face Recognition Test. *Perception*, *47*(3), 330–343. https://doi.org/10.1177/0301006617750045

Corrow, S. L., Davies-Thompson, J., Fletcher, K., Hills, C., Corrow, J. C., & Barton, J. J. S. (2019). Training face perception in developmental prosopagnosia through perceptual learning. *Neuropsychologia*, *134*, 107196. https://doi.org/10.1016/j.neuropsychologia.2019.107196

Costantino, A. I., Titoni, M., Bossi, F., Premoli, I., Nitsche, M. A., & Rivolta, D. (2017). Preliminary Evidence of “Other-Race Effect”-Like Behavior Induced by Cathodal-tDCS over the Right Occipital Cortex, in the Absence of Overall Effects on Face/Object Processing. *Frontiers in Neuroscience*, *11*, 661. https://doi.org/10.3389/fnins.2017.00661

Crawford, J. R., & Garthwaite, P. H. (2002). Investigation of the single case in neuropsychology: Confidence limits on the abnormality of test scores and test score differences. *Neuropsychologia*, *40*(8), 1196–1208. https://doi.org/10.1016/S0028-3932(01)00224-X

Crawford, J. R., Garthwaite, P. H., & Porter, S. (2010). Point and interval estimates of effect sizes for the case-controls design in neuropsychology: Rationale, methods, implementations, and proposed reporting standards. *Cognitive Neuropsychology*, *27*(3), 245–260. https://doi.org/10.1080/02643294.2010.513967

Crawford, J. R., Garthwaite, P. H., & Slick, D. J. (2009). On percentile norms in neuropsychology:

Proposed reporting standards and methods for quantifying the uncertainty over the percentile ranks of test scores. *Clinical Neuropsychologist*, *23*(7), 1173–1195. https://doi.org/10.1080/13854040902795018

Crawford, J. R., & Howell, D. C. (1998). Comparing an individual's test score against norms derived from small samples. *Clinical Neuropsychologist*, *12*(4), 482–486. https://doi.org/10.1076/clin.12.4.482.7241

Crookes, K., Favelle, S., & Hayward, W. G. (2013). Holistic Processing for Other-Race Faces in Chinese Participants Occurs for Upright but Not Inverted Faces. *Frontiers in Psychology*, *4*, 29. https://doi.org/10.3389/fpsyg.2013.00029

Cummine, J., Villarena, M., Onysyk, T., & Devlin, J. T. (2020). A Study of Null Effects for the Use of Transcranial Direct Current Stimulation (tDCS) in Adults With and Without Reading Impairment. *Neurobiology of Language*, *1*(4), 434–451. https://doi.org/10.1162/nol_a_00020

Dachille, L. R., Gold, J. M., & James, T. W. (2012). The response of face-selective cortex with single face parts and part combinations. *Neuropsychologia*, *50*(10), 2454–2459. https://doi.org/10.1016/j.neuropsychologia.2012.06.016

Dalrymple, K. A., Fletcher, K., Corrow, S., Barton, J. J. S., Yonas, A., & Duchaine, B. (2014). " A room full of strangers every day " : The psychosocial impact of developmental prosopagnosia on children and their families. *Journal of Psychosomatic Research*, *77*(2), 144–150. https://doi.org/10.1016/j.jpsychores.2014.06.001

Dalrymple, K. A., Garrido, L., & Duchaine, B. (2014). Dissociation between face perception and face memory in adults, but not children, with developmental prosopagnosia. *Developmental Cognitive Neuroscience*, *10*, 10–20. https://doi.org/10.1016/j.dcn.2014.07.003

Dalrymple, K. A., & Palermo, R. (2016). Guidelines for studying developmental prosopagnosia in adults and children. *Wiley Interdisciplinary Reviews: Cognitive Science*, *7*, 73–87. https://doi.org/10.1002/wcs.1374

Datta, A., Bansal, V., Diaz, J., Patel, J., Reato, D., & Bikson, M. (2009). Gyri-precise head model of transcranial direct current stimulation: Improved spatial focality using a ring electrode versus conventional rectangular pad. *Brain Stimulation*, *2*(4), 201–207. https://doi.org/10.1016/j.brs.2009.03.005

Datta, A., Truong, D., Minhas, P., Parra, L. C., & Bikson, M. (2012). Inter-Individual Variation during Transcranial Direct Current Stimulation and Normalization of Dose Using MRI-Derived Computational Models. *Frontiers in Psychiatry*, *3*, 91. https://doi.org/10.3389/fpsyt.2012.00091

David, M. K., Dealwis, C., & Kuang, C. H. (2017). Language policy and language use in multilingual Malaysia. In *In Pursuit of Societal Harmony: Reviewing the Experiences and Approaches in Officially Monolingual and Officially Multilingual Countries* (p. 83).

Davies-Thompson, J., Fletcher, K., Hills, C., Pancaroglu, R., Corrow, S. L., & Barton, J. J. S. (2017). Perceptual Learning of Faces: A Rehabilitative Study of Acquired Prosopagnosia. *Journal of Cognitive Neuroscience*, *29*(3), 573–591. https://doi.org/10.1162/jocn_a_01063

Davies-Thompson, J., Pancarohlu, R., & Barton, J. (2014). Acquired prosopagnosia structural basis and processing impairments. *Frontiers in Bioscience*, *6*(1), 159–174. https://doi.org/10.2741/E699

Davies, G., & Griffiths, L. (2008). Eyewitness identification and the English courts: A century of trial and error. *Psychiatry, Psychology and Law*, *15*(3), 435–449. https://doi.org/10.1080/13218710802101605

Davis, J. P., & Valentine, T. (2009). CCTV on trial: Matching video images with the defendant in the dock. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition*, *23*(4), 482–505. https://doi.org/https://doi.org/10.1002/acp.1490

de Heering, A., & Rossion, B. (2015). Rapid categorization of natural face images in the infant right hemisphere. *ELife*, *4*, e06564. https://doi.org/10.7554/eLife.06564

DeGutis, J., Bahierathan, K., Barahona, K., Lee, E., Evans, T. C., Shin, H. M., Mishra, M., Likitlersuang, J., & Wilmer, J. B. (2023). What is the prevalence of developmental prosopagnosia? An empirical assessment of different diagnostic cutoffs. *Cortex*, *161*, 51–64. https://doi.org/10.1016/j.cortex.2022.12.014

DeGutis, J., Bentin, S., Robertson, L. C., & D’Esposito, M. (2007). Functional plasticity in ventral temporal cortex following cognitive rehabilitation of a congenital prosopagnosic. *Journal of Cognitive Neuroscience*, *19*(11), 1790–1802. https://doi.org/10.1162/jocn.2007.19.11.1790

DeGutis, J., Cohan, S., Kahn, D. A., Aguirre, G. K., & Nakayama, K. (2013). Facial expression training improves emotion recognition and changes neural tuning in a patient with acquired emotion recognition deficits and prosopagnosia. *Journal of Vision*, *13*(9), 993–993.

DeGutis, J., Cohan, S., Mercado, R. J., Wilmer, J., & Nakayama, K. (2012). Holistic processing of the mouth but not the eyes in developmental prosopagnosia. *Cognitive Neuropsychology*, *29*(5–6), 419–446. https://doi.org/10.1080/02643294.2012.754745

DeGutis, J., Cohan, S., & Nakayama, K. (2014). Holistic face training enhances face processing in developmental prosopagnosia. *Brain*, *137*(6), 1781–1798. https://doi.org/10.1093/brain/awu062

DeGutis, J., Wilmer, J., Mercado, R. J., & Cohan, S. (2013). Using regression to measure holistic face processing reveals a strong link with face recognition ability. *Cognition*, *126*(1), 87–100. https://doi.org/10.1016/j.cognition.2012.09.004

Dennett, H. W., McKone, E., Tavashmi, R., Hall, A., Pidcock, M., Edwards, M., & Duchaine, B. (2012). The Cambridge Car Memory Test: A task matched in format to the Cambridge Face Memory Test, with norms, reliability, sex differences, dissociations from face memory, and expertise effects. *Behavior Research Methods*, *44*(2), 587–605. https://doi.org/10.3758/s13428-011-0160-2

Department of Statistics Malaysia. (2011). *Population Distribution and Basic Demographic Characteristic Report 2010 (Updated: 05/08/2011)*. https://www.dosm.gov.my/v1/index.php?r=column/ctheme&menu_id=L0pheU43NWJwRWVSZklWdzQ4TlhUUT09&bul_id=MDMxdHZjWTk1SjFzTzNkRXYzcVZjdz09

Devue, C., de Sena, S., & Wright, J. (2021). *A cost-efficient face learning mechanism: The impact of stability in appearance on the resolution of facial representations.* https://doi.org/10.31234/osf.io/fqd3v

Diedenhofen, B., & Musch, J. (2015). Correction: cocor: A Comprehensive Solution for the Statistical

Comparison of Correlations. *PLOS ONE*, *10*(6), e0131499. https://doi.org/10.1371/journal.pone.0131499

Dowle, M., & Srinivasan, A. (2021). *data.table: Extension of `data.frame`*. https://cran.r-project.org/package=data.table

Dowsett, A. J., & Burton, A. M. (2015). Unfamiliar face matching: Pairs out-perform individuals and provide a route to training. *British Journal of Psychology*, *106*(3), 433–445. https://doi.org/10.1111/bjop.12103

Dowsett, A. J., Sandford, A., & Burton, A. M. (2016). Face learning with multiple images leads to fast acquisition of familiarity for specific individuals. *Quarterly Journal of Experimental Psychology*, *69*(1), 1–10. https://doi.org/10.1080/17470218.2015.1017513

Duchaine, B. (2000). Developmental prosopagnosia with normal configural processing. *NeuroReport*, *11*(1), 79–83. https://doi.org/10.1097/00001756-200001170-00016

Duchaine, B., Germine, L., & Nakayama, K. (2007). Family resemblance: Ten family members with prosopagnosia and within-class object agnosia. *Cognitive Neuropsychology*, *24*(4), 419–430. https://doi.org/10.1080/02643290701380491

Duchaine, B., & Nakayama, K. (2006). The Cambridge Face Memory Test: Results for neurologically intact individuals and an investigation of its validity using inverted face stimuli and prosopagnosic participants. *Neuropsychologia*, *44*(4), 576–585. https://doi.org/10.1016/j.neuropsychologia.2005.07.001

Duchaine, B., Yovel, G., Butterworth, E. J., & Nakayama, K. (2006). Prosopagnosia as an impairment to face-specific mechanisms: Elimination of the alternative hypotheses in a developmental case. *Cognitive Neuropsychology*, *23*(5), 714–747. https://doi.org/10.1080/02643290500441296

Dyke, K., Kim, S., Jackson, G. M., & Jackson, S. R. (2016). Intra-Subject Consistency and Reliability of Response Following 2 mA Transcranial Direct Current Stimulation. *Brain Stimulation*, *9*(6), 819–825. https://doi.org/10.1016/j.brs.2016.06.052

Eick, C. M., Kovács, G., Rostalski, S. M., Röhrig, L., & Ambrus, G. G. (2020). The occipital face area is causally involved in identity-related visual-semantic associations. *Brain Structure and Function*, *225*(5), 1483–1493. https://doi.org/10.1007/s00429-020-02068-9

Eimer, M. (2000). Effects of face inversion on the structural encoding and recognition of faces. *Cognitive Brain Research*, *10*(1–2), 145–158. https://doi.org/10.1016/s0926-6410(00)00038-0

Ellis, H. D., & Young, A. W. (1988). Training in Face-Processing Skills for a Child With Acquired Prosopagnosia. *Developmental Neuropsychology*, *4*(4), 283–294. https://doi.org/10.1080/87565648809540412

Engfors, L. M., Jeffery, L., Gignac, G. E., & Palermo, R. (2017). Individual differences in adaptive norm-based coding and holistic coding are associated yet each contributes uniquely to unfamiliar face recognition ability. *Journal of Experimental Psychology: Human Perception and Performance*, *43*(2), 281–293. https://doi.org/10.1037/xhp0000265

Esmaeilpour, Z., Marangolo, P., Hampstead, B. M., Bestmann, S., Galletta, E., Knotkova, H., & Bikson, M. (2018). Incomplete evidence that increasing current intensity of tDCS boosts outcomes. *Brain Stimulation*, *11*(2), 310–321. https://doi.org/10.1016/j.brs.2017.12.002

Estudillo, A. J. (2012). Facial memory: The role of the pre-existing knowledge in face processing and recognition. *Europe's Journal of Psychology*, *8*(2), 231–244. https://doi.org/10.5964/ejop.v8i2.455

Estudillo, A. J. (2021). Self-reported face recognition abilities for own and other-race faces. *Journal of Criminal Psychology*, *11*(2), 105–115. https://doi.org/10.1108/JCP-06-2020-0025

Estudillo, A. J., & Bindemann, M. (2014). Generalization across view in face memory and face matching. *I-Perception*, *5*(7), 589–601. https://doi.org/10.1068/i0669

Estudillo, A. J., Lee, J. K. W., Mennie, N., & Burns, E. (2020). No evidence of other-race effect for Chinese faces in Malaysian non-Chinese population. *Applied Cognitive Psychology*, *34*(1), 270–276. https://doi.org/10.1002/acp.3609

Estudillo, A. J., Lee, Y. J., Álvarez-Montesinos, J. A., & García-Orza, J. (2023). High-frequency transcranial random noise stimulation enhances unfamiliar face matching of high resolution and pixelated faces. *Brain and Cognition*, *165*, 105937. https://doi.org/10.1016/j.bandc.2022.105937

Estudillo, A. J., & Wong, H. K. (2021). Associations between self-reported and objective face recognition abilities are only evident in above- And below-average recognisers. *PeerJ*, *9*, e10629. https://doi.org/10.7717/peerj.10629

Falissard, B. (2012). *psy: Various procedures used in psychometry*. https://cran.r-project.org/package=psy

Farkas, L. G., Katic, M. J., Forrest, C. R., Alt, K. W., Bagič, I., Baltadjiev, G., Cunha, E., Čvičelová, M., Davies, S., Erasmus, I., Gillett-Netting, R., Hajniš, K., Kemkes-Grottenthaler, A., Khomyakova, I., Kumi, A., Kgamphe, J. S., Kayo-Daigo, N., Le, T., Malinowski, A., … Yahia, E. (2005). International anthropometric study of facial morphology in various ethnic groups/races. *Journal of Craniofacial Surgery*, *16*(4), 615–646. https://doi.org/10.1097/01.scs.0000171847.58031.9e

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Favelle, S. K., Palmisano, S., & Avery, G. (2011). Face viewpoint effects about three axes: The role of configural and featural processing. *Perception*, *40*(7), 761–784. https://doi.org/10.1068/p6878

Feng, L., Liu, J., Wang, Z., Li, J., Li, L., Ge, L., Tian, J., & Lee, K. (2011). The other face of the other-race effect: An fMRI investigation of the other-race face categorization advantage. *Neuropsychologia*, *49*(13), 3739–3749. https://doi.org/10.1016/j.neuropsychologia.2011.09.031

Fischer, D. B., Fried, P. J., Ruffini, G., Ripolles, O., Salvador, R., Banus, J., Ketchabaw, W. T., Santarnecchi, E., Pascual-Leone, A., & Fox, M. D. (2017). Multifocal tDCS targeting the resting state motor network increases cortical excitability beyond traditional tDCS targeting unilateral motor cortex. *NeuroImage*, *157*, 34–44. https://doi.org/10.1016/j.neuroimage.2017.05.060

Fisher, K., Towler, J., & Eimer, M. (2016). Reduced sensitivity to contrast signals from the eye region in developmental prosopagnosia. *Cortex*, *81*(6), 64–78. https://doi.org/10.1016/j.cortex.2016.04.005

Fox, C. J., Iaria, G., & Barton, J. S. (2009). Defining the face processing network: Optimization of the functional localizer in fMRI. *Human Brain Mapping*, *30*(5), 1637–1651. https://doi.org/10.1002/hbm.20630

Fox, C. J., Moon, S., Iaria, G., & Barton, J. S. (2009). The correlates of subjective perception of identity and expression in the face network: An fMRI adaptation study. *NeuroImage*, *44*(2), 569–580. https://doi.org/10.1016/j.neuroimage.2008.09.011

Francis, D. R., Riddoch, M. J., & Humphreys, G. W. (2002). “Who’s that girl?” Prosopagnosia, person-based semantic disorder, and the reacquisition of face identification ability. *Neuropsychological Rehabilitation*, *12*(1), 1–26. https://doi.org/10.1080/09602010143000158

Fregni, F., Ligouri, P., Fecteau, S., Nitsche, M. A., Pascual-Leone, A., & Boggio, P. S. (2008). Cortical Stimulation of the Prefrontal Cortex With Transcranial Direct Current Stimulation Reduces Cue-Provoked Smoking Craving. *The Journal of Clinical Psychiatry*, *69*(1), 32–40. https://doi.org/10.4088/JCP.v69n0105

