Changing the question "Are faces special?" to "*In what way* are faces special?" : An investigation of face recognition and perceptual learning.

Submitted by Emika Waguri, to the University of Exeter as a thesis for the degree of *Doctor of Philosophy* in Psychology June 2022.

I certify that all material in this thesis which is not my own work has been identified and that any material that has previously been submitted and approved for the award of a degree by this or any other University has been acknowledged.

ABSTRACT

This thesis investigates the new possibility that both expertise and face specific mechanisms play a role in face recognition, which have conventionally been treated as two contending notions competing with one another (e.g., Yin, 1969, Diamond & Carey, 1986). Results will be provided from behavioral and transcranial-Direct Current Stimulation (tDCS) experiments using face stimuli and prototype-defined checkerboard stimuli that have been used in a line of research that has demonstrated a role for expertise via perceptual learning in face recognition (McLaren, 1997; Civile, Zhao, et al., 2014; Civile, Verbruggen, et al., 2016; Civile, McLaren, et al., 2018). Each of the 7 chapters in this thesis contribute to the further understanding of the role perceptual learning plays in face recognition, and the extent to which face specific processing is additionally involved. Chapter 1 discusses the background literature and key theories/debates in the face recognition research to set the scene. Chapter 2 compares the effects of tDCS on the face inversion and checkerboard inversion effect. It was this difference in the tDCS-induced decrement in the inversion effect between the two stimuli that instigated the suggestion of an additional component alongside perceptual learning, that is possibly face specific. The experiments reported here contributed to Civile, Quaglia, Waguri, Ward, McLaren, and McLaren (2021). Chapter 3 sets out to identify what the face specific component is, and whether this could be attributed to configural/holistic processing as indexed by the composite face effect. As a first step in testing this, the congruency effect (a component of the composite effect) was investigated with checkerboard stimuli. This experiment contributed to Waguri, McLaren, McLaren, and Civile, (2021). Chapter 4 extends the work in Chapter 3, and sets out to comparatively investigate the composite effect in checkerboards and faces. This work

contributed to Waguri, McLaren, McLaren, and Civile (2022). Chapter 5 investigated the role of proactive interference, as this was found to be contributing to the results on the composite effect in Chapter 4. This was investigated via the inversion effect and assessed to see if it would affect the perceptual learning interpretation of the role tDCS plays in modulating face recognition. Chapter 6 explores the behavioral and electrophysiological effects of the tDCS procedure (as used in Chapter 2), in circumstances where harmful generalization induced by Thatcherized faces has influenced the inversion effect for “normal” faces. This work contributed to Civile, Waguri, McLaren, Cooke, and McLaren, (under review). Finally, Chapter 7 summarizes the chapters and discuss the implications of the work for the face recognition literature and the key debates regarding the underlying mechanisms.

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I dedicate this thesis to my late paternal-grandparents and maternal grandfather, whom I wished to show in person.

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Chapter 1 : Literature Overview

1.1 **Mechanisms of face recognition: Specificity or Expertise?**

Humans have an exceptional skill in recognizing and distinguishing familiar faces effortlessly and rapidly, regardless of the faces' variations in angles, or changes in contours from different lighting or facial expressions (Bruce, 1982). Faces provide important information such as gender, ethnicity, facial expression and emotional states (Bruce & Young, 1986), therefore, having an accurate recognition skill is important as they serve as crucial cues in social interactions. Executing this skill may seem effortless to us, however, it is the contrary when it comes to identifying the underlying mechanisms of facial recognition, which is evident in the extensive literature of research in face recognition. Human face processing has long been one of the most active research areas with existing literature yet to be untangled from varying theories and debates. An ongoing discourse concerns how recognizing faces is different to recognizing non-face stimuli, and how they are processed cognitively. Primarily, there are two contending notions regarding the mechanisms of face recognition: one proposes 'specificity', which suggests there is an innate mechanism that specifically facilitates face processing; the other proposes 'expertise', which asserts that our face recognition ability is a consequence of life-time experience with seeing faces that are ever-present in our daily lives (e.g., Yin, 1969; Diamond & Carey, 1986). The evidence for both notions is based on behavioral findings using a robust index of face recognition, the *Face Inversion Effect* (Yin, 1969). Existing research provides support for both the specificity and expertise accounts that compete with one another with a vigorous 'back-and-forth' debate. This has been further perpetuated with the advancements in cognitive neuroscientific techniques, such as fMRI (functional Magnetic Resonance Imaging) and EEG

(Electroencephalography), which enabled the investigation of brain activity onset of face/non-face stimuli. To keep the overview of the discourse concise in this chapter, the general development of the specificity and expertise accounts will be discussed in terms of the Face Inversion Effect. Behavioral studies will be introduced first to maintain some consistency with the chronological development of the research and identify key terms. This will be followed by studies using cognitive neuroscientific techniques that provide evidence for either accounts. A heavier emphasis on face recognition studies in terms of the perceptual learning framework will be discussed towards the end, as this has served as the underpinning for the experiments conducted and reported in later chapters.

1.2 Specificity vs. Expertise: behavioral studies of the Face Inversion Effect

In every-day life, faces and objects in our surroundings are perceived in one particular orientation (i.e. mono-oriented). When they are presented upside down (i.e. inverted), the same stimuli that were once easy to recognize in their original orientation become difficult to recognize when they are presented inverted (e.g., Yin, 1969). This was especially prevalent in faces compared to object stimuli, simply due to worse recognition performance in upside down faces, compared to those in their normal upright orientation (Yin, 1969; Valentine & Bruce, 1986). Research from early-on interpreted this phenomenon as an indication of a face-specific mechanism (e.g., Köhler, 1940 with Thatcherized faces; Hochber & Galper, 1967), and therefore, was referred to as the Face Inversion Effect.

1.2.1. The specificity account: Yin's (1969) findings of the Face Inversion Effect

Yin (1969) was first to provide systematic evidence that demonstrated a significantly larger inversion effect in faces compared to non-face/object stimuli, and was, therefore, the first full-fledged account for the 'specificity' notion. In experiment 1, participants were shown upright or inverted images of faces, airplanes, houses, and men in motion, in either upright or inverted orientation. Those who studied and were subsequently tested on these stimuli in an upright orientation demonstrated better recognition for faces compared to other classes of upright stimuli. However, upon studying and testing the inverted counterparts of these stimuli, face stimuli were poorly recognized compared to the other classes. Experiment 2 tested the inversion effect, however, this time, participants were asked to first make mental inversions of the materials before testing them in the opposite orientations. This time, only upright faces showed a significant inversion effect. To differentiate whether the contributing factor of the face inversion effect is indeed something special to faces, or if it is simply due to the material's degree of difficulty, experiment 3 used line drawings of male faces to control for lighting and shadow effects of studio photographs from previous experiments. After presenting participants with either line drawings of faces or clothed faceless figures, upright faces were difficult to recognize compared to the faceless figures. Recognition for the face stimuli was further impaired when inverted, indicating that difficulty in recognizing inverted faces is not an artefact due to lighting or shadows of photographs. Yin (1969) concluded that a general mechanism affecting all mono-oriented stimuli, and a face 'specific' mechanism could be attributed to the difficulty in recognizing inverted faces. Subsequent studies have confirmed Yin's (1969) proposition using other stimuli such as houses and planes (Valentine & Bruce, 1986, 1988; Yovel & Kanwisher, 2005), which strengthened the face ‘specificity’ account. Based on the abundant observations of the face inversion effect from various studies, this inversion effect phenomenon was deemed as robust, and has since been employed as an index for face recognition.

1.2.2. Familiarity component of the specificity account

Extending on Yin’s (1969) finding, Scapinello and Yarmey (1970) examined the effects of familiarity on the inversion effect across various stimulus conditions (i.e., human faces, canine faces, and architectural stimuli). Participants were shown a set of stimuli (upright orientation), however, half of this set for participants in the low familiarity group were shown only once, while participants in the high familiarity group were given 7 successive inspection trials. Participants then underwent a recognition task, either immediately after or 20 minutes after, where each stimulus from the previous stage were presented either upright or inverted (30 of them were replaced with new images). The results demonstrated that recognition was significantly better in the high familiarity condition compared to low familiarity, and all recognition was worsened for inverted stimuli, especially for human face stimuli. Scapinello and Yarmey (1970) interpreted these results as implying that familiarity is independent of the inversion effect in human faces. A follow-up study by Yarmey (1971) further investigated the effect of familiarity on recognition and the inversion effect, by specifically testing whether verbal encoding (i.e., names) would counteract the decrement in recognizing upside down faces. The same stimuli classes as Scapinello and Yarmey (1970) were employed, but this time, an additional set of human faces were included for the familiar condition which was composed of famous celebrities/personalities that would elicit verbal encodings (e.g., Richard

Nixon, and Frank Sinatra). The study/test phase sequence, and immediate/20-minute delayed test phase groups remained the same. The general results were in-line with the previous study and showed that all inverted faces were difficult to recognize regardless of familiarity. A notably contrasting finding was that this time, the inversion effect was obtained in canine images as well. However, the authors argued that the overall findings were still in support for the specificity account on statistical grounds, of which the error variance ratio was twice for human faces compared to dogs. This was further treated as an anomaly and was speculated that the participants may have anthropomorphized the dogs exclusively. This is one major caveat of Scapinello and Yarmey's (1970) and Yarmey's (1971) studies where they inequivalently compare participants' familiarity with dogs and a life-time experience with human faces. Nevertheless, because the verbal encodings did not interfere with the inversion effect, it was ultimately asserted that the human faces are coded in a face-specific manner because face perception indexed by the inversion effect was disproportionate to the other stimuli classes, and that faces can evoke properties such as emotions and traits as opposed to objects.

1.2.3. The Alternative of the Specificity Account: the Expertise Account

The aforementioned research have so far provided findings and interpretations that are in support of the specificity account, although, they may be contentious given that the major limitation of the non-face stimuli, such as airplanes and dogs, employed in the experiments were not comparable to the familiarity level of faces considering that people are much more exposed to faces. Subsequent research has addressed this shortcoming and challenged the specificity notion. Diamond and Carey's (1986) study was notable in the face recognition literature which established a competing notion to the specificity account, which was the 'expertise' account. Experiment 2 of Diamond and Carey's (1986) study directly addressed the unequal familiarity between dogs and faces in Scapinello and Yarmey's (1970) study wherein the participants were undergraduate students and not particularly knowledgeable in dogs. Therefore, to compare the inversion effect between faces and dogs, they recruited dog experts (i.e., breeders and judges) and compared their recognition performance against novices. Both participant groups underwent an inspection phase where they were presented with dog and face images one at a time. Each inspection was immediately followed by a forced-choice recognition task, where they were shown another image and had to determine if it was the same image from the previous task. The results showed that numerically, dog experts were slightly more disadvantaged by the inversion effect (worse recognition in inverted dog images) compared to novices, however, this failed to reach significance. The authors determined that this was because the dog images that were shown to the dog expert participants were not of dog breeds or groups which the breeders/judges were experts in and therefore, did not possess the sufficient expertise. This was addressed in Experiment 3, where the participants underwent the same procedure of viewing dog images presented but this time, these were restricted to breeds or groups which the participants were experts in. The numerical results were in-line with the previous experiment, where dog experts compared to novices were affected more by the inversion effect and recognition performance declined for inverted dog images. However, this time, these results reached significance and the inversion effect was as robust as the face stimuli. This consolidated the notion that the inversion effect is vulnerable to expertise, and consequently, there may be other mechanisms that affect face recognition upon inversion that are not specific to faces (hence, faces are not special). Moreover, they proposed that our experience with configural information (i.e., spatial relationships of the main features on a face) facilitates face recognition, which is disrupted by the inversion effect, resulting in reduced recognition performance. The authors posited that configural processing includes sensitivity to first-order relations (spatial relationships among the main features within a stimulus), and second-order relations (the variations in first-order relations relative to the prototype for that stimulus set). The term configural processing has often been juxtaposed with 'featural processing' which contrastingly refers to the perception of each specific feature in isolation from the rest of a face. This contrasts with holistic processing, which refers to processing the stimulus as a gestalt (for a review, see Maurer, Le Grand, & Mondloch, 2002).

1.2.4.1 Expertise in Artificial Categories: Greebles (Gauthier & Tarr, 1997)

Perhaps the strongest evidence for the expertise account comes from the demonstration of a robust inversion effect after participants became familiar with artificial categories of objects that share a configuration (i.e., are prototype-defined). An example of this is the work conducted on perceptual expertise and the inversion effect for novel categories of objects named Greebles (Gauthier & Tarr, 1997). Gauthier and Tarr (1997) specifically investigated whether configural processing is exclusively sensitive to faces, or if it is responsive to stimuli of expertise. To test this, a set of nonface stimuli named Greebles were employed to control for expertise. To assess configural sensitivity, the variations of the stimuli were independent of the information required to perform the forced-choice recognition judgement. Based on this logic, if Greeble parts are coded independently, this would result in equivalent performance across all conditions (i.e., Isolated-parts, Transformed-configuration, and Studied-configuration). However, if parts of each Greeble are encoded configurally, by which the positions of individual parts are coded relative to each other, then the Studied-configuration condition should perform the best while the rest are poor in performance (particularly in experts compared to novices). Furthermore, recognition of upright Greebles should be more sensitive to configural transformations than inverted Greebles. Between expert participants who have gained extensive experience in the laboratory and novice participants, experts demonstrated faster and more accurate recognition, as well as higher sensitivity to configural changes. While it can be criticized that Greebles are still face-like (e.g., mono-orientated, similar configuration), the results found here not only showed how the face-recognition mechanism is more general than face-specific, but that it can be fine-tuned with expertise. Although, the contribution of these findings to the inversion effect narrative should be interpreted with caution given that a direct measurement of the inversion effect (i.e., interaction of the inversion effect between novice and experts) was not assessed.

1.2.4.2 Expertise in Artificial Categories: the perceptual learning account (McLaren, 1997)

A strong and direct evidence in support of an inversion effect for artificial stimuli and the expertise account is provided by McLaren (1997), who reported the first evidence of an inversion effect for checkerboards, which are an artificial, non mono-orientated prototype-defined category. This was also one of the first studies indicating that expertise through perceptual learning plays a role in face recognition. Perceptual learning refers to the improvement in discriminability that comes with experience of stimuli, often as a consequence of changes in the associations between stimulus features through the process of pre-exposure (McLaren, Kaye & Mackintosh, 1989). Learning takes place through experience by gaining familiarity of the stimuli, which is then used as discriminatory aids for distinguishing stimuli that look similar. Expertise manifests as perceptual learning for faces by enhancing the use of distinctive information for that face through the effective reduction in the salience of the common elements in a face, leaving the unique elements relatively salient which aids discrimination. Therefore, once perceptual information in upright faces has been disrupted (because they have been turned upside down thus altering the representation of the stimulus), the benefits conferred by our expertise with those faces would tend to decrease, making them less easy to discriminate from one another. This explanation has some empirical support. The first experiment by McLaren (1997) demonstrated that the inversion effect is dependent on the participant’s familiarity with both a category and on the category exemplars being defined by a prototype. The benefit of employing prototype defined checkerboards for researching face recognition is that the level of expertise can be controlled for, given that checkerboards are stimuli that people virtually never come across in a social setting (the closest similarity being QR codes in recent years, which not many individuals are likely to encounter to the point of expertise), as opposed to other non-face stimuli such as houses or dogs. Moreover, they are non-mono-orientated, meaning they have no predefined orientation, therefore, the orientation in which the participants become experts in can be dictated by which orientation they are introduced to in the categorization training phase. This differs from both faces and non-face stimuli, which already have a predefined orientation, making upright and inverted orientations definite and have little flexibility for controlling orientation. Returning to McLaren’s (1997) experiment 1, checkerboards of two categories were used as stimuli, each consisting of 16 x16 squares. Two base stimuli (each representing a category) were randomly generated (i.e., prototypes) for each participant. From these prototypes, a set of exemplars for each category were generated by adding noise to the base pattern, which involved the process of randomly selecting a row and replacing it with another randomly generated one, and repeating this process several times. Participants were then shown checkerboards from these two categories and were asked to categorize them into two different categories by trial-and-error (to which they received immediate feedback). Subsequently, participants took part in a discrimination task (old/new recognition test), where they were shown two pairs of checkerboards from a familiar category as seen in the categorization phase, in addition to two pairs of novel category checkerboards that served as controls. Each pair was either upright or inverted in orientation. Participants had no sense of an upright or inverted orientation for exemplars drawn from a novel category because the checkerboards are non-mono-orientated. This characteristic of the novel category exemplars served as a baseline for the inversion effect obtained for exemplars drawn from the familiar category. It was revealed that familiarity with a prototype-defined category enhanced discrimination between exemplars within said-category in upright orientation. Upon inversion, this enhancement was lost. Moreover, there was no effect of inversion for a familiar category not based on a prototype. Experiment 2 extended on this to show that these findings can be translated to recognition ability, and consequently, the inversion effect. A same/different matching task was used to enforce reliance on short-term recognition, which would control for any proactive interference from the categorization phase onto the discrimination task in Experiment 1. The results once again revealed that experience with a prototype-defined category resulted in a significant inversion effect. Together, the two experiments showed that experience with exemplars from a category defined by a prototype, which have varying second order relational structure (due to their construction from a specified prototype), leads to an increased ability in distinguishing exemplars of that category that is lost when these stimuli are presented in an inverted orientation. This phenomenon is predicted by a particular model of perceptual learning, the MKM model (McLaren, Kaye, & Mackintosh, 1989; McLaren & Mackintosh, 2000).

1.2.4.3 The MKM model : Abridged (McLaren, Kaye, et al., 1989)

In order to gain a better understanding of what the MKM model of perceptual learning states, it is important to understand the model's fundamental basis, which stems from associative learning. Associative learning theories date back to Pavlovian conditioning where a conditioned stimulus (CS) and reinforcers (predictors of consequential events) are repeatedly presented until the two form an association. Theories that were developed since sought to provide a more detailed explanation of how these associations are formed in learning, as it has been argued that simple repetitions of presenting the CS and reinforcer is insufficient for an adequate association to be made. Some point to the role of relative predictive validity, which suggest that the conditioned stimulus must convey valid and predictive information about the reinforcer (e.g., Kamin, 1968; Rescorla & Wagner, 1972). In a similar vein, the delta rule (Δ), or error term put forth by McClelland & Rumelhart (1985) posits that for learning to occur, the associative strength between internal and external inputs will continue to shift until they reach an equilibrium, and prediction error drops to the value of zero. However, the issues with these theories are the lack of consideration in how the

CS (e.g., tones, flashing lights) is represented and perceived, and the assumption that these stimuli are unitary events. Stimulus-sampling theory proposes that stimuli should be regarded as a set of constituent elements, and that a subset of them are active on any one occasion a stimulus is presented because only a subset of elements are sampled (this way, early trials of the sample contains few conditioned elements; e.g., Estes, 1950; Neimark and Estes, 1967). As a result, the sampled elements would control performance and enter into new associations on each conditioning trial. This can lead to generalization, which refers to the phenomenon when after a response has been conditioned to one stimulus, it will be elicited by another, yet similar, stimulus to the extent that the two stimuli share elements in common (e.g., Pearce, 1987). Altogether, this would suggest that repeated presentations of a CS should establish associations between random subsets within the sampled elements until associations are reached between all elements. McLaren and colleagues (1989) have argued that while certain facets of this interpretation suffices, it would still overlook other sets of consequences as a result of repetition, which are primarily two key (and contrasting) effects: latent inhibition (Lubow, 1973) and perceptual learning (Gibson & Walk, 1956). The MKM model accounts for both effects, which will all be described below.

1.2.4.4 The MKM model, prototype-defined categories, checkerboards, and the inversion effect (McLaren, Kaye, et al., 1989; McLaren, Forrest, et al., 2012; McLaren, 1997; McLaren & Mackintosh, 2000)

The MKM model, first developed by McLaren, Kaye, et al., (1989), accounts for perceptual learning, and attributes this effect to the differential latent inhibition of the common elements representing the stimuli. Latent inhibition refers to the effect where pre-exposure of a stimulus without any consequence results in slower subsequent learning of its stimulus-consequence relation (first reported by Lubow & Moore, 1959 in sheep). In terms of the MKM model, if a single stimulus ‘C’ is pre-exposed, its elements become less salient. The reduction in the salience of the features of said-stimulus consequent of pre-exposure is due to those features becoming predicted by other features present. This reduction in salience, and in this case learning rate for the pre-exposed features result in latent inhibition. However, this is better explained in non-human animals as the analysis is more complex for humans (e.g., see McLaren, Civile, et al., 2021).

We now focus on the perceptual learning aspect of the model (particularly due to its pertinence to the face recognition literature). The way the MKM model represents stimuli is that they can be broken down into ‘units’ that represent ‘micro-features’. These units are incorporated in an error-correcting associative network, where the error term is delta (*Δ*) and controls learning. The key difference of the MKM version of the delta to the standard delta is that it is also used to modulate unit salience. McLaren (1997) illustrated this difference in terms of training with category defined prototypes, where the standard delta rule could predict stimuli that activate a large proportion of units that are highly correlated will be more easily recognized as members of that category. By contrast, this has the tendency to produce strong association between units (and therefore, an increase in activity of the units) has the limitation where forming new associations are limited to the most active units. This means that because the coding units are shared between exemplars for prototypical features, through experience, it would make exemplars less distinguishable. McLaren and colleagues (1989) modified the delta rule so that it would predict that experience with stimuli from a category defined by a prototype should lead to the higher relative salience of unique features in exemplars drawn from that category (i.e., perceptual learning), through the modulation of unit salience. How active or salient a unit is, will depend on how predicted it is. If a unit is well predicted by other active units that correspond to certain features of a given stimulus, then error will be low, as well as its salience. Conversely, high error would lead to high activity, which will facilitate the formation of new associations (See Figure 1). This was later refined by McLaren and Mackintosh (2000) and McLaren, Forrest, et al., (2012), however, the fundamental idea remains unchanged regarding perceptual learning; discrimination between, for instance, 'AX' and 'BX', arise via pre-exposure resulting in the common 'X' elements to be better predicted and lower in salience than the unique 'A' and 'B' elements.

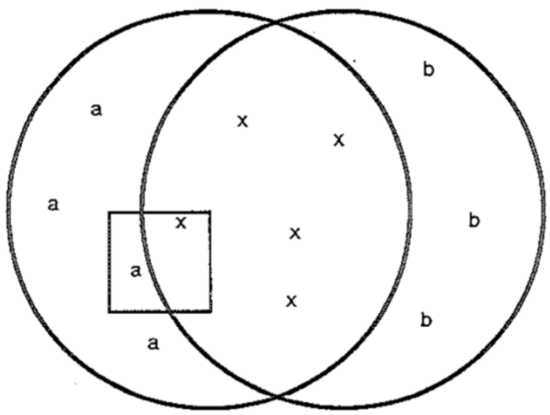

Figure.1. McLaren, Kaye, et al.'s (1989) schematic representation of the MKM model, where 'a' and 'b' are the unique elements, both sharing the 'x' elements.

If we apply this explanation to the checkerboards from McLaren (1997), the advantage in recognizing upright exemplars from a familiar prototype-defined category means that there is an enhanced ability in discrimination, because there is a *relatively* high salience of units that correspond to distinctive features of the exemplars. The presence of the units that make up shared/common features between exemplars will predict one another, and therefore, these common features are low in error terms and salience. The unique features of an exemplar (or in some cases shared) will be comprised of units that are higher in salience, in the sense that they “stand-out”, and therefore, would be the dominant features in learning in order to prevent unwanted generalization between checkerboard exemplars. This effect emerges for categories that were experienced (familiar) and in an upright orientation, which signifies perceptual learning. The explanation for inverted stimuli is rather simple, and it is the fact that this advantage no longer applies, because the previously experienced learning (in this case, specific to upright orientation) does not apply to the inverted stimuli. This explains the impaired performance on the inverted exemplars found in checkerboards from McLaren (1997) in the matching task.

1.2.4.5 Perceptual learning – checkerboards analogue to the face inversion effect (Civile, Zhao, et al., 2014 Experiments 1a, 1b, 2, 3)

McLaren’s (1997) findings with the checkerboard stimuli were later linked with the face inversion effect paradigm by Civile, Zhao, et al., (2014), through a systematic set of experiments, that produced analogous results to the face inversion effect using the *old/new recognition-task*, which is typically used to investigate this effect, demonstrating that recognizing faces and objects of expertise share feature salience modulation as per perceptual learning. The first three experiments will be introduced in this section as they pertain to the behavioral findings of face recognition, and the last experiment, which concerns the neural signature of face recognition, will be discussed in later sections where research regarding neuro-correlates of face recognition are discussed. First participants engaged in a similar categorization task as McLaren (1997) where they were asked to sort a set of checkerboards created from two prototype-defined categories. The checkerboard stimuli were 16 x 16 squares, containing roughly half black and half white squares. Four prototypes were randomly generated, each sharing 50% of their squares with each of the other prototypes. 48 squares were randomly changed to generate each exemplar (on average 24 of them would be expected to alter from black to white, or vice versa). Subsequently, participants were asked to memorize new checkerboards drawn from one of the two familiar categories previously seen in the categorization task and from a novel category not seen previously. Half of the checkerboard exemplars from the familiar category were presented in the orientation familiarized during the categorization task, (half upright, half inverted by rotating 180°). The same methodology was applied for the checkerboards taken from the novel category, but here rotation is just a dummy variable as the category is not familiar. The final task was the old/new recognition task, where the “old” exemplars (upright/inverted checkerboard exemplars seen in the study phase) were intermixed with “new” exemplars (novel upright/inverted checkerboards not seen in the study phase and taken from both the familiar and novel category). The participants were asked to indicate if they had or had not seen the presented exemplars in the study phase. The results showed a robust inversion effect for checkerboards from the familiar category compared to the novel category, partly due to the increased performance for upright checkerboards from the familiar category. Overall, there was a significant inversion effect for the familiar checkerboards, but there was no inversion effect for novel checkerboards. While the results were numerically in line with McLaren's (1997) Experiment 1A, the advantage for upright exemplars failed to reach significance.

Experiment 1B served as a replication for McLaren's (1997) experiment 1b, and control for Experiment 1A in some sense. This experiment aimed to show that familiarizing with a set of stimuli (i.e., checkerboards) that share a clear configuration plays a key role in obtaining a robust inversion effect. By using sets of checkerboards that do not share a prototype despite participants being familiar with them, an inversion effect would not be obtained. The exact same procedure as the previous experiment was used, however, this time, they used a "shuffled" version of the checkerboards by altering the algorithm in generating the checkerboard stimuli. McLaren's (1997) checkerboard stimuli were easy to classify as prototype-defined stimuli, but because they did not average to the base pattern used to generate them, therefore, the class itself did not possess a prototype themselves. There was no reliable inversion effect, and the inversion effect found with prototype-defined categories in Experiment 1a was significantly larger than that for shuffled categories, which confirmed that familiarity does play a role in the inversion effect obtained in Experiment 1a. In more detail: Civile, Zhao, et al., (2014) used a restricted algorithm where only three rows were shuffled to create an exemplar, as opposed to McLaren's (1997) alteration of all 16 rows of the base pattern in creating each exemplar. A maximum of 48 squares and an average of 24 squares were changed by shuffling three rows. Two rows (e.g., 1 and 2) were first selected and then swapped, then a new row (e.g., 3) was selected and swapped with 2. The outcome was predicted to be similar to McLaren's (1997) experiment 1b, and that this would not produce the inversion effect for both familiar and novel category exemplar, but a similar interaction with Experiment 1A would be observed. The results revealed that this alteration did not produce any of the effects that were observed in Experiment 1A, even though the number of squares changed was controlled to ensure the categorization and recognition was equally easy. The authors interpreted this result as an indication that this algorithm produces a category with a different structure, which results in reduced, or no perceptual learning.

Experiment 2 further investigates the inversion effect found in Experiment 1A, but used “clumpier” checkerboards to make them easier to recognize, and with the aim of obtaining a stronger inversion effect for familiar checkerboards. The clumpier checkerboards were made by making the probability of the color for each square dependent on its neighboring square colors; if the nearby squares were black, then that square had a greater chance of being black (the same logic applied to white colored squares). This resulted in the squares of a particular color to be clumped together, while retaining the proportion of 50% black and 50% white for each sets of prototype patterns (all overlapping 50% with one another). In total, 96 squares (on average 48) were randomly selected to alter when producing new exemplars. This time, the results revealed an increased inversion effect for checkerboards from a familiar category, confirming that the results from Experiment 1 was not due to a floor effect, and thus, strengthened the notion that familiar categories of prototype checkerboards are susceptible to the inversion effect.

Experiment 3 served as a cross-experiment comparison between Experiments 1A and 1B. The same procedure as Experiments 1A and 1B was employed, however, the clumpy checkerboards from Experiment 2 were used in Experiment 3A, and a “new shuffled” set of exemplars of the checkerboards (variant of the shuffled checkerboards in Experiment 1B) were used in Experiment 3B. The new shuffled exemplars were made by repeating the algorithm from Experiment 1B, which additionally required eight squares to change. This amounted to six rows being altered and an average of 48 squares (maximum 96 squares) were changed. Importantly, Experiment 3A and 3B were run concurrently. The results supported the conclusions from Experiments 1A and 1B and Experiment 1 by McLaren (1997). At the same time, this confirms that the clumpy checkerboards used in Experiment 2 are easier to recognize as stronger effects were found in comparison to Experiment 1.

These results confirmed that in order to obtain the inversion effect, it is required that the exemplars belong to familiar categories defined by a prototype and does not occur for sets of stimuli that lack this property and yet are similar to each other. Crucially, these findings support the MKM model of perceptual learning (McLaren, Kaye, et al., 1989) as the advantage of enhanced discrimination observed in familiar upright checkerboards signifies the increase in salience of the unique features of the exemplars, and upon inversion this advantage is lost. The results reflect this as they have shown that first, during the categorization task, participants focus on the common elements to correctly categorize the exemplars. By the end of the task, the common elements are highly associated with their corresponding category membership (i.e., decrease in salience), which leads to perceptual learning, as making new associations become slower and the unique elements of the exemplars remain relatively high in salience. It is this decrease in salience that leads to perceptual learning

More generally, these findings support research that argue expertise plays a role (i.e., that familiarity with a category plays a role), and therefore, strengthened the claim that perceptual learning plays a role in the inversion effect, and consequently, is involved in face recognition.

1.3 Specificity vs. Expertise: cognitive neuroscience studies of the Face Inversion Effect

Behavioral findings for recognition performance in face and non-face stimuli tackles one facet out of many for understanding human face recognition. Supplementing these findings with data from neuropsychological patients or modulating performance in neuro-typical participants with cognitive neuroscientific techniques, (e.g,. fMRI, EEG, non-invasive brain stimulation) help provide in depth, and potentially causal explanations of the underlying cognitive processes (e.g., Radman et al., 2009; Nitsche & Paulus, 2000). However, it can also be said that on the flip side, these findings simply fueled the ongoing debate of specificity vs expertise.

1.3.1.1 Neuropsychological findings to brain activations of the specificity account: brain lesions (Moscovitch et al., 1997)

Much of the latter behavioral research discussed above have leaned towards the expertise account, however, with the growing use of neuroimaging techniques in research, further compelling evidence for the specificity account had been obtained. This was foreshadowed by neuropsychological research, which on its own also provides strong evidence for the specificity account as it shows certain brain injuries or syndromes affect only face but not object recognition (e.g., right posterior lesions, Yin, 1970; face-blindness/prosopagnosia, Bodamer, 1947). One notable piece of evidence comes from Moscovitch et al's., (1997) study on a neurological patient, 'CK', with object agnosia and dyslexia due to a closed-head injury. Through a variety of tests, including IQ tests, it was revealed that CK was severely impaired in a wide range of visual tasks involving word and object recognition. Although, several experiments showed that in comparison to neurotypical individuals, CK's face recognition remained completely intact for faces presented in an upright orientation. Crucially, CK showed a face inversion disadvantage that was about six times greater than what would be obtained in neurotypical individuals. The authors proposed that this indicates a spared face specific mechanism in CK, and that this mechanism is unable to process inverted faces. Neuroimaging studies would later provide findings that complement these results, and further support the specificity account by the discovery of a focal region on the fusiform gyrus, or fusiform face area (FFA), which is located by the extrastriate cortex, and is a highly activated brain region in response to faces compared to non-face stimuli; (using fMRI: Kanwisher, McDermott, et al., 1997; McCarthy et al., 1997; using rCBF-PET finding: Haxby et al., 1994). This will be discussed in detail below.

1.3.1.2 Brain imaging findings of the specificity account: fusiform face area (FFA; Kanwisher, McDermott, et al., 1997)

Kanwisher, McDermott, et al., (1997) ran multiple functional magnetic resonance imaging (fMRI) tests with 20 healthy participants under the age of 40 to observe if any regions of occipotemporal cortex were significantly involved in viewing faces more than objects. Part I of their experiment aimed to localize anatomical candidates in the occipitotemporal areas that are potentially specialized in face perception. Participants underwent a passive viewing task where participants were shown photographs of faces and objects. One region was found to be consistently activated across participants when viewing faces compared to objects, and this was the fusiform gyrus.

Part II extended on the results of Part I, and the authors tested the activation for faces in comparison to objects by having participants view intact two-tone faces (these were modified photographs from Part I) and scrambled two-tone faces where the black regions were rearranged to create a stimulus that was unrecognizable as a face. Five participants from Part I participated in Part II in order to investigate the localized Regions of Interests (ROIs) from their previous results in Part I. The ROI was defined as the right fusiform region separately across the five participants, which was then averaged across all voxels. A pattern of higher activation for faces than non-face stimuli were observed in each participant. For a quantitative interpretation, they averaged the mean Magnetic Resonance (MR) signal intensity across each participant's ROI and across all images collected for each stimulus epoch. A three-way ANOVA across participants (face/control x epoch number x test) revealed that the only significant factor was the main effect of higher signal intensity during face epochs than during control stimulus epoch. Pairwise comparisons between face and control stimuli further confirmed this result because each stimulus reached significance independently. Together, the data indicated that the fusiform gyrus would respond more strongly to faces than objects in each participant, as well as intact faces as opposed to scrambled two-tone faces, and faces than houses.

Part III tested whether the activation for faces compared to objects found in Part I was due to a response to animate (i.e., human) as opposed to inanimate objects, visual attentional recruitment by faces rather than objects, or subordinate-level classification. Another five participants were recruited, although this included participants who took part in Part I from the same session, and two participants from Part II from a different session. Here, participants were presented with three-quarter-view face photographs (hair tucked inside a black knit ski hat) in comparison to photographs of human hands (control). Participants performed a "1-back" matching task where they were instructed to search for consecutive repetitions of identical stimuli by pressing a button when they detected a repetition. Same analyses as Part II were employed, which revealed the same region in the fusiform gyrus responded more strongly to faces than objects, and more strongly to faces than hands in both the passive viewing of the three-quarter views and 1-back matching task.

Overall the three experiments suggested that a region in the fusiform gyrus is responsive to face stimuli, and this is selectively activated by faces in comparison to other stimuli.

1.3.1.3 FFA and the inversion effect – the specificity account (Kanwisher, Tong, et al., 1998)

Considering Kanwisher, McDermott, et al., (1997) showed the FFA is a face specific region in face processing, the next important question to answer is how this region responds to the face inversion effect. Kanwisher, Tong, et al., (1998) aimed to investigate this and additionally test Moscovitch et al's., (1997) claim that inverted faces are exempt from being processed by face-specific mechanisms. The authors conducted two experiments, each using different sets of face stimuli. Experiment 1 (10 participants) used greyscale faces with the purpose of disrupting recognition ability, but conserving the ability to detect a face in order to reflect face recognition processes. Experiment 2 (11 participants) used Mooney faces (i.e., two-toned images of a face) to disrupt face detection, as a means of gauging sensitivity to face detection. Both experiments involved a 1-back matching task that required participants to give more attention to inverted faces than upright faces.