Friehs, M. A., & Frings, C. (2019). Offline beats online. *NeuroReport*, *30*(12), 795–799. https://doi.org/10.1097/WNR.0000000000001272

Frith, C. (2009). Role of facial expressions in social interactions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1535), 3453–3458. https://doi.org/10.1098/rstb.2009.0142

Fysh, M. C., & Bindemann, M. (2022). Molistic processing in facial image comparison. *Applied Cognitive Psychology*, *36*(4), 830–841. https://doi.org/10.1002/acp.3975

Gamaldo, A. A., & Allaire, J. C. (2016). Daily Fluctuations in Everyday Cognition: Is It Meaningful? *Journal of Aging and Health*, *28*(5), 834–849. https://doi.org/10.1177/0898264315611669

Gao, F., Edden, R. A. E., Li, M., Puts, N. A. J., Wang, G., Liu, C., Zhao, B., Wang, H., Bai, X., Zhao, C., Wang, X., & Barker, P. B. (2013). Edited magnetic resonance spectroscopy detects an age-related decline in brain GABA levels. *NeuroImage*, *78*, 75–82. https://doi.org/10.1016/j.neuroimage.2013.04.012

Gao, W., Cao, B., Shan, S., Chen, X., Zhou, D., Zhang, X., & Zhao, D. (2008). The CAS-PEAL large-scale chinese face database and baseline evaluations. *IEEE Transactions on Systems, Man, and Cybernetics Part A:Systems and Humans*, *38*(1), 149–161. https://doi.org/10.1109/TSMCA.2007.909557

Gauthier, I., & Bukach, C. (2007). Should we reject the expertise hypothesis? *Cognition*, *103*(2), 322–330. https://doi.org/10.1016/j.cognition.2006.05.003

Gauthier, I., Tarr, M. J., Moylan, J., Skudlarski, P., Gore, J. C., & Anderson, A. W. (2000). The fusiform “face area” is part of a network that processes faces at the individual level. *Journal of Cognitive Neuroscience*, *12*(3), 495–504. https://doi.org/10.1162/089892900562165

George, D., & Mallery, P. (2019). IBM SPSS Statistics 26 Step by Step. In *IBM SPSS Statistics 26 Step by Step*. Routledge. https://doi.org/10.4324/9780429056765

Germine, L. T., Duchaine, B., & Nakayama, K. (2011). Where cognitive development and aging meet: Face learning ability peaks after age 30. *Cognition*, *118*(2), 201–210. https://doi.org/10.1016/j.cognition.2010.11.002

Geskin, J., & Behrmann, M. (2018). Congenital prosopagnosia without object agnosia? A literature review. *Cognitive Neuropsychology*, *35*(1–2), 4–54. https://doi.org/10.1080/02643294.2017.1392295

Gill, J., Shah-Basak, P. P., & Hamilton, R. (2015). It’s the thought that counts: Examining the task-dependent effects of transcranial direct current stimulation on executive function. *Brain Stimulation*, *8*(2), 253–259. https://doi.org/10.1016/j.brs.2014.10.018

Giménez-Fernández, T., Kessel, D., Fernández-Folgueiras, U., Fondevila, S., Méndez-Bértolo, C., Aceves, N., García-Rubio, M. J., & Carretié, L. (2020). Prejudice drives exogenous attention to outgroups. *Social Cognitive and Affective Neuroscience*, *15*(6), 615–624. https://doi.org/10.1093/scan/nsaa087

Goffaux, V., Gauthier, I., & Rossion, B. (2003). Spatial scale contribution to early visual differences between face and object processing. *Cognitive Brain Research*, *16*(3), 416–424. https://doi.org/10.1016/S0926-6410(03)00056-9

Goh, J. O., Suzuki, A., & Park, D. C. (2010). Reduced neural selectivity increases fMRI adaptation with age during face discrimination. *NeuroImage*, *51*(1), 336–344. https://doi.org/10.1016/j.neuroimage.2010.01.107

Golby, A. J., Gabrieli, J. D. E., Chiao, J. Y., & Eberhardt, J. L. (2001). Differential responses in the fusiform region to same-race and other-race faces. *Nature Neuroscience*, *4*(8), 845–850. https://doi.org/10.1038/90565

Goldman, R. L., Borckardt, J. J., Frohman, H. A., O’Neil, P. M., Madan, A., Campbell, L. K., Budak, A., & George, M. S. (2011). Prefrontal cortex transcranial direct current stimulation (tDCS) temporarily reduces food cravings and increases the self-reported ability to resist food in adults with frequent food craving. *Appetite*, *56*(3), 741–746. https://doi.org/10.1016/j.appet.2011.02.013

Gonzalez-Perez, M., Wakui, E., Thoma, V., Nitsche, M. A., & Rivolta, D. (2019). Transcranial alternating current stimulation (tACS) at 40 Hz enhances face and object perception. *Neuropsychologia*, *135*, 107237. https://doi.org/10.1016/j.neuropsychologia.2019.107237

Grady, C. L., McIntosh, A. R., Horwitz, B., & Rapoport, S. I. (2000). Age-related changes in the neural correlates of degraded and nondegraded face processing. *Cognitive Neuropsychology*, *17*(1–3), 165–186. https://doi.org/10.1080/026432900380553

Gray, K. L. H., Biotti, F., & Cook, R. (2019). Evaluating object recognition ability in developmental prosopagnosia using the Cambridge Car Memory Test. *Cognitive Neuropsychology*, *36*(1–2), 89–96. https://doi.org/10.1080/02643294.2019.1604503

Grill-Spector, K., Weiner, K. S., Gomez, J., Stigliani, A., & Natu, V. S. (2018). The functional neuroanatomy of face perception: from brain measurements to deep neural networks. *Interface Focus*, *8*, 20180013. https://doi.org/10.1098/rsfs.2018.0013

Gschwind, M., Pourtois, G., Schwartz, S., Van De Ville, D., & Vuilleumier, P. (2012). White-matter connectivity between face-responsive regions in the human brain. *Cerebral Cortex*, *22*(7), 1564–1576. https://doi.org/10.1093/cercor/bhr226

Gueugneau, N., Pozzo, T., Darlot, C., & Papaxanthis, C. (2017). Daily modulation of the speed–accuracy trade-off. *Neuroscience*, *356*, 142–150. https://doi.org/10.1016/j.neuroscience.2017.04.043

Hassanzahraee, M., Nitsche, M. A., Zoghi, M., & Jaberzadeh, S. (2020). Determination of anodal tDCS duration threshold for reversal of corticospinal excitability: An investigation for induction of counter-regulatory mechanisms. *Brain Stimulation*, *13*(3), 832–839. https://doi.org/10.1016/j.brs.2020.02.027

Havard, C. (2021). The Importance of Internal and External Features in Matching Own and Other Race Faces. *Perception*, *50*(10), 861–875. https://doi.org/10.1177/03010066211043464

Haxby, J. V, Hoffman, E. a, & Gobbini, M. I. (2000). The distributed human neural system for face perception. *Trends Cogn Sci*, *4*(6), 223–233. https://doi.org/10.1016/S1364-6613(00)01482-0

Hayward, W. G., Rhodes, G., & Schwaninger, A. (2008). An own-race advantage for components as well as configurations in face recognition. *Cognition*, *106*(2), 1017–1027. https://doi.org/10.1016/j.cognition.2007.04.002

Hehman, E., Mania, E. W., & Gaertner, S. L. (2010). Where the division lies: Common ingroup identity moderates the cross-race facial-recognition effect. *Journal of Experimental Social Psychology*, *46*(2), 445–448. https://doi.org/10.1016/j.jesp.2009.11.008

Heitz, R. P. (2014). The speed-accuracy tradeoff: history, physiology, methodology, and behavior. *Frontiers in Neuroscience*, *8*, 150. https://doi.org/10.3389/fnins.2014.00150

Henderson, Z., Bruce, V., & Burton, A. M. (2001). Matching the Faces of Robbers Captured on Video. *Applied Cognitive Psychology*, *15*(4), 445–464. https://doi.org/10.1002/acp.718

Hershler, O., & Hochstein, S. (2005). At first sight: A high-level pop out effect for faces. *Vision Research*, *45*(13), 1707–1724. https://doi.org/10.1016/j.visres.2004.12.021

Herzmann, G., Young, B., Bird, C. W., & Curran, T. (2012). Oxytocin can impair memory for social and non-social visual objects: A within-subject investigation of oxytocin’s effects on human memory. *Brain Research*, *1451*(1), 65–73. https://doi.org/10.1016/j.brainres.2012.02.049

Hill, A. T., Fitzgerald, P. B., & Hoy, K. E. (2016). Effects of Anodal Transcranial Direct Current Stimulation on Working Memory: A Systematic Review and Meta-Analysis of Findings from Healthy and Neuropsychiatric Populations. *Brain Stimulation*, *9*(2), 197–208. https://doi.org/10.1016/j.brs.2015.10.006

Hittner, J. B., May, K., & Silver, N. C. (2003). A monte carlo evaluation of tests for comparing dependent correlations. *Journal of General Psychology*, *130*(2), 149–168. https://doi.org/10.1080/00221300309601282

Horvath, J. C., Vogrin, S. J., Carter, O., Cook, M. J., & Forte, J. D. (2015). Effects of transcranial direct current stimulation on motor evoked potential amplitude are neither reliable nor significant within individuals over 9 separate testing sessions. *Brain Stimulation*, *8*, 310–325. https://doi.org/10.1016/j.brs.2015.01.033

Hsu, W. Y., Zanto, T. P., Anguera, J. A., Lin, Y. Y., & Gazzaley, A. (2015). Delayed enhancement of multitasking performance: Effects of anodal transcranial direct current stimulation on the prefrontal cortex. *Cortex*, *69*, 175–185. https://doi.org/10.1016/j.cortex.2015.05.014

Hsu, W. Y., Zanto, T. P., Van Schouwenburg, M. R., & Gazzaley, A. (2017). Enhancement of multitasking performance and neural oscillations by transcranial alternating current stimulation. *PLoS ONE*, *12*(5), e0178579. https://doi.org/10.1371/journal.pone.0178579

Huber, R., Mäki, H., Rosanova, M., Casarotto, S., Canali, P., Casali, A. G., Tononi, G., & Massimini, M. (2013). Human cortical excitability increases with time awake. *Cerebral Cortex*, *23*(2), 332–338. https://doi.org/10.1093/cercor/bhs014

Hugenberg, K., & Corneille, O. (2009). Holistic processing is tuned for in-group faces. *Cognitive Science*, *33*(6), 1173–1181. https://doi.org/10.1111/j.1551-6709.2009.01048.x

Hugenberg, K., Miller, J., & Claypool, H. M. (2007). Categorization and individuation in the cross-race recognition deficit: Toward a solution to an insidious problem. *Journal of Experimental Social Psychology*, *43*(2), 334–340. https://doi.org/10.1016/j.jesp.2006.02.010

Hunnisett, N., & Favelle, S. (2021). Within-person variability can improve the identification of unfamiliar faces across changes in viewpoint. *Quarterly Journal of Experimental Psychology*, *74*(11), 1873–1887. https://doi.org/10.1177/17470218211009771

Huxley, A. F. (1972). The ionic basis of nervous conduction. *From Nobel Lectures, Physiology or Medicine 1963–1970.*

Inghilleri, M., Conte, A., Currà, A., Frasca, V., Lorenzano, C., & Berardelli, A. (2004). Ovarian hormones and cortical excitability. An rTMS study in humans. *Clinical Neurophysiology*, *115*(5), 1063–1068. https://doi.org/10.1016/j.clinph.2003.12.003

Ishai, A. (2008). Let's face it: It's a cortical network. *NeuroImage*, *40*(2), 415–419. https://doi.org/10.1016/j.neuroimage.2007.10.040

Iuculano, T., & Kadosh, R. C. (2013). The mental cost of cognitive enhancement. *Journal of Neuroscience*, *33*(10), 4482–4486. https://doi.org/10.1523/JNEUROSCI.4927-12.2013

Jack, R. E., Blais, C., Scheepers, C., Schyns, P. G., & Caldara, R. (2009). Cultural Confusions Show that Facial Expressions Are Not Universal. *Current Biology*, *19*(18), 1543–1548. https://doi.org/10.1016/j.cub.2009.07.051

Jack, R. E., & Schyns, P. G. (2015). The Human Face as a Dynamic Tool for Social Communication. *Current Biology*, *25*(14), R621–R634. https://doi.org/10.1016/j.cub.2015.05.052

Jacobson, L., Koslowsky, M., & Lavidor, M. (2012). TDCS polarity effects in motor and cognitive domains: A meta-analytical review. *Experimental Brain Research*, *216*, 1–10. https://doi.org/10.1007/s00221-011-2891-9

Jacoby, N., & Lavidor, M. (2018). Null tDCS Effects in a Sustained Attention Task: The Modulating Role of Learning. *Frontiers in Psychology*, *9*. https://doi.org/10.3389/fpsyg.2018.00476

Jacques, C., & Rossion, B. (2010). Misaligning face halves increases and delays the N170 specifically for upright faces: Implications for the nature of early face representations. *Brain Research*, *1318*, 96–109. https://doi.org/10.1016/j.brainres.2009.12.070

Janik, A. B., Rezlescu, C., & Banissy, M. J. (2015). Enhancing anger perception with transcranial alternating current stimulation induced gamma oscillations. *Brain Stimulation*, *8*(6), 1138–1143. https://doi.org/10.1016/j.brs.2015.07.032

JASP Team. (2022). *JASP (Version 0.16.3)[Computer software]*. https://jasp-stats.org/

Jaworska, K., Yi, F., Ince, R. A. A., van Rijsbergen, N. J., Schyns, P. G., & Rousselet, G. A. (2020). Healthy aging delays the neural processing of face features relevant for behavior by 40 ms. *Human Brain Mapping*, *41*(5), 1212–1225. https://doi.org/10.1002/hbm.24869

Jenkins, R., & Burton, A. M. (2011). Stable face representations. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*(1571), 1671–1683. https://doi.org/10.1098/rstb.2010.0379

Jenkins, R., White, D., Van Montfort, X., & Burton, A. M. (2011). Variability in photos of the same face. *Cognition*, *121*(3), 313–323. https://doi.org/10.1016/j.cognition.2011.08.001

Johnson, K. J., & Fredrickson, B. L. (2005). “We All Look the Same to Me”: Positive Emotions Eliminate the Own-Race Bias in Face Recognition. *Psychological Science*, *16*(11), 875–881. https://doi.org/10.1111/j.1467-9280.2005.01631.x

Johnston, R. J., & Edmonds, A. J. (2009). Familiar and unfamiliar face recognition: A review. *Memory*, *17*(5), 577–596. https://doi.org/10.1080/09658210902976969

Jones, A. L., Kramer, R. S., & Ward, R. (2012). Signals of personality and health: The contributions of facial shape, skin texture, and viewing angle. *Journal of Experimental Psychology: Human Perception and Performance, 38*(6), 1353. https://doi.org/https://doi.org/10.1037/a0027078

Kadosh, K. C., Walsh, V., & Kadosh, R. C. (2010). Investigating face-property specific processing in the right OFA. *Social Cognitive and Affective Neuroscience, 6*, 58–65. https://doi.org/10.1093/scan/nsq015

Kandel, S., Burfin, S., Méary, D., Ruiz-Tada, E., Costa, A., & Pascalis, O. (2016). The Impact of Early Bilingualism on Face Recognition Processes. *Frontiers in Psychology*, *7*, 1080. https://doi.org/10.3389/fpsyg.2016.01080

Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The Fusiform Face Area: A Module in Human Extrastriate Cortex Specialized for Face Perception. *The Journal of Neuroscience*, *17*(11), 4302–4311. https://doi.org/10.1523/JNEUROSCI.17-11-04302.1997

Kätsyri, J. (2018). Those Virtual People all Look the Same to me: Computer-Rendered Faces Elicit a Higher False Alarm Rate Than Real Human Faces in a Recognition Memory Task. *Frontiers in Psychology*, *9*, 1362. https://doi.org/10.3389/fpsyg.2018.01362

Ke, Y., Wang, N., Du, J., Kong, L., Liu, S., Xu, M., An, X., & Ming, D. (2019). The Effects of Transcranial Direct Current Stimulation (tDCS) on Working Memory Training in Healthy Young

Adults. *Frontiers in Human Neuroscience*, *13*, 19. https://doi.org/10.3389/fnhum.2019.00019

Kellaway, P. (1946). The Part Played by Electric Fish in the Early History of Bioelectricity and Electrotherapy. *Bulletin of the History of Medicine*, *20*(2), 112–137. https://www.jstor.org/stable/44441034?seq=1

Kelly, D. J., Jack, R. E., Miellet, S., De Luca, E., Foreman, K., & Caldara, R. (2011). Social Experience Does Not Abolish Cultural Diversity in Eye Movements. *Frontiers in Psychology*, *2*, 95. https://doi.org/10.3389/fpsyg.2011.00095

Kelly, D. J., Quinn, P. C., Slater, A. M., Lee, K., Ge, L., & Pascalis, O. (2007). The other-race effect develops during infancy: Evidence of perceptual narrowing. *Psychological Science*, *18*(12), 1084–1089. https://doi.org/10.1111/j.1467-9280.2007.02029.x

Kelly, D. J., Quinn, P. C., Slater, A. M., Lee, K., Gibson, A., Smith, M., Ge, L., & Olivier, P. (2005). Three-month-olds, but not newborns, prefer own-race faces. *Developmental Science*, *6*(8), 31–36. https://doi.org/10.1111/j.1467-7687.2005.0434a.x

Kemp, R., Towell, N., & Pike, G. (1997). When Seeing should not be Believing: Photographs, Credit Cards and Fraud. *Applied Cognitive Psychology*, *11*(3), 211–222. https://doi.org/10.1002/(sici)1099-0720(199706)11:3<211::aid-acp430>3.3.co;2-f

Kennerknecht, I., Grueter, T., Welling, B., Wentzek, S., Horst, J., Edwards, S., & Grueter, M. (2006). First report of prevalence of non-syndromic hereditary prosopagnosia (HPA). *American Journal of Medical Genetics Part A*, *140A*(15), 1617–1622. https://doi.org/10.1002/ajmg.a.31343

Kennerknecht, I., Ho, N. Y., & Wong, V. C. N. (2008). Prevalence of hereditary prosopagnosia (HPA) in Hong Kong Chinese population. *American Journal of Medical Genetics Part A*, *146A*(22), 2863–2870. https://doi.org/10.1002/ajmg.a.32552

Kerr, N. L., & Tindale, R. S. (2004). Group performance and decision making. *Annual Review of Psychology*, *55*, 623–655. https://doi.org/10.1146/annurev.psych.55.090902.142009

Kho, S. K., Leong, B. Q. Z., Keeble, D. R. T., Wong, H. K., & Estudillo, A. J. (2023). A new Asian version of the CFMT: The Cambridge Face Memory Test – Chinese Malaysian (CFMT-MY).