Results from Experiment 1 showed strong FFA activity for inverted greyscale faces, although it was weaker compared to the responses to its upright counterparts. Nevertheless, this FFA response to inverted greyscale faces opposed Moscovitch et al's., (1997) argument that inverted faces cannot activate face specific mechanisms. The authors posited that perhaps other than the FFA, there may have been other face-specific mechanisms that cannot be engaged by inverted faces, which could have been preserved in Moscovitch et al's., (1997) patient, CK. Contrasting to Experiment 1, Experiment 2 showed greater FFA activation for upright stimuli than inverted ones with two-toned Mooney faces consistently across all participants and tasks. Based on this low FFA response for inverted Mooney faces, it was interpreted that FFA activation cannot be explained as a result of haphazard presence of any visual features, but it is categorically receptive to perceiving something as a face.

In sum, the two experiments demonstrated that the FFA is specifically activated to the presence of face stimuli, and thereby, further consolidated the specificity account of face processing.

1.3.2 Experts can also activate the FFA, after training (Gauthier, Tarr, Anderson, et al., 1999)

Naturally, the discovery of the FFA was later questioned in terms of the expertise paradigm if the FFA is indeed a face specific module or if this brain region is responsive to an individual's expertise in faces. Gauthier, Tarr, Anderson, et al., (1999) investigated this by using the same Greeble stimuli devised by Gauthier and Tarr (1997) and tested whether the FFA can be activated in participants who are Greeble experts compared to novices. Participants first underwent an fMRI scan prior to any exposure with the Greebles. They were then scanned repeatedly as they underwent training for sets of Greebles in a categorization task. In order to compare expert processing between upright and inverted Greebles during each fMRI session, participants underwent a sequential matching task in four conditions involving upright or inverted unfamiliar faces and Greebles. In the first two scanning sessions, more activation was observed for upright faces than for Greebles. However, by the end of the training sessions, there was a reduction in preferential activation of the FFA for the upright faces over Greebles, and as a result, preferential activation for upright faces no longer reached significance. The FFA activation for upright minus inverted Greebles increased significantly across training, whereas the same activation for upright minus inverted faces did not, and instead decreased, although this was not statistically significant. This significant increase in activation for Greebles across training and the numerical decrease in faces showed that this is not a practice effect with Greebles, because the same should have been obtained from face stimuli as well. Instead, the authors posited that this is a reflection of the effect of developing expertise for the Greebles. These results show how the inversion effect in the FFA is possible to be obtained in both face stimuli and Greebles after sufficient training. Moreover, they show that the FFA activation can fluctuate; specifically in this case, activation can increase with expertise for novel objects.

Importantly, these findings contrast with the specificity account of the FFA and suggest that under certain conditions (i.e., training), non-face objects can also engage the same FFA area. Although, Kanwisher (2000) outlined one issue with the FFA paradigm, which was the inversion effect found for faces and especially for Greebles was relatively small, perhaps due to the fMRI not being sensitive enough to pick up this effect in a robust manner. They have also pointed out that the FFA may not be exclusive for expertise processing, but that expertise is one of the factors that may lead to specialization in the face area. This will be discussed more in Chapter 7.

1.4 Neurological Component of face recognition : N170 ERP

A more robust neural marker of the inversion effect has been reported from many studies using event-related brain potentials (ERP; see Eimer, 2011 for a review) obtained with electroencephalography (EEG). Much of the literature behind the neurological component for face recognition is parallel to the literature of the behavioral studies for the inversion effect, as early studies suggested that the neurological components are a neural signature of face “specificity” (e.g., Bentin et al., 1996) due to larger effects found at onset of human face stimuli, compared to other categories of non-face objects. Later studies would emerge with findings of similarly large effects in non-face stimuli after gaining expertise.

The first systematic ERP studies of face processing reported a positive potential that peaked between 140 and 180ms from onset of a face stimulus (Bötzel & Grüsser, 1989; Jeffreys, 1989). This was called the vertex positive potential (VPP). The VPP response was seen to be larger in amplitude in response to face than non-face visual objects. Jeffreys (1996) noted that the VPP presented a negative counterpart at the bilateral occipitotemporal sites, which may indicate sites of origin in areas of the temporal cortex. With changes in techniques of carrying out EEG research, subsequent studies were able to identify the VPP’s occipitotemporal negative counterpart as a negative peak between 160-170ms onset of a face stimulus, and larger in amplitude on the right hemisphere (Bötzel, Schulze, et al., 1995): this was later termed the N170 (Bentin et al., 1996).

The N170 neuro-correlate is a notable marker of face recognition and belongs to a family of the visually evoked N1 component, which responds to most visual stimuli irrespective of their category, and is the first negative deflection obtained from the posterior scalp regions that ensues following the early posterior visual components C1 (peaks at ~70ms) and P1 (peaks at ~100ms). The N1 has a peak latency of 130-200ms, however, with the onset of a face stimulus, the negative deflection peaks at an average of 160-170ms (for a review, see Rossion & Jacques, 2011). Therefore, some research has referred the N1 component to be a response for objects, while the N170 is a response to faces (Carmel & Bentin, 2002; Itier & Taylor, 2004). It should be noted that the N170 does not emerge by being 'triggered' in the sense of 'all or nothing' akin to the rise and fall of an action potential, but behaves rather 'face-sensitive', which means that it responds more in response to faces than non-face objects (although subsequent research would show it can also be quite large for non-face stimuli as well). The N170's sensitivity to face is indicated by the further increase in amplitude (in a negative direction) at onset of a face stimulus, *in comparison* to the amplitude at onset of a non-face stimulus (Eimer, 2011). Moreover, larger amplitude and longer latency have been observed in response to inverted faces in comparison to upright faces, which is the typical effect of inversion on the N170 (Eimer, 2000).

1.4.1 N170 - face <u>specific</u> neural signature (Bentin et al., 1996)

Earlier studies of the N170 component were supportive of the specificity account and suggested that this component is linked to cortical processes that are sensitive to category-selective processing of faces. Moreover, several studies have shown that the N170 is a marker for perceptual structural encoding of faces prior to recognition (e.g., Eimer, 2000; Sagiv & Bentin, 2001). This was demonstrated by showing that the N170 is unaffected by the familiarity of the faces (e.g., Bentin & Deouelle, 2000; Eimer, 2000), and indicated this to be associated with the processing stage rather than identifying a face. One notable study in support of the specificity account of the N170 is by Bentin et al., (1996), which showed that this component is highly sensitive to face inversion. The authors investigated the N170 properties through several experiments. In Experiment 1, participants were presented with live categories of visual stimuli (faces, scrambled faces, cars, scrambled cars, and butterflies). They were asked to mentally count the number of times a specified category (in this case, butterflies) appeared. Separately averaged ERPs for each categories revealed that the largest negative ERP of the N170 was found in faces compared to scrambled faces, cars, and scrambled cars. The latter three categories showed no significant differences. A numerically larger N170 for faces was found in the right hemisphere as opposed to the left, however this did not reach significance.

In Experiment 2, the authors investigated whether the N170 evoked by human faces from Experiment 1 was indeed specific to faces, or if it could be evoked by any familiar body part such as hands. Here, car images were designated as targets, and participants were asked to mentally count the number of times it appeared. Non-target categories were human faces, animal faces (excluding nonhuman primates due to their similarity to human faces), human hands, and furniture. Once again, it was revealed that human faces elicited a robust N170 that was significantly larger than all the other categories. In line with their Experiment 1, no significant difference was found among the other categories.

Testing the N170's exclusivity to faces came down to the inversion effect, which was conducted in Experiment 3. If the N170 component is indeed specific to detecting facial features, then inverting the faces should affect this ERP. Participants were presented with images of faces and cars, either upright or inverted, and were instructed to mentally count the number of the target butterflies. Consistent with the findings from the previous experiments, upright faces elicited an N170. Crucially, it was revealed that while the N170 amplitudes for upright and inverted faces were similar, there was a significant delay in the latency by about 10ms upon inversion, compared to normal upright faces. Cars and inverted cars elicited equivalent ERPs but not as prominent as an N170. This delay in latency has been interpreted to be a disruption of configural face processing, by which the spatial relationships between the elements on the face are altered due to inversion. This further supports the notion that the N170 reflects neural mechanisms that are involved in analyzing stimuli that facilitate categorizing face stimuli (Valentine & Bruce, 1988; Valentine, 1988).

1.4.2.1 <u>Expertise</u> account of the N170 (Tanaka & Curran, 2001)

The N170 research discussed thus far have indicated that the mechanisms for face perception/recognition are face specific, indexed by a clear N170 component for face stimuli, which is otherwise subdued in non-face stimuli. However, a number of subsequent ERP studies have reported findings of the N170 for objects of perceptual expertise. In a categorization task, Tanaka and Curran (2001) investigated the neural basis of expertise objects while recording the brain activity of experts in categorizing images of common dogs and birds. The results showed that the N170 responses were larger for participants categorizing objects they were expert in than with objects they were novices in. Moreover, the elicited N170 was not consequent on expectation primed by the category. This is because, for example, dog experts displayed an N170 of equal magnitude in response to an image of a German shepherd regardless of whether the presented image was preceded by the category labels “bird” or “animal”. Furthermore, the N170 in response to objects that participants were experts in, had similar latency and scalp distribution to the N170 elicited by faces found in many studies. While Tanaka and Curran's (2001) study did not involve the inversion effect, their results demonstrate that the N170 can be obtained with stimuli people are expert in when participants undergo a categorization task. Findings from subsequent research would also come to support the notion that expertise is involved in the N170 in the context of the inversion effect paradigm. This is discussed in the next section.

1.4.2.2 N170 upon inversion effect: Greeble Experts (Rossion, Gauthier, Goffaux, et al., 2002)

As indicated earlier, one version of the specificity account suggests that the N170 component signifies configural processing, due to its disruption being reflected in the N170. The expertise account does not refute the involvement of configural analysis for non-face stimuli in the context of the N170, but claims that non-face object stimuli (after sufficient perceptual expertise) would recruit the brain areas activated for face perception and recognition. This is the subordinate level expertise model (Tarr & Gauthier, 2000). The premise of this model is that faces are classified at subordinate or individual level based on a low-key analysis of configural information, while object categories involve basic level categorization (e.g., cars, houses). When processing categories of *expert* object, configural information is still relied on in order to discriminate objects at subordinate level. This ability to shift between levels in the same brain areas also points to a particular visual processing of stimuli that is based on tokens in addition to configural information instead of the brain modularity approach, where a particular area (e.g., FFA) corresponds to, and is dedicated in processing specific categories of stimuli. The configural subordinate-level processing is further supported by its susceptibility to the inversion effect, where delays in the

N170 latencies can be just as comparable to the delays observed onset of inverted faces. Rossion, Gauthier, Goffaux, et al., (2002) showed this in a three-phase experiment by having participants undergo intensive perceptual training with Greebles. Before and after ERPs were recorded for upright and inverted faces and Greebles to investigate the effects of perceptual expertise on the N170 compared to baseline and post-training with new sets of faces and Greebles. It is no surprise that a delay in the N170 was observed for inverted faces compared to upright faces. The crucial finding was the change in the N170 latency for both upright and inverted Greebles before and after the expertise training. It was only after the training that an N170 delay induced by inversion was found for the Greeble stimuli, and of similar magnitude to that of faces. A significant training effect for Greebles was seen on the N170, with an increased latency and amplitude for inverted Greebles. However, a complication was that this N170 pattern was obtained from the left hemisphere only; delays of the N170 are often observed in the right hemisphere, or at most, bilaterally, which are areas also found to be active in fMRI studies investigating expertise related effects. In contrast to Rossion, Gauthier, Goffaux, et al., (2002), Busey and Vanderkolk's (2005) study with fingerprint experts produced results in line with the conventional assumption, and showed that other than the usual N170 delay for inverted faces obtained from the right hemisphere, trained experts in fingerprints showed a right-lateralized N170 delay for inverted fingerprints. While the lateralization of the N170 is open for debate, the overall findings demonstrate that perceptual expertise in non-face stimuli produces an effect on the N170 that is comparable to that of face stimuli, and importantly, these stimuli may still be processed configurally in accordance with the subordinate-level expertise model. These results provide evidence that perceptual expertise can activate brain areas that are also face-sensitive, thus supporting Tarr and Gauthier's (2000) subordinate-level expertise model.

However, these results also remained subject to alternative explanations (primarily of confounding factors), therefore, Rossion, Kung, et al., (2004) extended on these findings to eliminate the possibility of attention, particularly, perceptual competition, as a confounding effect in modulating the N170 amplitude with stimuli for which people had expertise. The authors investigated the effects of perceptual training with Greebles on the N170 in comparison to faces. EEG was recorded before and after training. In each training trial, a Greeble appeared as fixation for 600ms, then a face was added in either the left or right visual hemifield. Participants had to report which side the face was presented. In line with previous results, the comparison between ERPs before and after training revealed that the N170 was affected by perceptual training, however, the amplitudes here were reduced for lateral faces after training with greebles. The exact roles the latencies, and especially the amplitudes play are at times obscure in the N170 literature; this will be revisited later in detail. Putting this aside, the interpretation offered by the authors is that after acquiring perceptual expertise to a non-face category, said-category stimuli will begin to activate regions in occipitotemporal cortex that are preferentially activated by faces.

1.4.2.3 N170 upon inversion effect: Checkerboard Experts (Civile, Zhao, et al., 2014, Experiment 4)

Experiment 4 from Civile, Zhao, et al., (2014) extends on the behavioral findings from Experiments 1A, 1B, 2 and 3, as described in the previous section. Given that the behavioral findings produced an inversion effect in checkerboards that are analogous to the face inversion effect, the authors investigated the N170 electrophysiological responses for these checkerboards. The procedure was identical to Experiment 2 using "clumpier" checkerboards, except for the trials which were doubled for the purpose of better signal averaging and obtaining a reliable ERP. To accommodate this change, the experiment had to be split into two parts where each part consisted of a categorization task, and an old/new recognition task. After the first part, the second part was immediately presented using a different set of stimuli. The categories were counterbalanced in a way that participants would not process the same categories in both parts.

The N170 latencies and amplitudes from PO7 (left occipitotemporal site) and PO8 (right occipitotemporal site) from the study phase were analyzed. N170 analyses from the recognition task were omitted as there were no significant differences in the ERP. This could be expected if the N170 modulation reflects perceptual expertise, therefore, a stronger N170 should be detected when simply perceiving a stimulus, which might then be diluted due to experience by the time participants reach the recognition phase. The behavioral results were in line with the main finding from the previous experiments, which was the finding of a significant inversion effect in stimuli drawn from familiar, prototype-defined categories of checkerboards, and the inversion effect was significantly larger in comparison to novel categories of checkerboards. Importantly, the N170 ERPs corresponded with these behavioral results. The behavioral results clearly show that the inversion effect for familiar checkerboards consists of two components; one is the advantage for upright familiar checkerboards compared to upright checkerboards, and the other is the disadvantage for inverted familiar checkerboards compared to novel checkerboards. On the N170, this was reflected by the prominent delayed latency and larger amplitude of the N170 for inverted familiar checkerboards than upright familiar checkerboards, as opposed to novel upright and inverted checkerboards. Upright familiar and novel categories both elicited a similar N170, however the difference in the N170 was observed between inverted checkerboards drawn from the familiar category with the rest of the stimuli. This suggests that the difference in the N170 response is driven by the disadvantage in seeing a familiar checkerboard upside down, which is also in accordance with the behavioral results. Familiar categories elicit a significant inversion effect in the N170 that is larger than the N170 elicited by novel categories. This was found in both of the left and right occipitotemporal sites, which match the narrative of the bilateral elicitation of the N170. In addition, the familiar, inverted checkerboards produced a larger and delayed N170 in the right occipitotemporal site which is also in line with the literature.

The findings from all these studies show that object categories for which people have expertise can modulate the N170 component in a way that is comparable to the N170 elicited by faces, and therefore it might be that face-selective brain processes are recruited to an extent for processing these objects configurally, which opposes a domain-specific perceptual module approach that involves mechanisms exclusively dedicated to face processing. However, it should be reiterated that this debate still lacks direction, largely due to the lack of an adequate interpretation for the effects on the N170 latency and amplitude.

1.5. Modulating face recognition with Neurostimulation: transcranial-Direct Current Stimulation (tDCS)

Another technique among the array of neuroscientific methods already mentioned is the use of non-invasive brain stimulation. The advantage of brain stimulation is that it can allow us to infer causal mechanisms of face processing and recognition. A recent line of research in our laboratory employed transcranial-Direct Current Stimulation (tDCS) to investigate face recognition (e.g., Civile, Verbruggen, et al., 2016; Civile, McLaren, et al.,, 2018). tDCS is a type of non-invasive brain stimulation, using two electrodes that pass low currents between different polarities (anodal and cathodal). Generally, performance is affected by the type of polarity, where anodal increases cortical excitability thus improving performance, and vice-versa for cathodal, (Nitsche & Paulus, 2000), however, this is not always the case, as it would be apparent in the studies introduced below. Civile, Verbruggen et al., (2016) were first to provide evidence of the modulation of perceptual learning and the modulation of the inversion effect, thereby linking Civile, Zhao, et al., (2014) and McLaren's (1997) findings, by using a particular tDCS procedure adapted from Ambrus et al., (2011). Ambrus et al's., (2011) study will be introduced first for a fundamental understanding of this specific tDCS procedure.

1.5.1.1 The 'particular' tDCS procedure and its effect on categorization performance (Ambrus et al., 2011)

Ambrus et al., (2011) investigated categorization learning by using a variation of a prototype distortion task, which is otherwise typically used in studying human categorization ability. The aim was to test the acquisition of category discrimination in order to distinguish it from categorization performance. The authors used tDCS to be able to infer some functional causation. Ambrus et al., (2011) administered cathodal and anodal tDCS over the left, dorsolateral prefrontal cortex (DLPFC, Fp3 area; reference at Cz on the 10/20 system) at 1.0mA, for 10 minutes. The DLPFC has often been suggested to be a source of top-down control that influences the course of bottom-up visual processing through increases in extra-striate neural activity by enhancing attention to elements of the visual field (e.g., Jackson et al., 2021; Miller & Cohen, 2001). Sham stimulation was delivered similarly to active stimulation, however, the stimulation ramped down after 30 seconds. 8 minutes after the stimulation started, participants underwent the training phase of the “A, not-A” version of the prototype distortion task during the last 2 minutes of the stimulation. The task employed dot pattern stimuli prototype and its derivatives with “low” and “high” distortions in terms of the placement of the dots. It was initially predicted that stimulation at DLPFC would modulate categorization performance; specifically, cathodal stimulation would decrease performance, and anodal stimulation would increase categorization effectiveness; this is the typical effect of the two different polarities of tDCS (see, e.g., Kincses et al., 2004; Fregni et al., 2005) as anodal stimulation increases and cathodal reduces neural excitability. But this is not always the case, as observed in the results of this study. It was revealed that rather than cathodal, it was anodal stimulation when administered before and during the training phase that resulted in impaired performance in terms of accuracy in the subsequent categorization task. Furthermore, cathodal stimulation did not provide significantly different results compared to sham.

1.5.1.2 Applying tDCS at DLPFC with checkerboard categorization task (Civile, Verbruggen et al., 2016)

For Civile and colleagues, (2016), employing tDCS was the next step in further bridging the parallels between the inversion and checkerboards as observed in Civile, Zhao, et al., (2014) to confirm the involvement of perceptual learning. Given that the checkerboard stimuli are a prototype-defined category, and the task involves pre-exposure via a categorization task, this is a shared similarity with Ambrus et al's., (2011) categorization learning study. Therefore, their established tDCS procedure of the DLPFC (or Fp3 site) montage seemed appropriate to adopt in Civile, Verbruggen et al's (2016) study in the context of an old/new recognition task with the checkerboard stimuli. Experiment 1 of Civile, Verbruggen et al., (2016) investigated the effects of tDCS on participants between-subjects (anodal or sham) while undergoing the old/new recognition task with checkerboards. The checkerboard stimuli were taken from Civile, Zhao et al's., (2014) Experiment 2 (i.e., "clumpy" checkerboards). 16 x 16 square checkerboards of four prototypes were created, with exemplars generated from each prototype. The same set of tasks from Civile, Zhao, et al., (2014) were used where participants underwent a pre-exposure/categorization phase, followed by the old/new recognition task. The tDCS of 1.5mA was administered for a total of 10 minutes at the DLPFC, with its reference positioned just above the right eyebrow. The duration which the tDCS was administered can be broken-down into two stages: the first 1.5 minutes was delivered before the categorization task (while participants listened to the instructions), and the remaining 8.5 minutes lasted during the categorization task. The tDCS in the Anodal group ramped up for 5 seconds, then stimulation was maintained, and finally faded out for 5 seconds at the end of stimulation. The Sham group only received 30 seconds of stimulation, and this was terminated before categorization, but participants in this group still received the same 5-second fade-in and -out. A double-blind procedure was used, which means that the stimulation polarity was concealed for both the participants receiving and the researcher administering the stimulation. The results showed the usual inversion effect obtained for familiar category checkerboard exemplars under sham tDCS, but remarkably, anodal stimulation eliminated the inversion effect and by inference perceptual learning for familiar category exemplars. Specifically, recognition performance for upright-familiar checkerboard stimuli was no better than for the inverted counterparts. In fact, *d'* performance accuracy for both upright and inverted familiar checkerboards were numerically below chance (where d' 0=50% chance) and not significantly different from it. Given that performance for upright familiar categories were affected, at least numerically, by the tDCS more than the inverted stimuli, this implied a 'reversal' in perceptual learning. It is important to highlight that this finding cannot be attributed to anodal stimulation simply causing poor performance overall, or eliciting general failure in learning/recall, because this diminished performance is observed only with exemplars from the familiar category that was shown during the pre-exposure phase. This is also supported by the marginally significant recognition performance between sham and anodal familiar upright conditions ($p = .053$), as opposed to the non-significant difference between sham and anodal inverted conditions. In addition to this, the average performance for novel category exemplars was numerically higher than sham.

In Experiment 2, anodal and cathodal stimulation were investigated between-subject, where the cathodal stimulation served as control. The exact same stimuli and procedure as Experiment 1 were used, with the exception of delivering the control (cathodal) stimulation. Here, cathodal stimulation was administered in the exact same manner as anodal stimulation, thereby, 'swapping' the cathodal and anodal electrodes (cathodal placed on Fp3, anodal on the forehead). It was predicted that for the Cathodal group, the inversion effect should be the same or larger than sham from Experiment 1, based on the presumption that it is the reverse polarity of anodal stimulation. The results revealed that this prediction was not supported sufficiently. The inversion effect for exemplars drawn from familiar-categories was once again abolished in the Anodal group.

Here, upright, novel-category exemplars were better recognized than familiar-category exemplars. This substantial difference in performance that was found in the Anodal group made the overall performance in the Cathodal group significantly better than in the Anodal group. Moreover, Anodal group showed a significant reduction in the inversion effect due to worse performance in upright familiar checkerboards, in comparison to Sham or Cathodal groups. Combining the results from both experiments, it is clear that anodal tDCS at Fp3 abolishes the inversion-effect in checkerboards by selectively affecting performance on familiar upright exemplars, and provides evidence for a reversal of enhanced generalization or perceptual learning.

1.5.1.3 The effect of tDCS on face recognition performance (Civile, McLaren, et al., 2018)

The next step was to apply the same tDCS procedure on to the inversion effect with face stimuli to confirm that the tDCS-induced effects on checkerboards (upright vs inverted) are analogous to those for faces, which would solidify the notion of the involvement of perceptual learning in face recognition. Civile, McLaren et al., (2018) investigated this across three experiments. In all experiments, participants underwent the same old/new recognition task as Civile, Zhao et al., (2014) and Civile, Verbruggen et al., (2016), however, instead of checkerboards, face stimuli were used (a set of 128 male and 128 female faces), and this time, a categorization task was not used. In the study phase, participants were shown 64 upright and 64 inverted male and female faces. This was followed by the old/new recognition task, which consisted of the 128 face stimuli seen in the study phase, with an additional set of 128 novel face stimuli. For each face shown, participants had to respond if they had or had not seen the face before.

The tDCS of 1.5mA for 10 minutes was administered, double-blind. In the anodal stimulation group, a direct current stimulation of 1.5mA was delivered for 10min (5s fade-in and 5s fade-out) that started as soon as the participants began the behavioral task, and continued throughout the study phase only.

Experiment 1 followed the same general procedure (minus the categorization task) as Civile, Verbruggen, et al., (2016), and the tDCS was administered on the left DLPFC on Fp3 site (reference was above the right eyebrow). The results showed that there was a significant reduction in the face inversion effect in comparison to sham control, due to the reduced performance on upright face stimuli. Experiment 2 served as a replication of Experiment 1 to establish reliability, and it indeed showed the same effects. The two experiments together provided complementary evidence for Civile, Verbruggen et al.'s., (2016) finding with the reduced checkerboard inversion effect that was induced by the same tDCS procedure, and therefore, strengthening the analogy between the checkerboard inversion effect and face inversion effect.

A further confirmation of the results was established by an active control in Experiment 3. The purpose of this was to test if stimulating a different brain area would produce the same reduction in the inversion effect, or if this effect was dependent on stimulating the DLPFC. The exact same procedure as the previous two experiments was used, however, instead of stimulating the left DLPFC, the right-Inferior Frontal Gyrus (rIFG) was targeted. The rIFG has been found to be effective in previous tDCS studies, such as in go/no go tasks (e.g., Cunillera, Brignani et al., 2014; Cunillera, Fuentemilla et al., 2016). As there had been no experiments that looked at the effects of tDCS administered on the rIFG when participants perform a perceptual learning task, this area was chosen for the active control. The reference was placed above the left eye brow. The results revealed that this did not produce a reduced inversion effect, and in fact, it was no different to the results from sham. This shows that stimulating a different brain area does not produce the same effects. These findings show that the tDCS procedure at Fp3 modulates perceptual learning and recognition in terms of feature-salience modulation predicted by the MKM model, by reducing the inversion-effect elicited by faces and checkerboards (after gaining expertise).

Overall, putting together the results from all the experiments of Civile, McLaren et al., (2018) with faces and Civile, Verbruggen et al., (2016) with checkerboards, they show a consistent anodal tDCS-induced reduction of the inversion effect, by specifically impairing recognition performance in upright stimuli. This has been replicated by a number of subsequent studies (e.g. Civile, Obhi et al., 2019; Civile, Waguri et al., 2020; Civile, Cooke et al., 2020, Civile, Quaglia et al., 2021; Civile, McLaren, Milton et al., 2021), thereby, establishing Civile, McLaren et al's., (2018) findings of the tDCS-induced reduction of the inversion effect. This will be discussed with detail in later sections. Next, we interpret the results of Civile Verbruggen et al., (2016) and Civile, McLaren et al., (2018), in terms of the MKM model.

1.5.1.4 MKM model of perceptual learning - Interpreting the effects of tDCS on face recognition (Civile, Verbruggen, et al., 2016; Civile, McLaren, et al., (2018)

Recall that the MKM model explains perceptual learning as discrimination between AX and BX, by which pre-exposure leads X elements to become better predicted (low salience) and increases relative salience for the unique A and B elements, due to their high error. This is because according to the MKM model, activation of an element/unit is a function of how much input it receives. Salience modulation by error operates by providing a boost to the input an element receives that depends on its error. This is how seemingly indistinguishable stimuli of the same category (e.g., faces, checkerboards) are recognized. Upon inversion, this is lost as there is no history of pre-exposure to the inverted stimuli. So how does this model explain the tDCS-induced reduction/abolishment of the inversion effect in Civile, Verbruggen et al., (2016) and Civile, McLaren, et al., (2018)? The authors posit that the tDCS procedure is in fact changing the error-based modulation of salience to the point that its typical operation no longer occurs. To be specific, the usual logic of high error producing high salience is now abolished by the tDCS procedure, as there is now no modulation of salience by error. This means that the predicted elements become more salient than the unpredicted, novel elements within a stimulus. One of the model's principle is that an element's input is made up of an *external input,* which is based on the feature that correspond to that element, and the *internal input* (i.e., prediction) from other elements present. The reduction/elimination of the modulation of salience based on error would result in this system to revert to its default, where the internal input is greater for elements that are well predicted and they would consequently be more active and salient. Now, low error units (where many other units are associated to them) have higher salience as a result of all the input they receive from the other units. Elements that are relatively high in salience/activation are now well-predicted, and those that are low in salience/activation are not well predicted.

In terms of *generalization,* the tDCS-induced reduction of the inversion effect for checkerboards and faces can be explained as a reconfiguration of the cognitive process for developing representations of stimuli. To be precise, instead of pre-exposure taking place for a prototype-defined category with the purpose of enhancing the discriminability of the exemplars taken from that category, it now promotes *generalization* between them. This makes the common features more prominent rather than magnifying the exemplar's differences denoted by the unique features, which is otherwise, normally enhanced by expertise for face processing acquired via experience. It is this change in the manifestation of perceptual learning that causes the reduction in the face inversion effect because it reduces the individual's ability to discriminate between different upright faces. All of this together explains why perceptual learning for stimuli drawn from a familiar category is abolished in checkerboards and reduced in faces, because instead of the unique elements, the common elements become more salient, which enhances generalization, which results in the difficulty of discriminating between exemplars from a category.

The findings from Civile, McLaren, Waguri et al., (2020) strengthen the argument that in <u>both</u> learning and performance, salience is modulated based on prediction error (i.e., past learning). The authors investigated the effects of anodal tDCS at Fp3 on the face inversion effect in the typical condition where stimulation is delivered during the Study phase of an old/new recognition task, in comparison to during the Recognition Phase (as well as sham during Study or Recognition phase). The results showed the consistent effect of impaired recognition for upright faces and reduced inversion effect. The novel finding was that this effect was observed in both anodal conditions delivered during Study and Recognition Phase as opposed to the sham conditions. Here, tDCS can be seen as preventing this error-based modulation of salience, which results in enhanced *generalization* between exemplars, thus reducing the inversion effect because recognition performance for upright faces declines (Civile, Verbruggen et al., 2016; Civile, McLaren et al., 2018). In previous studies where tDCS was always delivered during the study phase, it left the possibility to attribute these findings to the tDCS disrupting overall learning by either directly hindering the encoding of the studied faces, or preventing familiarization with checkerboard stimuli. However, this is not the case as the stimulation is capable of disrupting a lifetime's worth of familiarization with faces and the encoding of new, specific faces in the study phase. This is consistent with the MKM model's predictions that convey the salience modulation of stimulus representations, and the tDCS manipulation captures the immediate effect of stopping that modulation from occurring. Along with these findings, Civile, McLaren et al's., (2018) active-control study also reinforces the notion that this specific tDCS procedure is indeed able to modulate perceptual learning and performance, which supports the notion that these mechanisms to play a role in face recognition.

The question remaining is why this tDCS procedure is able to reduce the inversion effect by completely abolishing it for checkerboards, but for faces, it only reduces (albeit significantly) the inversion effect. One plausible explanation refers back to the specificity vs. expertise debate: while the tDCS is modulating perceptual learning, which is the component that is crucial for recognition in expert stimuli (encompassing both objects and faces), and is able to reduce recognition for familiar upright stimuli, perhaps the tDCS is unable to impact an additional component in faces and thus, it is not enough to reduce recognition for faces to the point of complete elimination of the inversion effect. It could be an indication of either the lack of life-time worth of experience in checkerboards compared to faces, or that there is indeed an additional component that might as well be something specific to face recognition, which the tDCS is unable to affect. Ascertaining this would provide further insight to the debate in the face recognition literature, but this also opens a new proposition that the correct outcome of the specificity vs expertise debate is neither one nor the other, but is in fact both; this would change the face recognition debate as it would no longer be treated as a mutually exclusive dichotomy.

1.6 Introduction to the experiments

The studies from the face recognition literature introduced thus far provide background regarding the development of the specificity vs. expertise debate (in terms of the inversion effect) and the role of perceptual learning in face recognition. This chapter concludes with an introduction to the experiments in each chapter. The main motivation for the experiments below was to entertain the possibility that the underlying mechanisms of face recognition combine both specificity and expertise, and to further develop the key findings from McLaren (1997), and Civile, Zhao et al., (2014), Civile, Verbruggen et al., (2016), Civile, McLaren et al., (2018); Civile, Waguri et al., (2020), and Civile, Cooke et al., (2020) to assert that perceptual learning plays a role in face recognition.

Chapter 2: Faces are and are not special

This chapter is the first study (n=96) to directly address the possibility that both specificity and expertise are involved. This was achieved by systematically comparing the effects of anodal tDCS procedure of Civile, Verbruggen, et al., (2016), and Civile, McLaren, et al., (2018) on both checkerboard and face stimuli in a matching task. The experiments reported here contributed to Civile, Quaglia, et al., (2021). I conducted Experiment 1b as part of my PhD work, however Experiment 1a is also reported for completeness and to assist with the interpretation.

Chapter 3 : Checkerboard Congruency Effect

This chapter follows on from Chapter 2 and investigated whether holistic processing is something that the tDCS procedure was unable to modulate, which would indicate that this could be the component specific to faces. Here, the congruency effect was investigated as the first step in investigating holistic processing indexed by the composite effect in checkerboards. The congruency effect refers to the effect of better performance in congruent composites in comparison to incongruent composites. A matching task was used to test if holistic processing is exhibited when recognizing checkerboards after gaining sufficient expertise. The two large experiments reported here (Experiment 1a n = 96, Experiment 1b n = 96) contributed to Waguri, et al., (2021).

Chapter 4: Composite Checkerboard Effect

This chapter continues the work from Chapter 3 by employing the full design in testing the composite effect, which was implemented by adding misaligned composite checkerboards. The aim here was to test for the first time in the literature whether a composite effect can be obtained with checkerboards under the full design, and also to confirm a novel finding, which was a trial order effect. This trial order effect appeared to influence the manifestation of the congruency effect, which is an integral component of the composite effect (Experiment 1, n=96). In collaboration with a Research Associate and an MSc student, I further investigated the composite effect in faces to allow a comparison between the composite effect obtained in faces and checkerboards, and to additionally investigate if the trial order is a confounding factor when face stimuli are used (Experiment 2a & 2b, n = 184). This work contributed to Waguri, et al., (2022).

Chapter 5: Proactive Interference in the Inversion Effect

This chapter set out to investigate if the order of trials as studied in Chapters 3 and 4 had an effect on the inversion effect in Chapter 2 (as well as Civile, Zhao et al., 2014 and McLaren, 1997 for that matter). This was the first investigation in the literature to observe if the robust face inversion effect could be influenced by proactive interference. The particular focus of the investigation was whether the effect of proactive interference found with sets of newly acquired checkerboards could also affect recognition performance with faces, which we are exposed to on a daily basis. This also served as a critical investigation for the theoretical framework of the tDCS procedure adopted in Chapter 2 and preceding studies (e.g., Civile, Verbruggen et al., 2016; Civile, McLaren et al., 2018), which would help determine whether proactive interference would influence the face inversion effect in a similar way as the adopted tDCS procedure. To test this, it was essential for this experiment to go back to the old/new recognition task that was originally used to test the inversion effect (as per Civile, Zhao, et al., 2014). Two large behavioral studies (n = 192) were conducted to address the question if proactive interference influenced the face inversion effect.

Chapter 6: The N170 when the inversion effect and face recognition is improved

This final experimental chapter used the same tDCS procedure as Chapter 2, but the aim was to achieve the opposite result of *increasing* the inversion effect through the *enhancement* of upright face recognition. This was based on the work of Civile, Cooke et al., (2020) that found this improvement in face recognition and the inversion effect when intermixing Thatcherized faces in the usual old/new recognition task with the anodal tDCS stimulation procedure. This chapter extended on their findings by further investigating the tDCS-induced effects on the N170 ERP neurocorrelate, which was a method implemented by Civile, Waguri et al., (2020) when investigating the tDCS-effects on the N170 for the inversion effect in normal faces. This was a large tDCS/EEG study (n = 72) that contributed to Civile, Waguri, et al., under review). Experiment 1 was part of my PhD work, while Experiments 2a and 2b were run by a fellow MbyRes student and a Research Associate. All experiments are reported here for completeness and to assist with interpretation.

Chapter 2: Faces are and are not special – a tDCS investigation

2.1 Introduction to the experiments

The aim here was to conduct the first study that directly compared faces and checkerboards as a preliminary investigation of the component of the face inversion effect that the tDCS procedure from previous studies (Civile, Verbruggen et al., 2016; Civile, McLaren et al., 2018) was unable to eliminate, even though it was able to fully eliminate the checkerboard inversion effect for stimuli drawn from a familiar category.

As discussed in the previous chapter, Civile, Verbruggen et al., (2016) showed that anodal tDCS at Fp3 eliminated the checkerboard inversion effect by worsening performance for familiar upright checkerboards. Civile, McLaren et al., (2018) showed that the same tDCS procedure significantly reduced the face inversion effect by affecting performance for upright faces. Both studies used an old/new recognition task, which is a relatively hard task. Overall performance for checkerboards has been shown to be lower than that for faces. Moreover, the inversion effect found in checkerboards behaviorally (Civile, Zhao et al., 2014) and in the sham group was smaller than the typical face inversion effect (Civile, Verbruggen et al., 2016; Civile, McLaren et al., 2018).

One possible explanation of this finding is that the upright faces also benefit from a face-specific advantage that the checkerboards do not have access to. Other possible interpretations of this difference in performance are that the difference in level of expertise between faces and checkerboards considering that the experience with checkerboards was inequivalent to the lifetime expertise of faces, and/or checkerboards are just more difficult than faces. If it is a matter of the level of expertise where we have more advantage in recognition performance for face stimuli than checkerboards, or that checkerboards are too difficult to process than faces, then this can be controlled by using a task that is less arduous than the old/new recognition task, which is subjectively laborious in retaining the memory of the stimuli shown in the study phase short-term and recalling these memories later in the old/new recognition test phase.

Taking this all into consideration, we revisited the matching task initially used by McLaren (1997) with checkerboard stimuli. The matching task paradigm allows a direct comparison for recognition performance between faces and checkerboards because of its simplicity. This matching task has also been used to study prosopagnosia. Prosopagnosia is a disorder referring to the inability of recognizing individual faces, which is usually acquired due to brain damage, and is not an impairment attributed to intellectual deficiency or related to visual problems (e.g., Bodamer, 1947; Rondot & Tzavaras, 1969). The matching task when applied to this condition involves participants to sequentially see a face stimulus, followed by a brief interstimulus interval, and then another face, to which they have to respond if this face is the same as or different to the face before the interstimulus interval. For the current study, this matching task was found to be appropriate because Civile, Verbruggen, et al., (2016) showed that while the tDCS reduced the inversion effect entirely by worsening performance for upright familiar checkerboards below chance level, performance was already low for checkerboards, which made it difficult to differentiate whether the abolishment of the inversion effect was because it was a genuine effect induced by the tDCS or because performance was already close to chance level. The matching task is easy enough for individuals with prosopagnosia (face blindness) to perform relatively well (Farah et al., 1995), therefore, healthy individuals should be able to perform well even when tDCS is delivered. This would be appropriate for the purpose of controlling the performance of both checkerboard and face stimuli to a comparable level. If the results confirm the same tDCS effect of a full reduction of the checkerboard inversion effect and the partial reduction of the face inversion effect, we will then have some evidence of a component (perhaps face-specific) in addition to the expertise component manifesting as perceptual learning in the face inversion effect.

The current study is broken down as the following: Experiment 1a will investigate the effects of tDCS on the matching task with face stimuli. Experiment 1b will investigate the same thing using the same procedure as Experiment 1a, but faces are replaced with checkerboard stimuli. The checkerboard stimuli used in this study were drawn from Civile, Zhao, et al's., (2014) Experiment 1a. Some considerations were made behind the decision in employing these checkerboards in combination with the matching task. As discussed in the previous chapter, the checkerboards used in Experiment 2 in Civile, Zhao, et al., (2014) were clumped with the intention of easing recognition performance in the old/new recognition task (and to obtain a stronger inversion effect), as opposed to the original checkerboards that were deemed as difficult. In a recent pilot study conducted in the lab, it was found that by using these clumpy checkerboards in combination with the already easy matching task, performance was at ceiling after the usual tDCS-induced reduction in performance for familiar upright stimuli. To counteract this ceiling effect, this study employed the original checkerboards that were used in Experiment 1a of Civile, Zhao, et al., (2014), in combination with the matching task used by McLaren (1997).

2.2 EXPERIMENTS 1a & 1b

2.2.1 Method

2.2.1.1 Participants

A large sample of 96 participants (66 female, 30 male; mean age = 20.9, age range = 18-27, all right-handed) were recruited upon selection in accordance to the tDCS safety screening approved by the University of Exeter's Ethics Committee. Participants were randomly assigned to either sham or anodal condition (24 in each condition, 48 in each group). All participants were students from the University of Exeter, who participated via the university's participant recruitment system SONA and were compensated with £7-8 or one course credit. The study was between-subjects and double-blind, in-line with previous tDCS studies conducted in the lab (Civile, Verbruggen, et al., 2016; Civile, McLaren, et al., 2018; Civile, Waguri, et al., 2020).

2.2.1.2 Materials and Stimuli

Experiment 1a

A total set of 256 face images (the same ones as Civile, Waguri, et al., 2020 and Civile, McLaren, et al., 2018), were used. The original images were selected from the Psychological Image Collection at Stirling open database, (http://pics.stir.ac.uk). All images were then cropped to a standardized oval shape, removing distracting features such as the hairline, and adjusted to standardize the image luminance. Dimensions were 5.63cm x 7.84cm, presented at a resolution of 1280 x 960 pixels, and standardized to greyscale on a black background.

Experiment 1b

The checkerboard exemplars used here were the same ones from Civile, Zhao, et al., (2014, Experiment 1A). Each were 5.50 cm x 5.50 cm, presented at the resolution of 1280 x 960 pixels. Category prototypes (16 x 16) were randomly generated with the constraint that they shared 50% of their squares with each of the other prototypes. The proportion of each squares were 50% black and the 50% white. Exemplars were generated from these prototypes by randomly changing forty-eight squares thus, on average, 24 squares would be expected to alter from black to white or white to black.

Figure.2.1. From Civile, Zhao, et al., (2014) – on the left shows the clumpier checkerboard used in their experiment 2; on the right is the 'regular' checkerboard.

tDCS Apparatus:

The same tDCS paradigm adopted in Civile, Verbruggen, et al., (2016) and Civile, McLaren, et al., (2018) was used for both experiments (see Figure.2.2.). The stimulation was delivered by a battery driven constant current stimulator (neuroConn DC-stimulation Plus), using a pair of surface sponge electrodes (7cm x 5cm, i.e., $35cm^2$), that were soaked in saline solution and applied to the scalp at the target area of stimulation. A bilateral bipolar-non-balanced montage was used with the anodal electrode placed over the target area of Fp3 and the cathodal electrode on the forehead, over the reference area (right-eyebrow). The study was conducted using a double-blind procedure operated by the neuroConn study mode, in which another experimenter unconnected to running the experiment provides numerical codes for the experimenter running the experiment them to input in the system. The codes signify the stimulation to switch between the normal anodal or “sham” stimulation, allowing both the participant and researcher to be naïve of the stimulation condition. In the anodal condition, a direct current stimulation of 1.5mA was delivered for 10 minutes (5 seconds fade-in and 5 seconds fade-out) immediately when the participants began the first computer task. In Experiment 1a, the stimulation commenced during the keyboard training phase, while in Experiment 1b, it commenced at the beginning of the categorization task. In sham, the neuroConn system would display the same stimulation mode as anodal, but the stimulation intensity of 1.5mA was delivered for only 30s. Following this a small current pulse was delivered every 550ms (0.1mA over 15ms) for the remainder of the 10 minutes to check impedance levels. Participants experienced the same 5 seconds fade-in and 5 seconds fade-out of stimulation.

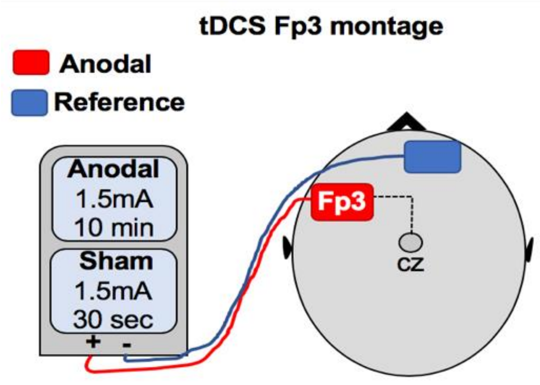

Figure.2.2. shows the employed tDCS apparatus, which is the used across Civile, Verbruggen, et al., (2016) and Civile, McLaren, et al's., (2018) studies.

2.2.1.3 Procedure & the Behavioral Task

Experiment 1a

Keyboard Training Phase

After participants gave their written informed consent and sat in front of the computer, the instructions for the "training phase" were presented on the screen. The task ran on Superlab 4.0.7b. on an iMac computer, to which participants sat about 70cm away from the screen. The aim of this task was to train participants in being able to associate the keyboard response for the matching-task after this phase. They were trained in the keys 'x' and '.' which were associated with the words SAME and DIFFERENT (counterbalanced). A total of 48 trials (24 SAME and 24 DIFFERENT) were presented randomly, one at a time. A fixation cross was first presented for 1 second, followed by the word 'SAME' or 'DIFFERENT'. for 1 second in alternation. Participants received feedback for their response.

Matching (same/different) task

Participants engaged in a *same/different* matching task which consisted of 128 trials (see Figure.2.3., panel a). Each trial began with a fixation cue presented in the center of the screen for 1 second, followed by a TARGET face stimulus for 1 second, an interstimulus interval for 1.5 seconds and a TEST face which they had ≤ 2 seconds to respond. The participants had to respond with either ‘x’ or ‘.’ on their keyboard to classify the test face as SAME or DIFFERENT to the target face. The response keys were counterbalanced across participants and corresponded to the same keys they were trained in the previous keyboard training phase. The first and second faces of a trial were always in the same orientation. Upright and inverted trials were randomly intermixed.

Experiment 1b

Categorization Task

Participants first engaged in a *categorization task* (pre-exposure/familiarization phase). A set of checkerboards appeared on the screen, one at a time randomly (see Figure.2.3, panel b). Participants were asked to sort these exemplars in two categories (A or C) through trial and error, by pressing keys 1 or 2 (counterbalanced). For each response, they received immediate feedback in whether it was correct or incorrect. Participants were shown 64 checkerboard exemplars drawn from categories A and C (total of 128 exemplars). Each checkerboard preceded with a fixation cross in the center of the screen presented for 1 second. Participants had 4 seconds to respond to the checkerboard presented until they were timed out.

Keyboard Training Phase

After the categorization task, participants engaged in a keyboard training phase, which was the same as Experiment 1a.

Checkerboard-Matching Task

Finally, participants engaged in the matching task. Each trial began with a fixation cue presented in the center of the screen for 1 second, followed by a TARGET checkerboard stimulus for 1 second, an interstimulus interval for 1.5 seconds, and a TEST checkerboard stimulus, which they had ≤ 2 seconds to respond. Participants had to respond whether the TEST checkerboard stimuli was SAME or DIFFERENT from the TARGET checkerboard, using the corresponding keys ('x' or '.') according to their counterbalanced group and in line with the keys they trained in the keyboard training phase. The first and second checkerboards in a trial were always in the same orientation. Upright and inverted checkerboard (rotated by 180°) trials were randomly intermixed. Half of the checkerboards presented were the same ones from categorization task (categories A and C), while the other half were novel exemplars that were not seen in the categorization task drawn from each of the two categories.

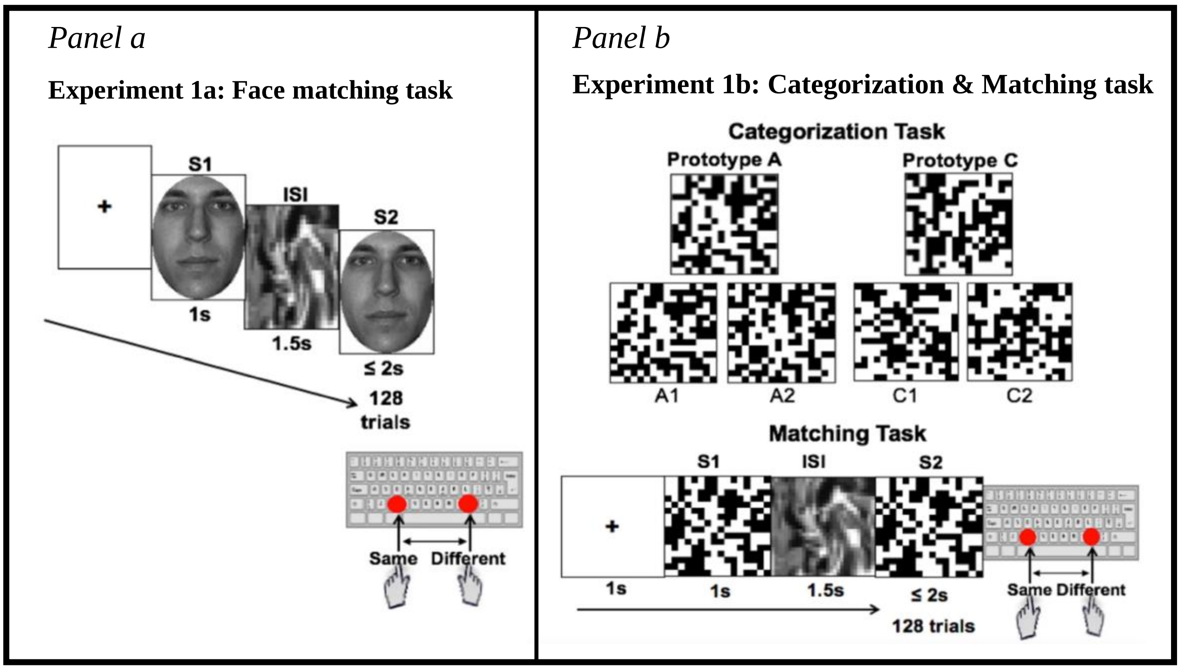

Figure.2.3. Panel a. shows Experiment 1a's with matching task sequence. Panel b. shows Experiment 1b's categorization and matching task sequence (Civile, Quaglia, et al., 2021).

2.2.2 Results

2.2.2.1 Behavioral Results

In both experiments the primary measure was the accuracy data from all participants in a given experimental condition which we used to compute a *d'* sensitivity measure (Stanislaw & Todorov, 1999) for the matching task (same and different stimuli for each stimulus type) where a *d'* of 0 indicates chance-level performance. To calculate *d'*, we computed using the difference between the z transforms of the participants' hit rate (H) (the proportion of SAME trials to which the participant responded SAME), and false alarm rate (F) (the proportion of DIFFERENT trials to which the participant responded SAME): d' =z(H) – z(F). We assessed performance against chance to show that stimulus' conditions were recognized significantly above chance (we found p <.001 for all conditions). We analyzed the reaction time data to check for any speed-accuracy trade-off. We do not report these analyses here because they do not add anything to the interpretation of our results.

Experiment 1a

ANOVA:

We computed a 2 × 2 mixed model design using, as a within-subjects factor, *Face Orientation* (upright or inverted), and the between-subjects factor *tDCS Stimulation* (sham or anodal). Analysis of Variance (ANOVA) revealed a significant main effect of *Face Orientation* $F(1, 46) = 82.81$, $p < .001$, $\eta^2_p = 0.64$ indicating the standard inversion effect, and a significant two-way interaction, $F(1, 46) = 8.17$, $p = .006$, $\eta^2_p = .14$, $d = .82$, CI = 1.44, 0.21, caused by the inversion effect being substantially reduced in the anodal group (Figure.2.4, Panel a). No main effect of *tDCS Stimulation* was found confirming that the tDCS does not simply reduce overall performance, $F(1, 46) = 1.06$, $p = .31$, $\eta^2_p = .02$.

t-Test Analyses:

A follow-up set of paired *t*-test analyses were conducted to assess the inversion effect by comparing performance in upright and inverted face stimuli in each tDCS group (sham and anodal). A significant inversion effect was found in sham group (*M(difference* = 0.82, *SD* = 0.52), $t(23) = 7.67$, $p < .001$, $\eta^2_p = .72$, and a <u>*reduced but still significant inversion effect*</u> was found in the anodal group (*M(difference)* = 0.43, *SD* = 0.43), $t(23) = 4.89$, $p < .001$, $\eta^2_p = .51$.

An independent sample *t*-test was conducted to compare the performance for upright faces between the two tDCS groups. The motivation in doing this was based on previous studies (i.e., Civile et al., 2018b), where the tDCS procedure significantly affected face recognition performance on upright face, but not inverted ones. It was revealed that there is a trend towards performance for upright faces in the anodal group (M = 2.63, SE = 0.80) being worse compared to that in the sham group (M = 3.01, SE = 0.48), *t*(46) = 1.95, *p* = .057, η^2_p = .07. Finally, no significant difference was found between performance for inverted faces in the anodal group (M=2.21, SE=0.14) compared to that for inverted faces in the sham group (M= 2.19, SE = 0.12), *t*(46)= 0.11, *p* = .92, η^2_p < .01.

Experiment 1b

Behavioral Results

ANOVA:

A 2 × 2 mixed model design using, as a within-subjects factor, *Checkerboard Orientation* (upright or inverted), and the between-subjects factor *tDCS Stimulation* (sham or anodal) revealed a significant main effect of *Checkerboard Orientation* *F*(1, 46) = 7.22, *p* = .010, η^2_p = .14, reflecting the inversion effect, and a significant two-way interaction, *F*(1, 46) = 7.12, *p* = .010, η^2_p = .13, *d* = .77, CI = 1.39, 0.15, which in this case signaled the absence of a significant inversion effect in the anodal group (Figure.2.4, Panel b). No main effect of *tDCS Stimulation* was found, *F*(1, 46) = 0.43, *p* = 0.52, η^2_p < .01.

t-Test Analyses:

Follow-up paired *t* test analyses revealed a significant inversion effect in the sham group (*M(difference)* = 0.57, *SD* = 0.70), *t*(23) = 3.94, *p* = .001, η^2_p = .40, but this was not the case for the anodal group (*M(difference)* = 0.00, *SD* = 0.75), *t*(23) = 0.13, *p* = .99, η^2_p < .01. We compared the performance for upright familiar checkerboards in the two tDCS groups as for Civile et al.'s (2016) study. Performance for upright familiar checkerboards in the anodal group (M = 2.61, SE = 0.93) was numerically reduced compared to that in the sham (M = 3.03, SE = 0.84), *t*(46) = 1.66, *p* = 0.10, η^2_p = .06. Finally, no significant difference was found between performance for inverted familiar checkerboards in the anodal group (M = 2.60, SE = 0.16) compared to that for inverted familiar checkerboards in the sham group (M = 2.47, SE = 0.18), *t*(46) = 0.58, *p* = .57, η^2_p < .01.

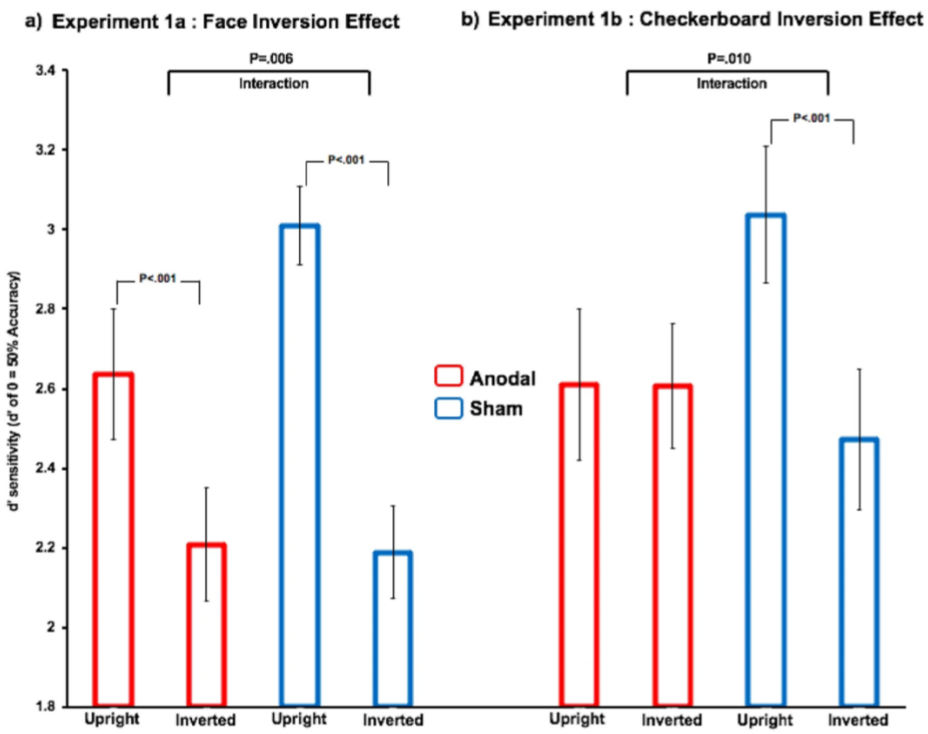

Figure.2.4. from Civile, Quaglia et al., (2021). Panel a shows a bar graph reporting the results from Experiment 1a. Panel b shows a bar graph reporting the results from Experiment 1b. For both graphs, the x-axis represents the stimulus conditions (upright face stimuli, or inverted stimuli). The y-axis shows d' scores. The error bars represent the standard error of the mean. The analysis of the results for both experiments showed that performance against chance in both the sham and anodal groups was significantly above chance (p < .001).

Analyses across experiments

We compared the inversion effect index (performance for upright – performance for inverted stimuli) for faces and checkerboards in anodal groups through an independent sample *t*-test, which revealed a significant difference between these differences, $t(46)=2.40$, $p = .021$, $\eta^2_p = .18$, $d = .69$, CI = 1.30, 0.08. The same analysis in sham groups did not give a significant difference, $t(46) = 1.43$, $p = 0.16$, $\eta^2_p = .11$, $d = .41$, CI = 1.01, -0.18. Finally, we compared overall recognition performance across all the stimulus' conditions averaged together in Experiment 1a (M = 2.51, SE = 0.10) and Experiment 1b (M = 2.68, SE = 0.11), which revealed no significant difference, $t(46) = 1.10$, $p = 0.28$, $\eta^2_p = .02$.

2.2.2.2 Bayes Factor Analysis

Experiment 1a

A Bayesian analysis was conducted to compare the difference between the 2 × 2 interaction of d' values for upright and inverted faces (i.e., the inversion effect score) between sham and anodal groups. The *priors* values were the differences found in Civile, McLaren, et al., (2018; Experiment 1 and 2 averaged together) setting the standard deviation of p (population value | theory) to the mean of the difference between the inversion effect in sham group vs that in the anodal group (0.30). We used the standard error (0.08) and mean difference (0.39) between the inversion effect in the sham group vs that in the anodal group in Experiment 1a. This gave a Bayes factor of 33,814, which is very strong evidence (greater than 10, for the conventional cut-offs, see Jeffrey, 1939/1961) that these results are in line with our previous work (i.e. the tDCS procedure used here reduces the face inversion effect).

Similarly, we also conducted a Bayes factor analysis setting the priors as the mean difference between sham upright faces and anodal upright faces found in Civile, McLaren, et al.'s (2018) Experiment 1 and 2 averaged together (0.28). We then used the standard error (0.11) and mean difference (0.37) between sham upright faces and anodal upright faces in Experiment 1a. This gave a Bayes factor of 98.35, which is also very strong evidence for the notion that performance to upright faces is reduced by our tDCS procedure, and this is consistent with our previous results.

Experiment 1b

For Experiment 1b we conducted the same Bayes analyses as Experiment 1a but this time the priors used were the mean results obtained in Civile, Verbruggen, et al., (2016). We first took the differences found in Civile, Verbruggen, et al., (2016; Experiment 1 and 2 averaged together) setting the standard deviation of p (population value | theory) to the mean for the difference between the inversion effect for familiar checkerboards in the sham group vs that in the anodal group (0.29). We used the standard error (0.14) and mean difference (0.57) between the inversion effect in the sham group vs anodal group in Experiment 1b. This gave a Bayes factor of 570, which is very strong evidence that these results are in line with our previous work indicating that the tDCS reduces the inversion effect in checkerboards taken from a familiar, prototype-defined category.

We then calculated the Bayes factor with priors set to the mean difference between sham and anodal upright familiar checkerboards found in Civile, Verbruggen, et al.'s, (2016) Experiment 1 and 2 averaged together (0.31). We used the standard error (0.17) and mean difference (0.43) between sham and anodal upright familiar checkerboards in Experiment 1b. This gave a Bayes factor of 11.11, which is strong evidence that performance to upright familiar checkerboards is reduced by tDCS, and also consistent with our previous results.

For the effect of anodal tDCS on the checkerboard inversion effect, we conducted a different Bayesian analysis, with the aim of answering the following question: Considering the effect can be as large as Sham condition, does the effect found in Anodal condition contribute to that part of the population, or is it better described as null (mean of zero)? As a prior, we used the mean difference (upright – inverted) for the checkerboard inversion effect in the sham group (0.57), and the standard error (0.15) and mean difference (0) for the checkerboard inversion effect in the anodal group. This gave a Bayes factor of 0.25, which is less than 0.3., and therefore, it can be considered as good evidence for the null. Moreover, we conducted the same calculations for Civile, Verbruggen, et al's., (2016) Experiment 1 (Bayes factor = 0.53) and Experiment 2 (Bayes Factor = 0.31) resulting in an overall factor (across the three studies) of 0.04 which is strong evidence for the null, supporting the claim that our anodal stimulation eliminates the checkerboard inversion effect.

Whilst this may convincingly establish that the effect observed in anodal stimulation is not from the distribution generating the sham condition results, it can still be argued that this may be generated by an equivalent distribution that produces the reduced but not eliminated inversion effect in face stimuli. This means that perhaps this effect is not null, but potentially drawn from a population with a reduced mean compared to sham. To assess this possibility, we conducted one final Bayesian analysis. This time, instead of using the raw mean difference for sham group, we reduced it by the same fractional amount as the face results. Anodal stimulation reduced the inversion effect for the faces by a factor of 0.52

in Experiment 1a (mean anodal inversion effect = 0.43 / mean sham inversion effect = 0.82). We take this reduction as the typical reduction expected if the checkerboards are affected by our tDCS procedure in the same way as faces.

To reduce it by the same amount for the checkerboards, we use this factor and multiply it by the original effect found in the sham condition. This gave 0.52 × 0.57 = 0.30 for the checkerboard effect rather than the original 0.57 used in our previous calculation. We used 0.30 as the prior (the standard deviation of population value | theory), and the standard error (0.15) and mean difference (0) for the checkerboard inversion effect in the anodal group (Experiment 1b). This resulted in a Bayes factor of 0.45. This is less than 1, which is evidence for the null, but by no means conclusive evidence that our result could not be obtained from the "reduced" distribution used as a prior.

We then conducted a similar calculation for the checkerboard inversion effect studies in Civile, Verbruggen, et al., (2016). We first calculated the fractional reduction of the face inversion effect in the anodal vs sham in Civile, McLaren, et al.’s (2018) Experiment 1 (mean anodal inversion effect = 0.24 / mean sham inversion effect = 0.50) and Experiment 2 (mean anodal inversion effect = 0.027 / mean sham inversion effect = 0.62). This gave values of 0.48 for Experiment 1 and 0.43 for Experiment 2. We calculated the average of these values, 0.45, and multiplied it by the sham checkerboard inversion effect from Civile, Zhao, et al.’s., (2014) Experiment 1 (0.27). This gave 0.45 × 0.27 = 0.12. Then we used 0.12 as the prior (the standard deviation of population value | theory), combined with the standard error (0.26) and mean difference (-0.12) for the checkerboard inversion effect in the anodal group from Civile, Verbruggen, et al’s., (2016) Experiment 1. This resulted in a Bayes factor of 0.78.

Finally, we multiplied 0.45 by the sham checkerboard inversion effect from Civile, Verbruggen, et al's., (2016) Experiment 2 (0.18). This gave 0.45 × 0.18 = 0.08. Using 0.08 as the prior (the standard deviation of population value | theory), and the standard error (0.09) and mean difference (-0.05) for the checkerboard inversion effect in the anodal group from Civile, Verbruggen, et al.'s (2016) Experiment 2 resulted in a Bayes factor of 0.57. The overall Bayes factor for these three experiments (0.45 × 0.78 × 0.57) is 0.20 which is good evidence for the null, supporting the claim that our anodal stimulation eliminates the checkerboard inversion effect.

2.2.3 Discussion

The two experiments reported here investigated the effects of a particular tDCS procedure applied to the inversion effect typically found for faces (Experiment 1a) and for familiarized, non-mono-orientated sets of checkerboard stimuli (Experiment 1b). The objective of this was to investigate whether the inversion effect for checkerboard stimuli would still be eliminated after attempting to ensure a high level performance that is comparable to faces. This was achieved by adopting a face-matching task to facilitate a high level of performance in both checkerboard and face stimuli. We assessed the extent to which our tDCS procedure could modulate the inversion effect for faces and checkerboards. Our results showed that the tDCS procedure reduced the inversion effect for faces compared to sham (Experiment 1a) and for checkerboards compared to sham (Experiment 1b). No main effect of *tDCS Stimulation* was found, thereby, confirming previous suggestions that that the tDCS does not simply reduce overall performance (e.g., Civile, Verbruggen, et al., 2018). Moreover, our Bayesian analyses indicated the results were in concordance with previous results in the literature, which also showed that the reduction of both the face inversion effect (Civile, McLaren, et al., 2018) and the checkerboard inversion effect (Civile, Verbruggen, et al., 2016) would seem to rely mainly on the impairment in performance at recognizing upright stimuli in the anodal group compared to sham.

The results indicate strong correspondence between the two different types of stimuli, however, alike previous findings from Civile, Verbruggen, et al., (2016) and Civile, McLaren, et al., (2018), the findings here also show that anodal tDCS selectively eliminates the inversion effect for checkerboards, whilst maintaining a high level of overall performance. At the same time, when this procedure is applied to face stimuli, it goes as far as reducing the inversion effect, which remains significant, but its reduction is not to the extent of eliminating the inversion effect, which was observed for the checkerboard stimuli. A direct comparison of the inversion effect in faces and checkerboards has been achieved here, and a significant difference in the inversion effect between the two stimuli in the anodal group has been observed. Upon first glance, it might be assumed that this is simply due to the discrepancy in the level of experience for faces and checkerboards stimuli. It can be argued in terms of the expertise notion that our life-long expertise in seeing upright faces produces better performance for faces; this performance is robust to the impairment induced by the tDCS procedure and thus the inversion effect remains significant. However, there are good reasons to reject this argument. Recognition performance for upright faces and checkerboards in the anodal group have similar levels of performance at baseline. There were no significant differences in additional analyses across the experiments in directly comparing the inversion effect in sham group for faces and checkerboards. Finally, in the additional analyses conducted across the experiments we found no significant differences between the overall recognition performance in Experiment 1a vs the overall recognition performance in Experiment 1b. Given these findings, we reject the argument that these results are due to different levels of expertise or performance, and instead, they suggest that the results rather indicate that faces are <u>both</u> special and not special. To be specific, they are equally not special in the sense that they benefit from expertise in the same way that checkerboards do, but are also special in that they benefit from other to-be-specified face-specific processes that checkerboards do not have access to. These results contribute to the face recognition literature by providing direct evidence for the reduction in the face inversion effect being partial and incomplete. Importantly, in the anodal group, the remaining face inversion effect was both significant and significantly larger than the non-significant checkerboard inversion effect, suggesting that there is a component to the face inversion effect that is not due to expertise via perceptual learning, and is not affected by our specific tDCS procedure, but it can be eliminated in the checkerboard inversion effect.

That being said, despite this study's attempt of equating the level of difficulty in recognition performance between faces and checkerboards, whether this definitely rules out the possibility of a lifetime's worth of expertise in faces compared to checkerboards remains a question. Furthermore, with anodal tDCS the upright face recognition performance is not comparably preserved as the upright checkerboards, there is also the alternative interpretation that there may be some differences in the inverted, rather than upright stimuli. These are potential areas of interest for future research to address and elucidate by potentially testing the differences in the length of checkerboard training, such as rigorous training across an hour or across several sessions across a week or two in comparison to our usual 10- to 15-minute training session.

These findings are in line with the perceptual learning theory and fits the explanation of the MKM model for the tDCS procedure on checkerboards and face stimuli (as explained in Chapter 1). Both Experiment 1a and 1b are in line with the interpretations of Civile, Verbruggen, et al., (2016) and Civile, McLaren, et al., (2018), that anodal tDCS-induced reduction of the inversion effect is due to the impaired recognition performance for upright stimuli based on the disruption of the salience modulation mechanism that would normally promote perceptual learning for upright stimuli. Anodal tDCS procedure increases the salience of the common elements between the category prototype and the exemplars. As opposed to the typical perceptual learning process where the different, unique elements are the most salient and are relied on to distinguish exemplars, the anodal tDCS procedures results in participants to become better at learning about commonalities (i.e., the common elements) than differences (i.e., unique elements) between exemplars resulting in enhanced *generalization*. Consequently, the unique elements typical of each exemplar are no longer easily usable to discriminate similar exemplars. Considering all of these factors, the inversion effect in checkerboards and faces are now impacted by a reduction in performance for upright <u>familiar</u> stimuli.

Future work should aim to investigate what specific component of the face inversion effect is not affected by our tDCS procedure. Interestingly, studies have shown that in addition to the specificity vs expertise components debated in the face recognition literature, a third factor may be considered as well. Zhao et al., (2016) showed that nonface stimuli (non mono-orientated line patterns) containing salient Gestalt information (i.e. connectedness, closure, and continuity between parts) can elicit face-like holistic/configural processing in the absence of expertise, which may suggest holistic processes of this kind are responsible for the residual face inversion effect in our study. Extending our tDCS procedure to the composite effect for faces and for the kind of stimuli used in Zhao et al., (2016) may improve our understanding of our tDCS procedure. Recently, Civile, McLaren, Milton, et al., (2021) have also reported holistic processing to be the factor which the tDCS procedure is unable to modulate in faces after showing the procedure's inability to significantly modulate the composite effect (index of holistic processing). This will be discussed in detail in the next chapter.

Chapter 3: Investigating the Congruency Effect in Prototype-Defined Checkerboards

3.1 Introduction to the Experiments

Here, we follow on from the previous chapter and investigate whether holistic/configural processing is involved in the residual face inversion effect induced by our tDCS procedure. The specificity vs expertise debate extends to the configural processing literature, however, to explain configural processing, faces will be referred to as examples in order to provide an easier description. Maurer et al., (2002) identified three types of configural processing: ‘first-order relations’ involve perceiving a stimulus as a face based on the features as arranged (two eyes above a nose, nose above a mouth); ‘holistic processing’, by which the features are joined together as a gestalt, and finally; ‘second-order relations’ which involve the perception of the variation in the distances among features (for a review about different types of configural processing, see Maurer et al., 2002). The authors also suggest that while the inversion effect affects all three types of configural processing, the *composite face effect* has been suggested to specifically affect holistic processing. The composite effect refers to the phenomenon when people are less accurate at recognizing the top half of one face when presented in composite with the bottom half of another face than when the two halves are offset laterally (misalignment, a manipulation that disrupts configural processing). This effect suggests that the features are so strongly integrated that it becomes difficult to separate the face into isolated components, resulting in the composite to be perceived as a “new” face (for a review, see Murphy et al., 2017) when the halves are aligned. As mentioned above, the configural processing literature is parallel to the inversion effect literature because the explanation of the composite effect has been argued to be indicative of either face specificity or expertise face processing. The claim that the composite effect is an index of face specificity is derived from the notion that when composite faces are aligned and shown upright, the perception of the intact facial arrangement may permit access to face-specific processing, and that the composite effect is robustly found in face stimuli than non-face stimuli (Tsao & Livingstone, 2008). In contrast, other authors were able to obtain the composite effect in objects of expertise (e.g., Gauthier & Tarr, 2002; Wong, Palmeri et al., 2009), and therefore, argue that the composite effect may reflect a form of processing recruited by objects of expertise, and thereby, suggest face recognition processing is driven by expertise. Consistent with the overall literature of face recognition, this is heavily disputed. We will revisit this later and discuss further of previous research investigating configural processing in non-face stimuli indexed by the composite effect .