Behavior Research Methods. https://doi.org/10.3758/s13428-023-02085-6

Kim, J. S., Yoon, H. W., Kim, B. S., Jeun, S. S., Jung, S. L., & Choe, B. Y. (2006). Racial distinction of the unknown facial identity recognition mechanism by event-related fMRI. *Neuroscience Letters*, *397*(3), 279–284. https://doi.org/10.1016/j.neulet.2005.12.061

Kim, M., Ducros, M., Carlson, T., Ronen, I., He, S., Ugurbil, K., & Kim, D. S. (2006). Anatomical correlates of the functional organization in the human occipitotemporal cortex. *Magnetic Resonance Imaging*, *24*(5), 583–590. https://doi.org/10.1016/j.mri.2005.12.005

Kimchi, R., & Amishav, R. (2010). Faces as perceptual wholes: The interplay between component and configural properties in face processing. *Visual Cognition*, *18*(7), 1034–1062. https://doi.org/10.1080/13506281003619986

Kit, L. C., & Chuan, L. W. (2012). Hollywood Films and Local Films: A Quantitative Study on Malaysian Young Generations' Preference. *Procedia – Social and Behavioral Sciences*.

Klimesch, W., Sauseng, P., & Gerloff, C. (2003). Enhancing cognitive performance with repetitive transcranial magnetic stimulation at human individual alpha frequency. *European Journal of Neuroscience*, *17*(5), 1129–1133. https://doi.org/10.1046/j.1460-9568.2003.02517.x

Koenigs, M., Ukueberuwa, D., Campion, P., Grafman, J., & Wassermann, E. (2009). Bilateral frontal transcranial direct current stimulation: Failure to replicate classic findings in healthy subjects. *Clinical Neurophysiology*, *120*, 80–84. https://doi.org/10.1016/j.clinph.2008.10.010

Konar, Y., Bennett, P. J., & Sekuler, A. B. (2010). Holistic processing is not correlated with face-identification accuracy. *Psychological Science*, *21*(1), 38–43. https://doi.org/10.1177/0956797609356508

Konar, Y., Bennett, P. J., & Sekuler, A. B. (2013). Effects of aging on face identification and holistic face processing. *Vision Research*, *88*, 38–46. https://doi.org/10.1016/j.visres.2013.06.003

Kramer, R. S. S., Jenkins, R., Young, A. W., & Burton, A. M. (2017). Natural variability is essential to learning new faces. *Visual Cognition*, *25*(4–6), 470–476. https://doi.org/10.1080/13506285.2016.1242522

Kramer, R. S. S., & Reynolds, M. G. (2018). Unfamiliar Face Matching With Frontal and Profile Views. *Perception*, *47*(4), 414–431. https://doi.org/10.1177/0301006618756809

Krause, B., & Cohen Kadosh, R. (2014). Not all brains are created equal: the relevance of individual differences in responsiveness to transcranial electrical stimulation. *Frontiers in Systems Neuroscience*, *8*, 25. https://doi.org/10.3389/fnsys.2014.00025

Kuo, H.-I., Bikson, M., Datta, A., Minhas, P., Paulus, W., Kuo, M., & Nitsche, M. A. (2013). Comparing Cortical Plasticity Induced by Conventional and High-Definition 4 × 1 Ring tDCS: A Neurophysiological Study. *Brain Stimulation*, *6*(4), 644–648. https://doi.org/10.1016/j.brs.2012.09.010

Laakso, I., Mikkonen, M., Koyama, S., Hirata, A., & Tanaka, S. (2019). Can electric fields explain inter-individual variability in transcranial direct current stimulation of the motor cortex? *Scientific Reports*, *9*, 626. https://doi.org/10.1038/s41598-018-37226-x

Lafontaine, M. P., Théoret, H., Gosselin, F., & Lippé, S. (2013). Transcranial direct current stimulation of the dorsolateral prefrontal cortex modulates repetition suppression to unfamiliar faces: An ERP study. *PLoS ONE*, *8*(12), e81721. https://doi.org/10.1371/journal.pone.0081721

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*. https://doi.org/10.3389/fpsyg.2013.00863

Langton, S. R. H., Law, A. S., Burton, A. M., & Schweinberger, S. R. (2008). Attention capture by faces. *Cognition*, *107*, 330–342. https://doi.org/10.1016/j.cognition.2007.07.012

Latinus, M., & Taylor, M. J. (2005). Holistic processing of faces: Learning effects with Mooney faces. *Journal of Cognitive Neuroscience*, *17*(8), 1316–1327. https://doi.org/10.1162/0898929055002490

Le Grand, R., Cooper, P. A., Mondloch, C. J., Lewis, T. L., Sagiv, N., de Gelder, B., & Maurer, D. (2006). What aspects of face processing are impaired in developmental prosopagnosia? *Brain and Cognition*, *61*(2), 139–158. https://doi.org/10.1016/j.bandc.2005.11.005

Learmonth, G., Felisatti, F., Siriwardena, N., Checketts, M., Benwell, C. S. Y., Märker, G., Thut, G., &

Harvey, M. (2017). No Interaction between tDCS Current Strength and Baseline Performance: A Conceptual Replication. *Frontiers in Neuroscience*, *11*. https://doi.org/10.3389/fnins.2017.00664

Lee, H. J., Macbeth, A. H., Pagani, J., & Young, W. S. (2009). Oxytocin: The Great Facilitator of Life. *Progress in Neurobiology*, *26*(3), 323–329. https://doi.org/10.1016/j.pneurobio.2009.04.001

Lee, Y., Duchaine, B., Wilson, H. R., & Nakayama, K. (2010). Three cases of developmental prosopagnosia from one family: Detailed neuropsychological and psychophysical investigation of face processing. *Cortex*, *46*(8), 949–964. https://doi.org/10.1016/j.cortex.2009.07.012

Lewis, M. B., & Hills, P. J. (2018). Perceived Race Affects Configural Processing but Not Holistic Processing in the Composite-Face Task. *Frontiers in Psychology*, *9*, 1456. https://doi.org/10.3389/fpsyg.2018.01456

Liesefeld, H. R., Fu, X., & Zimmer, H. D. (2015). Fast and careless or careful and slow? Apparent holistic processing in mental rotation is explained by speed-accuracy trade-offs. *Journal of Experimental Psychology: Learning Memory and Cognition*, *41*(4), 1140–1151. https://doi.org/10.1037/xlm0000081

Liu, J., Harris, A., & Kanwisher, N. (2010). Perception of face parts and face configurations: An fMRI study. *Journal of Cognitive Neuroscience*, *22*(1), 203–211. https://doi.org/10.1162/jocn.2009.21203

Liu, T. T., & Behrmann, M. (2014). Impaired holistic processing of left-right composite faces in congenital prosopagnosia. *Frontiers in Human Neuroscience*, *8*, 750. https://doi.org/10.3389/fnhum.2014.00750

Logan, A. J., Gordon, G. E., & Loffler, G. (2022). Healthy aging impairs face discrimination ability. *Journal of Vision*, *22*(9), 1–19. https://doi.org/10.1167/jov.22.9.1

Longmore, C. A., Liu, C. H., & Young, A. W. (2008). Learning Faces From Photographs. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(1), 77–100. https://doi.org/10.1037/0096-1523.34.1.77

Loo, C. K., Alonzo, A., Martin, D., Mitchell, P. B., Galvez, V., & Sachdev, P. (2012). Transcranial direct current stimulation for depression: 3-Week, randomised, sham-controlled trial. *British Journal of*

Psychiatry, *200*(1), 52–59. https://doi.org/10.1192/bjp.bp.111.097634

Lopatina, O. L., Komleva, Y. K., Gorina, Y. V., Higashida, H., & Salmina, A. B. (2018). Neurobiological aspects of face recognition: The role of oxytocin. *Frontiers in Behavioral Neuroscience*, *12*, 195. https://doi.org/10.3389/fnbeh.2018.00195

López-Alonso, V., Cheeran, B., Río-Rodríguez, D., & Fernández-Del-Olmo, M. (2014). Inter-individual variability in response to non-invasive brain stimulation paradigms. *Brain Stimulation*, *7*(3), 372–380. https://doi.org/10.1016/j.brs.2014.02.004

MacLin, O. H., & Malpass, R. S. (2001). Racial Categorization of Faces: The Ambiguous Race Face Effect. *Psychology, Public Policy, and Law*, *7*(1), 98–118. https://doi.org/10.1037/1076-8971.7.1.98

Macmillan, N. A., & Creelman, C. D. (2005). Detection Theory: A User's Guide (2nd edition). In *Lawrence Erlbaum Associates*.

Magon, N., & Kalra, S. (2011). The orgasmic history of oxytocin: Love, lust, and labor. *Indian Journal of Endocrinology and Metabolism*, *15*(7), 156. https://doi.org/10.4103/2230-8210.84851

Malpass, R. S., & Kravitz, J. (1969). Recognition for faces of own and other race. *Journal of Personality and Social Psychology*, *13*(4), 330–334. https://doi.org/10.1037/h0028434

Martin, D. M., Moffa, A., Nikolin, S., Bennabi, D., Brunoni, A. R., Flannery, W., Haffen, E., McClintock, S. M., Moreno, M. L., Padberg, F., Palm, U., & Loo, C. K. (2018). Cognitive effects of transcranial direct current stimulation treatment in patients with major depressive disorder: An individual patient data meta-analysis of randomised, sham-controlled trials. *Neuroscience & Biobehavioral Reviews*, *90*(2018), 137–145. https://doi.org/10.1016/j.neubiorev.2018.04.008

Marwick, K., & Hall, J. (2008). Social cognition in schizophrenia: A review of face processing. *British Medical Bulletin*, *88*, 43–58. https://doi.org/10.1093/bmb/ldn035

Matthews, C. M., & Mondloch, C. J. (2018). Finding an unfamiliar face in a line-up: Viewing multiple images of the target is beneficial on target-present trials but costly on target-absent trials. *British Journal of Psychology*, *109*(4), 758–776. https://doi.org/10.1111/bjop.12301

Maurer, D., Le Grand, R., & Mondloch, C. J. (2002). The many faces of configural processing. *Trends in*

Cognitive Sciences, *6*(6), 255–260. https://doi.org/10.1016/S1364-6613(02)01903-4

McCaffrey, R. J., & Westervelt, H. J. (1995). Issues associated with repeated neuropsychological assessments. *Neuropsychology Review*, *5*(3), 203–221. https://doi.org/10.1007/BF02214762

McCarthy, G., Puce, A., Gore, J. C., & Allison, T. (1997). Face-Specific Processing in the Human Fusiform Gyrus. *Journal of Cognitive Neuroscience*, *9*(5), 605–610. https://doi.org/10.1162/jocn.1997.9.5.605

McConachie, H. R. (1976). Developmental Prosopagnosia. A Single Case Report. *Cortex*, *12*(1), 76–82. https://doi.org/10.1016/S0010-9452(76)80033-0

McGugin, R. W., Van Gulick, A. E., & Gauthier, I. (2016). Cortical Thickness in Fusiform Face Area Predicts Face and Object Recognition Performance. *Journal of Cognitive Neuroscience*, *28*(2), 282–294. https://doi.org/10.1162/jocn_a_00891

McKone, E., Dawel, A., Robbins, R. A., Shou, Y., Chen, N., & Crookes, K. (2021). Why the other-race effect matters: Poor recognition of other-race faces impacts everyday social interactions. *British Journal of Psychology*, bjop.12508. https://doi.org/10.1111/bjop.12508

McKone, E., Hall, A., Pidcock, M., Palermo, R., Wilkinson, R. B., Rivolta, D., Yovel, G., Davis, J. M., & O'Connor, K. B. (2011). Face ethnicity and measurement reliability affect face recognition performance in developmental prosopagnosia: Evidence from the Cambridge Face Memory Test–Australian. *Cognitive Neuropsychology*, *28*(2), 109–146. https://doi.org/10.1080/02643294.2011.616880

McKone, E., Kanwisher, N., & Duchaine, B. C. (2007). Can generic expertise explain special processing for faces? *Trends in Cognitive Sciences*, *11*(1), 8–15. https://doi.org/10.1016/j.tics.2006.11.002

McKone, E., Stokes, S., Liu, J., Cohan, S., Fiorentini, C., Pidcock, M., Yovel, G., Broughton, M., & Pelleg, M. (2012). A Robust Method of Measuring Other-Race and Other-Ethnicity Effects: The Cambridge Face Memory Test Format. *PLoS ONE*, *7*(10), e47956. https://doi.org/10.1371/journal.pone.0047956

McKone, E., Wan, L., Robbins, R., Crookes, K., & Liu, J. (2017). Diagnosing prosopagnosia in East

Asian individuals: Norms for the Cambridge Face Memory Test–Chinese. *Cognitive Neuropsychology*, *34*(5), 253–268. https://doi.org/10.1080/02643294.2017.1371682

McLaren, M. E., Nissim, N. R., & Woods, A. J. (2018). The effects of medication use in transcranial direct current stimulation: A brief review. *Brain Stimulation*, *11*, 52–58. https://doi.org/10.1016/j.brs.2017.10.006

Medina, J., & Cason, S. (2017). No evidential value in samples of transcranial direct current stimulation (tDCS) studies of cognition and working memory in healthy populations. *Cortex*, *94*, 131–141. https://doi.org/10.1016/j.cortex.2017.06.021

Megreya, A. M. (2018). Feature-by-feature comparison and holistic processing in unfamiliar face matching. *PeerJ*, *6*(2), e4437. https://doi.org/10.7717/peerj.4437

Megreya, A. M., & Bindemann, M. (2015). Developmental improvement and age-related decline in unfamiliar face matching. *Perception*, *44*(1), 5–22. https://doi.org/10.1068/p7825

Megreya, A. M., & Bindemann, M. (2018). Feature instructions improve face-matching accuracy. *PLoS ONE*, *13*(3), e0193455. https://doi.org/10.1371/journal.pone.0193455

Megreya, A. M., White, D., & Burton, A. M. (2011). The other-race effect does not rely on memory: Evidence from a matching task. *Quarterly Journal of Experimental Psychology*, *64*(8), 1473–1483. https://doi.org/10.1080/17470218.2011.575228

Meinhardt-Injac, B., Persike, M., & Meinhardt, G. (2014). Holistic processing and reliance on global viewing strategies in older adults' face perception. *Acta Psychologica*, *151*, 155–163. https://doi.org/10.1016/j.actpsy.2014.06.001

Meissner, C. A., & Brigham, J. C. (2001). Thirty Years of Investigating the Own-Race Bias in Memory for Faces: A Meta-Analytic Review. *Psychology, Public Policy, and Law*, *7*(1), 3–35. https://doi.org/10.1037/1076-8971.7.1.3

Menon, N., White, D., & Kemp, R. I. (2015). Variation in Photos of the Same Face Drives Improvements in Identity Verification. *Perception*, *44*(11), 1332–1341. https://doi.org/10.1177/0301006615599902

Michel, C., Corneille, O., & Rossion, B. (2007). Race categorization modulates holistic face encoding.

Cognitive Science, 31(5), 911–924. https://doi.org/10.1080/03640210701530805

Mileva, M., & Burton, A. M. (2019). Face search in CCTV surveillance. *Cognitive Research: Principles and Implications, 4*, 37. https://doi.org/10.1186/s41235-019-0193-0

Minarik, T., Berger, B., Althaus, L., Bader, V., Biebl, B., Brotzeller, F., Fusban, T., Hegemann, J., Jesteadt, L., Kalweit, L., Leitner, M., Linke, F., Nabielska, N., Reiter, T., Schmitt, D., Spraetz, A., & Sauseng, P. (2016). The importance of sample size for reproducibility of tDCS effects. *Frontiers in Human Neuroscience, 10*, 453. https://doi.org/10.3389/fnhum.2016.00453

Miranda, P. C., Mekonnen, A., Salvador, R., & Ruffini, G. (2013). The electric field in the cortex during transcranial current stimulation. *NeuroImage, 70*, 48–58. https://doi.org/10.1016/j.neuroimage.2012.12.034

Moliadze, V., Atalay, D., Antal, A., & Paulus, W. (2012). Close to threshold transcranial electrical stimulation preferentially activates inhibitory networks before switching to excitation with higher intensities. *Brain Stimulation, 5*(4), 505–511. https://doi.org/10.1016/j.brs.2011.11.004

Mondloch, C. J., Elms, N., Maurer, D., Rhodes, G., Hayward, W. G., Tanakao, J. W., & Zhou, G. (2010). Processes underlying the cross-race effect: An investigation of holistic, featural, and relational processing of own-race versus other-race faces. *Perception, 39*(8), 1065–1085. https://doi.org/10.1068/p6608

Mooney, C. M. (1957). Age in the development of closure ability in children. *Canadian Journal of Psychology, 11*(4), 219–226. https://doi.org/10.1037/h0083717

Moran, L. V., & Hong, L. E. (2011). High vs low frequency neural oscillations in schizophrenia. *Schizophrenia Bulletin, 37*(4), 659–663. https://doi.org/10.1093/schbul/sbr056

Moscovitch, M., Winocur, G., & Behrmann, M. (1997). What is special about face recognition? Nineteen experiments on a person with visual object agnosia and dyslexia but normal face recognition. *Journal of Cognitive Neuroscience, 9*(5), 555–604. https://doi.org/10.1162/jocn.1997.9.5.555

Mulquiney, P. G., Hoy, K. E., Daskalakis, Z. J., & Fitzgerald, P. B. (2011). Improving working memory: Exploring the effect of transcranial random noise stimulation and transcranial direct current stimulation on the dorsolateral prefrontal cortex. *Clinical Neurophysiology*, *122*(12), 2384–2389. https://doi.org/10.1016/j.clinph.2011.05.009

Murphy, J., Ipser, A., Gaigg, S. B., & Cook, R. (2015). Exemplar variance supports robust learning of facial identity. *Journal of Experimental Psychology: Human Perception and Performance*, *41*(3), 577–581. https://doi.org/10.1037/xhp0000049

Murray, E., & Bate, S. (2020). Diagnosing developmental prosopagnosia: repeat assessment using the Cambridge Face Memory Test. *Royal Society Open Science*, *7*(9), 200884. https://doi.org/10.1098/rsos.200884

Natu, V., Raboy, D., & O’Toole, A. J. (2011). Neural correlates of own- and other-race face perception: Spatial and temporal response differences. *NeuroImage, 54*(3), 2547–2555. https://doi.org/10.1016/j.neuroimage.2010.10.006

Nelson, J. T., McKinley, R. A., Golob, E. J., Warm, J. S., & Parasuraman, R. (2014). Enhancing vigilance in operators with prefrontal cortex transcranial direct current stimulation (tDCS). *NeuroImage*, *85*, 909–917. https://doi.org/10.1016/j.neuroimage.2012.11.061

Nichols, D. F., Betts, L. R., & Wilson, H. R. (2010). Decoding of faces and face components in face-sensitive human visual cortex. *Frontiers in Psychology, 1*. https://doi.org/10.3389/fpsyg.2010.00028

Nikolin, S., Lauf, S., Loo, C. K., & Martin, D. (2019). Effects of High-Definition Transcranial Direct Current Stimulation (HD-tDCS) of the Intraparietal Sulcus and Dorsolateral Prefrontal Cortex on Working Memory and Divided Attention. *Frontiers in Integrative Neuroscience*, *12*, 64. https://doi.org/10.3389/fnint.2018.00064

Nilsson, J., Lebedev, A. V., & Lövdén, M. (2015). No Significant Effect of Prefrontal tDCS on Working Memory Performance in Older Adults. *Frontiers in Aging Neuroscience*, *7*. https://doi.org/10.3389/fnagi.2015.00230

Nilsson, J., Lebedev, A. V., Rydström, A., & Lövdén, M. (2017). Direct-Current Stimulation Does Little to Improve the Outcome of Working Memory Training in Older Adults. *Psychological Science*, *28*(7), 907–920. https://doi.org/10.1177/0956797617698139

Nitsche, M. A., Kuo, M.-F., Karrasch, R., Wächter, B., Liebetanz, D., & Paulus, W. (2009). Serotonin Affects Transcranial Direct Current–Induced Neuroplasticity in Humans. *Biological Psychiatry*, *66*(5), 503–508. https://doi.org/10.1016/j.biopsych.2009.03.022

Nitsche, M. A., Nitsche, M. S., Klein, C. C., Tergau, F., Rothwell, J. C., & Paulus, W. (2003). Level of action of cathodal DC polarisation induced inhibition of the human motor cortex. *Clinical Neurophysiology*, *114*(4), 600–604. https://doi.org/10.1016/S1388-2457(02)00412-1

Nitsche, M. A., & Paulus, W. (2000). Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. *Journal of Physiology*, *527*(3), 633–639. https://doi.org/10.1111/j.1469-7793.2000.t01-1-00633.x

Nitsche, M. A., & Paulus, W. (2001). Sustained excitability elevations induced by transcranial DC motor cortex stimulation in humans. *Neurology*, *57*(10), 1899–1901. https://doi.org/10.1212/WNL.57.10.1899

Noetscher, G. M., Yanamadala, J., Makarov, S. N., & Pascual-Leone, A. (2014). Comparison of cephalic and extracephalic montages for transcranial direct current stimulation-a numerical study. *IEEE Transactions on Biomedical Engineering*, *61*(9), 2488–2498. https://doi.org/10.1109/TBME.2014.2322774

Nozari, N., Woodard, K., & Thompson-Schill, S. L. (2014). Consequences of Cathodal Stimulation for Behavior: When Does It Help and When Does It Hurt Performance? *PLoS ONE*, *9*(1), e84338. https://doi.org/10.1371/journal.pone.0084338

O'Toole, A. J., Roark, D. A., & Abdi, H. (2002). Recognizing moving faces: a psychological and neural synthesis. *Trends in Cognitive Sciences*, *6*(6), 261–266. https://doi.org/10.1016/S1364-6613(02)01908-3

Ohn, S. H., Park, C. Il, Yoo, W. K., Ko, M. H., Choi, K. P., Kim, G. M., Lee, Y. T., & Kim, Y. H. (2008). Time-dependent effect of transcranial direct current stimulation on the enhancement of working memory. *NeuroReport*, *19*(1), 43–47. https://doi.org/10.1097/WNR.0b013e3282f2adfd

Palermo, R., Rossion, B., Rhodes, G., Laguesse, R., Tez, T., Hall, B., Albonico, A., Malaspina, M., Daini, R., Irons, J., Al-Janabi, S., Taylor, L. C., Rivolta, D., & McKone, E. (2017). Do people have insight into their face recognition abilities? *Quarterly Journal of Experimental Psychology*, *70*(2), 218–233. https://doi.org/10.1080/17470218.2016.1161058

Palermo, R., Willis, M. L., Rivolta, D., McKone, E., Wilson, C. E., & Calder, A. J. (2011). Impaired holistic coding of facial expression and facial identity in congenital prosopagnosia. *Neuropsychologia*, *49*(5), 1226–1235. https://doi.org/10.1016/j.neuropsychologia.2011.02.021

Palma, T. A., & Garcia-Marques, L. (2021). Does Repetition Always Make Perfect? Differential Effects of Repetition on Learning of Own-Race and Other-Race Faces. *Basic and Applied Social Psychology*, *43*(2), 90–109. https://doi.org/10.1080/01973533.2020.1843462

Parketny, J., Towler, J., & Eimer, M. (2015). The activation of visual face memory and explicit face recognition are delayed in developmental prosopagnosia. *Neuropsychologia*, *75*, 538–547. https://doi.org/10.1016/j.neuropsychologia.2015.07.009

Pashler, H., & Wagenmakers, E. J. (2012). Editors' Introduction to the Special Section on Replicability in Psychological Science: A Crisis of Confidence? *Perspectives on Psychological Science*, *7*(6), 528–530. https://doi.org/10.1177/1745691612465253

Pauker, K., Weisbuch, M., Ambady, N., Sommers, S. R., Adams, R. B., & Ivcevic, Z. (2009). Not so black and white: Memory for ambiguous group members. *Journal of Personality and Social Psychology*, *96*(4), 795–810. https://doi.org/10.1037/a0013265

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods*, *51*(1), 195–203. https://doi.org/10.3758/s13428-018-01193-y

Penton, T., Bate, S., Dalrymple, K. A., Reed, T., Kelly, M., Godovich, S., Tamm, M., Duchaine, B., & Banissy, M. J. (2018). Using high frequency transcranial random noise stimulation to modulate face memory performance in younger and older adults: Lessons learnt from mixed findings. *Frontiers in Neuroscience*, *12*, 863. https://doi.org/10.3389/fnins.2018.00863

Phillips, P. J., Yates, A. N., Hu, Y., Hahn, C. A., Noyes, E., Jackson, K., Cavazos, J. G., Jeckeln, G., Ranjan, R., Sankaranarayanan, S., Chen, J. C., Castillo, C. D., Chellappa, R., White, D., & O'Toole, A. J. (2018). Face recognition accuracy of forensic examiners, superrecognizers, and face recognition algorithms. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(24), 6171–6176. https://doi.org/10.1073/pnas.1721355115

Piepers, D. W., & Robbins, R. A. (2012). A review and clarification of the terms "holistic," "configural," and "relational" in the face perception literature. *Frontiers in Psychology*, *3*, 559. https://doi.org/10.3389/fpsyg.2012.00559

Pirulli, C., Fertonani, A., & Miniussi, C. (2016). On the Functional Equivalence of Electrodes in Transcranial Random Noise Stimulation. *Brain Stimulation*, *9*(4), 621–622. https://doi.org/10.1016/j.brs.2016.04.005

Pitcher, D., Dilks, D. D., Saxe, R. R., Triantafyllou, C., & Kanwisher, N. (2011). Differential selectivity for dynamic versus static information in face-selective cortical regions. *NeuroImage*, *56*(4), 2356–2363. https://doi.org/10.1016/j.neuroimage.2011.03.067

Pitcher, D., Duchaine, B., & Walsh, V. (2014). Combined TMS and fMRI reveal dissociable cortical pathways for dynamic and static face perception. *Current Biology*, *24*(17), 2066–2070. https://doi.org/10.1016/j.cub.2014.07.060

Pitcher, D., Ianni, G., & Ungerleider, L. G. (2019). A functional dissociation of face-, body- and scene-selective brain areas based on their response to moving and static stimuli. *Scientific Reports*, *9*(1), 8242. https://doi.org/10.1038/s41598-019-44663-9

Pitcher, D., Walsh, V., & Duchaine, B. (2011). The role of the occipital face area in the cortical face perception network. *Experimental Brain Research*, *209*(4), 481–493. https://doi.org/10.1007/s00221-011-2579-1

Pitcher, D., Walsh, V., Yovel, G., & Duchaine, B. (2007). TMS Evidence for the Involvement of the Right Occipital Face Area in Early Face Processing. *Current Biology*, *17*(18), 1568–1573. https://doi.org/10.1016/j.cub.2007.07.063

Polster, M. R., & Rapcsak, S. Z. (1996). Representations in learning new faces: Evidence from prosopagnosia. *Journal of the International Neuropsychological Society*, *2*(3), 240–248. https://doi.org/10.1017/s1355617700001181

Pope, P. A., & Miall, R. C. (2012). Task-specific facilitation of cognition by cathodal transcranial direct current stimulation of the cerebellum. *Brain Stimulation*, *5*(2), 84–94. https://doi.org/10.1016/j.brs.2012.03.006

Popescu, T., Krause, B., Terhune, D. B., Twose, O., Page, T., Humphreys, G., & Cohen Kadosh, R. (2016). Transcranial random noise stimulation mitigates increased difficulty in an arithmetic learning task. *Neuropsychologia*, *81*, 255–264. https://doi.org/10.1016/j.neuropsychologia.2015.12.028

Powell, J., Letson, S., Davidoff, J., Valentine, T., & Greenwood, R. (2008). Enhancement of face recognition learning in patients with brain injury using three cognitive training procedures. *Neuropsychological Rehabilitation*, *18*(2), 182–203. https://doi.org/10.1080/09602010701419485

Priori, A. (2003). Brain polarization in humans: A reappraisal of an old tool for prolonged non-invasive modulation of brain excitability. *Clinical Neurophysiology*, *114*(4), 589–595. https://doi.org/10.1016/S1388-2457(02)00437-6

R Core Team. (2021). *R: A Language and Environment for Statistical Computing.* R Foundation for Statistical Computing. https://www.r-project.org/

Ramon, M., Busigny, T., & Rossion, B. (2010). Impaired holistic processing of unfamiliar individual faces in acquired prosopagnosia. *Neuropsychologia*, *48*(4), 933–944. https://doi.org/10.1016/j.neuropsychologia.2009.11.014

Ramon, M., Miellet, S., Dzieciol, A. M., Konrad, B. N., Dresler, M., & Caldara, R. (2016). Super-memorizers are not super-recognizers. *PLoS ONE*, *11*(3), e0150972. https://doi.org/10.1371/journal.pone.0150972

Rangarajan, V., Hermes, D., Foster, B. L., Weiner, K. S., Jacques, X. C., Grill-Spector, K., & Parvizi, J. (2014). Electrical stimulation of the left and right human fusiform gyrus causes different effects in conscious face perception. *Journal of Neuroscience*, *34*(38), 12828–12836.

https://doi.org/10.1523/JNEUROSCI.0527-14.2014

Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D., Williamson, A., Dahle, C., Gerstorf, D., & Acker, J. D. (2005). Regional brain changes in aging healthy adults: General trends, individual differences and modifiers. *Cerebral Cortex*, *15*(11), 1676–1689. https://doi.org/10.1093/cercor/bhi044

Reato, D., Rahman, A., Bikson, M., & Parra, L. C. (2013). Effects of weak transcranial alternating current stimulation on brain activity-a review of known mechanisms from animal studies. *Frontiers in Human Neuroscience*, *7*, 687. https://doi.org/10.3389/fnhum.2013.00687

Reddy, L., Wilken, P., & Koch, C. (2004). Face-gender discrimination is possible in the near-absence of attention. *Journal of Vision*, *4*(2), 106–117. https://doi.org/10.1167/4.2.4

Reed, T., & Cohen Kadosh, R. (2018). Transcranial electrical stimulation (tES) mechanisms and its effects on cortical excitability and connectivity. *Journal of Inherited Metabolic Disease*, *41*(6), 1123–1130. https://doi.org/10.1007/s10545-018-0181-4

Reedy, M., & Devue, C. (2019). *New perspective on face learning: Stability modulates resolution of facial representations in the optimal observer.* https://doi.org/10.31219/osf.io/6s8c7

Reis, J., Schambra, H. M., Cohen, L. G., Buch, E. R., Fritsch, B., Zarahn, E., Celnik, P. A., & Krakauer, J. W. (2009). Noninvasive cortical stimulation enhances motor skill acquisition over multiple days through an effect on consolidation. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(5), 1590–1595. https://doi.org/10.1073/pnas.0805413106

Renzi, C., Ferrari, C., Schiavi, S., Pisoni, A., Papagno, C., Vecchi, T., Antal, A., & Cattaneo, Z. (2015). The role of the occipital face area in holistic processing involved in face detection and discrimination: A tDCS study. *Neuropsychology*, *29*(3), 409–416. https://doi.org/10.1037/neu0000127