As of now, there is no research investigating the composite effect in checkerboard stimuli. If the composite effect cannot be extracted from checkerboards (i.e. non-face stimuli that nevertheless give an inversion effect) it would suggest that holistic processing is the potential component, which the tDCS procedure at Fp3 is unable to modulate in faces, leading to an inability to completely abolish the inversion effect. A recent study by Civile, McLaren, Milton, et al., (2021) investigated the composite effect with face stimuli when the tDCS procedure at Fp3 (the same procedure used in Chapter 2 of this thesis) is administered and to test the procedure's effect on upright faces when inverted faces are not involved. It was predicted that if the results agree with the perceptual learning account regarding the tDCS procedure on the inversion effect, then an overall reduction in performance across all composite face conditions would be expected. This is because all stimuli presented are upright faces, which participants had never seen before taking part in the experiment, and according to the perceptual learning account, this meets the condition for the tDCS procedure to maintain salience of the common elements shared among all the upright faces at a relatively high level. This makes it harder for participants to learn the unique elements of each face, which consequently causes more difficulty at distinguishing whether the "target" face is the same or different from the "test" face in the matching task, despite the task being easier than the typical old/new recognition task, as reported in previous work (Civile, Verbruggen et al., 2016; Civile, McLaren, et al., 2018; and Civile, Waguri et al., 2020). A priori predictions of the effects tDCS on Fp3 site would have on the composite face effect were constrained because this study was the first to investigate this effect. Without any previous evidence to draw from, the authors surmised that if composite faces are equally affected by the tDCS procedure, then a decrement in performance, resulting in no effect on the size of the composite effect could be expected. Alignment/misalignment may influence the outcome, however, the only two studies that investigated this with tDCS were conflicting; Experiment 1 of Renzi et al., (2014) did not find tDCS to affect the composite face effect at PO8, while Yang et al's., (2014) Experiment 2 found the effect when stimulating the same site.

Civile, McLaren, Milton, et al., (2021) explored this further by conducting a series of experiments. In Experiment 1a, the tDCS procedure at Fp3 site was administered during the face-matching task (sham/anodal conditions were between-subjects). The matching task was employed for better assessment of the composite effect. This task entailed a sequential presentation of two composites, with participants asked to judge whether the target stimuli were identical or not to the test stimuli. 128 composite faces were created by using the top and bottom halves from two different faces (original faces were the same as Civile, McLaren, et al., 2018; Civile, Elchlepp, et al., 2018). Experiment 1b was a replication of Experiment 1a in Chapter 2 of this thesis so that the study includes the effects of tDCS at Fp3 on the inversion effect and the composite effect.

The results from Experiment 1a of Civile, McLaren, Milton, et al., (2021) revealed that the anodal tDCS group showed no effects on the *Congruency x Alignment* interaction (the index of the composite face effect) as opposed to sham. However, the anodal tDCS reduced the overall performance across all the composite face conditions compared to sham tDCS. Experiment 1b confirmed the findings from Chapter 2 of this thesis that the same tDCS procedure at Fp3 can specifically reduce the face inversion effect rather than overall performance. Putting all the results together, they suggest that the inversion effect is at least partly determined by perceptual learning, which the tDCS can modulate, this is not the case for the composite effect.

Civile, McLaren, Milton, et al's., (2021) experiment 2 was crucial in the sense that it replicated their Experiment 1a. In addition to the anodal and sham groups, this experiment added an active stimulation group, which involved a separate group of participants who were presented with the same task and stimulation as the other two groups, however, the stimulation was delivered at the occipital area PO8. The purpose of this active control was to confirm the prediction that tDCS delivered at Fp3 would influence perceptual learning (hence a reduction of overall performance in line with Experiment 1a). PO8 was chosen for the active control because this area has been reported as a common site for extracting the N170 ERP face-index, and its largest response upon modulation has been observed in this area. The only two previous experiments that had investigated this showed no main effect of the tDCS on overall performance in this area (Yang et al., 2014, Experiment 2; Renzi et al., 2014, Experiment 1), therefore, it was deemed to be an appropriate active control for stimulation at Fp3 site. However, Yang et al., (2014, Experiment 2) still found the tDCS to affect the composite effect as opposed to Renzi et al., (2014, Epxeriment1), therefore, this was also an opportunity to weigh in on the contrasting findings. As expected, the results revealed a significant composite effect, meaning better performance in congruent stimuli than incongruent stimuli when aligned, and a significant reduction of the difference between the congruent and incongruent stimuli upon misalignment. However, once again, there were no significant effects of stimulation on the composite effect. Consistent with Experiment 1a, Fp3 stimulation had an effect on the overall performance compared to sham, however, this time, a comparison was provided against the replicated sham and the active control at P08. Specifically, Anodal tDCS at Fp3 reduced the overall performance across all the composite conditions compared to sham and Anodal tDCS at P08. However, Anodal and Sham tDCS at PO8 showed no differences. Moreover, it was revealed that regardless of Anodal tDCS delivered at Fp3 or PO8, it does not influence the composite effect.

Crucially, the authors interpreted that their tDCS technique affects some aspects of face processing, but not others, based on the logic that if the composite effect was based on perceptual learning, then stimulation at Fp3 should have disrupted this and reduced the composite effect. Considering the claim that the composite face illusion is dependent on (and therefore, an index of) holistic processing of faces, the results suggested that this tDCS procedure would also <u>not</u> affect holistic processing. Based on this, it was argued that the composite effect may not be expertise-based. Moreover, if the tDCS stimulation results in the decrement of performance in upright faces, then the congruent and incongruent composite faces should suffer equivalently because both are upright faces. Only by alignment/misalignment, should the results vary based on whether a face is viewed as a whole or two separate halves, however, the results from this study determined that this factor acts independently of the tDCS. As suggested by Maurer et al., (2002) the composite effect might be a domain of the specificity account of face recognition, and specifically signifies holistic processing. Interpretations of holistic processing varies and are subject to debate, however, if the notion is that this processing is triggered by anything that may conform to any basic plan of a face (e.g., Hole et al., 1999), this would suggest first- and second-order relational processing are pertinent to both face and object recognition, while holistic processing is independently specific to faces.

These are important implications when taken in conjunction with the results from Chapter 2, because there, the exact same tDCS procedure was used to reverse the perceptual learning component of face recognition indexed by inversion, and Civile, McLaren, Milton, et al., (2021) have shown that this procedure is unable to influence the composite effect, and therefore, this provides some evidence supporting the idea that the composite effect is an index of face specificity. Moreover, if the composite effect is based on holistic processing, this means that holistic processing is specific to faces and would provide further evidence that it could be the component the tDCS was unable to modulate in Chapter 2. The current chapter aimed to directly test whether perceptual learning mechanisms are involved in the composite effect. If the speculation that holistic processing is indeed the component the tDCS procedure was unable modulate as observed in Civile, McLaren, Milton, et al., (2021), then this should be reflected in the checkerboard stimuli and the composite effect would not be obtained in non-face stimuli. However, the question is: Are checkerboard stimuli fundamentally susceptible to the composite effect? As briefly stated earlier, the literature investigating the composite effect in non-face stimuli is divided. A few studies have reported findings that are consistent with the claim that the composite face effect is based on expertise, as this effect has been found in non-face objects including cars (Bukach et al,. 2010), words (Wong, Bukach, Yuen, et al., 2011) and Chinese characters (Wong, Bukach, Hsiao, et al., 2012). A composite effect was also found for mono orientated artificial stimuli (e.g., Greebles or Ziggerins) after participants were trained with them (Gauthier & Tarr, 2002; Wong, Palmeri, et al., 2009) and for images of bodies with expressive postures (Willems et al., 2014). However, other authors have failed to obtain a composite effect with dog images (Robbins & McKone, 2007), Greebles (Gauthier, Williams, et al., 1998) and with neutral body images (Soria et al., 2011), hence the debate. It has also been argued that these contrasting results may be attributed to the idiosyncrasies in the design and stimuli used, as well as emotional valence across studies.

Only two previous studies reported a composite effect for non-face artificial stimuli after participants had been trained with them in the lab. One study used Greebles and the other used Ziggerins (Gauthier & Tarr 2002; Wong, Palmeri, et al., 2009). Gauthier and Tarr (2002) trained participants through categorization with Greebles at the “Family” and “Individual” levels. Five family names were introduced to the participants in the first session and individual names for five Greebles were learnt in each of the first four sessions through different tasks (e.g., giving inspection trials when Greebles were shown). Participants then trained in an association response keys task, where the names of specific Greebles and the correct name appeared, or no name but feedback for their correct responses were shown. Subsequently, Naming tasks in alternation with a Verification task was presented. The Naming task involved participants seeing a Greeble on a screen and had to press the first letter of its individual name. The Verification task required participants to judge whether a label (family, individual, or NIL) matched with the later-presented Greeble and respond with either “same” or “different”. In the composite task, participants were presented with four conditions (aligned/original, misaligned/original, aligned/composite, misaligned/composite). Half of the trials presented composites with a top half that matched the target composite’s top half and the other half of the trials presented a top half from a distractor. The results showed a significant composite effect.

Interestingly, a previous study by Gauthier, Williams et al., (1998) did not find a composite effect for Greebles. The difference was that Gauthier and Tarr (2002) adopted the ‘complete’ design of the composite task, which has been shown that using the complete and partial/original designs do not correlate (Richler & Gauthier, 2014). Despite many authors arguing that the partial design may be influenced by differences in response bias the debate remains open.

Wong, Palmeri, et al., (2009) conducted a similar experiment where they tested the composite effect, also using the complete design in artificial stimuli called Ziggerins. Participants were allocated to one of the two training groups: Categorization training or Individuation training. In the categorization training group, participants learned to categorize 36 Ziggerins into 6 classes, while the individuation training group learned individual names for 18 of the 36 Ziggerins (the remaining 18 were distractors), and randomly assigned two-syllable nonsense words as names for classes or individuals. Subsequently, participants underwent a sequential matching task, where they had to judge if two sequentially presented Ziggerins were the same or different. Finally, participants took part in a composite task where aligned or misaligned Ziggerin composites were presented. Each trial involved the presentation of one Ziggerin, followed by a two-pattern mask, a top/bottom cue, and a second composite. Participants were instructed to indicate if the top or bottom halves of the two composites were the same or different. The results revealed changes in holistic processing denoted by the significant composite effect only in the group that underwent the individuation training task.

The current chapter marked as the first step in investigating whether the composite effect can indeed be found in mono-orientated, artificial non-face, checkerboard stimuli, and therefore, we focused on the *congruency effect* to test if this could be obtained in checkerboards. This is defined as the difference in performance to congruent composites (both halves require the same response) compared to performance on incongruent composites (the two halves require different responses). The congruency effect is crucial in producing the composite effect. The latter effect is calculated by subtracting the congruency effect in response to misaligned stimuli from the large congruency effect obtained in aligned composites. In the two experiments reported here, we made a first step towards the investigation of a composite effect for checkerboards. We adopted the same complete design as previous studies that have obtained a composite effect for artificial non-face stimuli (Gauthier & Tarr, 2002; Wong, Palmeri, et al., 2009). A key difference between complete and partial/original designs is the *congruency effect,* which is an essential component for determining the composite effect. In the complete design, composites can be congruent or incongruent on both “same” and “different” trials. Congruent trials occur when the top half and bottom half of a composite facilitate the required response for the top half. In the “same” condition, the target and test composites are identical whereas in the “different” condition, the test composite is made by two completely different (to the target composite) halves. Incongruent trials occur when the bottom half of the composite promotes the opposite response to the top half. In the “same” condition, target and test composites have matching top halves but different bottom halves whereas in the “different” condition, target and test composites have mismatching top halves and matching bottom halves. A significant congruency effect (higher performance for congruent vs incongruent stimuli) is found in aligned composites, and in misaligned composites, this effect is reduced. It is the difference between the congruency effect in aligned vs misaligned composites that constitutes the composite effect.

3.2 EXPERIMENT 1a

3.2.1 Method

3.2.1.1 Participants

96 naïve students from the University of Exeter (mean age = 20.5, age range = 18-58) were recruited through the university online recruitment system SONA. They were compensated with course credits. All methods were performed in accordance with the guidelines and regulations approved by the CLES Psychology Ethics Committee at the University of Exeter. Informed consent was obtained from all participants. The sample size was determined from earlier studies using the same checkerboard stimuli (Civile, Zhao, et al., 2014), and studies on perceptual learning in the composite face effect (Civile, McLaren, Milton, et al., 2021).

3.2.1.2 Materials

The stimuli consisted of 4 prototype-defined categories of checkerboards (A, B, C, D), which were previously used in Civile, Zhao, et al., (2014, Experiment

1a). Category prototypes (16 x 16) were randomly generated with the constraint that they shared 50% of their squares with each of the other prototypes and were 50% black squares and 50% white squares. Exemplars were generated from these prototypes by randomly changing forty-eight squares thus, on average, 24 squares would be expected to alter from black to white or white to black. Composite checkerboards were presented at the resolution of 256 x 256 pixels on a grey background. The composites consisted of top and bottom halves of different checkerboards (each containing 16 x 16 squares) drawn from the same prototype-defined category (e.g., A65 Top, A73 Bottom). The experiment was programmed and run on the online platform Gorilla.

3.2.1.3 Procedure

The Behavioral Task

The experiment consisted of a categorization phase (pre-exposure phase), a training phase, and a test phase (checkerboard-matching task).

Categorization phase:

Upon providing consent, participants were shown instructions for the categorization task, which were in line with Civile, Zhao, et al., (2014). They were shown checkerboard exemplars from categories A and C one at a time in a random order (64 from each category, total of 128). They were instructed to sort these exemplars into two categories (A or C) through trial-and-error, by pressing one of the two keys on the keyboard. They were given immediate feedback on whether their response was correct or incorrect.

Training phase:

The aim of this task was to train participants in associating the response keys ‘x’ and ‘.’ with the words ‘SAME’ and ‘DIFFERENT’ (keys were counterbalanced). 48 trials (24 SAME, 24 DIFFERENT) were presented randomly, one at a time for <1 second after a fixation cross (1s). Participants were instructed to press the ‘x’ or ‘.’ as quickly as possible when classifying them as either SAME or DIFFERENT. They received feedback on each response as correct or incorrect.

Checkerboard-Matching task:

This phase involved a matching-task with composite checkerboards (128 trials). Each trial commenced with a fixation cross (1s), followed by a TARGET composite checkerboard stimulus (1s), an interstimulus interval (1.5s), and a TEST composite checkerboard stimulus (≤2s). Participants were to press the response keys from their counterbalanced group in the keyboard training phase (‘x’ or ‘.’ key) to identify the top halves of the TARGET and TEST stimulus as same or different (See Figure 3.1). In line with previous studies investigating the composite face effect (e.g., Civile, McLaren, Milton, et al., 2021), half of the participants were first engaged with the *congruent* trials and following this the *incongruent* trials. The other half of the participants had the reverse order. Within congruent and incongruent trials, composites taken from familiar and novel categories were presented at random.

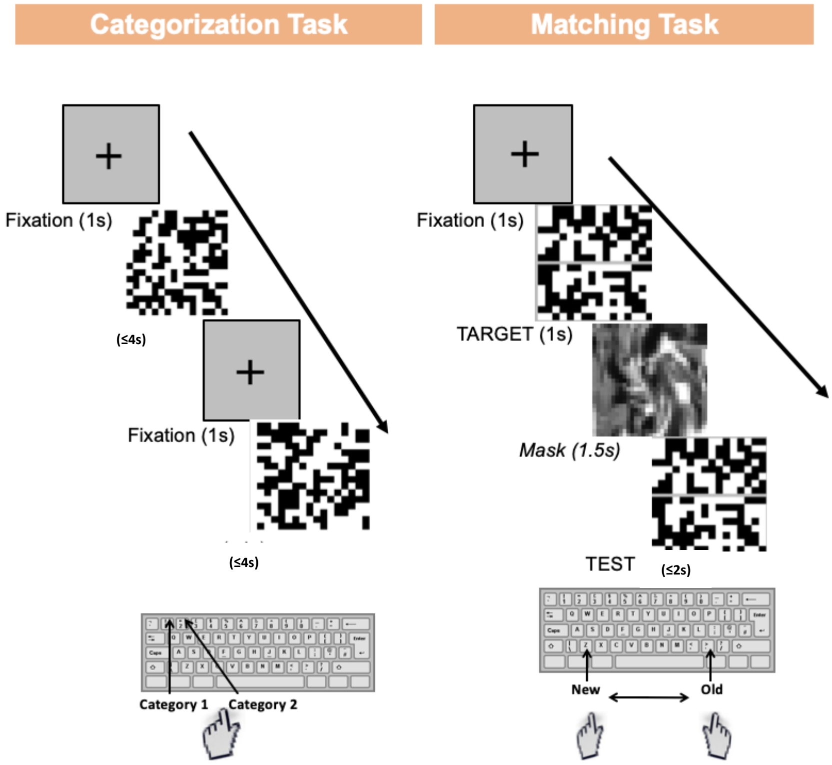

Figure.3.1. shows the trial sequence of the categorization, and the final matching task.

In the congruent familiar trials, participants first saw a TARGET composite checkerboard created by selecting the top and bottom halves of two different new (not seen in the categorization task) exemplars selected from the familiar categories (A and C) previously seen in the categorization phase (e.g., top-half of exemplar A65 and bottom-half of A73 or top-half of exemplar C65 and bottom-half of C73). In the TEST trial, they would either see the “same” composite or a “different” one created by selecting the top and bottom halves of two different exemplars within the same categories (e.g., top-half of A89 and bottom-half of A81 or top-half of exemplar C89 and bottom-half of C81). Overall, 32-A and 32-C composites were presented (16 same, 16 different) in a random order. An A-TARGET composite would correspond to an A-TEST composite, and a C-TARGET composite would correspond to a C-TEST composite. The congruent novel trials TARGET and TEST “same” or “different” composites were also created by selecting the top and bottom halves of exemplars drawn from prototype-defined checkerboard categories (B and D in this case, 32 each, 16 same and 16 different) not seen during the categorization task. In line with the familiar composites, the novel composites were also created from exemplars drawn from the same novel category (either B or D). So that a B-TARGET composite would always be followed by a B-TEST composite, and to a D-TARGET composite would always be followed by a D-TEST composite.

Incongruent familiar and novel trials utilized a different combination of the composites from the congruent trials. Here, the TARGET and TEST would be considered ‘same’ if the top halves of the composites were the same, but both would have different bottom halves (e.g., TARGET: A65/81; TEST: A65/A73). The converse was for different, wherein the top halves of the TARGET and TEST are different, but have the same bottom halves (e.g., TARGET: A89/A73; TEST: A65/A73, see Figure 3.2). Participants saw 128 trials in total (64 “same”, 64 “different”) split by four stimulus conditions: 32 familiar congruent (16 A and 16 C), 32 novel congruent (16 B and 16 D), 32 familiar incongruent (16 A and 16 C) and 32 novel incongruent (16 B and 16 D).

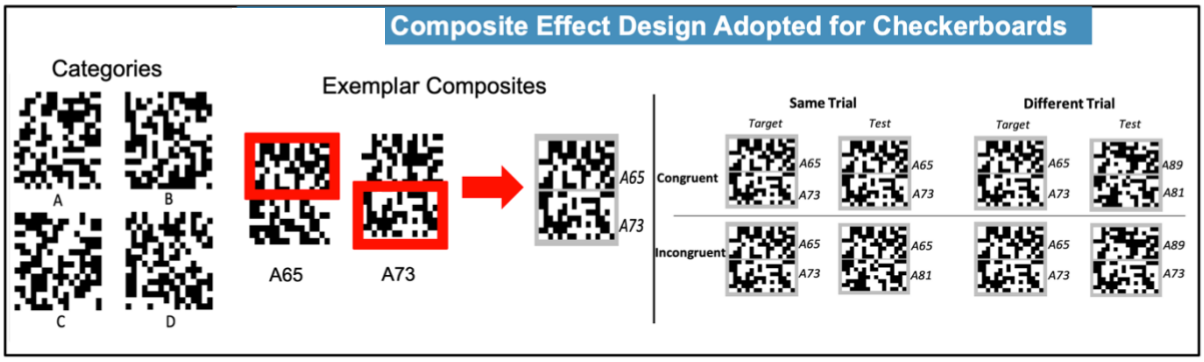

Figure.3.2. illustrates the study design. In each checkerboard pair, the first composite is the target, and the second one is the test. In the congruent condition, the target and the test composite halves are either both the same or are both different. In the incongruent condition, the bottom halves of the target and test composites have the opposite relationship to that in the top halves.

3.2.2 Results

The primary measure was the accuracy data from all participants in a given experimental condition which we used to compute a *d'* sensitivity measure (Stanislaw & Todorov, 1999) for the matching task (same and different stimuli for each stimulus type) where a *d'* of 0 indicates chance-level performance. To calculate *d'*, we computed using the difference between the z transforms of the participants' hit rate (H) (the proportion of SAME trials to which the participant responded SAME), and false alarm rate (F) (the proportion of DIFFERENT trials to which the participant responded SAME): $d' = z(H) - z(F)$. We assessed performance against chance to show that the stimulus' conditions were recognized significantly above chance (we found $p < .001$ for all four conditions). We analyzed the reaction time data to check for any speed-accuracy trade-off. We do not report these analyses here because they do not add anything to the interpretation of our results.

In the categorization phase, the mean percentage correct was 58%. In the test phase we computed a 2 x 2 x 2 mixed model design using the within-subjects factors *Congruency* (congruent or incongruent), and *Familiarity* (familiar or novel) and the between-subjects factor *Order of Trials* (congruent-incongruent or incongruent-congruent) for our matching task data. Analysis of Variance (ANOVA) showed no significant main effect of *Congruency* $F(1, 94) = 0.93$, $p = .337$, $\eta^2_p = .10$, nor of *Familiarity* (though there were signs of a trend towards better performance with familiar than novel) $F(1, 94) = 2.62$, $p = .108$, $\eta^2_p = .27$, nor of *Order of Trials* $F(1, 94) = 0.71$, $p = .402$, $\eta^2_p < .01$. The three-way interaction was not significant, $F(1, 94) = 2.44$, $p = .121$, $\eta^2_p = .03$, nor was the interaction between Congruency x Familiarity, $F(1, 94) = 1.04$, $p = .308$, $\eta^2_p = .01$. We did find a significant *Congruency* x *Order of Trials* interaction, $F(1, 94) = 5.63$, $p = .020$, $\eta^2_p = .06$, and a significant *Familiarity* x *Order of Trials* interaction, $F(1, 94) = 5.14$, $p = .026$, $\eta^2_p = .05$. The first interaction seems to reflect the fact that the congruency effect is bigger when Incongruent trials are taken first (Incongruent-Congruent), and it is numerically reversed for Congruent-Incongruent. The second interaction seems to be due to performance for Incongruent-Congruent being substantially worse in the novel category stimuli, whereas performance to both novel and familiar category stimuli was roughly equivalent (with performance for novel category slightly better) in Congruent-Incongruent.

Post-hoc paired-sample t-tests

To further explore the interactions of the Order of Trials, we ran some post-hoc analyses to investigate this further. A paired-sample *t*-test comparing Congruent (M = 1.89, SE = 0.13) vs Incongruent (M = 1.60, SE = 0.16) stimuli in the group where incongruent trials were presented before congruent trials, revealed a clear trend towards a significant difference indicative of a congruency effect, $t(47) = 1.94$, $p = .058$, $\eta^2_p = .07$ (see Figure 3.3) with an advantage for congruent stimuli than incongruent stimuli. The same analysis for the group where congruent trials were presented before incongruent trials showed a reverse numerical pattern where Incongruent stimuli (M = 1.96, SE = 0.15) was higher in performance than Congruent stimuli (M = 1.84, SE = 0.14), although this was not statistically significant $t(47) = 1.38$, $p = .174$, $\eta^2_p = .04$.

We conducted a paired *t*-test between performance across Familiar (M = 1.88, SE = 0.15) vs Novel (M = 1.91, SE = 0.13) stimuli in the group where congruent trials were presented before incongruent trials, which revealed no significant difference in the overall performance at recognizing the top halves of familiar composite exemplars compared to novel ones, $t(47) = 0.51$, $p = .612$, $\eta^2_p < .01$. The same analysis across Familiar (M = 1.85, SE = 0.13) vs Novel (M = 1.64, SE = 0.12) stimuli in the group where incongruent trials were presented before congruent trials, revealed a significant difference in the overall performance for recognizing the top halves of familiar composite exemplars compared to novel ones, $t(47) = 2.51$, $p = .016$, $\eta^2_p = .12$, with an advantage for familiar stimuli.

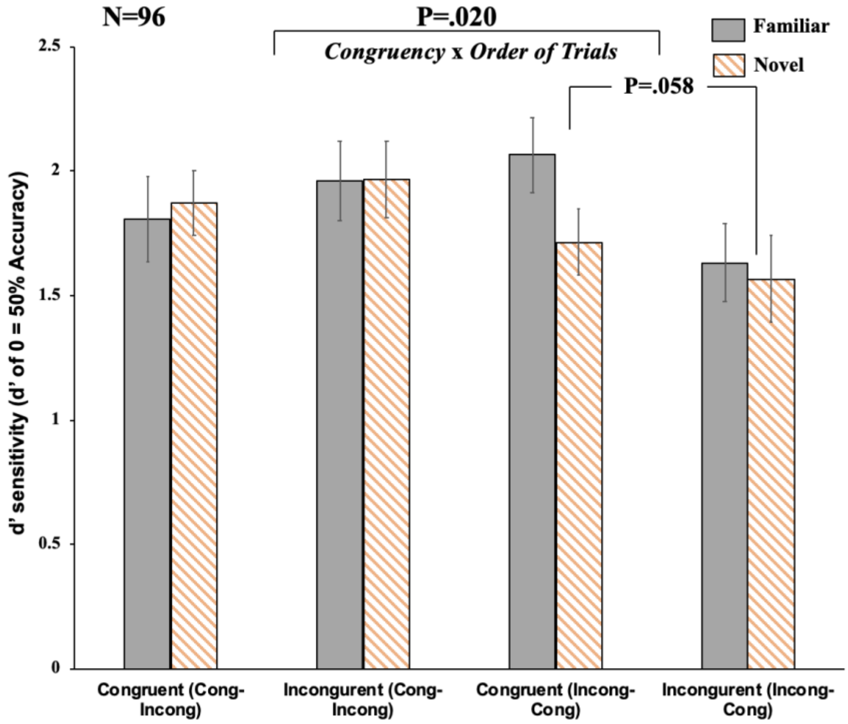

Figure.3.3. Bar chart showing results of the congruency effect obtained in Experiment 1a. The x-axis represents the stimuli condition, and the y-axis shows the d' performance. The results across conditions showed a significant effect of congruency and order of trials, meaning, the congruency effect appeared in trials where incongruent stimuli were shown first but not vice versa.

3.2.3 Discussion

Here, we investigated one of the main contributors to the robust composite face effect often used as an index of holistic processing. We focused on the congruency effect, which refers to better performance at detecting the top half of a face when in the congruent condition compared to when presented in the incongruent condition. Sets of artificial non-mono-orientated stimuli previously used in the inversion effect research (Civile, Zhao, et al., 2014) were employed to ascertain whether a congruency effect could be obtained in non-face, checkerboard stimuli. The results revealed that we have succeeded in finding an effect of congruency for our checkerboard composites in one of our conditions, and the additional effect of the order of trials presented, which affected the congruency effect. To confirm these findings, a replication is required. Additional reasons for the replication are so that we can fully counterbalance the categories of the checkerboards and to fix an issue that was found in the novel checkerboard stimuli (a small number of stimuli were constructed incorrectly, where the bottom halves for 12 of the composites consisted of top-halves: $\frac{Top-half}{Top-half}$ as opposed to the correct halves consisting of one top-half and one bottom-half $\frac{Top-half}{Bottom-half}$ for the composite to be either congruent or incongruent). If the same findings can be obtained through replication, this would provide a strong foundation to test the full composite effect in checkerboards. This would also be the first evidence in the literature that shows the order of the congruent and incongruent trials modulate the congruency effect.

3.3 EXPERIMENT 1b

3.3.1 Method

3.3.1.1 Participants

In line with Experiment 1a, 96 naïve participants (mean age = 23.8, age range = 18-38) were recruited via Prolific. They had an approval rating of at least 90% from participation in other studies and received monetary compensation adhering to the fair pay policies of Prolific Academic. All methods were performed in accordance with the guidelines and regulations approved by the CLES Psychology Ethics Committee at the University of Exeter. Informed consent was obtained from all participants.

3.3.1.2 Materials & Procedure

All materials (with a few stimuli corrected) and the procedure were exactly the same as Experiment 1a. The only difference was that the 4 categories of checkerboards (A, B, C, D) were fully counterbalanced. Across all participants in the categorization and test phases, categories A-C and B-D were presented equal number of times as familiar or novel stimuli conditions. Furthermore, after a careful examination of the stimuli used in Experiment 1a, we found imprecisions in the way 12 of the novel composites had been made, where the bottom-halves were made of the top-halves. Experiment 1b fixed that by replacing the incorrect bottom-halves with the correct ones, allowing the composites to be congruent or incongruent.

3.3.2 Results

In line with Experiment 1a, the primary measure was the accuracy data from all participants in a given experimental condition which we used to compute a *d'* sensitivity measure (Stanislaw & Todorov, 1999) for the matching task (same and different stimuli for each stimulus type) where a *d'* of 0 indicates chance-level performance. To calculate *d'*, we computed using the difference between the z transforms of the participants' <u>hit rate (H)</u> (the proportion of SAME trials to which the participant responded SAME), and <u>false alarm rate (F)</u> (the proportion of DIFFERENT trials to which the participant responded SAME): d' =z(H) – z(F).

In the categorization phase, the mean percentage correct was 63%. In line with Experiment 1a, a 2 x 2 x 2 mixed model design was calculated using the same factors. Analysis of Variance (ANOVA) revealed no significant main effect of *Congruency* $F(1, 94) = 2.27$, $p = .135$, $\eta^2_p = .02$, of *Familiarity* $F(1, 94) = 1.62$,

p = .206, η^2_p = .01, nor of *Order of Trials* F(1, 94) = 0.01, p = .897, $\eta^2_p < .01$. The overall three-way interaction (Congruency x Familiarity x Order of Trials) was not significant, F(1, 94) = 2.77, p = .10, η^2_p = .03, nor was the interaction Congruency x Familiarity, F(1, 94) = 0.75, p = .39, $\eta^2_p < .01$. Once again we found a significant *Congruency* x *Order of Trials* interaction, F(1, 94) = 7.58, p = .007, η^2_p = .08, and a significant *Familiarity* x *Order of Trials* interaction, F(1, 94) = 5.28, p = .024, η^2_p = .053. As in Experiment 1a, the congruency interaction was due to the congruency effect being larger in the Incongruent-Congruent trial order (and numerically reversed in the Congruent-Incongruent trial order). The top halves of the familiar composites were better recognized than novel ones in the group where incongruent trials were presented before congruent, whereas this effect was numerically reversed for the group where congruent trials were presented before incongruent.

Paired-sample t-test

To further explore these interactions with the *Order of Trials* we conducted the same additional analyses. A paired-sample *t*-test this time comparing Congruent (M = 1.97, SE = 0.12) vs Incongruent (M = 1.52, SE = 0.16) stimuli in the group where incongruent trials were presented before congruent trials, revealed a significant difference, t(47) = 2.83, p = .007, η^2_p = .15 (see Figure 3.4), indicating a robust congruency effect with better performance at detecting the top half of a composite in the congruent condition compared to incongruent. A paired-sample *t*-test between performance for Congruent (M = 1.65, SE = 0.15) vs Incongruent (M = 1.79, SE = 0.16) stimuli in the group where congruent trials were presented before incongruent trials, revealed no significant differences, t(47) = 0.94, p = .350, η^2_p = .02.

Finally, a paired-sample *t*-test between performance across Familiar (M= 1.62, SE = 0.14) vs Novel (M = 1.82, SE = 0.15) stimuli in the group where congruent trials were presented before incongruent trials revealed a significant difference, $t(47) = 2.38$, $p = .021$, $\eta^2_p = .11$ with better performance in recognizing the top halves of novel composites as opposed to familiar composites. The same analysis across Familiar (M = 1.77, SE = 0.12) vs Novel (M = 1.72, SE = 0.13) stimuli in the group where incongruent trials were presented before congruent trials, was not significant, $t(47) = 0.77$, $p = .443$, $\eta^2_p = .01$. These results differ from the *Familiarity x Order of Trials* interaction reported in Experiment 1a, which was mainly due to better performance for Familiar stimuli as opposed to Novel stimuli in the group where incongruent trials were presented before congruent. Here, the *Familiarity x Order of Trials* interaction appears to be mainly due to performance being better with Novel stimuli than Familiar in the group where Congruent trials were presented first. These difference could perhaps be due to the change in the experiment design structure or problems with the stimuli in Experiment 1a.

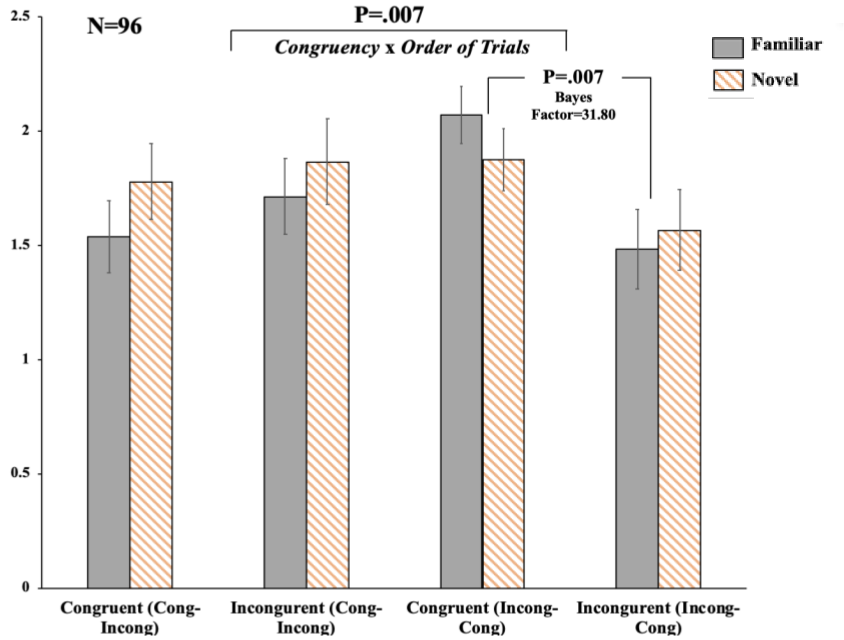

Figure.3.4. Bar chart showing results obtained in Experiment 1b. The x-axis represents the stimuli from which order of block condition, and the y-axis shows the d' performance. The results across conditions confirmed significant effects of congruency and familiarity interacting with order of trials.

Bayes Factor Analysis

We conducted a Bayes analysis on the significant difference between the d' values for Congruent and Incongruent stimuli in Experiment 1b when incongruent trials were presented before congruent trials. We used as the *priors* the difference found in Experiment 1a setting the standard deviation of p (population value | theory) to the mean for the difference between the Congruent vs Incongruent stimuli (0.29). We used the standard error (0.15) and mean difference (0.45) between the Congruent vs Incongruent stimuli in Experiment 1b. This gave a Bayes factor of 31.80, which is very strong evidence (greater than 10) that these results are in line with that shown in Experiment 1a i.e., a better performance for Congruent vs Incongruent composites when incongruent trials were presented before the congruent trials.

3.4 Overall Discussion

In the two experiments reported here we investigated the congruency effect (better performance for congruent vs incongruent composites) in checkerboard composite stimuli as a first step in examining the composite effect. The results from Experiment 1b replicated Experiment 1a, and therefore, the two studies taken together shows that the congruency effect can be obtained in checkerboard composites under certain conditions, which is by presenting incongruent before congruent trials, and not the vice-versa of congruent before incongruent trials. Interestingly, this also means we have uncovered an additional effect of the order of trials presented, and this is associated with the familiarity of the stimuli; we will discuss this subsequently in detail and the implications it poses.

The only two previous studies that reported a composite effect for lab trained non-face artificial stimuli were by Gauthier and Tarr (2002) using Greebles, and Wong, Palmeri, et al., (2009) using Ziggerins. Both employed a complete design to enable the extraction of the composite effect by subtracting the congruency effect in response to misaligned stimuli from the large congruency effect obtained with aligned composites. This is a key contrast to partial/original design used by Gauthier, Williams et al., (1998) who were unable to obtain a significant composite effect, which demonstrated how the congruency effect is extracted impacts the final composite effect. The contribution of our results to the previous literature is that we have shown we can obtain a congruency effect for non mono-oriented composite checkerboards after participants received a brief pre-exposure to them. The critical result is the additional finding of the effect counterbalancing of the trial order has on the overall results. The intention behind counterbalancing the trials in the first place was to follow previous studies within the lab that investigated the composite effect in faces, which also had an experiment counterbalancing the orders (among other combinations of trials). Here, it was revealed that with the checkerboard composites, the effect of congruency is only found in participants who were first presented with incongruent trials, followed by congruent trials. A significant impact on the congruency effect by the order of presentation of trials was observed in both experiments.

On the one hand, these results provide grounds for a full extension of the complete design and test aligned vs misaligned composites. Future studies should, therefore, investigate if a robust composite effect can be found in checkerboards, and how misaligning the composite checkerboards may influence the congruency effect for aligned checkerboards. If a composite effect comparable to Greebles and Ziggerins is obtained with checkerboards, then a reduced congruency effect in misaligned composites should be expected compared to aligned composites. Alternatively, this may not be attained which would be in line with Civile, McLaren, Milton, et al's., (2021) findings.

On the other hand, these results also revealed a new pattern of effects based on the order the composite checkerboards were presented. This is perhaps the first study that directly investigated the order of trial effects on the congruency effect. There are few possibilities behind the emergence of this order of trial effects (e.g., practice effect); one possible explanation of this could be attributed to generalization taking place from the categorization phase to the congruent trials presented before incongruent trials. This appears to primarily affect familiar stimuli for congruent trials, which may drive the order of trial effects found for both familiarity and congruency. The reason why congruent trials are affected is because the generalization results in the different stimuli to seem more recent with stimuli from the familiar category. The outcome of this is a decreased d-prime for the congruent familiar composites as opposed to novel composites, only if those trials are presented first, but not if they are presented after in which case, the typical effect of expertise is observed (larger d-prime for familiar stimuli). A numerically reduced d-prime for congruent familiar composites can be seen in each experiment when congruent trials are presented first as opposed to being presented second. Importantly, this is the first study to our knowledge that systematically investigated the order of presentations for congruent and incongruent trials in a between-subjects design. The findings of the order of trials effect could contribute to one of the key debates in the composite effect literature regarding the polarizing results in non-face stimuli. Previous research has explained the varying results as individual differences in susceptibility to the composite effect, however, there has been little investigation regarding other possible factors; for instance, some facial composites induce a stronger composite effect than others (although there is little explanation regarding the differences). Others explain that the differences are potentially due to the low-level image differences (e.g., image scale, spatial frequency and color), or perhaps differences in shape and texture variation (Murhpy et al., 2017). Our findings contribute by suggesting this order of trials has an effect (at least for non-mono-orientated composites). Future studies should extended on this by systematically investigating the effect of order of trials with the traditional composite face effect in order to ascertain if this effect is exclusive to artificial non-face stimuli.

On a general note, our results showed how a congruency effect, which is a key factor in the composite effect, can be obtained with prototype-defined categories of checkerboards that were used in previous research to investigate the inversion effect.

Chapter 4: Investigating the Composite Face Effect in Prototype-Defined Checkerboards

4.1 Introduction to the experiments

I will summarize the narrative thus far. Chapter 3 extended the work in Chapter 2, which found that the tDCS procedure removes the perceptual learning component of face recognition indexed by the inversion effect, and has fully reduced the checkerboard inversion effect, and partially (although significantly) reduced the face inversion effect. Recent findings by Civile, McLaren, Milton, et al., (2021) showed that the same tDCS procedure used in Chapter 2 does not affect the composite face effect, which indicates that the unabolished face inversion effect in Chapter 2 could potentially be due to face-specific holistic processing. Based on the notion that the *composite effect* is a specific index for holistic processing, Chapter 3 marked the first step in investigating whether a *congruency effect* (which is the index for the composite effect) can be obtained in checkerboards as this has never been investigated before. A cut-down version of the complete design of the composite effect was used in line with studies that have obtained a composite effect for artificial non-face stimuli (i.e., Gauthier & Tarr 2002; Wong, Palmeri, et al., 2009), but only aligned checkerboard composites were investigated as the focus was on the congruency effect. The congruency effect in the checkerboard stimuli was found under certain conditions, however, an additional finding emerged from counterbalancing the trial order. This was the novel finding of an *effect of order of presentation*, wherein participants presented with incongruent trials first, followed by congruent trials revealed a significant congruency effect (the vice versa order showed no congruency effect). Several factors could potentially be driving this order of trials effect, for instance, a practice effect and/or a carryover effect, considering the results demonstrate a mild congruency effect. Another possible explanation is that this order of trials effect may be attributed to proactive interference (i.e., prior learning reduces memory for similar, recently learned materials, Anderson & Neely, 1996).

The current study continues the work of Chapter 3 in directly investigating the composite effect in checkerboards by including misaligned trials (**Experiment 1**), and to ascertain if the order of trial effect can be replicated. **Experiment 2** served as a control for Experiment 1 by using face stimuli, which served as a direct comparison to the checkerboard stimuli. This was also to investigate if the order of trial effect can be obtained in the composite face effect as well. There are two possible outcomes here; if the findings are in line with Civile, McLaren, Milton, et al., (2021) where the tDCS was unable to modulate the composite effect in faces, and therefore unable to abolish the inversion effect signifies holistic processing to be intact, then holistic processing/the composite effect should not be observed behaviorally in the checkerboard stimuli. That being said, if the extraction of the composite effect is reliant on the type of design employed, then employing the same complete design as Gauthier and Tarr (2002) and Wong, Palmeri, et al., (2009) should result in the finding of the composite effect in these checkerboard stimuli.

4.2 EXPERIMENT 1

4.2.1 Method

4.2.1.1 Participants

96 naïve participants (mean age = 25.4, age range = 18-40) were recruited via Prolific. They had an approval rating of at least 90% from participation in other studies and received monetary compensation adhering to the fair pay policies of

Prolific Academic. All methods were performed in accordance with the guidelines and regulations approved by the CLES Psychology Ethics Committee at the University of Exeter. Informed consent was obtained from all participants. The same sample size was used from the previous study that investigated the congruency effect in checkerboards by using part of the complete composite effect design (Chapter 3; Waguri et al., 2021).

4.2.1.2 Materials

The same stimuli and design as Experiment 1b from Chapter 3 (Waguri et al., 2021), was used but with misaligned composite checkerboards added. The same 4 prototype-defined categories of checkerboards (A, B, C, D) from Civile, Zhao, et al (2014, Experiment 1a) were used. Category prototypes (16 x 16) were randomly generated with the constraint that they shared 50% of their squares with each of the other prototypes (50% black squares and 50% white squares). Exemplars were generated from these prototypes by randomly changing 48 squares, thus, 24 squares on average would be expected to alter from black to white/white to black. Composite checkerboards were presented at the resolution of 256 x 256 pixels on a grey background. The composites consisted of top and bottom halves of different checkerboards (each containing 16 x 16 squares) drawn from the same prototype-defined category (e.g., A65 Top, A73 Bottom). 64 composites were aligned, while the other 64 were modified into misaligned checkerboards by shifting the top half to the left (total of 128 composite checkerboard stimuli). The experiment was programmed and ran on the online platform Gorilla.

4.2.1.3 Procedure

The Behavioral Task

In line with Experiment 1b of Chapter 3, as well as Waguri et al., (2021), the experiment consisted of a categorization phase (pre-exposure phase), a training phase, and a test phase (checkerboard-matching task).

Checkerboard categorization phase:

This commenced after participants provided their consent and were shown the instructions. Participants were presented with exemplar checkerboards from categories A-C or B-D depending on the counterbalance group they were assigned to (64 from each category; 128 in total). Each exemplar was shown one at a time in a random order. They were instructed to sort these exemplars into two categories (A-C or B-D) through trial-and-error by pressing one of the two keys on the keyboard (counterbalanced). They were given immediate feedback on whether their response was correct or incorrect. If they did not respond within 4 seconds, they were timed out. A fixation cross preceded each stimulus presentation in the center of the screen (1 s).

Training phase:

The purpose of this task was to train participants in associating the response keys ‘x’ and ‘.’ with the words SAME and DIFFERENT. They were instructed to press ‘x’ or ‘.’ as quickly as possible when classifying them as SAME or DIFFERENT (counterbalanced). 48 trials (24 SAME, 24 DIFFERENT) were presented randomly one at a time for < 1s after a fixation cross (1s). They received feedback on each response as correct or incorrect.

Checkerboard matching-task:

This phase involved a matching-task with composite checkerboards (128 trials). Overall, participants saw 32 trials of “same” aligned, 32 “different” aligned, 32 “same” misaligned and 32 “different” misaligned composites split by the 8 stimulus conditions (each 16 aligned, 16 misaligned trials, see Figure 4.1): familiar and novel congruent aligned/misaligned, familiar and novel incongruent aligned/misaligned. Each trial commenced with a fixation cross (1s), followed by a TARGET composite checkerboard stimulus (1s), an interstimulus interval (1.5s), and a TEST composite checkerboard stimulus (≤2s). Participants were to press either the ‘x’ key or ‘.’ key in accordance to their training in the keyboard training phase when identifying the top halves of the TARGET and TEST stimulus as same or different. Half of the participants were randomly assigned to first engage with the *congruent* trials followed by the *incongruent* trials, and the other half had the reverse order.

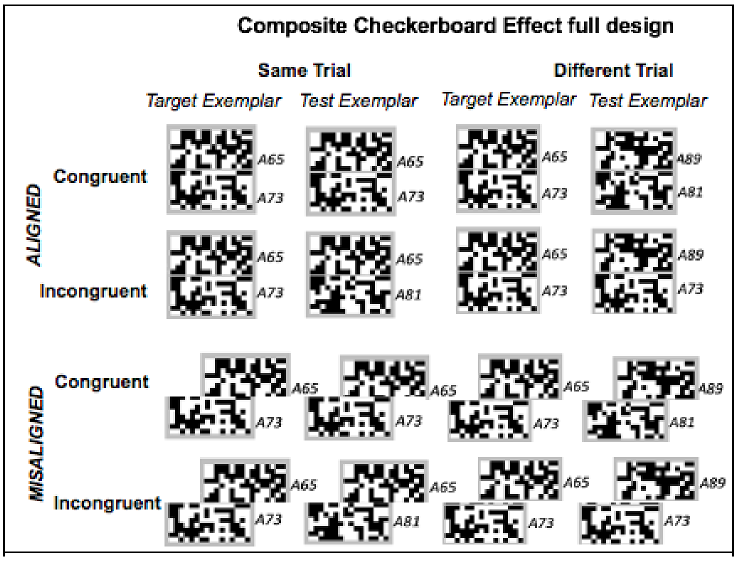

Figure.4.1. illustrates the full design for Experiment 1a with aligned and misaligned checkerboard composites. The same design was used for ‘familiar’ and ‘novel’ category exemplars.

In the *congruent familiar trials*, participants first saw a TARGET composite checkerboard created by selecting the top and bottom halves of two different new (not seen in the categorization task) exemplars selected from familiar categories (A-C or B-D) as seen in the categorization phase (e.g., top-half of exemplar A65 and bottom-half of A73 or top-half of exemplar C65 and bottom-half of C73). In the TEST trial, they would either see the “same” or a “different” composite. In the latter case the top and bottom halves are different exemplars from the same categories (e.g., top-half of A89 and bottom-half of A81 or top-half of exemplar C89 and bottom-half of C81). Overall, 32 A or B and 32 C or D composites were presented (16 same, 16 different) randomly. An A-TARGET composite would correspond to an A-TEST composite, and a C-TARGET composite would correspond to a C-TEST composite. The same applied to B- and D-TARGET/TEST. The *congruent novel trials* TARGET and TEST “same” or “different” composites were created by selecting the top and bottom halves of exemplars drawn from that participant's novel categories (A-C or B-D, 32 each, 16 same and 16 different) not seen during the categorization task. The novel composites were also created from exemplars drawn from the same novel category, and the TARGET/TEST would correspond to the same category. For *incongruent familiar and novel trials*, the TARGET/TEST would be considered as ‘same’ if the top halves of the composites were the same, but both would have different bottom halves (e.g., TARGET: A65/81; TEST: A65/A73). The converse was for ‘different’, wherein the top halves of the TARGET and TEST are different, but have the same bottom halves (e.g., TARGET: A89/A73; TEST: A65/A73). See Figure.4.1 for an illustration of these descriptions.

4.2.2 Results

The primary measure was the accuracy data from all participants in a given experimental condition which we used to compute a *d'* sensitivity measure (Stanislaw & Todorov, 1999) for the matching task (same and different stimuli for each stimulus type) where a *d'* of 0 indicates chance-level performance. To calculate *d'*, we computed the difference between the z transforms of the participants' hit rate (H) (the proportion of SAME trials to which the participant responded SAME), and false alarm rate (F) (the proportion of DIFFERENT trials to which the participant responded SAME): d' =z(H) – z(F). We assessed performance against chance to show that the stimulus' conditions were recognized significantly above chance (for all four conditions we found $p <.001$). The reaction time was analyzed to check for speed-accuracy trade-off, however, they are not reported here as they do not add anything to the interpretation of our results. In the categorization phase, the mean percentage correct was 82%.

We conducted a 4-way ANOVA using within-subjects factors *Congruency* (congruent or incongruent), *Familiarity* (familiar or novel), and *Alignment* (Aligned or Misaligned) and the between-subjects factor *Order of Trials* (congruent-incongruent or incongruent-congruent). Analysis of Variance (ANOVA) showed a significant main effect of *Congruency* $F(1, 94) = 10.01$, $p = .002$, $\eta^2_p = .10$, which is the expected one, with better overall performance for congruent stimuli (M = 1.80, SD = 0.91) than for incongruent ones (M = 1.49, SD = 1.18). There were no significant main effects for *Familiarity* $F(1, 94) = 0.87$, $p = .870$, $\eta^2_p < .01$, nor *Alignment* $F(1, 94) = 0.06$, $p = .806$, $\eta^2_p < .01$. The interaction between *Congruency x Alignment* was not significant, $F(1,94)= 2.06$, $p = .154$, $\eta^2_p = .02$, indicating no reliable composite effect. Similar to Chapter 3 Experiment 1b, the main effect of the between-subject factor of *Order of Trial* was not significant, F(1, 94) = 2.35, p = .129, η^2_p = .02.

There was a significant interaction for *Familiarity* x *Order of Trial* F(1, 94) = 4.80, p = .031, η^2_p = .05, which represents the numerically reverse advantage found in performances for Novel vs Familiar stimuli between Incongruent-Congruent and Congruent-Incongruent order groups. The three-way interaction of *Familiarity* x *Alignment* x *Order of Trial* was also significant, F(1, 94) = 5.29, p = .024, η^2_p = .05. There was a trend for the interaction *Familiarity x Alignment*, F(1,94) = 3.08, p = .082, η^2_p = .03.

Measure	Congruent-Incongruent Order Group		Incongruent-Congruent Order Group	
	M	*SD*	*M*	*SD*
Familiar				
Congruent Aligned	1.7737	1.03178	1.9715	.78259
Congruent Misaligned	1.6075	.90223	1.9029	.84174
Incongruent Aligned	1.5555	1.25888	1.4447	1.50178
Incongruent Misaligned	1.3452	1.25030	1.6179	.99770
Novel				
Congruent Aligned	1.5649	1.02282	2.0081	.74737
Congruent Misaligned	1.6557	1.04198	1.9204	.82980
Incongruent Aligned	1.2195	1.31422	1.6109	1.35175
Incongruent Misaligned	1.4842	1.15469	1.7053	1.01213

Table 4.1. *Table of descriptive statistics for d' performance in all conditions of Experiment 1.*

Additional Paired-Sample t-tests

To further investigate the *Familiarity x Order of Trials* interaction, a paired-sample *t*-test was conducted across the overall performance in Familiar vs Novel stimuli in the Congruent-Incongruent and Incongruent-Congruent order groups. In the Congruent-Incongruent order group, performance for Familiar and Novel stimuli showed no significant difference, $t(47) = 1.49$, $p = .144$, $\eta^2_p = .05$, although there was a slight numerical advantage for Familiar stimuli (M = 1.57, SE = 0.14) compared to the Novel stimuli (M = 1.48, SE = 0.55). The same analysis in the Incongruent-Congruent order group also revealed no significant difference in performance for Familiar and Novel stimuli, $t(47) = -1.66$, $p = .103$, $\eta^2_p = .06$, with the numerical advantage now being for Novel trials (M = 1.81, SE = 0.10), as opposed to Familiar trials (M = 1.73, SE = 0.09), which was the reverse of the Congruent-Incongruent order group. It is this pattern of numerical reverse in the effect that led to the significant interaction of *Familiarity x Order of Trials*.

The *Familiarity x Alignment* interaction was further investigated by conducting another set of paired samples *t*-test across the overall performance in Familiar and Novel trials in comparison with Aligned vs Misaligned stimuli. The analyses showed that in the Congruent-Incongruent order group, performance for the Familiar Aligned stimuli compared to Familiar Misaligned was near significant, $t(47) = 1.90$, $p = .064$, $\eta^2_p = .07$, with a numerical advantage for Familiar Aligned stimuli (M = 1.66, SE = 0.15) as opposed to Familiar Misaligned stimuli (M = 1.47, SE = 0.14). Performance for Novel Aligned stimuli compared to Novel Misaligned was significantly different, $t(47) = -2.19$, $p = .034$, $\eta^2_p = .09$, where participants performed higher in Novel Misaligned stimuli (M = 1.57, SE = 0.14) as opposed to Novel Aligned stimuli (M = 1.39, SE = 0.15), showing the reverse effect to Familiar stimuli. We then ran the same analysis for performance in Familiar Aligned (M = 1.66, SE = 0.15) and Novel Aligned stimuli (M = 1.39, SE = 0.15), which showed a significant difference, $t(47) = 3.18$, $p = .003$, $\eta^2_p = .18$, with higher performance for Familiar Aligned stimuli as opposed to Novel Aligned.

The same analysis for performance in Familiar Misaligned (M = 1.48, SE = 0.14) and Novel Misaligned stimuli (M = 1.57, SE = 0.14) was not significant, $t(47) = -1.06$, $p = .293$, $\eta^2_p = .02$, with a numerical advantage for Novel Misaligned compared to Familiar Misaligned stimuli.

The same analyses for the Incongruent-Congruent order group showed that performance for Familiar Aligned (M = 1.71, SE = 0.09) and Familiar Misaligned (M = 1.76, SE = 0.11) was not significantly different, $t(47) = 0.63$, $p = .533$, $\eta^2_p = .01$. The same analysis for performance in Novel Aligned (M = 1.81, SE = 0.12) and Novel Misaligned (M = 1.81, SE = 0.11) stimuli also revealed to be not significant, $t(47) = 0.03$, $p = .973$, $\eta^2_p = .00$.

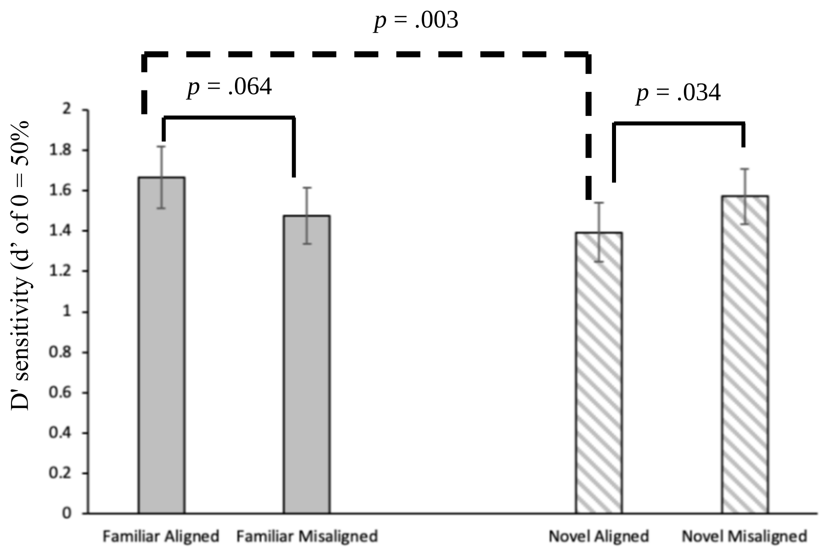

Figure.4.2. reports the Familiar and Novel Aligned and Misaligned trials results from the Congruent-Incongruent group in Experiment 1. The *x*-axis shows the stimulus conditions, the *y*-axis shows *d'*. Error bars represent s.e.m.

Additional Paired-Sample t-test of Familiarity x Order of Trials interaction without misaligned stimuli

We further investigated the *Familiarity x Order of Trials* interaction, but this time, without the misaligned stimuli. The reason for doing this is because in Chapter 3 the *Familiarity x Order of Trials* interaction was either driven by higher performance in Familiar stimuli than Novel stimuli where Incongruent trials were presented first in Experiment 1a; and driven by higher performance for Novel stimuli than Familiar stimuli where Congruent trials were presented first in Experiment 1b. In the current experiment the interaction does not appear to be due to neither specific differences between Familiar and Novel stimuli in both groups where Incongruent trials were presented first and Congruent trials were presented first. The clear difference between both experiments in Chapter 3 and the current experiment is the additional misaligned stimuli, therefore, an additional paired-sample *t*-test of the *Familiarity x Order of Trials* without the misaligned stimuli should provide better indication of whether the results aligned more with Chapter 3's Experiment 1a or Experiment 1b.

A paired-sample *t*-test was conducted across the overall performance in Familiar vs Novel stimuli in the Congruent-Incongruent and Incongruent-Congruent order groups (this time, misaligned trials were omitted). In the Congruent-Incongruent order group, performance for Familiar and Novel stimuli showed a significant difference, $t(47) = 3.18$, $p = .003$, $\eta^2_p = .18$, with higher performance in Familiar stimuli (M = 1.66, SE = 0.15) than Novel stimuli (M = 1.39, SE = 0.15). The same analysis in the Incongruent-Congruent order group revealed no significant difference in performance for Familiar and Novel stimuli, $t(47) = -1.25$, $p = .219$, $\eta^2_p = .03$, although there was a numerical advantage for Novel stimuli (M = 1.81, SE = 0.12) than Familiar stimuli (M = 1.71, SE = 0.09), which was the reverse of the Congruent-Incongruent order group. This indicates that the *Familiarity x Order of Trials* interaction aligns more (at least numerically) with Experiment 1b from Chapter 3.

Additional two-way ANOVA

To further explore the significant three-way interaction of *Familiarity x Alignment x Order of Trial,* we ran some additional two-way ANOVAs using the within subjects factor *Familiarity* and *Alignment.* In the group that saw congruent trials before incongruent trials, there were no significant effects of both *Familiarity,* $F(1, 47) = 0.31$, $p = .532$, $\eta^2_p < .01$, and *Alignment,* $F(1, 47) = 0.23$, $p = .637$, $\eta^2_p < .01$. The interaction of *Familiarity x Alignment* was significant, $F(1, 47) = 8.28$, $p = .006$, $\eta^2_p < .15$. The same analysis in the group that saw incongruent trials before congruent trials showed no significant effects for both *Familiarity,* $F(1, 47) = 2.76$, $p = .103$, $\eta^2_p = .06$, and *Alignment,* $F(1, 47) = 0.19$, $p = .667$, $\eta^2_p < .01$. The interaction of *Familiarity x Alignment* was also not significant, $F(1, 47) = 0.14$, $p = .708$, $\eta^2_p < .01$. These results are indicative of the higher performance in the Familiar Aligned trials compared to Familiar Misaligned and Novel aligned, and Novel Misaligned trials compared to Novel Aligned, only in the Congruent-Incongruent order group, as reported in the additional *t*-test earlier.

2 x 2 x 2 ANOVA

Next, we conducted 2 x 2 x 2 ANOVAs for familiar and novel checkerboard trials separately, using the within-subjects factors *Congruency* and *Alignment* and between-subjects factor *Order of Trial*. This was reported to provide a better comparison of the results from the current experiment with the composite checkerboard effect with the subsequent experiment investigating the composite face effect.

In the familiar category a significant effect was found for only *Congruency*, *F*(1,94) = 10.82, *p* = .001, η^2_p = .10, reflecting the higher overall performance for congruent stimuli than for incongruent ones. *Alignment x Order of Trial*, reached near significance *F(*1,94) = 3.45, *p* = .066, η^2_p = .03, reflecting the higher performance in both Aligned and Misaligned stimuli for the Incongruent-Congruent order group, as opposed to the Congruent-Incongruent order group. All other interactions were not significant (next interaction closest to significance was *Congruency x Alignment x Trial Order*, *F*(1,94) = 1.30, *p* = .257, η^2_p = .01). An additional 2 x 2 ANOVA was conducted for Familiar Aligned trials, with the within-subjects factors *Familiar Congruent Aligned, and Familiar Incongruent Aligned,* and the between-subjects factors *Order of Trials.* Once again, only the factor *Congruency* was significant *F*(1,94) = 9.32, *p* = .003, η^2_p = .09 (next interaction nearest to significance being *Congruency x Trial Order*, *F*(1,94) = 1.60, *p* = .209, η^2_p = .01).

In the novel category trials, the only significant effect found was for *Congruency*, *F*(1,94) = 6.72, *p* = .011, η^2_p = .06. The between-subjects factor *Order of Trial* reached near significance, *F*(1,94) = 3.82, *p* = .054, η^2_p = .04, which reflects the higher overall performance in the Incongruent-Congruent order group as opposed to the Congruent-Incongruent order group. All other effects and interactions were not significant (next interaction closest to significance was *Congruency x Alignment*, *F*(1,94) = 2.03, *p* = .158, η^2_p = .02.

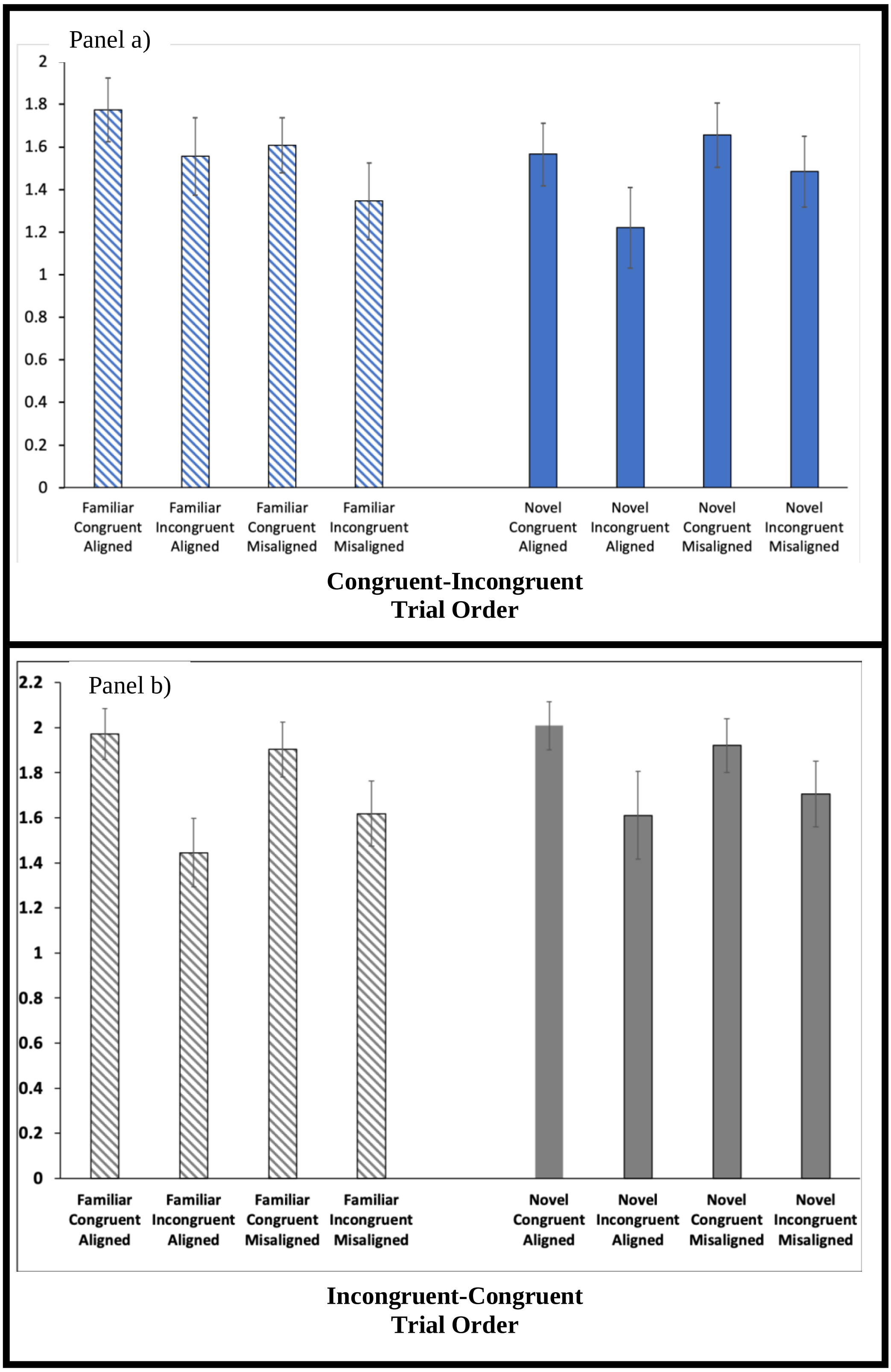

Figure.4.3. reports results from each condition in both trial order groups (panel a: Congruent-Incongruent group, panel b: Incongruent-Congruent group) in Experiment 1. The *x*-axis shows the stimulus conditions, the *y*-axis shows *d'*. Error bars represent s.e.m.

An additional 2 x 2 ANOVA was conducted for Novel Aligned trials with the within-subjects factors *Novel Congruent Aligned* and *Novel Incongruent Aligned*, and the between-subjects factors *Order of Trials.* Once again, the effect of *Congruency* was significant, $F(1, 94) = 7.29$, $p = .008$, $\eta^2_p = .07$. However, this time, the between subjects factor *Order of Trial* was significant, $F(1, 94) = 5.00$, $p = .028$, $\eta^2_p = .05$, also reflecting the higher performance in Incongruent-Congruent order group, as opposed to Congruent-Incongruent trials.

Additional Paired-Sample t-tests

To further investigate the *Alignment x Order of Trial* interaction, a paired-sample *t*-test was conducted for the overall performance in Aligned and Misaligned trials in Congruent-Incongruent and Incongruent-Congruent order groups. In the Congruent-Incongruent order group, there was no difference between Aligned (M = 1.53, SE = 0.14) and Misaligned trials (M = 1.52, SE = 0.13), $t(47) = 0.08$, $p = .936$, $\eta^2_p < .01$. In the Incongruent-Congruent order group, there was also no difference between Aligned and Misaligned trials, $t(47) = -0.43$, $p = .667$, $\eta^2_p < .01$, with a slight numerical advantage for Misaligned (M = 1.79, SE = 0.10) than Aligned trials (M = 1.76, SE = 0.10).

4.2.3 Discussion

Experiment 1 revealed a congruency effect in checkerboards in line with Chapter 3. However, the composite effect was not obtained. These results are in line with Civile, McLaren, Milton, et al., (2021), and simultaneously contradict with findings from Gauthier & Tarr (2002) and Wong, Palmeri, et al., (2009), wherein the composite effect was obtained in two different types of artificial stimuli (Greebles and Ziggerins). Moreover, the order of trial effect was less pronounced than the results from Chapter 3 (particularly with Experiment 1b based on the additional analyses), however, they were still numerically in-line with higher overall performance observed in the group where Incongruent trials were shown first before Congruent trials, as opposed to the vice-versa order. Before we interpret the results any further, we will present Experiment 2, which investigated the composite effect in face stimuli.

4.2.4. EXPERIMENT 2

Experiment 2 consisted of part **a)** (n=93) and **b) replication** (n=91), due to a mistake in the counterbalancing of the trials across participants, and programming difficulties in the synchronization of the number of participants allocated to each condition group in part **a)**. To be specific, the program for randomly allocating participants to each condition group was not synchronized well, which resulted in uneven numbers of participants in each condition and the required quota for each condition groups were not fulfilled. Experiment 2a methods and results are reported for completeness.

4.2.4.1 EXPERIMENT 2a

4.2.4.2 Method

4.2.4.2.1 Participants

A total of 93 naïve participants (mean age = 25.2, age range = 19-40) were recruited via Prolific with the same inclusion criterion and compensation as Experiment 1. The sample size remained the same as Experiment 1 to be able to corroborate the overall results.

4.2.4.2.2 Materials

A total of 256 face images were used, all standardized to greyscale on a black background, cropped to a standardized oval shape (Civile, McLaren, Milton, et al., 2021). Dimensions were 174 x 225 pixels, presented at the resolution of 72 x 72 using the exact same design and stimuli manipulations as Experiment 1, but the checkerboards were replaced with the face stimuli. Half of these face images (128) comprised of male and female faces (64 each), which were for the categorization task. The other half consisted of only male faces, and were used to construct the composite faces.

4.2.4.2.3 Procedure

In line with Experiment 1, participants in Experiment 2 were first presented with a **categorization phase** followed by a **training phase,** and a **matching-task.**

Face categorization phase:

This commenced after participants provided their consent and were shown the instructions for this task. Participants were presented with 128 regular faces one at a time in random order, and they were asked to press one of the two keys (counterbalanced) to categorize if the face was male or female (64 each). Each face was preceded by a fixation cross in the center of the screen (1 second) and participants had ≤ 4 seconds to respond until they were timed out. Immediate feedback was provided on whether their response was correct or incorrect.

Training phase:

This remained the same as Experiment 1.

Composite face matching task:

This followed the same procedure as Civile, McLaren, Milton, et al., (2021). Each trial began with a fixation cue presented in the center of the screen (1 second), followed by a TARGET face stimulus (1 second), an interstimulus interval (1.5 seconds), and a TEST face stimulus (≤ 2 seconds). Participants pressed either the ‘x’ key or ‘.’ key in line with their training from the keyboard training phase to identify the top half of the test face as “same” or “different” to the top half of the target face. All the composite faces were presented upright and were split by four conditions (Congruent Aligned, Incongruent Aligned, Congruent Misaligned and Incongruent Misaligned). Here, there was no ‘novel’ condition. This resulted in a total of 64 trials. Congruent and incongruent trials were presented in a counterbalanced fashion across participants with aligned and misaligned stimuli randomly intermixed.

In the *congruent aligned* trials, participants first saw a TARGET face composite, which was created by selecting the top and bottom halves of two different faces (e.g., A-B, where A is the top half and B is the bottom half). In the TEST face trial, they would either see the same TARGET face or a new face composite created by selecting the top and bottom halves of two different faces (e.g., C-D). The *Incongruent aligned* trials were presented either with the same top halves for the TARGET faces but with different bottom halves (A-D), or with different top halves from the TARGET faces but the same bottom halves (C-B). In line with Experiment 1, the congruent and incongruent misaligned trials the top and bottom halves of each composite were shifted horizontally in order to overlap across half their length (see Figure.4.4).