Reteig, L. C., Talsma, L. J., van Schouwenburg, M. R., & Slagter, H. A. (2017). Transcranial Electrical Stimulation as a Tool to Enhance Attention. *Journal of Cognitive Enhancement*, *1*, 10–25. https://doi.org/10.1007/s41465-017-0010-y

Retter, T. L., & Rossion, B. (2015). Global shape information increases but color information decreases the composite face effect. *Perception*, *44*(5), 511–528. https://doi.org/10.1068/p7826

Rezlescu, C., Danaila, I., Miron, A., & Amariei, C. (2020). More time for science: Using Testable to create and share behavioral experiments faster, recruit better participants, and engage students in hands-on research. In *Progress in Brain Research* (Vol. 253, pp. 243–262). https://doi.org/10.1016/bs.pbr.2020.06.005

Rezlescu, C., Susilo, T., Wilmer, J. B., & Caramazza, A. (2017). The inversion, part-whole, and composite effects reflect distinct perceptual mechanisms with varied relationships to face recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *43*(12), 1961–1973. https://doi.org/10.1037/xhp0000400

Rhodes, G. (1993). Configural Coding, Expertise, and the Right Hemisphere Advantage for Face Recognition. *Brain and Cognition*, *22*(1), 19–41. https://doi.org/10.1006/brcg.1993.1022

Rhodes, G., Locke, V., Ewing, L., & Evangelista, E. (2009). Race coding and the other-race effect in face recognition. *Perception*, *38*(2), 232–241. https://doi.org/10.1068/p6110

Rhodes, G., Michie, P. T., Hughes, M. E., & Byatt, G. (2009). The fusiform face area and occipital face area show sensitivity to spatial relations in faces. *European Journal of Neuroscience*, *30*(4), 721–733. https://doi.org/10.1111/j.1460-9568.2009.06861.x

Rhodes, M. G., & Anastasi, J. S. (2012). The own-age bias in face recognition: A meta-analytic and theoretical review. *Psychological Bulletin*, *138*(1), 146–174. https://doi.org/10.1037/a0025750

Richler, J. J., Cheung, O. S., & Gauthier, I. (2011). Holistic Processing Predicts Face Recognition. *Psychological Science*, *22*(4), 464–471. https://doi.org/10.1177/0956797611401753

Rimmele, U., Hediger, K., Heinrichs, M., & Klaver, P. (2009). Oxytocin makes a face in memory familiar. *Journal of Neuroscience*, *29*(1), 38–42. https://doi.org/10.1523/JNEUROSCI.4260-08.2009

Ritchie, K. L., & Burton, A. M. (2017). Learning faces from variability. *Quarterly Journal of Experimental Psychology*, *70*(5), 897–905. https://doi.org/10.1080/17470218.2015.1136656

Ritchie, K. L., Kramer, R. S. S., Mileva, M., Sandford, A., & Burton, A. M. (2021). Multiple-image arrays in face matching tasks with and without memory. *Cognition*, *211*, 104632. https://doi.org/10.1016/j.cognition.2021.104632

Ritchie, K. L., Mireku, M. O., & Kramer, R. S. S. (2020). Face averages and multiple images in a live matching task. *British Journal of Psychology*, *111*(1), 92–102. https://doi.org/10.1111/bjop.12388

Rivolta, D., Palermo, R., Schmalzl, L., & Williams, M. A. (2012). Investigating the features of the M170 in congenital prosopagnosia. *Frontiers in Human Neuroscience*, *6*, 45. https://doi.org/10.3389/fnhum.2012.00045

Robbins, R., & McKone, E. (2007). No face-like processing for objects-of-expertise in three behavioural tasks. *Cognition*, *103*, 34–79. https://doi.org/10.1016/j.cognition.2006.02.008

Röhner, F., Breitling, C., Rufener, K. S., Heinze, H.-J., Hinrichs, H., Krauel, K., & Sweeney-Reed, C. M. (2018). Modulation of Working Memory Using Transcranial Electrical Stimulation: A Direct Comparison Between TACS and TDCS. *Frontiers in Neuroscience*, *12*, 761. https://doi.org/10.3389/fnins.2018.00761

Romanska, A., Rezlescu, C., Susilo, T., Duchaine, B., & Banissy, M. J. (2015). High-frequency transcranial random noise stimulation enhances perception of facial identity. *Cerebral Cortex*, *25*(11), 4334–4340. https://doi.org/10.1093/cercor/bhv016

Ross, L. A., McCoy, D., Coslett, H. B., Olson, I. R., & Wolk, D. A. (2011). Improved proper name recall in aging after electrical stimulation of the anterior temporal lobes. *Frontiers in Aging Neuroscience*, *3*, 16. https://doi.org/10.3389/fnagi.2011.00016

Ross, L. A., McCoy, D., Wolk, D. A., Coslett, H. B., & Olson, I. R. (2010). Improved proper name recall by electrical stimulation of the anterior temporal lobes. *Neuropsychologia*, *48*(12), 3671–3674. https://doi.org/10.1016/j.neuropsychologia.2010.07.024

Rossion, B. (2013). The composite face illusion: A whole window into our understanding of holistic face perception. *Visual Cognition*, *21*(2), 139–253. https://doi.org/10.1080/13506285.2013.772929

Rossion, B. (2014). Understanding face perception by means of prosopagnosia and neuroimaging. *Frontiers in Bioscience*, *6*(2), 706. https://doi.org/10.2741/e706

Rossion, B., Caldara, R., Seghier, M., Schuller, A. M., Lazeyras, F., & Mayer, E. (2003). A network of occipito-temporal face-sensitive areas besides the right middle fusiform gyrus is necessary for normal face processing. *Brain*, *126*(11), 2381–2395. https://doi.org/10.1093/brain/awg241

Rossion, B., Gauthier, I., Tarr, M. J., Pierenne, D., Debatisse, D., & Despland, P. A. (1999). The N170 occipito-temporal component is delayed to inverted faces but not to inverted objects: Electrophysiological evidence of face-specific processes in the human brain. *NeuroImage*, *9*(6 PART II), 69–74.

Rossion, B., & Michel, C. (2011). An Experience-Based Holistic Account of the Other-Race Face Effect. *Oxford Handbook of Face Perception*, 215–244. https://doi.org/10.1093/oxfordhb/9780199559053.013.0012

RStudio Team. (2021). *RStudio: Integrated Development Environment for R*. http://www.rstudio.com/

Rufener, K. S., Krauel, K., Meyer, M., Heinze, H. J., & Zaehle, T. (2019). Transcranial electrical stimulation improves phoneme processing in developmental dyslexia. *Brain Stimulation*, *12*(4), 930–937. https://doi.org/10.1016/j.brs.2019.02.007

Ruffini, G., Fox, M. D., Ripolles, O., Miranda, P. C., & Pascual-Leone, A. (2014). Optimization of multifocal transcranial current stimulation for weighted cortical pattern targeting from realistic modeling of electric fields. *NeuroImage*, *89*, 216–225. https://doi.org/10.1016/j.neuroimage.2013.12.002

Russell, R., Duchaine, B., & Nakayama, K. (2009). Super-recognizers: People with extraordinary face recognition ability. *Psychonomic Bulletin and Review*, *16*(2), 252–257. https://doi.org/10.3758/PBR.16.2.252

Rütsche, B., Hauser, T. U., Jäncke, L., & Grabner, R. H. (2015). When problem size matters: Differential effects of brain stimulation on arithmetic problem solving and neural oscillations. *PLoS ONE*, *10*(3), e0120665. https://doi.org/10.1371/journal.pone.0120665

Sadeh, B., Podlipsky, I., Zhdanov, A., & Yovel, G. (2010). Event-related potential and functional MRI measures of face-selectivity are highly correlated: A simultaneous ERP-fMRI investigation. *Human*

Brain Mapping, *31*(10), 1490–1501. https://doi.org/10.1002/hbm.20952

Sadeh, B., & Yovel, G. (2010). Why is the N170 enhanced for inverted faces? An ERP competition experiment. *NeuroImage*, *53*(2), 782–789. https://doi.org/10.1016/j.neuroimage.2010.06.029

Salvador, R., Ramirez, F., V'Yacheslavovna, M., & Miranda, P. C. (2012). Effects of tissue dielectric properties on the electric field induced in tDCS: A sensitivity analysis. *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS*, 787–790. https://doi.org/10.1109/EMBC.2012.6346049

Sandford, A., & Ritchie, K. L. (2021). Unfamiliar face matching, within-person variability, and multiple-image arrays. *Visual Cognition*, *29*(3), 143–157. https://doi.org/10.1080/13506285.2021.1883170

Saravanamuttu, J. (2010). Malaysia: Multicultural society, Islamic state, or what? *State and Secularism: Perspectives from Asia*, 279–300. https://doi.org/10.1142/9789814282383_0016

Sarkar, A., Dowker, A., & Kadosh, R. C. (2014). Cognitive enhancement or cognitive cost: Trait-specific outcomes of brain stimulation in the case of mathematics anxiety. *Journal of Neuroscience*, *34*(50), 16605–16610. https://doi.org/10.1523/JNEUROSCI.3129-14.2014

Sarmiento, C. I., San-Juan, D., & Prasath, V. B. S. (2016). Letter to the Editor: Brief history of transcranial direct current stimulation (tDCS): From electric fishes to microcontrollers. *Psychological Medicine*, *46*(15), 3259–3261. https://doi.org/10.1017/S0033291716001926

Savage, N. (2012). Gaining wisdom from crowds. *Communications of the ACM*, *55*(3), 13–15. https://doi.org/10.1145/2093548.2093553

Savaskan, E., Ehrhardt, R., Schulz, A., Walter, M., & Schächinger, H. (2008). Post-learning intranasal oxytocin modulates human memory for facial identity. *Psychoneuroendocrinology*, *33*(3), 368–374. https://doi.org/10.1016/j.psyneuen.2007.12.004

Schiltz, C., Dricot, L., Goebel, R., & Rossion, B. (2010). Holistic perception of individual faces in the right middle fusiform gyrus as evidenced by the composite face illusion. *Journal of Vision*, *10*(2), 1–16. https://doi.org/10.1167/10.2.25

Schiltz, C., & Rossion, B. (2006). Faces are represented holistically in the human occipito-temporal cortex. *NeuroImage*, *32*(3), 1385–1394. https://doi.org/10.1016/j.neuroimage.2006.05.037

Schmalzl, L., Palermo, R., Green, M., Brunsdon, R., & Coltheart, M. (2008). Training of familiar face recognition and visual scan paths for faces in a child with congenital prosopagnosia. *Cognitive Neuropsychology*, *25*(5), 704–729. https://doi.org/10.1080/02643290802299350

Schultz, J., & Pilz, K. S. (2009). Natural facial motion enhances cortical responses to faces. *Experimental Brain Research*, *194*(3), 465–475. https://doi.org/10.1007/s00221-009-1721-9

Schwartz, L., & Yovel, G. (2019). Learning faces as concepts rather than percepts improves face recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *45*(10), 1733–1747. https://doi.org/10.1037/xlm0000673

Schwarzer, G., Kretzer, M., Wimmer, D., & Jovanovic, B. (2010). Holistic face processing among school children, younger and older adults. *European Journal of Developmental Psychology*, *7*(4), 511–528. https://doi.org/10.1080/17405620903003697

Senholzi, K. B., & Ito, T. A. (2013). Structural face encoding: How task affects the N170’s sensitivity to race. *Social Cognitive and Affective Neuroscience*, *8*(8), 937–942. https://doi.org/10.1093/scan/nss091

Serafini, L., & Pesciarelli, F. (2022). Neural timing of the other-race effect across the lifespan: A review. *Psychophysiology*, *October 2022*, 1–46. https://doi.org/10.1111/psyp.14203

Shah, P., Gaule, A., Sowden, S., Bird, G., & Cook, R. (2015). The 20-item prosopagnosia index (PI20): a self-report instrument for identifying developmental prosopagnosia. *Royal Society Open Science*, *2*(6), 140343. https://doi.org/10.1098/rsos.140343

Shah, P., Sowden, S., Gaule, A., Catmur, C., & Bird, G. (2015). The 20 item prosopagnosia index (PI20): relationship with the Glasgow face-matching test. *Royal Society Open Science*, *2*(11), 150305. https://doi.org/10.1098/rsos.150305

Shakeshaft, N. G., & Plomin, R. (2015). Genetic specificity of face recognition. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(41), 12887–12892. https://doi.org/10.1073/pnas.1421881112

Shiozawa, P., Da Silva, M. E., Cordeiro, Q., Fregni, F., & Brunoni, A. R. (2013). Transcranial direct current stimulation (tDCS) for the treatment of persistent visual and auditory hallucinations in schizophrenia: A case study. *Brain Stimulation*, *6*(5), 831–833. https://doi.org/10.1016/j.brs.2013.03.003

Shriver, E. R., Young, S. G., Hugenberg, K., Bernstein, M. J., & Lanter, J. R. (2008). Class, race, and the face: Social context modulates the cross-race effect in face recognition. *Personality and Social Psychology Bulletin*, *34*(2), 260–274. https://doi.org/10.1177/0146167207310455

Silvanto, J., Muggleton, N. G., Cowey, A., & Walsh, V. (2007). Neural adaptation reveals state-dependent effects of transcranial magnetic stimulation. *European Journal of Neuroscience*, *25*(6), 1874–1881. https://doi.org/10.1111/j.1460-9568.2007.05440.x

Silvanto, J., Muggleton, N., & Walsh, V. (2008). State-dependency in brain stimulation studies of perception and cognition. *Trends in Cognitive Sciences*, *12*(12), 447–454. https://doi.org/10.1016/j.tics.2008.09.004

Sinha, P., Balas, B., Ostrovsky, Y., & Russell, R. (2006). Face recognition by humans: Nineteen results all computer vision researchers should know about. *Proceedings of the IEEE*, *94*(11), 1948–1961. https://doi.org/10.1109/JPROC.2006.884093

Smith, M. J., Adams, L. F., Schmidt, P. J., Rubinow, D. R., & Wassermann, E. M. (2002). Effects of ovarian hormones on human cortical excitability. *Annals of Neurology*, *51*(5), 599–603. https://doi.org/10.1002/ana.10180

Smith, M. J., Keel, J. C., Greenberg, B. D., Adams, L. F., Schmidt, P. J., Rubinow, D. A., & Wassermann, E. M. (1999). Menstrual cycle effects on cortical excitability. *Neurology*, *53*(9), 2069–2069. https://doi.org/10.1212/WNL.53.9.2069

Snowball, A., Tachtsidis, I., Popescu, T., Thompson, J., Delazer, M., Zamarian, L., Zhu, T., & Cohen Kadosh, R. (2013). Long-term enhancement of brain function and cognition using cognitive training and brain stimulation. *Current Biology*, *23*(11), 987–992. https://doi.org/10.1016/j.cub.2013.04.045

Solomon-Harris, L. M., Mullin, C. R., & Steeves, J. K. E. (2013). TMS to the “occipital face area” affects recognition but not categorization of faces. *Brain and Cognition*, *83*(3), 245–251. https://doi.org/10.1016/j.bandc.2013.08.007

Sporer, S. L. (2001). Recognizing Faces of Other Ethnic Groups: An Integration of Theories. *Psychology, Public Policy, and Law*, *7*(1), 36–97. https://doi.org/10.1037/1076-8971.7.1.36

Sporer, S. L., & Horry, R. (2011). Recognizing faces from ethnic in-groups and out-groups: Importance of outer face features and effects of retention interval. *Applied Cognitive Psychology*, *25*(3), 424–431. https://doi.org/10.1002/acp.1709

Sriganeshvarun, N., & Abdul Aziz, M. M. (2019). Local Films or Hollywood Films: Malaysian's Preferences. *INTI JOURNAL*, *2019*, 45.

Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. *Behavior Research Methods, Instruments, & Computers*, *31*(1), 137–149. https://doi.org/10.3758/BF03207704

Steeves, J. K. E., Culham, J. C., Duchaine, B. C., Pratesi, C. C., Valyear, K. F., Schindler, I., Humphrey, G. K., Milner, A. D., & Goodale, M. A. (2006). The fusiform face area is not sufficient for face recognition: Evidence from a patient with dense prosopagnosia and no occipital face area. *Neuropsychologia*, *44*(4), 594–609. https://doi.org/10.1016/j.neuropsychologia.2005.06.013

Strube, W., Bunse, T., Malchow, B., & Hasan, A. (2015). Efficacy and Interindividual Variability in Motor-Cortex Plasticity following Anodal tDCS and Paired-Associative Stimulation. *Neural Plasticity*, *2015*, 530423. https://doi.org/10.1155/2015/530423

Surowiecki, J. (2004). *The wisdom of crowds*. Anchor Books.