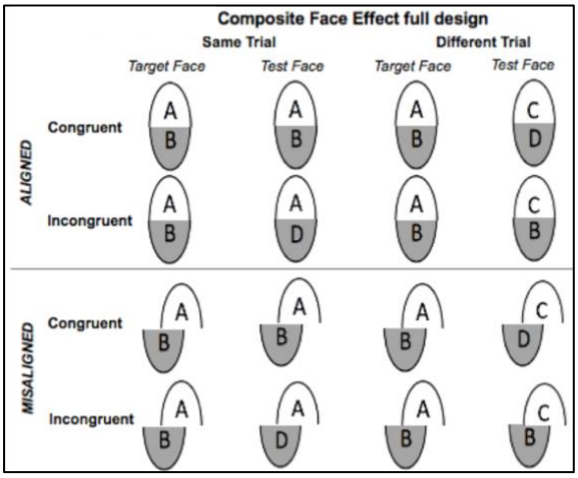

Figure.4.4. illustrates the full design for Experiment 1b which followed the same logic, except with composite faces instead of checkerboards (Waguri et al., 2022).

4.2.4.3 Results

In the categorization phase, the mean percentage correct was 92%. A 2 x 2 x 2 mixed model design was computed for the matching phase using the within-subjects factors *Congruency*, *Alignment* and between-subjects factor *Order of Trials*. ANOVA did not show a significant effect of *Congruency,* $F(1, 91) = 0.69$, $p = .409$, $\eta^2_p = .01$, nor *Alignment,* $F(1, 91) = 0.15$, $p = .701$, $\eta^2_p = .00$. *Order of Trials* was also not significant, $F(1, 91) = 2.11$, $p = .149$, $\eta^2_p = .30$, this time, with the reverse numerical advantage for the Congruent-Incongruent order group as opposed to the Incongruent-Congruent order group (see Table 4.2 for descriptive statistics). Here, *Congruency x Alignment* was significant, $F(1,91)= 25.69$, $p < .001$, $\eta^2_p = .22$, indicating that there is a robust composite effect. A significant interaction was found for *Alignment x Order of Trials,* $F(1, 91) = 4.21$, $p = .043$, $\eta^2_p = .04$. The interaction *Congruency x Alignment x Order of Trials* was not significant, $F(1, 91) = 0.40$, $p = .240$, $\eta^2_p = .02$.

Measure	Congruent-Incongruent Order Group		Incongruent-Congruent Order Group	
	M	*SD*	*M*	*SD*
Congruent Aligned	2.2412	1.14703	2.2467	1.11825
Congruent Misaligned	2.1590	1.13532	1.8094	.95916
Incongruent Aligned	2.0700	1.3633	1.6651	1.33841
Incongruent Misaligned	2.4185	1.39778	1.9205	1.52400

Table 4.2. Table of descriptive statistics for d' performance in Congruent Aligned/Misaligned and Incongruent Aligned/Misaligned trials conditions in groups that were shown Congruent trials before Incongruent trials, and Incongruent trials before Congruent trials in Experiment 2a.

Additional paired samples t-tests:

We conducted two additional paired sample *t*-tests that revealed a significant congruency effect in aligned trials with congruent composites (M = 2.24, SE = 0.11) being better identified than incongruent ones (M = 1.84, SE = 0.13), $t(50) = 3.00$, $p = .004$, $\eta^2_p = .15$. Thus, the congruency effect was fully reduced (actually reversed) for misaligned trials with congruent composites (M = 1.95, SE = 0.11) being numerically worse identified than incongruent ones (M = 2.15, SE = 0.16), $t(50) = -1.28$, $p = .205$, $\eta^2_p = .03$ (Figure.4.4).

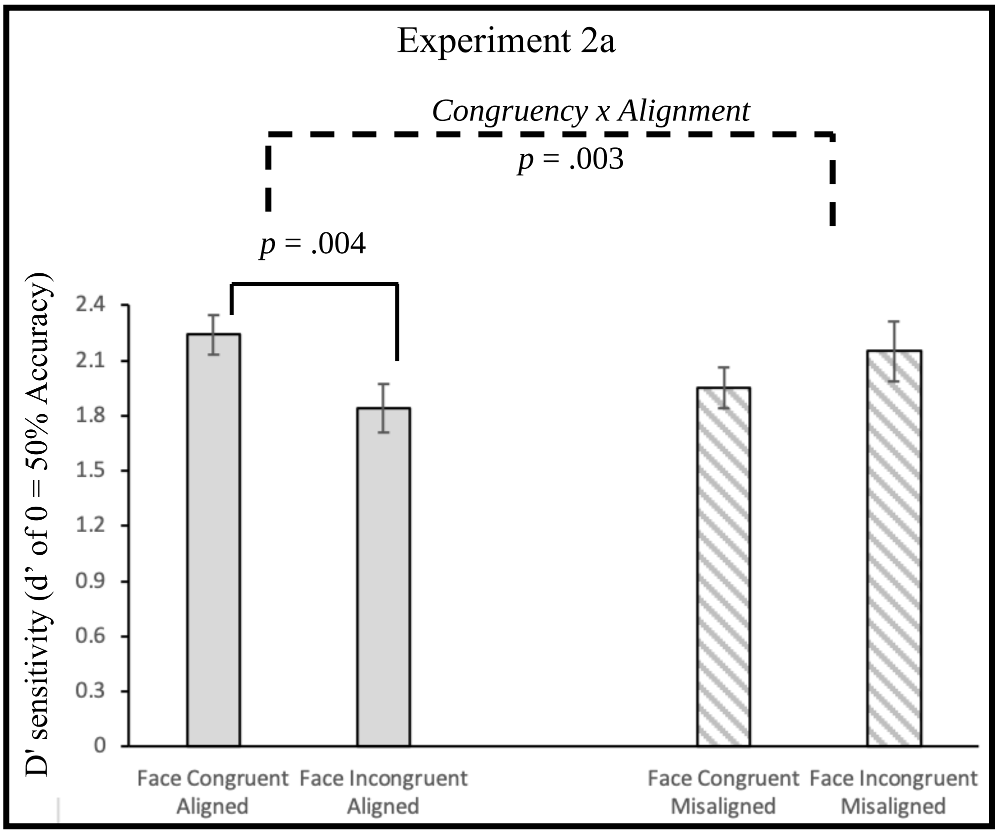

Figure.4.5. reports the composite effect results from Experiment 2a. The *x*-axis shows the stimulus conditions, the *y*-axis shows *d'*. Error bars represent s.e.m.

To further investigate the significant interaction of *Alignment x Order of Trials,* a paired-sample *t*-test was conducted across the overall performance in Aligned vs Misaligned trials in the Congruent-Incongruent and Incongruent-Congruent order groups. In the Congruent-Incongruent order group, performance for Aligned and Misaligned stimuli showed no significant difference, *t*(45) = -1.53, *p* = .134, η^2_p = .05, although there was a slight numerical advantage in Misaligned trials (M = 2.29, SE = 0.16) compared to the Aligned trials (M = 2.16, SE = 0.14). The same analysis in the Incongruent-Congruent order group also revealed no significant difference in Aligned and Misaligned trials, *t*(47) = 1.41, *p* = .166, η^2_p= .04, this time, with the numerical advantage for Aligned trials (1.96, SE =

0.15), as opposed to Misaligned trials (M = 1.86, SE = 0.16) which was the reverse of the Congruent-Incongruent order group.

4.2.4.4 Discussion

The results revealed a significant composite effect in faces, however, the *Order of Trials* effect was not significant. Furthermore, the direction of the numerical advantage for overall performance had reversed to Congruent-Incongruent order trials as opposed to Incongruent-Congruent order trials. We do not interpret the results any further, because as mentioned earlier, there was a mistake in the counterbalancing of the trials across participants, and programming difficulties in the synchronization of the number of participants allocated to each condition group in this experiment. Below is the replication of this experiment with the necessary corrections implemented.

4.2.4.5 EXPERIMENT 2b

4.2.4.6 Method

4.2.4.6.1 Participants

A total of 93 participants (mean age = 25.4, age range = 18-40) were recruited via Prolific with the same inclusion criterion and compensation as Experiment 1. The sample remained the same as Experiment 2a and Experiment 1.

4.2.4.6.2 Materials & Procedure

Both remained the same as Experiment 2a, however, counterbalancing of the trials across participants were corrected. The study had been reprogrammed to correctly synchronize and allocate the correct number of participants to each condition and group.

4.2.4.7 Results

In the categorization phase, the mean percentage correct was 88%. A 2 x 2 x 2 mixed model design was computed using the within-subjects factors *Congruency*, *Alignment* and between-subjects factor *Order of Trials*. ANOVA did not show a significant effect of *Congruency* $F(1, 94) = 0.00$, $p = .985$, $\eta^2_p < .01$, nor *Alignment* $F(1, 94) = 0.06$, $p = .809$, $\eta^2_p < .01$. The between-subjects factor *Order of Trials* was also not significant, $F(1, 94) = 1.05$, $p = .308$, $\eta^2_p = .01$, although the overall performance is numerically higher for the Incongruent-Congruent group compared to the Congruent-Incongruent group, which is in-line with the findings of Chapter 3. Importantly, in line with previous studies that adopted the same full design (e.g., Civile, McLaren, Milton, et al., 2021), the interaction *Congruency x Alignment* was significant, $F(1,94)= 5.30$, $p < .001$, $\eta^2_p = .16$, indicating that there was a robust composite face effect. A significant interaction was found for *Congruency x Order of Trials,* $F(1,94) = 5.288$, $p = .024$, $\eta^2_p = .053$. The interaction *Congruency x Alignment x Order of Trials* was not significant, $F(1, 91) = 0.40$, $p = .240$, $\eta^2_p = .02$.

Measure	Congruent-Incongruent Order Group		Incongruent-Congruent Order Group	
	M	*SD*	*M*	*SD*
Congruent Aligned	2.1636	1.23347	2.6477	1.12909
Congruent Misaligned	1.9809	1.17337	2.3173	1.08294
Incongruent Aligned	2.1151	1.10560	2.1169	1.16366
Incongruent Misaligned	2.4345	1.37414	2.1990	1.41880

Table 4.3. Table of descriptive statistics for d' performance in Congruent Aligned/Misaligned and Incongruent Aligned/Misaligned trials conditions in groups that were shown Congruent trials before Incongruent trials, and Incongruent trials before Congruent trials in Experiment 2b.

Additional paired samples t-tests:

We conducted two additional paired sample *t*-tests that revealed a significant congruency effect in aligned trials with congruent composites (M = 2.42, SE = 0.14) being better identified than incongruent ones (M = 2.09, SE = 0.12), $t(47) = 3.53$, $p < .001$, $\eta^2_p = .21$. Thus, the congruency effect was once again, fully reduced (and reversed in actuality) for misaligned trials with congruent composites (M = 2.17, SE = 0.13) being numerically worse identified than incongruent ones (M = 2.33, SE = 0.15), $t(47) = -2.48$, $p = .017$, $\eta^2_p = .12$ (Figure.4.6).

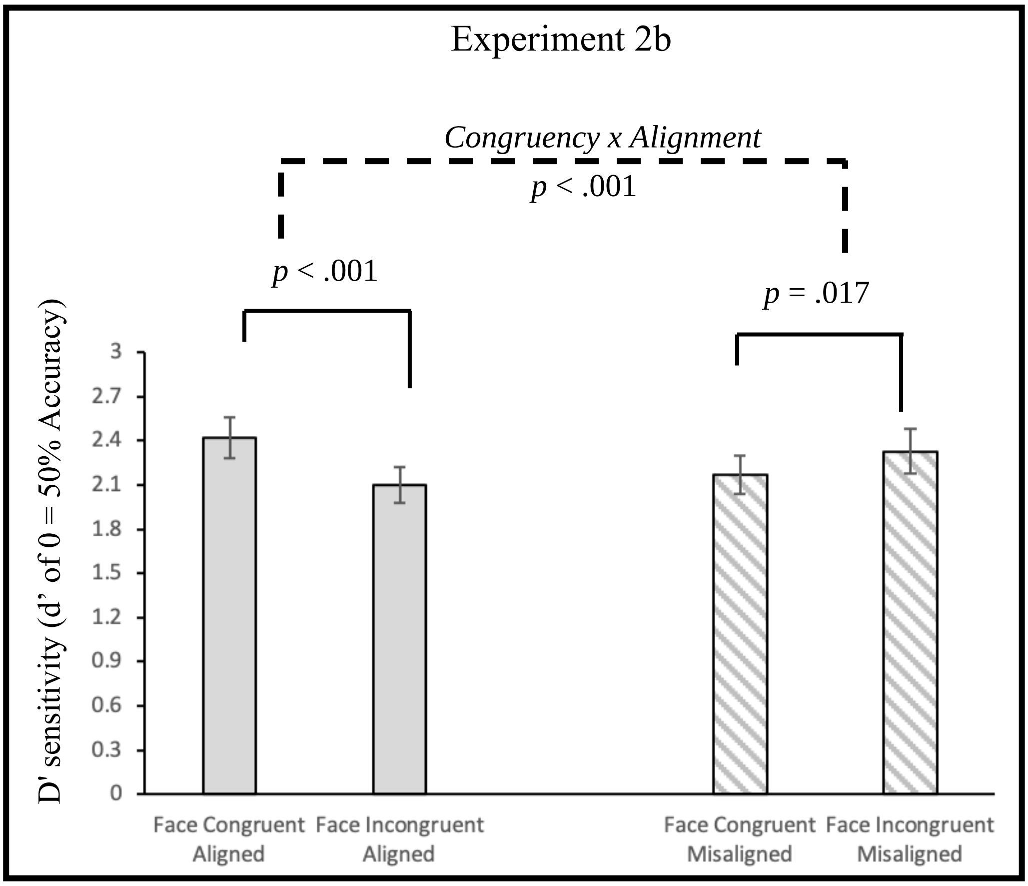

Figure.4.6. reports the composite effect results from Experiment 2b. The *x*-axis shows the stimulus conditions, the *y*-axis shows *d'*. Error bars represent s.e.m.

Analysis between Experiments 2a and 2b:

A 4-way ANOVA was computed in comparing Experiments 2a and 2b using the within-subjects factors, *Congruency*, *Alignment,* and between-subjects factors *Order of Trials*, *Study* (Experiment 2a Pilot, Experiment 2b Replication). ANOVA revealed *Order of Trial,* $F(1,180) = 0.27$, $p = .601$, $\eta^2_p = .00$, and *Study,* $F(1, 180) = 1.31$, $p = .254$, $\eta^2_p = .01$) were not significant. The interaction *Congruency x Alignment x Order of Trials x Study* showed no significant differences, $F(1, 180) = 1.35$, $p = .246$, $\eta^2_p = .01$. and *Study* did not significantly interact with any other factors (*Congruency x Order of Trials x Study* interaction being the next closest to significance, $F(1, 180) = 0.79$, $p = .376$, $\eta^2_p < .01$).

Analyses between the composite checkerboard vs face effect

We conducted some additional analyses with the aim of directly testing if the composite face effect found in Experiments 2a and 2b were significantly larger than the composite effect (not significant) in Experiment 1. Hence, we extracted the composite effect index from each experiment by subtracting the congruency effect found in misaligned trials from that found in aligned trials.

Following this, we first conducted an independent sample *t*-test between Experiment 2a and Experiment 1, which revealed a significant difference, $t(195) = -2.69$, $p = .008$, $\eta^2_p = .07$, indicating a larger composite effect in Experiment 2a (M = 0.53, SE = 0.10) than Experiment 1 (M = 0.14, SE = 0.10).

Next, we conducted the same analysis between Experiment 2b and Experiment 1, which revealed a significant difference, $t(190) = -2.16$, $p = .032$, $\eta^2_p = .04$ indicating a larger composite effect in Experiment 2b (M = 0.43, SE = 0.10) than that found in Experiment 1 (M = 0.14, SE = 0.10).

Finally, the same analysis was conducted between the average composite face effect in Experiments 2a and 2b combined compared with the composite checkerboard effect in Experiment 1, which revealed a significant difference, $t(195) = -2.75$, $p = .007$, $\eta^2_p = .07$ indicating a larger composite effect in Experiments 2a and 2b on average (M = 0.47, SE = 0.08) than Experiment 1 (M = 0.14, SE = 0.10).

4.2.4.8 Overall Discussion

The three experiments (Experiments 1, 2a and 2b) reported here aimed to investigate whether the robust composite effect could be obtained in non-mono-orientated, non-face, prototype-based categories of checkerboard stimuli, which have previously been used in investigating the face inversion effect (Civile, Zhao, et al., 2014). We particularly aimed to investigate the role of holistic processing as outlined by Civile, McLaren, Milton, et al., (2021) and whether this is a face specific component that the tDCS procedure was unable to modulate in faces, but able to modulate in checkerboards as reported in Chapter 2. The current chapter extended the work in Chapter 3, which reported a congruency effect (a component of the composite effect) in these checkerboards, with the additional finding of an order effect determining the manifestation of the congruency effect. To investigate the composite effect, this chapter incorporated misaligned trials using the complete matching task design and compared the composite effect between checkerboard and face stimuli.

The findings revealed a congruency effect in Experiment 1, which was in line with Chapter 3, however, it was also found that the composite effect could not be obtained with checkerboards. Experiment 2 revealed a composite effect in faces, which was expected. These results are in line with Civile, McLaren, Milton, et al., (2021) but contradict with findings from Gauthier & Tarr (2002) and Wong, Palmeri, et al., (2009), wherein the composite effect was obtained in two different types of artificial stimuli (Greebles and Ziggerins). Crucially, a significant effect for order of trials was found in my experiments for both the congruency and composite effect in faces. We will first discuss the latter finding of the order effect. It is evident in the literature that the extraction of the composite effect differs by using either the original/partial design or the refined complete design. A clear illustration of this is the inability to obtain the composite effect in Greebles when using the partial design (Gauthier, Williams, et al., 1998), that was later obtained when using the complete design (Gauthier & Tarr, 2002). It has already been argued that the two versions of the task do not measure the same construct, mostly owing to the shortcoming of the partial design, which can be sensitive to response biases, (inequivalent “same”/“different” trials for congruent/incongruent conditions), hence unreliable to test holistic processing (Richler & Gauthier, 2014). Our findings contribute to these claims and provide an additional explanation that perhaps there is another bias at play, which is the order of the trials presented. We have shown that presenting incongruent trials first, followed by congruent trials results in both the congruency effect (only in novel checkerboards) and the composite effect in faces, but neither are extracted when the trials are presented in the reverse order. This order effect can be attributed to several factors, such as a practice effect and/or a carryover effect. The practice effect may explain the relatively mild congruency effect, while a carryover effect from the categorization/pre-exposure phase onto the matching task may have contributed to the order of trials effect. Another explanation is proactive interference, which is when prior learning reduces memory for similar materials recently learned (Anderson & Neely, 1996). Here, congruent (i.e., familiar congruent) stimuli are drawn from the same category learned in the previous categorization task. Therefore, participants undergoing congruent trials immediately after categorization may experience interference resulting in worse recognition performance, as opposed to those who underwent incongruent trials after categorization. More research is needed to determine if this confound is important when extracting the composite effect. Future research should also examine the role of proactive interference in other face recognition indices.

Next, we attempt to answer why the composite effect was not obtained with our checkerboard stimuli in Experiment 1. As mentioned, this supports Civile, McLaren, Milton, et al’s., (2021) finding where the anodal tDCS procedure reduced performance for upright faces but did not significantly modulate the composite effect. Consequently, this indicates that holistic processing is the face specific component which the tDCS procedure was unable to modulate for the face inversion effect. On the other hand, our findings also contradicts with the results of Gauthier and Tarr (2002), and Wong, Palmeri, et al., (2009). We do know that using the same complete design does indeed test the composite effect, as this very procedure successfully obtained the composite effect in Experiment 2 with faces (control). Looking at the *Congruency x Alignment* interaction in checkerboards at glance, it could be interpreted that our findings simply point to holistic processing being face-specific and not a function of expertise. However, we find the interaction *Alignment x Order of Trial* significant in familiar composite checkerboards, and *Familiarity x Alignment x Order of Trial* trends towards significance. There is some indication that the level of familiarity plays a role. So we will now shift the focus onto the training phase/categorization task. A clear difference in the training task between our Experiment 1 (checkerboards) and those of Greebles/Ziggerins (Gauthier & Tarr, 2002; Wong, Palmeri, et al., 2009), is utilizing a categorization task or individuation training. Both are aimed to train participants in becoming experts, but it is nuanced in the sense that individuation particularly emphasizes subordinate level training as opposed to basic-level by categorization. While there is much debate as to what it exactly promotes and whether subordinate level can indeed increase holistic processing strategies, Wong, Plameri, et al., (2009) have demonstrated that individuation training (i.e., learning and identifying individual Ziggerins) similar to Gauthier and Tarr (2002) does yield a composite effect in artificial stimuli as opposed to categorization training (class level expertise). This would indicate that there may be a top-down effect of personification/humanization affecting the manifestation of the composite effect. Therefore, there may be an additional component other than lower-level perceptual processes (e.g., holistic) that influences face processing, which has also been suggested by Civile, McLaren, Milton, et al., (2021). Humanization has been shown to affect the inversion effect with faces labeled with dehumanizing characteristics (hence, no inversion effect). After providing humanizing information, this inversion effect was re-established (Civile, Colvin, et al., 2019). However, future research should directly investigate this factor in the composite effect. Other top down factors or motivations shown to affect the composite effect should also be considered (e.g., task relevancy vs irrelevancy, Liu et al., 2020; occupational status, Ratcliff et al., 2011, Experiment 3). Furthermore, our Experiment 2 did not have novel face stimuli, as opposed to Experiment 1 with novel checkerboards. While the novelty of faces may be disparate compared to checkerboards (i.e., life-time experience), future studies should incorporate novel face stimuli for an apt comparison.

Other factors that may have led to the difference between the findings of the current experiment and Gauthier and Tarr, (2002)/Wong, Palmeri, et al., (2009) may be attributed to the overall difference in the nature of the stimuli and the amount of pre-exposure training. Other than the clear difference in the visual appearance between the checkerboards and Greebles/Ziggerins, the way how these stimuli are introduced to the participants should perhaps be considered. Both Greebles and Ziggerins can be broken down to different parts, each having a unique name which the participants can learn, unlike the checkerboards used in this chapter. The checkerboard exemplars are built to fit in with the assumption that they are comprised of micro-features (similar/different across each exemplars and categories) that varies in salience based on the level of exposure/experience (i.e., feature-salience modulation), however, this is not explicitly brought to the attention of the participants as Gauthier and Tarr, (2002) and Wong, Palmeri, et al., (2009) have with the Greebles and Ziggerins.

Moreover, the duration of the pre-exposure training participants underwent in the current sets of experiments with the checkerboards is considerably shorter (10-15 minutes) than the pre-exposure phase in both Gauthier and Tarr, (2002) and Wong, Palmeri, et al's., (2009) experiments, where participants spent 7-10 hours spread across multiple sessions. It is arguable that the brief pre-exposure phase may have been insufficient to draw out holistic processing in non-face stimuli, and was instead sufficient with Gauthier and Tarr, (2002) and Wong, Palmeri, et al's., (2009) method of pre-exposure. It would be an area of interest for future research to conduct a comparative investigation regarding the types of non-face stimuli, as well as the duration of pre-exposure to ascertain how these factors affect the extraction of holistic processing in non-face, artificial stimuli.

Overall, the results from this chapter contribute to the findings of chapter 2 and 3; Chapter 2 showed that the tDCS procedure delivered at Fp3 removes the perceptual learning component of face recognition, as indexed by the inversion effect, and consequently abolishes the inversion effect in checkerboard stimuli and partially (while significant), in face stimuli. This opened the question regarding what the remaining component unaffected by the tDCS procedure in the face inversion effect could be. Civile, McLaren, Milton, et al., (2021) showed that the very same tDCS procedure employed in Chapter 2 does not modulate the composite face effect, which provided the indication that perhaps the remaining inversion effect in face stimuli is due to holistic processing, and would therefore, suggest such processing to be specific to face stimuli. This is based on the premise that the composite face effect is a direct index that is specific to holistic processing (Maurer et al., 2002). For a direct investigation of this postulation, it was crucial to examine whether a composite effect can be obtained with checkerboard stimuli, which was conducted in two parts: Chapters 3 and 4.

Chapter 3 took the first step by investigating the *congruency effect*, the index of the composite effect, in checkerboards. The current chapter extended on this finding and investigated the composite effect in checkerboards fully. Taking both findings from Chapters 3 and 4 together, it was revealed that while a congruency effect could be obtained in checkerboard stimuli, 1) A composite effect cannot be obtained with checkerboards; 2) The order of trials presented, specifically proactive interference, appears to determine the extraction of the congruency effect with checkerboard stimuli. The former finding provides a direct evidence that the composite effect is specific to faces, and therefore, supports the explanation that the remaining inversion effect in Chapter 2 is due to holistic processing. On the other hand, the latter finding opens the possibility of an alternative explanation for the checkerboard inversion effect found in Chapter 2, as well as previous studies such as Civile, Zhao, et al., (2014) and Civile, Verbruggen, et al., (2016), to name a few. The possibility that proactive interference is involved would suggest that all previous research using this particular design had not been able to capture the 'pure' checkerboard inversion effect but the inversion effect that is obtained after the influence of proactive interference. This also poses the uncertainty regarding the role the tDCS played in the inversion effect paradigm; is the tDCS enhancing or inducing proactive interference rather than perceptual learning? The next chapter aims to address these potential issues by investigating the effect of proactive interference directly on the face inversion effect.

Chapter 5: The Role of Proactive Interference in the Inversion Effect

5.1 Introduction to the experiments

This chapter investigates the issue of the order of trial presentation in the context of the inversion effect paradigm. The previous chapters uncovered this order of trial effect where we have shown that presenting incongruent trials first, followed by congruent trials results in both the congruency effect (only in novel checkerboards) and the composite effect in faces, but neither are observed when the trials are presented in the reverse order. It was speculated that this is the manifestation of a phenomenon called proactive interference. This refers to the effect when prior learning reduces memory for similar materials recently learned (Anderson & Neely, 1996). This is typically the case the longer a participant is engaged in studying a set of materials (e.g., lists, notes), as it becomes more difficult to learn later materials the more time passes (Underwood, 1957; Postman & Keppel, 1977). If we apply this explanation to the behavioral outcomes in Chapters 3 and 4, first, consider that the faces viewed or checkerboard categories learnt in the initial categorization task are used for the congruent (i.e., familiar congruent) stimuli in the congruent trials of the subsequent matching task. The stimuli used in the categorization task and in the congruent trials of the matching task can be considered similar as they are drawn from the same prototype defined familiar categories. With checkerboards, they are categories A, B, C, or D, and with faces, they are Western Caucasian regular faces. As per proactive interference, participants who undergo the categorization task that is immediately followed by the congruent trials of the matching task would have a poorer memory for the stimuli during the congruent trials, and consequently, worse performance in the matching task. Contrastingly, participants who undergo the categorization task followed by the incongruent trials, and then congruent trials would not show a decline in memory (and therefore, consistent performance) during the later congruent trials, as the incongruent trials would serve as an interval between the categorization task and congruent trials which reduces proactive interference.

While proactive interference satisfies the interpretation for the order of trials affecting the congruency effect (only in novel checkerboards) and the composite effect in faces, this raises the concern of whether proactive interference was involved as a confounding factor in the inversion effect paradigms found in the studies of Chapter 2, as well as prior studies that investigated this in checkerboards. If we take the original checkerboard inversion effect from the old/new recognition task (Civile, Zhao, et al., 2014), the authors used the same categorization task as Chapters 3 and 4 that preceded the study and recognition phase in order to pre-expose and familiarize the participants to the checkerboard categories. One detail regarding the findings in Civile, Zhao, et al., (2014) and the sham studies in Civile, Verbruggen, et al., (2016) that also used this task, is that despite the significant and well replicated inversion effect for exemplars drawn from a familiar category, the size of the inversion effect, was always lower than that for faces. When the tDCS procedure was applied (Civile, Verbruggen, et al., 2016) the checkerboard inversion effect was fully reduced, whereas the inversion effect for faces, despite being significantly reduced compared to sham, was still present. One potential explanation was that the old/new recognition task was too difficult to perform when presented with checkerboards that participants were just familiarized with upon entering the lab. This was one of the main reasons that motivated the studies reported in Chapter 2, which demonstrated that by adopting a task of the kind used in the prosopagnosia literature to study the inversion effect, we can then obtain a comparable inversion effect between faces and checkerboards. Importantly, when the tDCS procedure is applied, we showed how it can significantly reduce the checkerboard and face inversion effect in comparison to sham. Moreover, we showed that while anodal stimulation for checkerboards once again fully eliminated the inversion effect, with the faces, there was a significant inversion effect remaining. We interpreted this critical result as evidence in support of two factors determining the face inversion effect: 1) Expertise manifesting through perceptual learning, which can be fully eliminated by the tDCS as shown by the checkerboard inversion effect; 2) Face specific mechanisms as shown by the remaining face inversion effect and perhaps linked to holistic processing as suggested by the lack of a composite effect for checkerboards (Chapter 4).

However, with the findings from Chapters 3 and 4, there is now another possible explanation of proactive interference that could be contributing to the smaller checkerboard inversion effect obtained by Civile, Zhao, et al., (2014), the sham condition in Civile, Verbruggen, et al., (2016), which all used the old/new recognition task typically adopted in the literature to obtain the inversion effect. One could now argue that the checkerboard inversion effect when using an old/new recognition task is smaller compared to faces because of proactive interference induced by the categorization task preceding the study phase. Therefore, when the tDCS procedure is applied to this already reduced checkerboard inversion effect it would make it disappear entirely. In the case of the face inversion effect, the old/new recognition task consists of a study phase and recognition phase, but no categorization task is used (because people already have familiarity with this category of stimuli), and therefore, this is not subject to the effects of proactive interference, which allowed us to obtain the "pure" face inversion effect, which the tDCS was only able to partially reduce. In this chapter we aimed to directly address this issue by looking at the effects of proactive interference on the face inversion effect when using an old/new recognition task that has been adapted and used by Civile, Zhao, et al., (2014) and Civile, Verbruggen, et al., (2016) to obtain a checkerboard inversion effect. This can be achieved by adding a face categorization task to induce proactive interference on the faces.

Two experiments were conducted concurrently to test the effect of proactive interference on faces. In **Experiment 1a**, participants underwent a face categorization task, followed by the usual old/new face recognition that was employed in previous studies that investigated perceptual learning and the face inversion effect (e.g., Civile, Zhao, et al., 2014, Civile, Verbruggen, et al., 2016; Civile, McLaren, et al., 2018). **Experiment 1b** served as a control, and participants underwent a checkerboard categorization task followed by the old/new recognition task with faces. If proactive interference does take effect, then worse recognition performance in the old/new face recognition task should be observed in participants who underwent the face categorization task first, given that the stimuli presented in the categorization and old/new recognition tasks are from the familiar category of faces (regular Western Caucasian faces). Following this logic, participants who undergo a checkerboard categorization task would not experience impairment in the old/new face recognition task since the stimuli of the two tasks are different in nature.

5.2 Method

5.2.1 Participants

A total of 192 (96 in each experiment) naïve participants (mean age = 24.0, age range = 18-46) were recruited from the University of Exeter, through the participant recruitment platform SONA. All methods were performed in accordance with the guidelines and regulations approved by the CLES Psychology Ethics Committee at the University of Exeter. Informed consent was obtained from all participants. Participants received course credits as compensation.

5.2.2 Materials

Experiment 1a used a total set of 256 upright and inverted face stimuli (the same as Chapter 2 of this thesis, Civile, Waguri, et al., 2020 and Civile, McLaren, et al., 2018). The original images were selected from the Psychological Image Collection at Stirling open database, (http://pics.stir.ac.uk). All the distracting features such as the hairline were removed. The dimensions of the images were 5.63cm x 7.84cm, presented at a resolution of 1280 x 960 pixels, and standardized to greyscale on a black background.

Experiment 1b used 128 upright and inverted faces (the same ones as Experiment 1) and a total of 128 prototype-defined checkerboard exemplars (64 from Category A, 64 from Category C) that were used in the experiments of Chapter 2 and previously used in Civile, Zhao, et al., (2014, Experiment 1a). Category prototypes (16 x 16) were randomly generated with the constraint that they shared 50% of their squares with each of the other prototypes and were 50% black squares and 50% white squares. Exemplars were generated from these prototypes by randomly changing forty-eight squares thus, on average, 24 squares would be expected to alter from black to white or white to black. Each exemplar was presented at the resolution of 256 x 256 pixels on a grey background. Both experiments were programmed and ran on the online platform Gorilla.

5.2.3 Procedure

The Behavioral Task

Both experiments comprised of a categorization/pre-exposure phase, and test phase (old/new recognition task).

Experiment 1a

Face categorization phase:

This phase commenced after participants provided consent and were first shown the instructions for this task. They were shown normal male and female upright faces one at a time in a random order (64 each, total of 128 face stimuli). They were instructed to sort each face as ‘female’ or ‘male’ by pressing one of the two keys on the keyboard (counterbalanced). They were given immediate feedback on whether their response was correct or incorrect. If they did not respond within 4 seconds, they were timed out. A fixation cross preceded each stimulus presentation in the center of the screen for 1 second.

Study Phase:

Here, participants saw 32 upright and 32 inverted male and female faces, presented one at a time in a random order (these face stimuli were different from the previous categorization phase). For each trial, participants first saw a fixation cross in the center of the screen (1 second), followed by a face image (3 seconds). Participants were instructed to watch each face and try to remember as many as possible. Once all 64 face stimuli had been presented, the program displayed a set of the instructions for the subsequent recognition task.

Old/New Recognition Task:

A total 128 stimuli were presented one at a time in random order: 64 upright and inverted novel faces intermixed with the same 64 faces seen in the previous study phase. The orientation each stimulus appeared varied, depending on the participant. Each face was shown for 3 seconds, which was preceded by a 1-second fixation cross. Participants were instructed to press '.' key if they recognized the face as from the study phase or press 'x' if they did not (the keys were counterbalanced across participants).

Experiment 1b

Checkerboard categorization phase:

Upon providing consent, participants were shown instructions for the categorization phase (in line with Experiment 1a and Civile, Zhao, et al., 2014). They were shown exemplar checkerboards from categories A and C one at a time in a random order, and were instructed to sort these exemplars into two categories (A-C) through trial-and-error, by pressing one of the two keys on the keyboard (counterbalanced). They were given immediate feedback on whether their response was correct or incorrect. If they did not respond within 4 seconds, they were timed out. A fixation cross preceded each stimulus presentation in the center of the screen for 1 second. Participants saw 64 exemplars drawn from each of category A and category C (total of 128 stimuli).

Study phase & Old/New recognition task:

The procedure and stimuli the two phases were the same as Experiment 1a.