Susilo, T., McKone, E., Dennett, H., Darke, H., Palermo, R., Hall, A., Pidcock, M., Dawel, A., Jeffery, L., Wilson, C. E., & Rhodes, G. (2010). Face recognition impairments despite normal holistic processing and face space coding: Evidence from a case of developmental prosopagnosia. *Cognitive Neuropsychology*, *27*(8), 636–664. https://doi.org/10.1080/02643294.2011.613372

Tan, C. B. Y., Stephen, I. D., Whitehead, R., & Sheppard, E. (2012). You Look Familiar: How Malaysian Chinese Recognize Faces. *PLoS ONE*, *7*(1), e29714. https://doi.org/10.1371/journal.pone.0029714

Tanaka, J. W., & Farah, M. J. (1993). Parts and Wholes in Face Recognition. *The Quarterly Journal of*

Experimental Psychology Section A, *46*(2), 225–245. https://doi.org/10.1080/14640749308401045

Tanaka, J. W., Heptonstall, B., & Hagen, S. (2013). Perceptual expertise and the plasticity of other-race face recognition. *Visual Cognition*, *21*(9–10), 1183–1201. https://doi.org/10.1080/13506285.2013.826315

Tanaka, J. W., Kiefer, M., & Bukach, C. M. (2004). A holistic account of the own-race effect in face recognition: evidence from a cross-cultural study. *Cognition*, *93*, B1–B9. https://doi.org/10.1016/j.cognition.2003.09.011

Tanaka, J. W., & Simonyi, D. (2016). The "Parts and Wholes" of Face Recognition: A Review of the Literature. *Quarterly Journal of Experimental Psychology*, *69*(10), 1876–1889. https://doi.org/10.1080/17470218.2016.1146780

Tardif, J., Morin Duchesne, X., Cohan, S., Royer, J., Blais, C., Fiset, D., Duchaine, B., & Gosselin, F. (2019). Use of Face Information Varies Systematically From Developmental Prosopagnosics to Super-Recognizers. *Psychological Science*, *30*(2), 300–308. https://doi.org/10.1177/0956797618811338

Terney, D., Chaieb, L., Moliadze, V., Antal, A., & Paulus, W. (2008). Increasing Human Brain Excitability by Transcranial High-Frequency Random Noise Stimulation. *Journal of Neuroscience*, *28*(52), 14147–14155. https://doi.org/10.1523/JNEUROSCI.4248-08.2008

Thair, H., Holloway, A. L., Newport, R., & Smith, A. D. (2017). Transcranial Direct Current Stimulation (tDCS): A Beginner's Guide for Design and Implementation. *Frontiers in Neuroscience*, *11*, 641. https://doi.org/10.3389/fnins.2017.00641

Theeuwes, J., & Van der Stigchel, S. (2006). Faces capture attention: Evidence from inhibition of return. *Visual Cognition*, *13*(6), 657–665. https://doi.org/10.1080/13506280500410949

Thirugnanasambandam, N., Sparing, R., Dafotakis, M., Meister, I. G., Paulus, W., Nitsche, M. A., & Fink, G. R. (2011). Isometric contraction interferes with transcranial direct current stimulation (tDCS) induced plasticity - Evidence of state-dependent neuromodulation in human motor cortex. *Restorative Neurology and Neuroscience*, *29*(5), 311–320. https://doi.org/10.3233/RNN-2011-0601

Thomas, C., Moya, L., Avidan, G., Humphreys, K., Kwan, J. J., Peterson, M. A., & Behrmann, M. (2008). Reduction in white matter connectivity, revealed by diffusion tensor imaging, may account for age-related changes in face perception. *Journal of Cognitive Neuroscience*, *20*(2), 268–284. https://doi.org/10.1162/jocn.2008.20025

Towler, A., Kemp, R. I., Burton, A. M., Dunn, J. D., Wayne, T., Moreton, R., & White, D. (2019). Do professional facial image comparison training courses work? *PLOS ONE*, *14*(2), e0211037. https://doi.org/10.1371/journal.pone.0211037

Towler, A., Keshwa, M., Ton, B., Kemp, R. I., & White, D. (2021). Diagnostic feature training improves face matching accuracy. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *47*(8), 1288–1298. https://doi.org/10.1037/xlm0000972

Towler, A., White, D., & Kemp, R. I. (2014). Evaluating training methods for facial image comparison: The face shape strategy does not work. *Perception*, *43*(2–3), 214–218. https://doi.org/10.1068/p7676

Towler, A., White, D., & Kemp, R. I. (2017). Evaluating the feature comparison strategy for forensic face identification. *Journal of Experimental Psychology: Applied*, *23*(1), 47–58. https://doi.org/10.1037/xap0000108

Towler, J., Fisher, K., & Eimer, M. (2018). Holistic face perception is impaired in developmental prosopagnosia. *Cortex*, *108*(6), 112–126. https://doi.org/10.1016/j.cortex.2018.07.019

Truong, D. Q., Magerowski, G., Blackburn, G. L., Bikson, M., & Alonso-Alonso, M. (2013). Computational modeling of transcranial direct current stimulation (tDCS) in obesity: Impact of head fat and dose guidelines. *NeuroImage: Clinical*, *2*(1), 759–766. https://doi.org/10.1016/j.nicl.2013.05.011

Tsantani, M., Gray, K. L. H., & Cook, R. (2020). Holistic processing of facial identity in developmental prosopagnosia. *Cortex*, *130*, 318–326. https://doi.org/10.1016/j.cortex.2020.06.003

Tseng, P., Hsu, T. Y., Chang, C. F., Tzeng, O. J. L., Hung, D. L., Muggleton, N. G., Walsh, V., Liang, W. K., Cheng, S. K., & Juan, C. H. (2012). Unleashing potential: Transcranial direct current stimulation over the right posterior parietal cortex improves change detection in low-performing individuals.

Journal of Neuroscience, *32*(31), 10554–10561. https://doi.org/10.1523/JNEUROSCI.0362-12.2012

Tullis, J. G., Benjamin, A. S., & Liu, X. (2014). Self-pacing study of faces of different races: metacognitive control over study does not eliminate the cross-race recognition effect. *Memory and Cognition*, *42*(6), 863–875. https://doi.org/10.3758/s13421-014-0409-y

Turkeltaub, P. E., Benson, J., Hamilton, R. H., Datta, A., Bikson, M., & Coslett, H. B. (2012). Left lateralizing transcranial direct current stimulation improves reading efficiency. *Brain Stimulation*, *5*(3), 201–207. https://doi.org/10.1016/j.brs.2011.04.002

Tüttenberg, S. C., & Wiese, H. (2019). Learning own- and other-race facial identities from natural variability. *Quarterly Journal of Experimental Psychology*, *72*(12), 2788–2800. https://doi.org/10.1177/1747021819859840

Ulrich, P. I. N., Wilkinson, D. T., Ferguson, H. J., Smith, L. J., Bindemann, M., Johnston, R. A., & Schmalzl, L. (2017). Perceptual and memorial contributions to developmental prosopagnosia. *Quarterly Journal of Experimental Psychology*, *70*(2), 298–315. https://doi.org/10.1080/17470218.2016.1177101

Valentine, T. (1991). A Unified Account of the Effects of Distinctiveness, Inversion, and Race in Face Recognition. *The Quarterly Journal of Experimental Psychology Section A*, *43*(2), 161–204. https://doi.org/10.1080/14640749108400966

Valentine, T., Lewis, M. B., & Hills, P. J. (2016). Face-space: A unifying concept in face recognition research. *Quarterly Journal of Experimental Psychology*, *69*(10), 1996–2019. https://doi.org/10.1080/17470218.2014.990392

Van Belle, G., de Graef, P., Verfaillie, K., Rossion, B., & Lefèvre, P. (2010). Face inversion impairs holistic perception: Evidence from gaze-contingent stimulation. *Journal of Vision*, *10*(5), 1–13. https://doi.org/10.1167/10.5.10

Vandierendonck, A. (2017). A comparison of methods to combine speed and accuracy measures of performance: A rejoinder on the binning procedure. *Behavior Research Methods*, *49*(2), 653–673. https://doi.org/10.3758/s13428-016-0721-5

Vannorsdall, T. D., Van Steenburgh, J. J., Schretlen, D. J., Jayatillake, R., Skolasky, R. L., & Gordon, B. (2016). Reproducibility of tDCS results in a randomized trial: Failure to replicate findings of tDCS-induced enhancement of verbal fluency. *Cognitive and Behavioral Neurology*, *29*(1), 11–17. https://doi.org/10.1097/WNN.0000000000000086

Vergallito, A., Romero Lauro, L. J., Bonandrini, R., Zapparoli, L., Danelli, L., & Berlingeri, M. (2018). What is difficult for you can be easy for me. Effects of increasing individual task demand on prefrontal lateralization: A tDCS study. *Neuropsychologia*, *109*(2018), 283–294. https://doi.org/10.1016/j.neuropsychologia.2017.12.038

Verhallen, R. J., Bosten, J. M., Goodbourn, P. T., Lawrance-Owen, A. J., Bargary, G., & Mollon, J. D. (2017). General and specific factors in the processing of faces. *Vision Research*, *141*, 217–227. https://doi.org/10.1016/j.visres.2016.12.014

Villamar, M. F., Volz, M. S., Bikson, M., Datta, A., DaSilva, A. F., & Fregni, F. (2013). Technique and Considerations in the Use of 4x1 Ring High-definition Transcranial Direct Current Stimulation (HD-tDCS). *Journal of Visualized Experiments*, *77*, e50309. https://doi.org/10.3791/50309

Wan, L., Crookes, K., Dawel, A., Pidcock, M., Hall, A., & McKone, E. (2017). Face-blind for other-race faces: Individual differences in other-race recognition impairments. *Journal of Experimental Psychology: General*, *146*(1), 102–122. https://doi.org/10.1037/xge0000249

Wan, L., Crookes, K., Reynolds, K. J., Irons, J. L., & McKone, E. (2015). A cultural setting where the other-race effect on face recognition has no social-motivational component and derives entirely from lifetime perceptual experience. *Cognition*, *144*(0010), 91–115. https://doi.org/10.1016/j.cognition.2015.07.011

Wang, R., Li, J., Fang, H., Tian, M., & Liu, J. (2012). Individual differences in holistic processing predict face recognition ability. *Psychological Science*, *23*(2), 169–177. https://doi.org/10.1177/0956797611420575

Wang, Y., Xu, Q., Liao, S., & Jia, D. (2017). Unfamiliar faces in recognition memory: Spaced learning enhances subsequent recognition memory by reducing repetition priming. *NeuroReport*, *28*(14), 872–878. https://doi.org/10.1097/WNR.0000000000000847

Weigelt, S., Koldewyn, K., Dilks, D. D., Balas, B., Mckone, E., & Kanwisher, N. (2014). Domain-specific development of face memory but not face perception. *Developmental Science*, *17*(1), 47–58. https://doi.org/10.1111/desc.12089

Weigelt, S., Koldewyn, K., & Kanwisher, N. (2012). Face identity recognition in autism spectrum disorders: A review of behavioral studies. *Neuroscience and Biobehavioral Reviews*, *36*(3), 1060–1084. https://doi.org/10.1016/j.neubiorev.2011.12.008

Westwood, S. J., & Romani, C. (2018). Null Effects on Working Memory and Verbal Fluency Tasks When Applying Anodal tDCS to the Inferior Frontal Gyrus of Healthy Participants. *Frontiers in Neuroscience*, *12*. https://doi.org/10.3389/fnins.2018.00166

White, D., Burton, A. M., Jenkins, R., & Kemp, R. I. (2014). Redesigning photo-ID to improve unfamiliar face matching performance. *Journal of Experimental Psychology: Applied*, *20*(2), 166–173. https://doi.org/10.1037/xap0000009

White, D., Burton, A. M., Kemp, R. I., & Jenkins, R. (2013). Crowd effects in unfamiliar face matching. *Applied Cognitive Psychology*, *27*(6), 769–777. https://doi.org/10.1002/acp.2971

White, D., Jonathon Phillips, P., Hahn, C. A., Hill, M., & O’Toole, A. J. (2015). Perceptual expertise in forensic facial image comparison. *Proceedings of the Royal Society B: Biological Sciences*, *282*(1814). https://doi.org/10.1098/rspb.2015.1292

White, D., Kemp, R. I., Jenkins, R., & Burton, A. M. (2014). Feedback training for facial image comparison. *Psychonomic Bulletin and Review*, *21*(1), 100–106. https://doi.org/10.3758/s13423-013-0475-3

White, D., Kemp, R. I., Jenkins, R., Matheson, M., & Burton, A. M. (2014). Passport officers’ errors in face matching. *PLoS ONE*, *9*(8). https://doi.org/10.1371/journal.pone.0103510

Wickelgren, W. A. (1977). Speed-accuracy tradeoff and information processing dynamics. *Acta Psychologica*, *41*(1), 67–85. https://doi.org/10.1016/0001-6918(77)90012-9

Wickham, H. (2007). Reshaping data with the reshape package. *Journal of Statistical Software*, *21*(12).

http://www.jstatsoft.org/v21/i12/paper

Wickham, H. (2021). *tidyr: Tidy Messy Data*. https://cran.r-project.org/package=tidyr

Wickham, H., François, R., Henry, L., & Müller, K. (2021). *dplyr: A Grammar of Data Manipulation*. https://cran.r-project.org/package=dplyr

Wiese, H. (2013). Do neural correlates of face expertise vary with task demands? event-related potential correlates of own- And other-race face inversion. *Frontiers in Human Neuroscience*, *7*(DEC). https://doi.org/10.3389/fnhum.2013.00898

Wiethoff, S., Hamada, M., & Rothwell, J. C. (2014). Variability in response to transcranial direct current stimulation of the motor cortex. *Brain Stimulation*, *7*(3), 468–475. https://doi.org/10.1016/j.brs.2014.02.003

Willis, M. L., Costantino, A. I., Nitsche, M. A., Palermo, R., & Rivolta, D. (2019). Anodal tDCS and High-Frequency tRNS Targeting the Occipitotemporal Cortex Do Not Always Enhance Face Perception. *Frontiers in Neuroscience*, *13*, 78. https://doi.org/10.3389/fnins.2019.00078

Willis, M. L., Murphy, J. M., Ridley, N. J., & Vercammen, A. (2015). Anodal tDCS targeting the right orbitofrontal cortex enhances facial expression recognition. *Social Cognitive and Affective Neuroscience*, *10*(12), 1677–1683. https://doi.org/10.1093/scan/nsv057

Wilmer, J. B. (2017). Individual Differences in Face Recognition: A Decade of Discovery. *Current Directions in Psychological Science*, *26*(3), 225–230. https://doi.org/10.1177/0963721417710693

Wilmer, J. B., Germine, L., Chabris, C. F., Chatterjee, G., Williams, M., Loken, E., Nakayama, K., & Duchaine, B. (2010). Human face recognition ability is specific and highly heritable. *Proceedings of the National Academy of Sciences of the United States of America*, *107*(11), 5238–5241. https://doi.org/10.1073/pnas.0913053107

Wilson, B. A. (2003). *Neuropsychological Rehabilitation* (1st ed.). CRC Press. https://doi.org/10.1201/b16986

Woltz, D. J., & Was, C. A. (2006). Availability of related long-term memory during and after attention focus in working memory. *Memory and Cognition*, *34*(3), 668–684.

https://doi.org/10.3758/BF03193587

Wong, H. K., Estudillo, A. J., Stephen, I. D., & Keeble, D. R. T. (2021). The other-race effect and holistic processing across racial groups. *Scientific Reports*, *11*, 8507. https://doi.org/10.1038/s41598-021-87933-1

Wong, H. K., Stephen, I. D., & Keeble, D. R. T. (2020). The Own-Race Bias for Face Recognition in a Multiracial Society. *Frontiers in Psychology*, *11*, 208. https://doi.org/10.3389/fpsyg.2020.00208

Wu, D., Zhang, P., Liu, N., Sun, K., & Xiao, W. (2021). Effects of High-Definition Transcranial Direct Current Stimulation Over the Left Fusiform Face Area on Face View Discrimination Depend on the Individual Baseline Performance. *Frontiers in Neuroscience*, *15*, 704880. https://doi.org/10.3389/fnins.2021.704880

Xu, X., & Biederman, I. (2010). Loci of the release from fMRI adaptation for changes in facial expression, identity, and viewpoint. *Journal of Vision*, *10*(14), 1–13. https://doi.org/10.1167/10.14.1

Yamada, Y., & Sumiyoshi, T. (2021). Neurobiological Mechanisms of Transcranial Direct Current Stimulation for Psychiatric Disorders; Neurophysiological, Chemical, and Anatomical Considerations. *Frontiers in Human Neuroscience*, *15*, 631838. https://doi.org/10.3389/fnhum.2021.631838

Yang, L. Z., Zhang, W., Shi, B., Yang, Z., Wei, Z., Gu, F., Zhang, J., Cui, G., Liu, Y., Zhou, Y., Zhang, X., & Rao, H. (2014). Electrical stimulation over bilateral occipito-temporal regions reduces N170 in the right hemisphere and the composite face effect. *PLoS ONE*, *9*(12), e115772. https://doi.org/10.1371/journal.pone.0115772