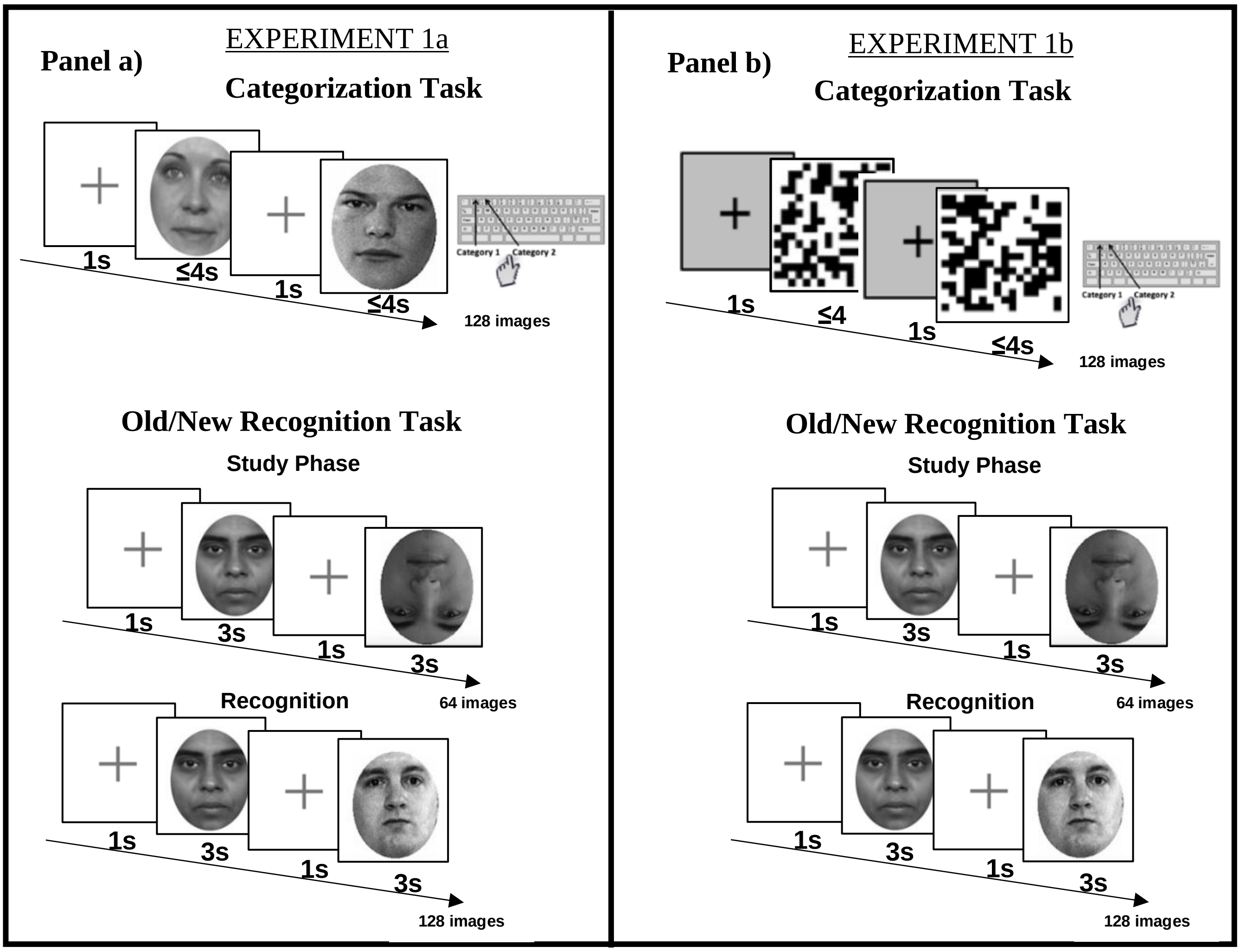

Figure.5.1. shows the task sequence for the categorization task (top), the old/new recognition task (bottom) for Experiment 1a (panel a) and Experiment 1b (panel b).

5.3 Results

Both experiments used accuracy as the primary measure from all participants which was used to compute a *d'* sensitivity measure (Stanislaw & Todorov, 1999) for 'seen' and 'not seen' responses in the old/new recognition task. To calculate *d'*, we computed using the difference between the z transforms of the participants' hit rate (H) (the proportion of SEEN trials to which the participant responded SEEN), and false alarm rate (F) (the proportion of NOT SEEN trials to which the participant responded SEEN): d' =z(H) – z(F). A *d'* of 0 indicates chance-level performance. In the categorization phase, the mean percentage correct was 90%.

We conducted a 2 x 2 ANOVA for the performance across experiments, with the within-subjects factor, *Orientation* (Upright and Inverted) and the between-subjects factor, *Categorization task* (Face Categorization and Checkerboard Categorization). A significant effect was found for *Orientation*, $F(1, 184) = 44.13$, $p < .001$, $\eta^2_p = .19$, indicating the standard inversion effect (better performance for upright than inverted faces), and *Categorization task*, $F(1,184) = 4.88$, $p = .028$, $\eta^2_p = .03$, reflecting higher performance in checkerboard than face categorization experiments. However, the interaction of *Categorization task x Orientation* was not significant, $F(1, 184) = .62$, $p = .433$, $\eta^2_p = .00$.

Following on from the main effect of Categorization task, we then ran an additional independent samples *t*-test comparing performance in upright faces between the group that underwent the face and the group that underwent the checkerboard categorization tasks. This revealed a near significant difference, $t(184) = 1.95$, $p = .053$, $\eta^2_p = .46$, with a higher average performance in the checkerboard categorization group (M = 0.57, SD = 0.50) than the face categorization group (M = .41, SE = 0.59). The same analysis for inverted faces also revealed a near significant difference, $t(184) = 1.77$, $p = .079$, $\eta^2_p = .46$, with a higher average performance in the checkerboard categorization group (M = 0.29, SD = .33) than the face categorization group (M = 0.19, SD = 0.40).

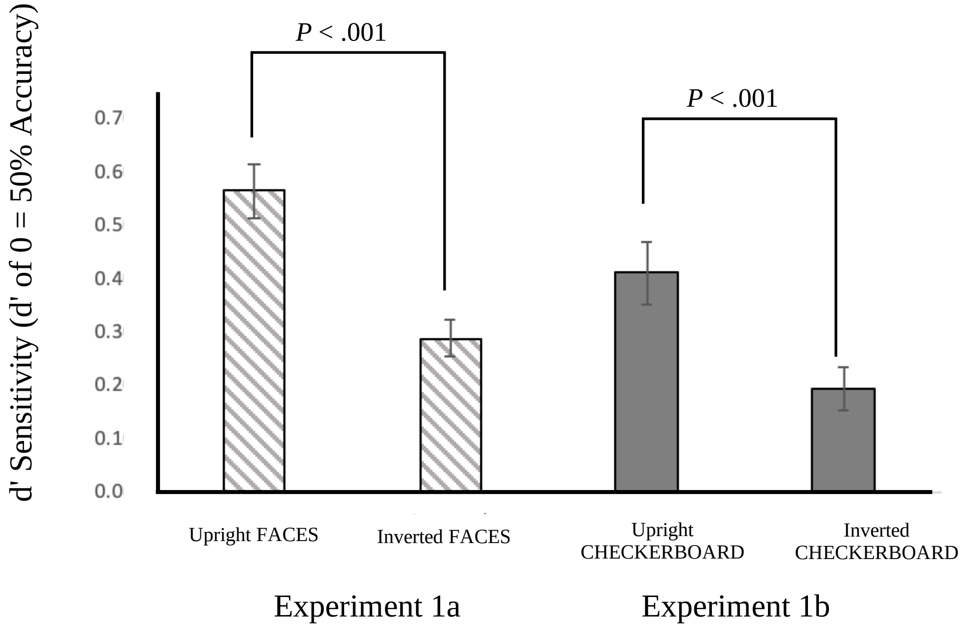

Figure.5.2. reports the inversion effect results from Experiments 1a and 1b. The *x*-axis shows the stimulus conditions, the *y*-axis shows *d'*. Error bars represent s.e.m.

5.4 Discussion

The purpose of this chapter was to investigate whether proactive interference had any confounding effect on the inversion effect using the old/new recognition task used in Civile, Zhao, et al,. (2014), Civile, Verbruggen, et al., (2016), Civile, McLaren, et al., (2018) and Civile, Waguri, et al., (2020), as this was highlighted as an influencing factor in the congruency and composite effect in the experiments of Chapters 3 and 4. To directly test the effects of proactive interference on the inversion effect, Experiment 1a employed the old/new recognition task which preceded with a face categorization task, while Experiment 1b preceded with a checkerboard categorization task. The results revealed a significantly robust inversion effect in both experiments. While there was a significant overall effect of proactive interference on the average performance overall, it was clear that this was not to the extent of affecting the inversion effect. This finding has several implications. Firstly, the results provide inference that the checkerboard inversion effect that was obtained using an old/new recognition task by Civile, Zhao, et al., (2014), and Civile, Verbruggen, et al., (2016) captured the “pure” inversion effect, and although average performance may have overall been affected by proactive interference, the inversion effect appeared to be least likely influenced by proactive interference induced by the categorization task. The results also suggest that proactive interference does not affect the face inversion effect under standard conditions despite its effect on the overall performance. Importantly, it is still the case that the difference in the checkerboard inversion effect and the face inversion effect induced by the tDCS could be partly due to the difficulty of the old/new recognition task when performing with checkerboards, and as that Chapter 2 fixed this we can therefore, attribute the residual difference to something like holistic processing. There is the remaining question of why proactive interference would affect the overall performance for checkerboards in an old/new recognition task as observed in the current study, but not for the matching task in Chapter 2. If we look back at the analysis conducted in Chapter 2, it showed that there was no difference in the overall performance between the checkerboards in sham and faces in sham. A potential explanation is that in the old/new recognition task used here, the study comes straight after the categorization task, while for the matching task used in Chapter 2, there is a keyboard practice task in between the categorization task and the matching task. Therefore, the keyboard practice task may facilitate as a break that would prevent the buildup of proactive interference. However, this should be tested further in future. A potential method of investigating this is to conduct the old/new recognition task with checkerboards, where one group of participants have a break between the categorization task and study phase, while the other group would not have a break. A final, but important implication of the findings is that the effects of proactive interference differ from the tDCS effect on the inversion effect. Proactive interference affected the average performance (while the inversion effect remained significant), however, the tDCS procedure at Fp3 specifically affects the performance for upright faces rather than reducing performance across all conditions. This reinforces the perceptual learning explanation based on the feature salience modulation rather than attributing the tDCS effect to proactive interference. This now leads us to suggest that proactive interference appears to specifically affect the congruency effect (Chapter 3) and/familiarity (Experiment 1, Chapter 4) and the composite effect (Experiment 2, Chapter 4). Future research should investigate this further. Future research should also aim to test the effect of proactive interference directly by using the tDCS paradigm and matching tasks from Chapter 2 for an immediate corroboration of the findings reported here.

Chapter 6: Enhancing Perceptual Learning and Face Recognition with Thatcherized faces, tDCS and EEG

6.1 Overview

This chapter aimed to extend on the tDCS-induced effects on the face inversion effect, however, this time when the inversion effect is increased. In Chapter 2, it was shown how the tDCS can influence the face inversion effect by selectively reducing recognition performance in upright faces, resulting in the reduced inversion effect. However, recent studies have also shown that the same tDCS procedure can increase the face inversion effect for normal faces when these are presented with sets of Thatcherized faces that generalize onto them (e.g., Civile, Cooke, et al., 2020). Therefore, this tDCS procedural capacity for systematically increasing and decreasing the inversion effect was interpreted as further evidence of the perceptual learning component involved in the inversion effect. In the context of the MKM theory, it was proposed that in circumstances where other stimuli generalize onto normal faces to reduce the inversion effect, the tDCS procedure removes this negative effect of generalization and returns the inversion effect to its usual face-specific form, and does this by enhancing the performance for upright faces, which consequently increases the inversion effect. This chapter investigates this further by adopting the concurrent tDCS and EEG technique which was first developed in my MSc work (Civile, Waguri, et al., 2020). The aim was to explore if this behavioral modulation of the enhanced inversion effect would correspond to the electrophysiological modulation on the N170 ERP component. The sections below provide an overview of the key literature.

6.1.1 Thatcherized faces and tDCS (Civile, Cooke, et al., 2020)

So far, the experiments reported here and the literature introduced in prior chapters mostly concerned the investigation of the inversion effect. In order to further understand the role of perceptual learning and thereby, uncover the mechanisms of face recognition, tDCS has been used to worsen recognition performance in upright faces/checkerboard stimuli (e.g., Civile, Verbruggen, et al., 2016, Civile, McLaren, et al., 2018). So what happens if we use the same tDCS procedure for the converse purpose of improving face recognition performance? This was recently achieved by Civile, Cooke, et al., (2020), through a series of experiments using the same old/new recognition task to investigate the inversion effect in normal faces while tDCS was administered. The only difference was the intermixing of upright and inverted “Thatcherized faces” with the normal faces. Thatcherized faces refer to the effect of rotating the eyes and mouth 180º in situ, and rotating the entire image once these components are inverted to produce the illusion that the inverted eyes and mouth within the face become hard to detect, and therefore, the image does not look unusual other than the fact that the face appears upside down. However, when this manipulated face is presented upright, the odd configurations of the inverted eyes and mouth become noticeable and is striking. The original manipulation was conducted on images of then British prime-minister, Margaret Thatcher, hence the term Thatcherized (Thompson, 1980). This “Thatcher Illusion” is an orientation sensitive illusion and is an example of sensitivity to configural information. The provided explanation for this is that upon inversion, the use of configural information in the face is reduced and instead, discrete processing is recruited, which results in the mouth and eyes to appear as ordinary. When the face is shown in the normal, upright orientation, we revert to the configural processing, which results in the distorted mouth and eyes to stand out (Thompson, 1980; Lewis & Johnston, 1997; Lewis, 2001; Civile, McLaren, et al., 2016).

Experiment 1 of Civile, Cooke, et al., (2020) examined the inversion effect in an old/new recognition task, with upright and inverted, male and female normal and Thatcherized faces to determine whether these Thatcherized faces would suffer from extra salience as predicted by the MKM model. Given that the upright Thatcherized images are striking, the MKM model posits that the elements of these features are now high in salience and predictability. However, these predictions would be incorrect because the inverted eyes and mouth configurations that are common across the Thatcherized faces are incorrect. With the increased salience, this would be generalized across the Thatcherized faces, which should then result in the reduced recognition performance for the upright Thatcherized faces. Its inverted counterparts would not suffer from this generalization to the same extent as the upright Thatcherized faces because of the lack of experience with inverted faces, and the unreliable prediction for the orientation of the mouth and eyes within the inverted faces. Considering all of this, the authors predicted a reduced inversion effect in Thatcherized faces compared to the inversion effect in normal faces as a consequence of the reduced advantage in upright Thatcherized faces. The behavioral results confirmed the predictions. This was further supported by the N170 ERPs obtained by the EEG recordings during the task. The results showed a strong inversion effect on the N170 in terms of latency and amplitude for normal faces. There was a trend towards a significant difference for the N170 amplitudes in upright normal and Thatcherized faces, and no difference between their inverted counterparts. The authors deemed these results were close enough to the MKM predictions, given that the overall latency and amplitude of the N170 showed a larger inversion effect in normal faces than Thatcherized faces, and these results somewhat correspond to the behavioral results.

Experiment 2 further examined the results from Experiment 1 by administering tDCS during the same old/new recognition task, but this time, only using male normal and Thatcherized faces. The authors predicted that the tDCS would improve performance in the Thatcherized faces. This prediction was based on the tDCS' function in modulating error-based salience, which emphasizes the common features across the face rather than the unique features (e.g., Civile, Verbruggen, et al., 2016; Civile, McLaren, et al., 2018), and therefore, results in worse recognition for upright faces. With Thatcherized faces, Experiment 1 demonstrated that the already incorrect and striking inverted features are highly salient, which enhances generalization that results in worse recognition performance for normal upright faces. Therefore, the tDCS should improve performance in the Thatcherized faces by suppressing the highly salient, incorrect features, because the inverted Thatcherized faces would be less affected due to our limited experience in them. Consequent to this, the tDCS should enhance the inversion effect by improving the recognition for upright Thatcherized faces. Furthermore, it was suggested that the tDCS on normal faces should result in the same reduced inversion effect via reduced performance in upright faces as observed in Experiment 1. This prediction was based on the assumption that performance on normal and Thatcherized faces would be quite independent of one another. However, the results interestingly revealed that the predicted enhancement of the inversion effect was obtained in both normal and Thatcherized face stimuli. This was the reverse of the tDCS effect on the inversion effect with only normal faces found in Civile, McLaren, et al., (2018).

Experiment 3 served as both a replication (Experiment 3a, male and female faces intermixed) and a direct comparison by using male normal and Thatcherized faces (Experiment 3b) of the tDCS effect between the enhanced inversion effect observed in Experiment 2 and the reduced inversion effect demonstrated by Civile, McLaren, et al., (2018) and Civile, Waguri, et al., (2020). The results confirmed the previous findings that anodal tDCS at Fp3 is able to significantly reduce performance in upright faces, and thereby, reduce the inversion effect. When normal faces are intermixed with Thatcherized faces, performance in normal upright faces significantly increases, resulting in an increased inversion effect for normal faces.

The authors interpreted these results in terms of the MKM perceptual learning model. The typical inversion effect for Thatcherized faces is reduced due to the eyes and mouth being upright upon inversion (Thompson, 1980). However, the anodal tDCS counter-intuitively increased this inversion effect by enhancing recognition for upright faces. This can be attributed to the abolishment of the harmful generalization between Thatcherized and regular faces which facilitated the inversion effect in normal faces to return to the usual pattern and further enhanced it because the abolished generalization helped recognition performance for these regular faces. How generalization occurs between faces is dependent on their similarities to each other. The higher the similarity, the more generalizations are made between the stimuli and this makes the task difficult. The MKM model depicts generalization as how common the features are. Features common to most of the faces would promote generalization, while the features that are shared by only a few faces and are unique to a particular face would play an important role in recognizing a face correctly. Thatcherized faces also have common features, however, there are two groups of them: features that are common to all faces, and features common across Thatcherized faces. The latter is the inverted eyes and mouth features that is specific to, and distinctive of a Thatcherized face. According to the MKM model, these eyes and mouth on a Thatcherized face are “super” salient, and these features do not meet the expectation in context to the rest of the face, which is regular unlike the features. The predicted features have, instead, been replaced by inverted features. The replacement of correct predictions by incorrect predictions results in an even higher salience than the high salience typically found in novel features. This higher salience promotes generalization between Thatcherized faces, which results in the harder discrimination between these types of faces. We now turn to the other remaining common feature of the Thatcherized face. These other common features are now also higher in salience than usual because of the lower predictability compared to normal faces, because some of the usual predictors as described are now incorrect and unreliable. This generalizes across Thatcherized faces, but this increase in salience also manifests onto normal faces making any discrimination more difficult. This shows that while Thatcherized faces are a novel set of faces, they share many common features with normal faces that can be generalized between the two types of faces. The tDCS would then reduce this negative effect of generalization on the regular faces.

6.1.2 Concurrent tDCS and EEG (Civile, Waguri, et al., 2020)

Examining the underlying electrophysiological responses that supplement the behavioral results would provide an in-depth understanding of the mechanisms in play for this effect. Recent work by Civile, Waguri, et al., (2020) used a new concurrent tDCS and EEG system to examine the electrophysiological responses (N170 ERP) on the inversion effect when the tDCS montage is delivered during the old/new recognition task with normal faces only. The behavioral results confirmed the finding of anodal tDCS reducing the inversion effect compared to sham by means of impaired recognition performance for upright faces. On the other hand, the tDCS procedure on the ERP from the P08 channel revealed a novel effect. Notably, the ERP results provided an intriguing insight into the tDCS stimulation's ability to influence the face-inversion-effect on the N170 obtained from the P08 channel. The result was a dissociation for the tDCS-induced effects. For the *latencies*, the tDCS reduced the usual face-inversion-effect (delayed N170 in response to inverted vs. upright faces) compared to sham, thus paralleling the behavioral results. Contrary to this, the same tDCS procedure increased the inversion effect seen in the *amplitudes* by making the negative deflection for the inverted faces much greater than for the upright faces. The tDCS induced results for the latency are analogous to the behavioral results and can be taken to support the N170 literature in which the latency delay is attributed to the response to inverted faces taking more time due to the disruption of configural information (for a review, see Eimer, 2011). However, as briefly discussed in Chapter 1, the precise explanation for the increase in amplitude remains unclear based on the current literature on the N170, other than the fact that inverted faces sometimes elicit it. Rossion, Gauthier, Tarr, et al., (2000) proposed an explanation, which relies on the assumption that both inverted and upright faces activate face-specific neurons, however, inverted faces additionally recruit object-sensitive neurons, resulting in increased N170 amplitudes elicited by inverted faces. Other research attributes this increase to higher involvement of eye-sensitive cells for inverted faces (Itier, Alain, et al., 2007). This is based on the assumption that upright faces activate face-selective cells, but inhibit activation of separate, eye-selective cells (Perret et al., 1988). The eye-selective cells are released in an inverted context due to the disruption of configurations, which was demonstrated by Itier, Alain, et al., (2007), wherein the N170 amplitude pattern for face inversion disappeared for face stimuli without eyes. The literature regarding the tDCS-effects on the N170 suggests that the N170 latency changes are caused by disrupted expertise at exploiting configural processing leading to a reduction of the inversion effect similar to that recorded for faces with altered configural information. Based on studies that found an increased inversion effect on the N170 amplitude when fixations are enforced on the eye regions, or when the eyes are presented in isolation (Itier, Latinus, et al., 2006; Itier, Alain, et al., 2007; Nemrodov et al., 2014), the tDCS-effects on the N170 amplitude were interpreted as a switch from configural processing to a more feature-based processing that enhances the effect of the eyes of the faces. This suggestion is somewhat along the lines of some behavioral studies that suggested the N170 amplitudes are a result of configural coding disruption on face stimuli, demonstrated by, for example, scrambled facial features, or composites of a face which are split in half and misaligned (e.g., George et al., 2005).

Civile, Waguri, et al., (2020) proposed an alternative explanation, suggesting that the N170 latency and amplitude could index different mechanisms. The increase in the N170 amplitude was not linked with any increase in behavioral performance from this study (rather, a decrease in performance to upright faces), therefore, the enlarged N170 inversion effect on the amplitudes could be an index of the increased generalization induced by the tDCS procedure when normal faces only are presented in the study. This postulation derives from the MKM model's premise that the tDCS procedure alters feature salience modulation by making the salience of the common elements (which do not help in discrimination tasks) relatively high, thus increasing *generalization*. This would have the effect of making the faces look in some sense more similar causing a reduction in recognition performance, and thus, result in the reduced inversion effect on the N170 latency.

6.2 Introduction to the Experiments

Taking the two key studies together, they provide established evidence that shows anodal tDCS delivered at Fp3 site can either reduce or enhance the inversion effect in normal faces depending on the stimuli they are presented with (Civile, Cooke, et al., 2020; Civile, Waguri, et al., 2020). Critically, this modulation of the inversion effect is mainly attributed to the tDCS making performance on normal upright faces either worse or better, and not the tDCS affecting learning or recognition in general. Both appear to be a result of the modulation in generalization. However, more work is needed to examine the effect of generalization from manipulated faces (i.e., Thatcherized faces) onto regular faces to further establish this interpretation. More research is also needed to substantiate the suggestion that the N170 amplitude reflects modulation of generalization itself. Establishing the notion that adding a set of manipulated faces to regular faces actually affects recognition of the regular faces would change the face recognition literature, and would simultaneously provide a better understanding of the tDCS-effects on the N170. The two large studies reported here addressed this to further advance the theoretical framework of perceptual learning and face recognition.

Experiment 1 investigated the tDCS-induced effects on the N170 inversion effect when normal faces are presented with Thatcherized faces intermixed (n = 72). Based on the previous work by Civile, Cooke, et al,. (2020), the anodal tDCS procedure should be able to reduce the harmful generalization induced by Thatcherized faces and thus enhance the inversion effect for normal faces. No study has investigated the tDCS effects on the N170 inversion effect for normal faces when intermixed with Thatcherized faces. Therefore, by applying tDCS and EEG simultaneously on the same recognition task with normal and Thatcherized faces used in Civile, Cooke, et al., (2020), we aim to advance our understanding into the mechanisms of the tDCS effects on the face inversion effect and perceptual learning in general. If the reduced inversion effect on the N170 latency found in Civile, Waguri, et al., (2020) is the neuro-signature of the tDCS altering feature salience modulation, a similar reduction should be recorded in our study as well irrespective to the enhanced behavioral inversion effect for normal faces. Considering this, we would expect the anodal tDCS to also reduce the inversion effect for normal faces on the N170 amplitude as a result of the reduced generalization. If confirmed, we would have a tDCS procedure capable of selectively increasing or decreasing the behavioral inversion effect and control the modulation of the inversion effect on the N170.

Experiment 2 complements Experiment 1 and provides the first direct evidence in the literature of the harmful effect of generalization on the face inversion effect. This comprised of two large tDCS studies to directly compare the effects of adding Thatcherized faces (i.e., harmful generalization;

Experiment 2a) vs checkerboard stimuli (i.e., no generalization; **Experiment 2b**) on the inversion effect for normal faces. It was predicted that the results from sham would show that intermixing Thatcherized faces would reduce the inversion effect for normal faces as opposed to the 'pure' inversion effect in normal faces by intermixing normal faces with stimuli that cannot generalize onto them to the same extent (e.g., checkerboards).

6.3 EXPERIMENT 1

6.3.1 Method

6.3.1.1 Participants

A total of 72 naïve (right handed) participants (20 male, 52 Female; Mean age = 20.4 years, age range = 18-30) who passed a tDCS safety screening took part in the experiment. All participants were students from the University of Exeter and were compensated with either course credit or cash payment. All methods were performed in accordance with the guidelines and regulations approved by the CLES Psychology Ethics Committee at the University of Exeter. Informed consent was obtained from all participants.

6.3.1.2 Materials

The same 128 image set of faces from Civile, Cooke, et al., (2020; Experiment 2) were used. The images were originally retrieved from Psychological Image Collection at Stirling open database, (https://pics.stir.ac.uk). All faces were standardized using a grayscale color on a black background, and cropped the hair and ears. Four different versions of the faces were prepared: normal upright, normal inverted, Thatcherized upright, and Thatcherized inverted. The Thatcherized faces were produced by rotating the mouth and each of the eyes individually by 180 degrees. The stimuli (5.63 cm x 7.84 cm in dimensions) were presented at resolution of 1280 x 960 pixels.

Concurrent tDCS and EEG

The Starstim tDCS system previously used by Civile, Waguri, et al., (2020) was employed as it allows simultaneous EEG recording with the Enobio EEG system (Neuroelectrics; https://www.neuroelectrics.com). The tDCS stimulation was delivered by a battery driven, constant current stimulator, via a pair of surface sponge electrodes (35 cm^2), soaked in a saline solution and applied to the scalp at the target areas of stimulation.

EEG Recordings

As in Civile, Waguri, et al., (2020), EEG recordings were obtained using the Enobio system from Neuroelectrics (20-channel, 10-20 configuration; see Figure 6.1, panel a). which is a wireless electrophysiology sensor system. The Necbox (control unit) connects through Wi-Fi to the Neuroelectrics-Instrument-Controller (NIC) software running on a computer. The EEG data is streamed via Wi-Fi, sampled at 500 SPS with a bandwidth of 0 to 125 Hz (DC coupled). The Driven-Right-Leg (DRL) and the Common-Mode-Sense (CMS) connections corresponded to the electrical reference, or "ground", of the system. The CMS is the reference channel, compared to which all the EEG signals are measured. The DRL is responsible for bringing the potential of the subject as close as possible to the "zero" of the electrical system. Specifically, the Enobio 20-channel (10-20 configuration) here used the CMS/DRL electrode is represented by the EarClip, an additional dual electrode system applied to the earlobe through conductive gel. In NIC (version 2) the quality of the EEG signal is assessed via the quality index

(QI) which is computed every 2 seconds and is dependent on the following parameters: i) Line Noise power (μV2) of the signal in the standard line noise frequency band (50±1 Hz); ii) Main noise signal power of the standard EEG band (1-40Hz); iii) Offset, mean value of the waveform; iv) Drift, which is measured but not included in the QI computation because it has a high inter-subject variability. Before starting the recording (and the tDCS stimulation), we made sure the QI for each channel was indicated as "good" (i.e. displayed as orange/green in NIC2).

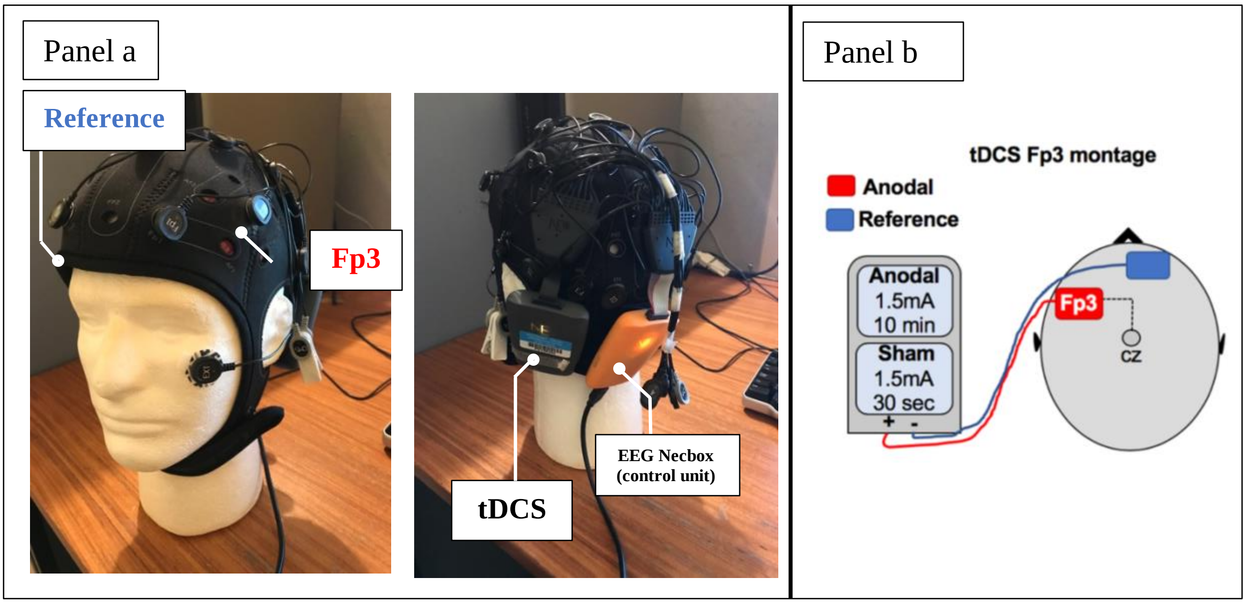

Figure.6.1. Panel (a) shows the concurrent tDCS and EEG setup. Panel (b) shows the tDCS apparatus used in Civile, Verbruggen, et al., (2016), Civile, McLaren et al., (2018), Civile, Cooke, et al., (2020), Civile, Waguri, et al., (2020), Civile, McLaren, Milton, et al., (2021), and Civile, Quaglia, et al., (2021).

6.3.1.3 Procedure

The Behavioral Task

The same behavioral task as Civile, Cooke, et al., (2020; Experiment 2) was used, which consisted of a study phase and an old/new recognition phase (see Figure.6.2).

Study Phase:

After participants provided consent and received instructions for the task, they saw a fixation cross in the center of the screen (1 second), followed by a face image (4 seconds) for each trial. Once all 64 face stimuli (16 upright normal, 16 inverted normal, 16 upright Thatcherized, 16 inverted Thatcherized) had been presented, the program displayed a set of the instructions for the subsequent recognition task.

Old/New Recognition Phase:

A total of 128 stimuli were presented one at a time in random order: 64 upright and inverted novel faces (32 normal, 32 Thatcherized) intermixed with the same 64 faces seen in the previous study phase. The orientation each stimulus appeared varied, depending on the participant. Each face was shown for 4 seconds, which was preceded by a 1-second fixation cross. Participants were instructed to press ‘.’ key if they recognized the face as having been shown in the study phase or press ‘x’ if they did not (the keys were counterbalanced across participants).

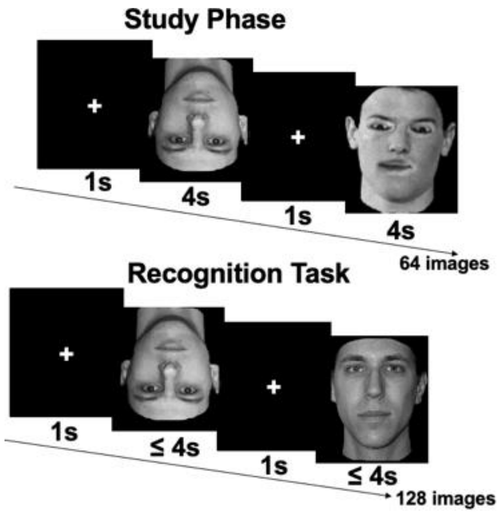

Figure.6.2. shows the task sequence for study phase (top) and recognition phase (bottom).

The tDCS paradigm

The tDCS montage was the same as previous procedures by Civile, Verbruggen, et al., (2016), Civile, McLaren, et al., (2018), Civile, Cooke, et al., (2020), and Civile, Waguri, et al., (2020). This was a bilateral bipolar-non-balanced montage with one of the electrodes (anode/target) placed at Fp3 and the reference was placed on the forehead (above the right eyebrow). In the anodal condition group, a direct current stimulation of 1.5mA was delivered continuously for 10 minutes (with a 5-second fade-in and -out) started as soon as the participant began the task, and continued throughout the study phase. Participants in sham group experienced the same 1.5mA intensity with 5-second fade-in and -out, but stimulation was delivered for only 30 seconds (see Figure.6.1, panel b). For this group, the stimulation also started at the beginning of the study phase, but it ended before the recognition task started. A double-blind procedure was used, which was reliant on the Neuroelectrics system double-blind mode, by which a researcher unassociated with running the experiment had created and managed the anodal and sham stimulation protocols.

This was then locked and hidden by a password. A list of protocol names corresponding to the participants were given to the researcher running the experiment, but the information regarding which protocols refer to anodal and sham mode was hidden by the password.

EEG Data Processing and Analysis of the N170

EEG data processing was in line with the procedure adopted in Civile, Elchlepp, et al., (2018), Civile, Cooke, et al., (2020, Experiment 1) and Civile, Waguri, et al., (2020, Experiment 1). We used MATLAB with the open-source EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) toolboxes. Data were filtered off-line using a noncausal Butterworth bandpass filter (half-amplitude cutoffs at 0.1 and 20 Hz, 24 dB/octave roll-off). All scalp electrodes were referenced off-line to a Cz reference. Bad parts of the EEG recording were identified and removed using EEGLab's *pop_rejcont* function. To correct for blink artefacts, independent component analysis (ICA) was applied to the continuous data after the deletion of sections containing extreme values (Jung et al., 2000). Artefact-free data were then segmented into epochs ranging from 250 ms before to 800 ms after stimulus onset for all conditions (Zion-Golumbic & Bentin, 2007).

ERPs were created by averaging the segmented trials (and baseline corrected) according to the stimulus' conditions in the study phase and recognition phase. The absolute peak of the N170 was determined using the ERPLAB Measurement Tool based on the option to select the most negative peaks between 130 and 220 ms. Subsequent visual scrutiny was applied to ensure that the values represented real peaks rather than end points of the epoch. The ERP N170 latency and amplitude analyses were restricted to electrode PO8 over the right temporal hemisphere, which often in the literature has shown bigger effects on the N170 in response to face stimuli (Rossion & Jacques, 2008, Alonso-Prieto et al., 2011, Navajas et al., 2013, Civile, Zhao, et al., 2014; Civile, Elchlepp, et al., 2018; Civile, Cooke et al., 2020; Civile, Waguri et al., 2020).

6.3.2 Results

In both experiments (Experiment 1, Experiment 2a & 2b) the primary measure was the accuracy data from all subjects only for the normal faces to compute a *d'* sensitivity measure (Stanislaw & Todorov, 1999) for the old/new recognition task (seen and unseen stimuli for each stimulus type) where a *d'* of 0 indicates chance-level performance. To calculate *d'*, we used subjects' hit rate (H), the proportion of SEEN (i.e., "old") trials to which the participant responded SEEN, and false alarm rate (F), the proportion of Not SEEN (i.e., "new") trials to which the participant responded SEEN. Each p-value reported for the comparisons between conditions is two-tailed, and we also report the F or t value along with effect size (η^2_p). In both experiments, (Experiment 1, Experiment 2a & 2b) we assessed performance against chance to show that normal faces in both the tDCS sham and anodal groups were recognized significantly above chance (For all conditions we found $p < .001$ for this analysis).