Yang, T., & Banissy, M. J. (2017). Enhancing anger perception in older adults by stimulating inferior frontal cortex with high frequency transcranial random noise stimulation. *Neuropsychologia*, *102*(2017), 163–169. https://doi.org/10.1016/j.neuropsychologia.2017.06.017

Yao, Q., & Zhao, L. (2019). Using spatial frequency scales for processing own-race and other-race faces: An ERP analysis. *Neuroscience Letters*, *705*(January), 167–171. https://doi.org/10.1016/j.neulet.2019.04.059

Yardley, L., McDermott, L., Pisarski, S., Duchaine, B., & Nakayama, K. (2008). Psychosocial consequences of developmental prosopagnosia: A problem of recognition. *Journal of Psychosomatic Research*, *65*(5), 445–451. https://doi.org/10.1016/j.jpsychores.2008.03.013

Yin, R. K. (1969). Looking at upide-down faces. *Journal of Experimental Psychology*, *81*(1), 141–145. https://doi.org/10.1037/h0027474

Young, A. W., & Burton, A. M. (2018). Are We Face Experts? *Trends in Cognitive Sciences*, *22*(2), 100–110. https://doi.org/10.1016/j.tics.2017.11.007

Young, A. W., Hay, D. C., & Ellis, A. W. (1985). The faces that launched a thousand slips: Everyday difficulties and errors in recognizing people. *British Journal of Psychology*, *76*(4), 495–523. https://doi.org/10.1111/j.2044-8295.1985.tb01972.x

Young, A. W., Hellawell, D., & Hay, D. C. (1987). Configurational information in face perception. *Perception*, *16*, 747–759. https://doi.org/10.1068/p160747n

Young, S. G., Bernstein, M. J., & Hugenberg, K. (2010). When do own-group biases in face recognition occur? encoding versus post-encoding. *Social Cognition*, *28*(2), 240–250. https://doi.org/10.1521/soco.2010.28.2.240

Young, S. G., & Hugenberg, K. (2012). Individuation motivation and face experience can operate jointly to produce the own-race bias. *Social Psychological and Personality Science*, *3*(1), 80–87. https://doi.org/10.1177/1948550611409759

Yovel, G., & Kanwisher, N. (2004). Face perception: Domain specific, not process specific. *Neuron*, *44*(5), 889–898. https://doi.org/10.1016/j.neuron.2004.11.018

Yovel, G., & Kanwisher, N. (2005). The neural basis of the behavioral face-inversion effect. *Current Biology*, *15*(24), 2256–2262. https://doi.org/10.1016/j.cub.2005.10.072

Zaehle, T., Rach, S., & Herrmann, C. S. (2010). Transcranial Alternating Current Stimulation Enhances Individual Alpha Activity in Human EEG. *PLoS ONE*, *5*(11), e13766. https://doi.org/10.1371/journal.pone.0013766

Zaghi, S., Acar, M., Hultgren, B., Boggio, P. S., & Fregni, F. (2010). Noninvasive brain stimulation with low-intensity electrical currents: Putative mechanisms of action for direct and alternating current stimulation. *Neuroscientist*, *16*(3), 285–307. https://doi.org/10.1177/1073858409336227

Zhang, J., Li, X., Song, Y., & Liu, J. (2012). The Fusiform Face Area Is Engaged in Holistic, Not Parts-Based, Representation of Faces. *PLoS ONE*, *7*(7), e40390. https://doi.org/10.1371/journal.pone.0040390

Zhou, X., Burton, A. M., & Jenkins, R. (2021). Two Factors in Face Recognition: Whether You Know the Person's Face and Whether You Share the Person's Race. *Perception*, *50*(6), 524–539. https://doi.org/10.1177/03010066211014016

Zoefel, B., Huster, R. J., & Herrmann, C. S. (2011). Neurofeedback training of the upper alpha frequency band in EEG improves cognitive performance. *NeuroImage*, *54*(2), 1427–1431. https://doi.org/10.1016/j.neuroimage.2010.08.078

Appendices

Appendix A: Perceived sensation after FFA and OFA stimulation for Experiment 1a.

Perceived sensation

A Wilcoxon signed-rank test was conducted on the effect of stimulation type (OFA vs. FFA) on the rating score for how much the stimulation affected participant's general state (0 = not at all, 1 = slightly, 2 = considerably, 3 = much and 4 = very much). The stimulation did not produce a statistically significant change in the rating score for general state, $W = 85.5$, $p = 1$. Wilcoxon signed-rank test was also conducted on the effect of stimulation type (OFA vs. FFA) on the rating score (0 = none, 1 = mild, 2 = moderate and 3 = strong) for the different sensations perceived (itching, pain, burning, warmth/heat, metallic/iron taste and fatigue/decreased alertness). Rating score for itching was higher for FFA stimulation ($M = 1.429$, $SD = 1.065$) compared to OFA stimulation ($M = .9429$, $SD = .765$), $W = 199$, $p = .013$. No difference was found between FFA stimulation and OFA stimulation on the rating score for pain ($W = 176$, $p = .075$), burning ($W = 62$, $p = .549$), warmth/heat ($W = 38.5$, $p = .627$), metallic/iron taste ($W = 4$, $p = .773$) and fatigue/decreased alertness ($W = 50$, $p = .768$). For additional remarks on the sensation of stimulation, refer to Table A.

The results revealed that the rating score for itching was higher for the FFA stimulation compared to the OFA stimulation. Although participants reported more itching during the FFA stimulation than the OFA stimulation, no difference was reported for participant's rating of their general state after the FFA stimulation and OFA stimulation. Additionally, the stimulation was administered in an offline manner (before task). Hence, the itching sensation should have had minimal to no effect on the performance of the face recognition tasks.

Table A

Additional remarks on the sensation of stimulation for Experiment 1a.

Stimulation	Additional remarks
OFA	Felt calmer and more relaxed.
FFA	Cold burn
	Ticklish

Note. Remarks provided by three participants

Appendix B: Perceived sensation after the FFA, OFA and sham stimulation and an analysis on baseline scores to compare face recognition ability and age between stimulation groups for Experiment 1b.

Perceived sensation

Kruskal-Wallis test was conducted on the rating score (0 = none, 1 = mild, 2 = moderate and 3 = strong) of perceived sensation (itching, pain, burning, warmth/heat, metallic/iron taste and fatigue/decreased alertness) of the stimulation type (FFA vs. OFA vs. sham). No difference was found for rating score of itching ($H(2) = 3.33$, $p = .19$), pain ($H(2) = .05$, $p = .97$), burning ($H(2) = 2.21$, $p = .33$), warmth/heat ($H(2) = 2.32$, $p = .31$), metallic/iron taste ($H(2) = .43$, $p = .81$) and fatigue/decreased alertness ($H(2) = 2.53$, $p = .28$) between stimulation type. Kruskal-Wallis test also revealed no difference between stimulation type on the rating score of how much the participant's general state was affected after stimulation (0 = not at all, 1 = slightly, 2 = considerably, 3 = much and 4 = very much), ($H(2) = 1.09$, $p = .58$). For additional remarks on the sensation of stimulation and participant's belief on whether they have received real or placebo stimulation, refer to Table B and Table C. Our results showed no difference in sensation perceived between FFA, OFA and sham stimulation.

Table B

Additional remarks on the sensation of stimulation for Experiment 1b.

Stimulation	Additional remarks
OFA	Decreased alertness and felt tired even when the cartoon video reached the funny part.
FFA	Sleepy
Sham	The tingling sensation started at the beginning of the stimulation very mildly and faded away gradually. The sensation became much more intense

in the middle of the stimulation period and persisted until the end until it was stopped.

I felt sleepier at the second half of the video.

Really sleepy for some reason but the cartoon kept me alert.

Felt in the initial minute and final minute of the stimulation period.

Note. Remarks provided by six participants.

Table C

Participant's belief on whether they have received real or placebo stimulation for Experiment 1b.

	Number of participants		
Stimulation	Real	Placebo	Not sure
FFA	12	1	7
OFA	16	1	3
Sham	8	2	10

Note. Each stimulation group had 20 participants.

Baseline (pre-stimulation)

One-way ANOVA was conducted to examine if there was any age difference between stimulation groups. No significant age difference was found between stimulation group, $F(2, 57) = 0.346$, $p = .709$.

A mixed 2 (task type: features vs. whole faces) × 3 (simulation group: FFA vs. OFA vs. sham) ANOVA was conducted to examine if there were any difference in accuracy between stimulation group prior to stimulation. Accuracy reported is in proportion correct. Analysis revealed no main effect of stimulation group on accuracy, $F(2, 57) = .258$, $p = .773$, $\eta_p^2 = .009$. A main effect of task type was found, $F(1, 57) = 45.978$, $p < .001$, $\eta_p^2 = .446$, where features task ($M = .659$, $SD = .082$) had lower accuracy compared to whole faces task (*M* = .732, *SD* = .08). No significant interaction effect was found between stimulation group and task type on accuracy, *F*(2, 57) = .504, *p* = .607, η_p^2 = .017.

A second mixed ANOVA was conducted to examine if there was any difference in reaction time for correct trials between stimulation group prior to stimulation. Analysis revealed no main effect of stimulation group, *F*(2, 57) = .389, *p* = .679, η_p^2 = .013. A main effect of task type was found, *F*(1, 57) = 20.909, *p* < .001, η_p^2 = .268, where the features task (*M* = 1.14s, *SD* = .253s) had longer reaction time for correct trials compared to the whole faces task (*M* = 1.05s, *SD* = .214s). No significant interaction effect was found between stimulation group and task type on reaction time for correct trials, *F*(2, 57) = 2.403, *p* = .1, η_p^2 = .078.

Altogether, the results showed no difference in face recognition ability and age between stimulation groups prior to receiving stimulation. However, the features task had lower accuracy and longer reaction time compared to the whole faces task.

Appendix C: Exclusion of possible prosopagnosia cases for Experiment 2a.

Possible prosopagnosia cases were excluded to provide calculation representing “norm” participants in order to be able to use the test for diagnosing prosopagnosia cases (see Bowles et al., 2009 and McKone et al., 2017 for a similar procedure). Percentile ranks (Crawford et al., 2009) were calculated to determine the bottom 2% of the sample using the formula $(m + 0.5k) / N \times 100$ where m is the number of participants scoring below a given score, k is the number of participants which have obtained the given score and N is the total sample size. Using this formula, CFMT-MY score of 39/72 was equivalent to a percentile rank of 1.87% of the total sample size ($N = 134$) and the score after, 42/72 was equivalent to 2.61%. Three participants (participant ID: 71, 102 and 75) which scored ≤ 39 were excluded. Based on the scores in Table A1, these participants scored quite well in the learning stage of CFMT-Chinese and CFMT-MY, showing that the low scores were not attributable to lack of effort. Similarly, the scores for CFMT-Chinese were at the lower end of the normal distribution. Raw data file showed no indication of repeated same key pressing.

The standard method was used to calculate the cut-off value of the CFMT-Chinese for prosopagnosia, $M - 2SD$. The cut-off score was 36.46/72. Five participants (participant ID: 78, 105, 123, 83 and 45) which scored ≤ 36 were excluded. Based on the scores in Table D, these participants scored quite well in the learning stage of CFMT-Chinese and CFMT-MY, showing that the low scores were not attributable to lack of effort. However, they unexpectedly scored in the average to high range for CFMT-MY, except for participant 105. Raw data file showed no indication of repeated same key pressing, however, participant 123 had 16/72 trials (22.22%) with response time < 500ms and four trials with abnormally long response time (12194-168585ms) in the CFMT-Chinese block showing that the participation may be distracted during the task. Additionally, all five participants completed the CFMT-Chinese as the last block as per randomization, hence, the low performance could be attributed to fatigue or loss of attention/effort towards the end of the experiment.

It is unclear if these cases presented are prosopagnosia as some of the participants may have scored on the lower end due to fatigue or loss of attention towards the end of the experiment. Other measures such as the 20-item prosopagnosia index (PI20) (Shah, Gaule, et al., 2015), famous face test and a clinical interview are needed to confirm these cases.

Table D

Possible prosopagnosia cases based on CFMT-MY and CFMT-Chinese scores.

	CFMT-MY		CFMT-Chinese		CCMT		
Participant ID	All trials (/72)	Learning stage (/18)	All trials (/72)	Learning stage (/18)	All trials (/72)	Learning stage (/18)	Order of tasks
71	39	18	37	14	49	14	CCMT > CFMT-MY > CFMT-Chinese
102	31	11	40	17	37	8	CCMT > CFMT-Chinese > CFMT-MY
75	36	15	43	18	41	17	CCMT > CFMT-MY > CFMT-Chinese
78	61	18	30	18	47	13	CCMT > CFMT-MY > CFMT-Chinese
105	44	15	33	17	44	15	CFMT-MY > CCMT > CFMT-Chinese
123	53	17	33	15	32	10	CFMT-MY > CCMT > CFMT-Chinese
83	53	17	34	14	46	17	CCMT > CFMT-MY > CFMT-Chinese
45	56	18	35	17	51	18	CCMT > CFMT-MY > CFMT-Chinese

Note. Participant 71, 102 and 75 scored below percentile rank of 2% for CFMT-MY and participant 78, 105, 123, 83 and 45 scores below cut-off score (*M* - 2*SD*).

Appendix D: Exclusion of possible prosopagnosia cases for Experiment 2b.

Possible prosopagnosia cases were excluded to provide calculation representing “norm” participants (see Bowles et al., 2009 and McKone et al., 2017 for a similar procedure). The standard method, *M* – 2*SD,* was used to calculate the cut-off value of the CFMT-original for prosopagnosia. The cut-off score was 37.79/72. Four participants (ID: 49, 87, 43 and 96) which scored ≤ 38 were excluded. Based on the scores in Table B1, these participants scored quite well in the learning stage of all test versions of CFMT, showing that the low scores were not attributable to lack of effort (except for participant 43 in the CFMT-MY learning stage). Similarly, the scores for CFMT-Chinese and CFMT-MY were at the lower end of the normal distribution. Raw data file showed no indication of repeated same key pressing, however, participant 43 had 32/72 trials (44.44%) for the CFMT-Chinese block, 17/72 trials (23.61%) for the CFMT-MY block and 34/72 trials (47.22%) for the CFMT-original block with response time < 500ms indicating that the participation may be pressing some of the keys randomly during the task.

The standard method to calculate the cut-off value, *M* – 2*SD*, was used to determine participants which had average score ranked in the bottom 2% of the sample for CFMT-Chinese (for similar procedure, see Wan et al., 2017). The cut-off value was 31.49/72. Four participants (ID: 129, 115, 37 and 9) which scored ≤ 31 were excluded. Based on the scores in Table E, these participants scored quite well in the learning stage of all test versions of CFMT, showing that the low scores were not attributable to lack of effort. Similarly, the scores for CFMT-MY were at the lower end of the normal distribution (except for participant 9). Raw data file showed no indication of repeated same key pressing. It is unclear if the participants were possible prosopagnosia cases or if they were severely affected by the other-race effect (ORE). For example, participant 37 scored on the lower end for both CFMT-Chinese and CFMT-MY (other-race) but scored on the average range for CFMT-original (own-race).

Cut-off value was also calculated using the standard method, *M* – 2*SD*, to determine participants which had average score ranked in the bottom 2% of the sample for CFMT-MY. The cut-off value was

32.8/72. Two participants (ID: 71 and 104) which scored ≤ 33 were excluded. Based on the scores in Table 7, these participants scored quite well in the learning stage of all test versions of CFMT, showing that the low scores were not attributable to lack of effort. Similarly, the scores for CFMT-Chinese were at the lower end of the normal distribution. Raw data file showed no indication of repeated same key pressing.

All 10 participants were excluded from the data analysis (except for internal reliability analysis). As in Experiment 1, it is unclear if the participants scoring below the cut-off value on the CFMT-original were indicative of possible prosopagnosia as further diagnosis using other measures are needed to confirm these cases. It is also unclear if the participants which had average score ranked in the bottom 2% of the sample for CFMT-MY and CFMT-Chinese were possible prosopagnosia cases, or if they were severely affected by the other-race effect with average face recognition ability for own-race faces (Wan et al., 2017).

Table E

Possible prosopagnosia cases based on CFMT-original, CFMT-Chinese and CFMT-MY scores.

	CFMT-MY		CFMT-Chinese		CFMT-original		
Participant ID	All trials (/72)	Learning stage (/18)	All trials (/72)	Learning stage (/18)	All trials (/72)	Learning stage (/18)	Order of tasks
49	35	15	41	18	34	17	CFMT-Chinese > CFMT-original > CFMT-MY
87	39	15	39	18	34	16	CFMT-MY > CFMT-Chinese > CFMT-original
43	26	6	37	18	36	11	CFMT-Chinese > CFMT-original > CFMT-MY
96	36	17	37	16	38	18	CFMT-Chinese > CFMT-original > CFMT-MY

129	38	15	30	18	39	16	CFMT-MY > CFMT-Chinese > CFMT-original
115	34	12	31	14	43	15	CFMT-original > CFMT-Chinese > CFMT-MY
37	39	13	31	15	56	18	CFMT-MY > CFMT-original > CFMT-Chinese
9	46	17	31	12	41	16	CFMT-Chinese > CFMT-original > CFMT-MY
71	30	14	40	13	48	15	CFMT-Chinese > CFMT-MY > CFMT-original
104	31	17	44	16	45	18	CFMT-original > CFMT-Chinese > CFMT-MY

Note. Participants scored below percentile rank of 2% for CFMT-original (49, 87, 43 and 96), CFMT-Chinese (129, 115, 37 and 9) and CFMT-MY

Appendix E: Analysis of internal reliability, internal consistency and validity for Experiment 2b.

Internal reliability

The internal reliability of the test was measured using Cronbach's α. For all trials, internal reliability was α = .87 for CFMT-MY. Results showed high internal reliability for CFMT-MY which was in line with previous work such as CFMT-Chinese, α = .86 (McKone et al., 2017).

Internal consistency

The internal consistency of the CFMT-MY at stage level (i.e., learning, novel and novel-with-noise) was measured using Pearson correlation (*r*). Results showed positive correlation between the learning and novel stage, *r*(133) = .45, *p* < .001, learning and novel-with-noise stage, *r*(133) = .34, *p* < .001 and novel and novel-with-noise stage, *r*(133) = .67, *p* < .001 showing that the scores were highly consistent across the different stages of CFMT-MY.

Validity

Convergent validity was measured using Pearson correlation (*r*). Convergent validity was measured by examining the correlation between the CFMT-MY and CFMT-Chinese and between the CFMT-MY and CFMT-original. Results showed positive correlation between the scores of CFMT-MY and CFMT-Chinese, *r*(123) = .57, *p* < .001 and of CFMT-MY and CFMT-original, *r*(123) = .52, *p* < .001. The difference between the two correlation was further analyzed by comparing the dependent overlapping correlations (Diedenhofen & Musch, 2015; Hittner et al., 2003). The test showed that the correlation between CFMT-MY and CFMT-Chinese was no different compared to the correlation between CFMT-MY and CFMT-original (*z* = 0.7, *p* = .49).

Appendix F: Additional remarks on the sensation of stimulation and participants' beliefs about whether they had received real or sham stimulation in Experiment 3.

Table F

Additional remarks on the sensation of stimulation.

Stimulation	Additional remarks
a-tDCS	Random electrical pinch on wrist
	Very slight itch experienced
	Fatigue (3 participants)
	I felt a little sleepy half way of watching the video
	Slightly more alert
	I had a slight decrease in terms of awareness. Mild dizziness starting only towards the end of the video.
c-tDCS	Less focus and face recognition skills reduced
	Fatigue
	Feeling a little bit sleepy, but otherwise no difference to usual tiredness before bed time
	Felt fatigue in the middle of the experiment
	Pin prickling sensation
Sham stimulation	Dizzy
	Feeling a bit tired and loss of focus after the stimulation
	Not much sensation from the device but feeling a bit dizzy at the initial moment
	I felt the itching at the beginning and the end, not in the middle

Note. Remarks provided by 17 participants

Table G

Participants' beliefs about whether they had received real or placebo stimulation.

	Number of participants		
Stimulation	Real	Placebo	Not sure
a-tDCS	21	3	6
c-tDCS	17	1	12
Sham stimulation	15	4	11

Note. Each stimulation group had 30 participants.

Appendix G: Results of 2 (CFMT type: own-race vs. other-race) × 2 (session: pre vs. post) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA and 2 (CFMT type: own-race vs. other-race) × 3 (task stage: learn vs. novel vs. novel-with-noise) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA for CFMT performance conducted on accuracy, reaction time and efficiency for Experiment 3.

2 (CFMT type: own-race vs. other-race) × 2 (session: pre vs. post) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA for CFMT performance

A mixed 2 (CFMT type: own-race vs. other-race) × 2 (session: pre vs. post) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA was conducted to examine if there was any difference in accuracy between stimulation groups (Figure 3.4). Accuracy reported is in proportion correct. Analysis revealed no main effect of stimulation group, $F(2, 87) = 1.927$, $p = .152$, $\eta_p^2 = .042$, and session, $F(1, 87) = 3.460$, $p = .066$, $\eta_p^2 = .038$, on accuracy. A main effect of CFMT type was found, $F(1, 87) = 265.053$, $p < .001$, $\eta_p^2 = .753$, where own-race face recognition (*M* = .802, *SD* = .121) had higher accuracy compared to other-race face recognition (*M* = .669, *SD* = .107). No significant interaction effect was found between stimulation group and CFMT type, $F(2, 87) = .538$, $p = .586$, $\eta_p^2 = .012$, stimulation group and session, $F(2, 87) = .458$, $p = .634$, $\eta_p^2 = .010$, session and CFMT type, $F(1, 87) = .063$, $p = .802$, $\eta_p^2 = 7.232e – 4$, and stimulation, session and CFMT type, $F(2, 87) = 2.688$, $p = .074$, $\eta_p^2 = .058$.

A mixed 2 (CFMT type: own-race vs. other-race) × 2 (session: pre vs. post) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA was also conducted on median reaction time for correct trials (Figure 3.4). Analysis revealed no main effect of stimulation group on reaction time, $F(2, 87) = .525$, $p = .594$, $\eta_p^2 = .012$. A significant main effect of session was found, $F(1, 87) = 13.570$, $p < .001$, $\eta_p^2 = .135$, where pre-stimulation (*M* = 2.284s, *SD* = .645s) had longer reaction time compared to post-stimulation (*M* = 2.157s, *SD* = .568s) sessions. A main effect of CFMT type was found, $F(1, 87) = 46.122$, $p < .001$, $\eta_p^2 = .346$, where own-race face recognition (*M* = 2.097s, *SD* = .566) had shorter reaction time compared to other-race face recognition (*M* = 2.344s, *SD* = .649s). No significant interaction effect was found between stimulation group and CFMT type, *F*(2, 87) = .217, *p* = .805, η_p^2 = .005, stimulation group and session, *F*(2, 87) = 1.782, *p* = .174, η_p^2 = .039, session and CFMT type, *F*(1, 87) = .613, *p* = .436, η_p^2 = .007, and stimulation, session and CFMT type, *F*(2, 87) = .114, *p* = .893, η_p^2 = .003.

A mixed 2 (CFMT type: own-race vs. other-race) × 2 (session: pre vs. post) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA was conducted on RCS (Figure 3.4). Analysis revealed no main effect of stimulation group, *F*(2, 87) = 1.346, *p* = .266, η_p^2 = .030, and session, *F*(1, 87) = 3.843, *p* = .053, η_p^2 = .042, on efficiency. A main effect of CFMT type was found, *F*(1, 87) = 115.738, *p* < .001, η_p^2 = .571, where own-race face recognition (*M* = .348, *SD* = .134) had higher efficiency compared to other-race face recognition (*M* = .248, *SD* = .076). No significant interaction effect was found between stimulation group and CFMT type, *F*(2, 87) = .114, *p* = .892, η_p^2 = .003, stimulation group and session, *F*(2, 87) = .354, *p* = .703, η_p^2 = .008, session and CFMT type, *F*(1, 87) = .475, *p* = .493, η_p^2 = .005, and stimulation, session and CFMT type, *F*(2, 87) = 1.094, *p* = .339, η_p^2 = .025.

2 (CFMT type: own-race vs. other-race) × 3 (task stage: learn vs. novel vs. novel-with-noise) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA for CFMT performance

Mixed ANOVA was conducted to examine difference in accuracy and median reaction time for correct trials for own- and other-race CFMT task among the stimulation groups (a-tDCS vs. c-tDCS vs. sham stimulation). When Mauchly’s test indicated that the assumption of sphericity had been violated, the degrees of freedom was corrected using Greenhouse-Geisser estimates of sphericity.

Accuracy

A mixed 2 (CFMT type: own-race vs. other-race) × 3 (task stage: learn vs. novel vs. novel-with-noise) × 3 (simulation group: a-tDCS vs. c-tDCS vs. sham) ANOVA was conducted to examine if there was any difference in accuracy between stimulation groups. Accuracy reported is in proportion correct. Analysis revealed no main effect of stimulation group on accuracy, *F*(2, 87) = 1.152, *p* = .321, η_p^2 = .026.

A main effect of CFMT type was found, $F(1, 87) = 171.982$, $p < .001$, $\eta_p^2 = .664$, where own-race face recognition ($M = .795$, $SD = .132$) had higher accuracy compared to other-race face recognition ($M = .660$, $SD = .121$). No significant interaction effect was found between stimulation group and CFMT type on accuracy, $F(2, 87) = .737$, $p = .481$, $\eta_p^2 = .017$.

A main effect of task stage was found, $F(1.562, 135.921) = 389.430$, $p < .001$, $\eta_p^2 = .817$. Post-hoc Holm–Bonferroni test revealed that the learning stage ($M = .958$, $SD = .068$) had higher accuracy compared to the novel stage ($M = .685$, $SD = .178$), $p < .001$, $d = 1.894$. The learning stage also had higher accuracy compared to the novel-with-noise stage ($M = .608$, $SD = .210$), $p < .001$, $d = 2.430$. Accuracy for novel stage was higher compared to novel-with-noise stage, $p < .001$, $d = .536$. No significant interaction effect was found between stimulation group and task stage on accuracy, $F(4, 174) = .846$, $p = .498$, $\eta_p^2 = .019$.

A significant interaction effect was found between CFMT type and task stage on accuracy, $F(2, 174) = 94.308$, $p < .001$, $\eta_p^2 = .520$. Simple main effect analysis revealed that scores of the own-race CFMT was higher than other-race CFMT in the learning stage (own-race: $M = .967$, $SD = .063$, other-race: $M = .949$, $SD = .071$), $F(1, 89) = 4.961$, $p = .028$, $\eta^2 = .053$, novel stage (own-race: $M = .743$, $SD = .181$, other-race: $M = .627$, $SD = .156$), $F(1, 89) = 51.356$, $p < .001$, $\eta^2 = .366$, and novel-with-noise stage (own-race: $M = .731$, $SD = .174$, other-race: $M = .486$, $SD = .167$), $F(1, 89) = 262.331$, $p < .001$, $\eta^2 = .747$. No significant interaction effect was found between stimulation group, task stage and CFMT type on accuracy, $F(4, 174) = 1.431$, $p = .226$, $\eta_p^2 = .032$.

Reaction time

A mixed ANOVA was conducted to examine if there were any difference in median reaction time for correct trials between stimulation group. Analysis revealed no main effect of stimulation group on reaction time, $F(2, 87) = .953$, $p = .390$, $\eta_p^2 = .021$. A main effect of CFMT type was found, $F(1, 87) = 47.650$, $p < .001$, $\eta_p^2 = .354$, where own-race face recognition ($M = 2.046$s, $SD = .561$s) had shorter reaction time compared to other-race face recognition ($M = 2.269$s, $SD = .630$s). No significant interaction effect was found between stimulation group and CFMT type on reaction time, *F*(2, 87) = .036, $p = .964$, $\eta_p^2 = .001$.

A main effect of task stage was found, *F*(1.659, 144.348) = 98.913, $p < .001$, $\eta_p^2 = .532$. Post-hoc test revealed that the learning stage (*M* = 1.639s, *SD* = .488s) had shorter reaction time compared to the novel stage (*M* = 2.534s, *SD* = .849s), $p < .001$, *d* = 1.275. The learning stage also had shorter reaction time compared to the novel-with-noise stage (*M* = 2.547s, *SD* = 1.120s), $p < .001$, *d* = 1.293. No difference was found in reaction time for novel and novel-with-noise stage, $p = .867$, *d* = .018. No significant interaction effect was found between stimulation group and task stage on reaction time, *F*(4, 174) = 1.415, $p = .231$, $\eta_p^2 = .032$.

A significant interaction effect was found between CFMT type and task stage on reaction time, *F*(1.678, 145.977) = 4.823, $p = .014$, $\eta_p^2 = .053$. Simple main effect analysis revealed that reaction time of the own-race CFMT was shorter than other-race CFMT in the learning stage (own-race: *M* = 1.545s, *SD* = .439s, other-race: *M* = 1.732s, *SD* = .517s), *F*(1, 89) = 28.026, $p < .001$, $\eta^2 = .239$, novel stage (own-race: *M* = 2.396s, *SD* = .861s, other-race: *M* = 2.672s, *SD* = .819s), *F*(1, 89) = 19.618, $p < .001$, $\eta^2 = .181$, and novel-with-noise stage (own-race: *M* = 2.307s, *SD* = .803s, other-race: *M* = 2.786s, *SD* = 1.328s), *F*(1, 89) = 22.830, $p < .001$, $\eta^2 = .204$. No significant interaction effect was found between stimulation group, task stage and CFMT type on reaction time, *F*(4, 174) = .384, $p = .820$, $\eta_p^2 = .009$.

Efficiency

A mixed ANOVA was conducted to examine if there were any difference in efficiency between stimulation group. Analysis revealed no main effect of stimulation group, *F*(2, 87) = .778, $p = .462$, $\eta_p^2 = .018$. A main effect of CFMT type was found, *F*(1, 87) = 118.325, $p < .001$, $\eta_p^2 = .576$, where own-race face recognition (*M* = .408, *SD* = .213) had higher efficiency compared to other-race face recognition (*M* = .308, *SD* = .190). No significant interaction effect was found between stimulation group and CFMT type, *F*(2, 87) = .301, $p = .741$, $\eta_p^2 = .007$.

A main effect of task stage was found, $F(1.324, 115.174) = 644.304$, $p < .001$, $\eta_p^2 = .881$. Post-hoc test revealed that the learning stage ($M = .568$, $SD = .175$) had higher efficiency compared to the novel stage ($M = .261$, $SD = .121$), $p < .001$, $d = 2.263$. The learning stage also had higher efficiency compared to the novel-with-noise stage ($M = .244$, $SD = .132$), $p < .001$, $d = 2.394$. No difference was found in efficiency for novel and novel-with-noise stage, $p = .083$, $d = .131$. No significant interaction effect was found between stimulation group and task stage, $F(2.648, 115.174) = 1.071$, $p = .359$, $\eta_p^2 = .024$.

A significant interaction effect was found between CFMT type and task stage on efficiency, $F(1.513, 131.639) = 6.719$, $p = .004$, $\eta_p^2 = .072$. Simple main effect analysis revealed that efficiency of the own-race CFMT was higher than other-race CFMT in the learning stage (own-race: $M = .613$, $SD = .186$, other-race: $M = .523$, $SD = .150$), $F(1, 89) = 38.622$, $p < .001$, $\eta^2 = .303$, novel stage (own-race: $M = .301$, $SD = .138$, other-race: $M = .222$, $SD = .085$), $F(1, 89) = 44.529$, $p < .001$, $\eta^2 = .333$, and novel-with-noise stage (own-race: $M = .309$, $SD = .137$, other-race: $M = .178$, $SD = .087$), $F(1, 89) = 128.817$, $p < .001$, $\eta^2 = .591$. No significant interaction effect was found between stimulation group, task stage and CFMT type, $F(3.026, 131.639) = 2.002$, $p = .116$, $\eta_p^2 = .044$.

Appendix H: A comparison of hit rates (in the high variability condition) and correct rejections for Chinese stimuli and Caucasian stimuli for Chinese Malaysian participants in Experiment 4b.

Paired samples t-test revealed that in the high variability condition, Chinese Malaysian participants had similar hit rates for Chinese stimuli (*M* = 0.730, *SD* = 0.170) and Caucasian stimuli (*M* = 0.707, *SD* = 0.191), *t*(94) = 1.244, *p* = .217, *d* = .128. However, Chinese Malaysian participants showed higher correct rejections for Chinese stimuli (*M* = 0.816, *SD* = 0.766) than Caucasian stimuli (*M* = 0.766, *SD* = 0.143), *t*(94) = 3.954, *p* < .001, *d* = .406.

Appendix I: Statements in the Autism Spectrum Quotient - 10 items (AQ-10).

1. I often notice small sounds when others do not.
2. I usually concentrate more on the whole picture, rather than on the small
3. I find it easy to do more than one thing at once.
4. If there is an interruption, I can switch back to what I was doing very quickly.
5. I find it easy to 'read between the lines' when someone is talking to me.
6. I know how to tell if someone listening to me is getting bored.
7. When I'm reading a story, I find it difficult to work out the characters' intentions.
8. I like to collect information about categories of things (e.g., types of cars, birds, trains, plants).
9. I find it easy to work out what someone is thinking or feeling just by looking at their face.
10. I find it difficult to work out people's intentions.