Behavioral Data Analysis

A 2 x 2 mixed model design was computed using the within-subjects factor *Face Orientation* (normal upright or normal inverted) and between-subjects factor *tDCS Stimulation* (sham or anodal). ANOVA revealed a significant main effect of *Face Orientation* $F(1, 70) = 40.36$, $p < .001$, $\eta^2_p = .36$, this simply reflects the fact that performance was generally better for upright faces than inverted ones. A significant interaction between *Face Orientation* x *tDCS Stimulation* was also found, $F(1, 70) = 5.26$, $p = .025$, $\eta^2_p = .07$, consequent to the significantly larger inversion effect (difference between performance for upright and inverted faces) in the anodal group as opposed to sham. No significant main effect of the between-subjects factor *tDCS Stimulation* was found, supporting the fact that the tDCS does not simply affect overall performance, $F(1, 70) = 0.87$, $p = .35$, $\eta^2_p = .01$. This corroborates Civile, Cooke, et al's., (2020) findings as we found an enhanced face inversion effect in the anodal group with performance for upright faces (M = 1.25, SD = 0.72) being significantly higher than that for inverted faces (M = 0.33, SD = 0.12), $t(35) = 5.94$, $p < .001$, $\eta^2_p = .50$. A significant but smaller inversion effect was found in the sham group with performance for upright faces (M = 0.87, SD = 0.14) being significantly higher than that for inverted faces (M = 0.44, SD = 0.11), $t(35) = 2.96$, $p = .006$, $\eta^2_p = .20$. In line with Civile, Cooke, et al., (2020), an additional analysis was conducted to compare the performance between upright faces in the sham group and anodal group. Our results confirmed that the anodal tDCS manipulation has improved recognition performance for upright faces, $t(70) = 2.02$, $p = .047$, $\eta^2_p = .05$. No significant difference was found between performance for inverted faces in the sham vs anodal condition, $t(70) = 0.64$, $p = .52$, $\eta^2_p < .01$ (see Figure.6.3).

Additional Bayes Factor analysis

Here, we conducted a Bayes analysis on the difference between the *d'* values for upright and inverted faces (i.e., the inversion effect score) comparing the sham and anodal groups (thus capturing the 2 × 2 interaction). The *priors* used were the differences found in Civile, Cooke, et al (2020)'s Experiment 2 and

3b averaged together, setting the standard deviation of p (population value | theory) to the mean for the difference between the inversion effect in sham group vs that in the anodal group (0.35). We used the standard error (0.15) and mean difference (0.49) between the inversion effect in the sham group vs that in the anodal group in Experiment 1. This gave a Bayes factor of 33.41, which is very strong evidence (greater than 10, using the conventional cut-offs) that these results are in line with previous work (i.e., the tDCS procedure used here increases the face inversion effect under these conditions).

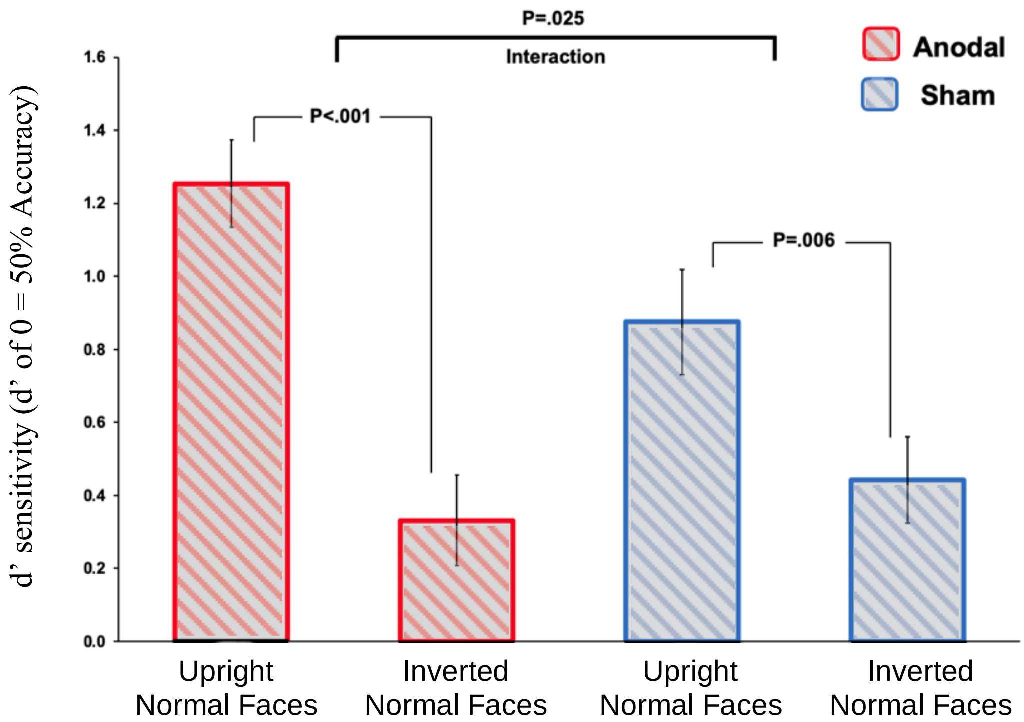

Figure.6.3. shows the behavioural results from Experiment 1 for the normal faces only. The x-axis represents the normal upright and inverted faces across the two tDCS conditions (anodal, sham). The y-axis represents d' sensitivity measure. Error bars are standard error means.

N170 Peak Latency Analysis

A 2 x 2 x 2 ANOVA was computed using the within-subjects factor, *Face Orientation* (normal upright or normal inverted), *Experiment Phase* (study phase or Recognition) and between-subjects factor *tDCS Stimulation* (sham or anodal). It was revealed that there were no significant main effect of *Experiment Phase* $F(1, 70) = 1.06$, $p = .31$, $\eta^2_p = .01$, nor was the interaction *Experiment Phase* x *tDCS Stimulation*, $F(1, 70) = 0.47$, $p = .49$, $\eta^2_p < .01$, or the interaction *Experiment Phase* x *Face Orientation*, $F(1, 70) = 2.97$, $p = .09$, $\eta^2_p = .04$ significant. No significant three-way interaction (*Face Orientation x Experiment Phase x tDCS Stimulation*) was found, $F(1, 70) = 0.02$, $p = .88$, $\eta^2_p < .01$. We found a significant main effect of *Face Orientation*, $F(1, 70) = 7.29$, $p = .009$, $\eta^2_p = .09$, reflecting the usual face inversion effect with the latency greater for inverted faces. Importantly the interaction *Face Orientation x tDCS Stimulation* was significant, $F(1, 70) = 4.70$, $p = .034$, $\eta^2_p = .06$, showing that tDCS did influence the face inversion effect on this latency measure. No significant main effect of *tDCS Stimulation* was found, $F(1, 70) = 0.23$, $p = .63$, $\eta^2_p < .01$. In line with Civile, Waguri et al., (2020), we found a significant inversion effect on the N170 latency in the sham condition where normal inverted faces (M = 175 ms, SD = 20.69) elicited a delayed N170 vs that elicited by upright faces (M = 168 ms, SD = 17.80), $t(35) = 3.47$, $p < .001$, $\eta^2_p = .26$. But the inversion effect on the N170 in the anodal group was not significant , with normal inverted faces (M = 170 ms, SD = 19.79) eliciting a similar N170 latency to that for the upright faces (M = 169 ms, SD = 20.31), $t(35) = 0.37$, $p = .71$, $\eta^2_p < .01$. No difference was found between the N170 latency for upright stimuli in the sham vs anodal group, $t(70) = 0.16$, $p = .87$, $\eta^2_p < .01$. Despite a numerically delayed N170 for the inverted faces in the sham compared to the anodal group, no significant difference was found, $t(70) = 0.31$, $p = .75$, $\eta^2_p < .01$. (see Figure.6.4 panel a).

Additional Bayes Factor analysis

A Bayes Factor analysis was conducted for the difference between the N170 latencies for inverted and upright faces (i.e., the inversion effect on the N170 latency) comparing the sham and anodal groups capturing the 2 × 2 interaction. For the priors, we used the differences found in Civile, Waguri, et al's., (2020) Experiment 1 and 2 averaged together, setting the standard deviation of p (population value | theory) to the mean for the difference between the inversion effect in sham group vs that in the anodal group (7.08). We used the standard error (2.11) and mean difference (5.89) between the inversion effect on the N170 latency in the sham group vs that in the anodal group in Experiment 1. This gave a Bayes factor of 20.21, which is strong evidence that these results are in line with previous work i.e., the tDCS procedure reduces the inversion effect on the N170 latency.

N170 Peak Amplitude Analysis

ANOVA revealed no significant main effect of *Experiment Phase* $F(1, 70) = 0.04$, $p = .84$, $\eta^2_p < .01$, nor was the interaction *Experiment Phase* x *tDCS Stimulation*, $F(1, 70) = .178$, $p = .67$, $\eta^2_p < .01$, or the interaction *Experiment Phase* x *Face Orientation*, $F(1, 70) = 2.30$, $p = .13$, $\eta^2_p = .03$, significant. Nor was a significant three-way interaction (*Face Orientation x Experiment Phase x tDCS Stimulation*) found, $F(1, 70) = 2.87$, $p = .095$, $\eta^2_p = .04$. We found no significant main effect of *Face Orientation*, $F(1, 70) = 2.80$, $p = .098$, $\eta^2_p = .04$, though the trend did follow the usual pattern of more negative amplitude for inverted faces, nor a significant main effect of *tDCS Stimulation*, $F(1, 70) = 0.15$, $p = .700$, $\eta^2_p < .01$. Importantly, the interaction *Face Orientation x tDCS Stimulation* was significant, $F(1, 70) = 4.95$, $p = .029$, $\eta^2_p = .06$. A significant inversion effect on the N170 amplitude was found in the sham group where normal inverted faces (M = -0.108 μV, SD = 2.01) elicited a larger N170 compared to that elicited by upright faces (M = 0.614 μV, SD = 0.34), $t(35) = 2.48$, p = .018, $\eta^2_p = .15$. Critically, in the anodal group, the inversion effect on the N170 amplitude was not significant, with normal inverted faces (M = 0.46 μV, SD = 0.29) eliciting a similar N170 amplitude to that for the upright faces (M = .354 ms, SD = 0.26), $t(35) = 0.45$, p = .650, $\eta^2_p < .01$. No difference was found between the N170 amplitude for upright stimuli in the sham vs anodal group, $t(70) = 0.71$, p = .480, $\eta^2_p < .01$. (see Figure.6.4 panel b).

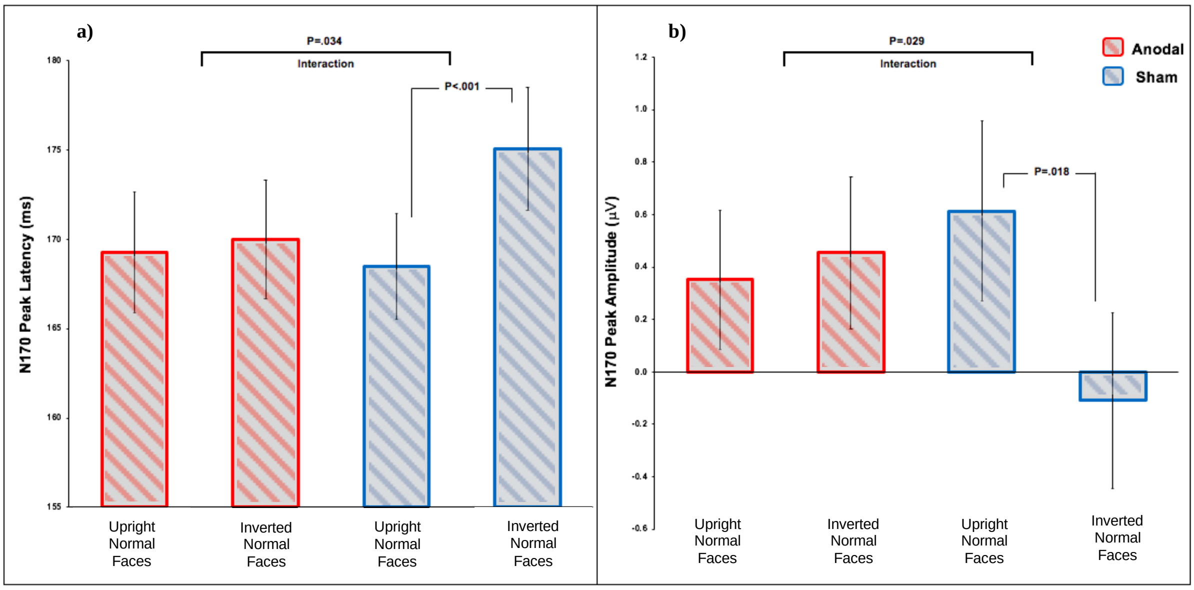

Figure.6.4. *Panel a* shows the peak latencies of waveforms recorded at P08 for normal faces across the two tDCS conditions in Experiment 1. The y-axis shows the elapsed time after a stimulus was presented. *Panel b*, shows the peak amplitudes. The y-axis shows the amplitudes (μV). For both tables, the ERPs in the study phase and recognition phase averaged together for the N170 component in all conditions.

Additional Bayes Factor analyses

Here, a slightly different Bayesian analysis was conducted for the effect anodal tDCS had on the inversion effect on the N170 amplitude based on the consideration that if the effect can be just as large as the effect found in the sham condition, should the effect from the anodal tDCS condition then be considered as part of that population, or is it more appropriate to describe it as null? The *priors* used here were the mean difference for upright and inverted faces N170 amplitudes, or in other words, the inversion effect, in the sham group (0.72), and the standard error (0.16) and mean difference (-0.10) for the inversion effect on the N170 amplitude in the anodal group. This gave a Bayes factor of 0.03, which is less than 0.3, therefore, this can be considered as strong evidence for the null, supporting the claim that the anodal stimulation reduces the face inversion effect on the N170 amplitudes.

6.3.3 Discussion

Experiment 1 investigated the tDCS effects on the inversion effect recorded on the N170 component when normal faces are presented with Thatcherized faces. The behavioral results from our study were in line with previous findings by Civile, Cooke, et al., (2020), which was the increase in the inversion effect by enhancing performance for upright normal faces when anodal tDCS was delivered with the presentation of normal faces intermixed with Thatcherized faces. This was further supported by the Bayesian analysis, which confirmed that our results are in line with the previous work. Further evidence has been provided regarding the beneficial effect anodal tDCS delivered at Fp3 has when normal faces are intermixed with Thatcherized faces, which results in better recognition in upright faces. No significant differences were found between recognition performance for inverted faces in the anodal condition compared to sham, which is in line with previous tDCS studies (Civile, McLaren, et al., 2018; Civile, Waguri, et al., 2020; Civile, Cooke, et al., 2020; Civile, McLaren, Waguri, et al., 2020; Civile, McLaren, Milton, et al., 2021; Civile, Quaglia et al., 2021).

The ERPs showed a reduced inversion effect in normal faces on the N170 latencies in the anodal condition compared to sham, which is in line with previous findings from Civile, Waguri, et al., (2020) as supported by the Bayes factor analaysis, which used the same concurrent tDCS/EEG technique applied on the old/new recognition task with only normal faces. Important findings of the N170 latencies and amplitudes were uncovered. Regarding the latencies, anodal tDCS in Civile, Waguri, et al., (2020) led to a reduced behavioral inversion effect and a reduction on the ERP N170 latencies, however, in the current study where the inversion effect for normal faces was behaviorally enhanced by intermixing Thatcherized faces, the same reduction in the N170 latencies were observed. When it comes to the amplitudes, contrasting effects were found. Civile, Waguri, et al., (2020) found an increased inversion effect on the N170 amplitudes for normal faces in anodal condition compared to sham, however, the current study showed a reduction in the inversion effect on the N170 amplitudes. Further support is provided by the Bayes Factor analysis regarding this. An in-depth discussion of these findings will be provided in the General Discussion section at the end of this chapter.

6.4 EXPERIMENT 2

The next step was to measure the harmful generalization the Thatcherized faces passed onto normal faces. To achieve this, two between-subjects experiments were run to compare the face inversion effect size in normal faces presented with Thatcherized faces (Experiment 2a) and in normal faces presented with a set of artificial, non-mono-orientated checkerboard stimuli that would not generalize onto normal faces (Experiment 2b). The two large studies ran in collaboration with a Masters by Research student and a Research Fellow. Given that generalization should not occur between checkerboards and faces, it can be predicted that the inversion effect in the sham condition would be smaller for Experiment 2a in comparison to Experiment 2b

6.4.1 Method

6.4.1.1 Participants

A total of 128 naïve students from the University of Exeter (right-handed) participants (40 male, 88 Female; Mean age = 20.7 years, age range = 18-29), who passed the tDCS safety-screening criteria took part in the two experiments (64 randomly allocated to each). In each experiment, participants were randomly allocated to sham or anodal tDCS groups (32 each). All methods were in line with the regulations approved by the CLES Psychology Research Ethics Committee at the University of Exeter. Informed consent was obtained from all participants, and were compensated with either course credit or cash payment.

6.4.1.2 Materials

Both experiments consisted of the same numbers of normal face stimuli, however, participants in Experiment 2a saw an additional set of Thatcherized faces and those in Experiment 2b additionally saw checkerboard stimuli.

Experiment 2a:

The same set of normal and Thatcherized faces as Experiment 1 were used.

Experiment 2b:

The same normal faces as Experiments 1 and 2a were used. The checkerboard exemplars used were the same as Experiment 2 of Civile, Zhao, et al., (2014). Each retained the proportion of 50% black and 50% white for each sets of prototype patterns (all overlapping 50% with one another). In total, 96 squares (average of 48) were randomly selected to alter when producing new exemplars.

6.4.1.3 Procedure

The Behavioral Task:

Experiment 2a:

This replicated Experiment 1 in this chapter but without EEG recording.

Experiment 2b:

This experiment consisted of a categorization task (pre-exposure/familiarization phase), study phase and an old/new recognition phase.

Categorization Task:

This was in line with the categorization task used in Civile, Zhao, et al., (2014), Civile, Verbruggen, et al., (2016) and Civile, Quaglia, et al., (2021). A total set of 128 checkerboard exemplars appeared on the screen, one at a time randomly drawn from two prototype-defined categories (64 each). Participants were asked to sort these exemplars in two categories through trial and error, by pressing keys 1 or 2 (counterbalanced). For each response, they received immediate feedback in whether it was correct or incorrect. Each checkerboard was preceded with a fixation cross in the center of the screen presented for 1 second. Participants had 4 seconds to respond to the checkerboard presented until they were timed out.

Study Phase:

Here, participants saw a set of checkerboards and faces presented (32 each), 16 upright and 16 inverted stimuli for both sets one at a time in a random order. For each trial, participants first saw a fixation cross in the center of the screen (1 second), followed by a face image (4 seconds). Participants were instructed to watch each face and try to remember as many as possible. Once all 64 face stimuli had been presented, the program displayed a set of the instructions for the subsequent recognition task.

Old/New Recognition Task:

A total of 128 stimuli were presented one at a time in random order: 64 stimuli seen in the previous phase intermixed with 32 upright and 32 inverted novel checkerboards drawn a familiar category, and 32 upright and 32 inverted novel, normal faces were presented. The orientation each stimulus appeared in varied for each participant. Participants were instructed to press '.' key if they recognized the face as having been shown in the study phase or pressed 'x' if they did not (the keys were counterbalanced across participants).

The tDCS Paradigm:

The procedure was the same as Experiment 1. Stimulation began when the first task started and finished before they began the old/new recognition task.

6.4.2 Results

A 2 x 2 x 2 mixed model ANOVA was computed on the d' measure using the within-subjects factor: *Face Orientation* (normal upright or normal inverted); and the between-subjects factors: *tDCS Stimulation* (sham or anodal) and *Experiment* (2a or 2b). This revealed a significant main effect of *Face Orientation* $F(1, 124) = 104.11$, $p < .001$, $\eta^2_p = .45$, which is a reflection of the usual face inversion effect with performance greater for upright than inverted faces. No significant interaction was found between *Face Orientation* x *Experiment*, $F(1, 124) = 0.26$, $p = .611$, $\eta^2_p < .01$. A significant interaction between *Face Orientation* x *tDCS Stimulation* was found, $F(1, 124) = 4.60$, $p = .034$, $\eta^2_p = .03$, consequent to the significantly larger inversion effect (difference between performance for upright and inverted faces) in the anodal group as opposed to sham. The overall three-way interaction (*Face Orientation* x *tDCS Stimulation x Experiment*) was also significant, $F(1, 124) = 12.30$, $p = .001$, $\eta^2_p = .09$, which is driven by the significantly larger inversion effect in Experiment 2a compared to Experiment 2b. No significant main effect of the between-subjects factor *tDCS Stimulation* was found, which supported the notion that the tDCS does not simply affect the recognition performance at an overall level, $F(1, 124) = 1.26$, $p = .26$, $\eta^2_p = .01$.

Independent Samples t-test

An independent samples *t*-test was conducted between Experiments 2a and 2b sham groups for the inversion effect (performance for upright – inverted stimuli) in normal faces. This revealed a significantly larger inversion effect in

Experiment 2b (*M* = 1.10, *SD* = 0.95) compared to Experiment 2a (*M* = 0.67, *SD* = 0.68), *t*(62) = 2.07, *p* = .042, η^2_p = .13. The same analysis in the anodal groups revealed a significantly larger inversion effect in Experiment 2a (*M* = 0.87, *SD* = 0.70) compared to Experiment 2b (*M* = 0.29, *SD* = 0.87), *t*(62) = 2.90, *p* = .005, η^2_p = .26 (see Figure.6.5).

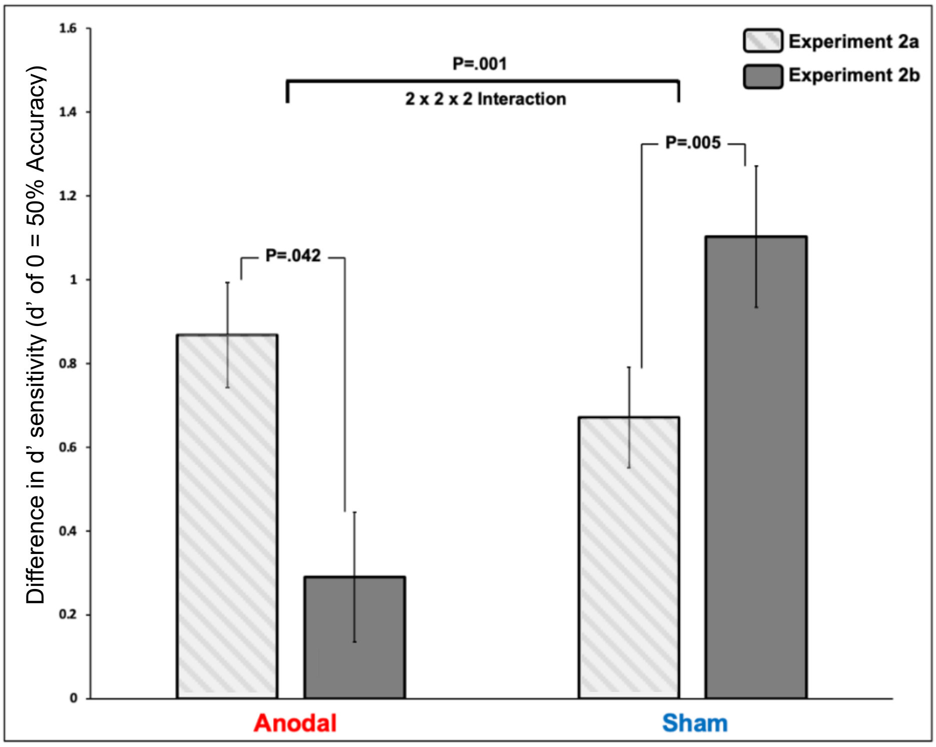

Figure.6.5. illustrates the inversion effect index (extracted by calculating the difference in performance for upright – inverted face)for normal faces across Experiment 2a and 2b. The x-axis represents the inversion effect index for each tDCS condition in the two experiments. The y-axis represents the d' sensitivity measure difference. Error bars are s.e.m.

Measure	Sham		Anodal	
	M	*SD*	*M*	*SD*
Experiment 2a				
Normal Face Upright	1.2596	.6292	1.2127	.6021
Normal Face Inverted	.5875	.6457	.3448	.4698
Thatcherized Upright	.6292	.4814	.6342	.6110
Thatcherized Inverted	.5022	.6750	.3392	.5192
Experiment 2b				
Normal Face Upright	1.7379	.8689	1.8248	1.2376
Normal Face Inverted	.6350	.4855	1.4690	.8753
Checkerboard Upright	.0444	.4722	.2760	.2760
Checkerboard Inverted	.0984	.4368	.1575	.5260

Table 6.1. ***Table of descriptive statistics for d' performance in individual upright and inverted stimuli for Experiments 2a and 2b.***

Additional Behavioral Analyses for Experiment 1 and Experiment 2a:

I can provide a combined analysis for Experiments 1 and 2a given that the two experiments used the same tDCS montage, and identical structure of the behavioral task. A 2 x 2 x 2 mixed model design was computed using the within-subjects factor: *Face Orientation* (normal upright or normal inverted), the between-subjects factors: *tDCS Stimulation* (sham or anodal) and *Experiment* (1 or 2a). There were no significant effects of *Experiment*, $F(1, 132) = 1.74$, $p = .189$, $\eta^2_p = .01$, *Experiment x tDCS Stimulation,* $F(1, 132) = 2.16$, $p = .144$, $\eta^2_p = .016$, nor *Face Orientation* x *Experiment*, $F(1, 132) = 0.44$, $p = .510$, $\eta^2_p < .01$. The three-way interaction of *Face Orientation* x *Stimulation* x *Experiment*) was also not significant, $F(1, 132) = 1.10$, $p = .295$, $\eta^2_p < .01$. This indicates that the *Experiment* factor does not contribute to the results, and further analyses can be conducted.

There was a significant main effect of *Face Orientation*, $F(1, 132) = 107.44$, $p < .001$, $\eta^2_p = .45$, and importantly, the interaction *Face Orientation x tDCS Stimulation* was significant, $F(1, 132) = 6.01$, $p = .015$, $\eta^2_p = .04$. No significant main effect of *tDCS Stimulation* was found, $F(1, 132) = .001$, $p = .958$, $\eta^2_p < .01$. This indicated that there was an enhanced face inversion effect in the anodal group with performance for upright faces (M = 1.23, SD = 0.66) that was significantly higher than that for inverted faces (M = 0.34, SD = 0.62), $t(67) = 8.93$, $p < .001$, $\eta^2_p = .54$. A significant, but numerically smaller inversion effect was found in the sham group, where performance for upright faces (M = 1.05, SD = .78) was significantly higher than inverted faces (M = 0.51, SD = 0.68), $t(67) = 5.66$, $p < .001$, $\eta^2_p = .32$.

Additional Bayes Factor analysis:

Consistent with results of Experiment 1, we provide a Bayes Factor analysis of the 2 x 2 interaction, but with Experiment 1 and 2a combined. The *prior* used here was the differences found in Civile, Cooke, et al (2020) 's Experiment 2 and 3b averaged together (0.35). The standard error (0.09) and mean difference (0.34) were the inversion effect in sham and anodal groups in Experiment 1 and 2a combined. This gave a Bayes factor of 59.20, providing strong evidence and confirmation that the tDCS procedure used increases the face inversion effect for normal faces when presented intermixed with Thatcherized faces.

Additional analyses Experiment 2b:

A 2 x 2 mixed model design was computed using the within-subjects factor:

Face Orientation (normal upright or normal inverted); and the between-subjects factor: *tDCS Stimulation* (sham or anodal). This revealed a significant main effect of *Face Orientation*, $F(1, 62) = 36.97$, $p < .001$, $\eta^2_p = .37$, and a significant interaction for *Face Orientation* x *tDCS Stimulation,* $F(1, 62) = 5.28$, $p = .001$, $\eta^2_p = .17$. No significant main effect of *tDCS Stimulation* was found, $F(1, 62) = 0.29$, $p = .595$, $\eta^2_p < .01$.

This shows that our results, in line with the previous line of works (Civile, McLaren, et al., 2018; Civile, Waguri, et al., 2020; Civile, Cooke, et al., 2020; Civile, McLaren, Waguri, et al., 2020; Civile, Quaglia, et al., 2021), found a near-significantly reduced face inversion effect in the anodal group (which would be significant one-tailed), $t(31) = 1.87$, p = .069, $\eta^2_p = .10$, compared to the robust inversion effect in the sham group, $t(31) = 6.51$, p < .001, $\eta^2_p = .58$. Crucially, the recognition performance for upright faces was significantly reduced by the anodal tDCS vs sham, $t(31) = 2.09$, p = .04, $\eta^2_p = .06$, which is also in agreement with previous findings.

6.4.3 Discussion

Results from Experiments 2a and 2b confirmed the main prediction that in the sham condition, Thatcherized faces generalized onto normal faces sufficiently to reduce the inversion effect (Experiment 2a), while such generalization could not be observed when normal faces were presented with checkerboards (Experiment 2b). Because the generalization of checkerboards onto faces were prevented, the typical face inversion effect was manifested in Experiment 2b. This is the first study in the literature to show that the inversion effect for normal faces can be modulated by intermixing particular stimuli with normal face stimuli. These findings also support the perceptual learning theory interpretation that the modulation of the inversion effect is attributed to the generalization between the particular stimuli onto normal faces.

While the between-subjects factor *tDCS Stimulation* was not significant (*p* = .26), there was a numerical trend of a larger inversion effect in the sham group of Experiment 2b compared to the anodal group in Experiment 2a. This suggests that this anodal tDCS procedure is capable of enhancing the inversion effect in normal faces when affected by harmful generalizations (i.e., Thatcherized faces onto normal faces), however, the typical inversion effect on normal faces is greater than this when harmful generalization is not present. Moreover, a significant difference in the inversion effect for normal faces in anodal groups between Experiments 2a and 2b support previous finding that anodal tDCS can reduce the inversion effect, or with a simple addition of a stimuli with normal faces, it can increase it.

The additional analyses conducted between experiments strengthens the evidence obtained. The analysis of Experiments 1 and 2a confirms that anodal stimulation increased the inversion effect in normal faces as opposed to sham condition. This is supplemented and reinforced by the Bayes factor analysis. The additional analysis for Experiment 2b also confirms that the anodal tDCS procedure once again produces the significantly reduced inversion effect, as observed in previous studies (Civile, McLaren, et al., 2018; Civile, Waguri, et al., 2020; Civile, Cooke, et al., 2020; Civile, McLaren, Waguri, et al., 2020; Civile, Quaglia, et al., 2021), as a result of the checkerboard stimuli not generalizing onto the normal faces. We will explain the findings of Experiments 1 and 2 in detail below in the General Discussion.

6.5 General Discussion

This chapter reported two large studies that directly investigated the tDCS-induced effects on perceptual learning when the face inversion effect is increased. This was motivated by two key lines of research. The first concerned the different effects anodal tDCS at Fp3 for 10 minutes at 1.5mA intensity can have on the inversion effect. Chapter 2 demonstrated that when the stimuli (e.g., checkerboards or normal faces) are presented on their own, anodal tDCS decreases the inversion effect. Contrastingly, intermixing Thatcherized faces with the presentation of normal faces result in the increase of the inversion effect (Civile, Cooke et al., 2020). The second key study was by Civile, Waguri et al., (2020), which investigated the N170 neuro-signature when the tDCS modulated the face inversion effect via concurrent tDCS and EEG for the first time. The crucial finding was the diverging effect the anodal tDCS had on the N170 amplitude and latency. While N170 latencies corroborated with the behavioral results of the reduced inversion effect induced by anodal tDCS, its amplitude was increased. What the latency and amplitude of the N170 signify remains unclear in the literature. The authors interpreted that perhaps that the effect anodal tDCS has on the inversion effect of the N170 latency may reflect a disruption for expertise in configural processing.

Applying the concurrent tDCS and EEG system from Civile, Waguri, et al., (2020)'s work, on to the same task used by Civile, Cooke et al (2020) with normal and Thatcherized faces, provided the opportunity to explore an alternative explanation that based on the MKM model of perceptual learning, which is the reduced face inversion effect on the N170 latency may reflect the neurosignature of the tDCS procedure affecting feature salience modulation. This would then explicate the enlarged amplitudes on the N170 inversion effect as an index of increased generalization induced by the anodal tDCS when normal faces only are presented. This alternative explanation was confirmed in Experiment 1, which demonstrated that anodal tDCS reduced the inversion effect on the N170 latency in normal faces, which did not match with the behavioral results of the enhanced face inversion effect. Given that the inversion effect on the latency was also reduced in Civile, Waguri, et al., (2020) when the face inversion effect was reduced, this indicates that the anodal tDCS at Fp3 will always significantly reduce the inversion effect on the N170 latency, irrespective of the enhancement or reduction of the behavioral inversion effect in normal faces. We further explicate in terms of generalization of the MKM model of how the inversion effect for normal faces can be enhanced behaviorally, and how this is not pertinent to the reduced inversion effect of the N170 latency. We propose that the N170 latency reflects changes to the feature salience modulation. In this case, the anodal tDCS stimulation poses an effect on this feature salience modulation. When normal faces are presented alone, the anodal stimulation affects the feature salience modulation by increases generalization, and consequently reduce the discriminability among the faces, hence the reduced inversion effect for normal faces (Civile, McLaren, et al., 2018). When normal faces are presented in combination with sets of manipulated faces (i.e., Thatcherized faces), harmful generalizations between the two types of faces occur, however, the anodal tDCS now serves to remove this harmful generalization, which results in the improved performance.

However, our results of the N170 amplitudes contrast with the interpretations from previous work, as it revealed a reduced inversion effect. Accordingly, this does not support the suggestion of the N170 amplitude indexing increased featural processing. Instead, we attribute modulations of the N170 amplitude to modulations in generalization. We have observed in Experiment 2 that the tDCS procedure can increase generalization when normal faces only are presented, and reduce generalization when normal faces are presented with Thatcherized faces. If we attribute this explanation to Civile, Waguri, et al., (2020)'s, it can be inferred that this tDCS increase in generalization, which resulted in the increased inversion effect for the N170 amplitude of the inversion effect for normal faces. On the other hand, the study conducted here demonstrated that the N170 amplitude had reduced, and so did the generalization of the inversion effect for normal faces. In sum, based on the results from Experiment 1, we posit that the N170 component may index two different mechanisms; the latency index the anodal tDCS affecting feature salience modulation, whereas, the amplitude index the increase or decrease in generalization that is induced by the anodal tDCS, depending on whether the normal faces are presented alone or with other faces that generalize onto them.

We will now proceed with the discussion of the results from **Experiments 2a** and **2b**. This was the first in the literature to show the generalization of Thatcherized faces onto normal faces, to the extent that it influences recognition for normal faces. Experiment 2b served as a control by intermixing checkerboards that would not generalize onto normal faces, and this way, the sham condition measured the typical inversion effect in normal faces. On the other hand, sham in Experiment 2a, which had intermixed Thatcherized faces with normal faces, demonstrated a smaller inversion effect in normal faces. This difference in the inversion effect for normal faces between the two experiments show that generalization occurred between Thatcherized faces and normal faces. Fundamentally, both Thatcherized and normal faces are nonetheless, faces despite the Thatcherized manipulation, therefore, it is fathomable that there are shared units that paves the way for generalization to occur between them.

6.5.1 Thatcherized Faces according to the MKM model

We will explain this generalization between Thatcherized faces and normal faces in detail in reference to the MKM model. Firstly, we need to define the elements that are at play, which are two for each face type. In normal faces, there is the common feature, and the unique features. With Thatcherized faces, the elements are the altered features distinctive of a Thatcherized face, and features that are specifically unique to the Thatcherized faces. Some of the common and unique features found in normal faces will also be found in Thatcherized faces among with the latter two elements. These common features of normal faces will be shared across all the other Thatcherized faces, and now, they will become very salient. The detailed process of this is as follows: the common features of normal faces will be shared because incorrect predictions are made in Thatcherized faces from relying on other features present. This means that the mouth and/or the eyes will be predicted to be the right way up, and not inverted. Naturally, when the Thatcherized face is presented in an orientation that reveals the eyes and mouth are not the right way up, they will look striking because the expectation of the eyes and mouth in context to the rest of the face is not met. This is how these features seem exceptionally novel, which consequentially result in them to appear highly salient. We tend to learn more about commonalities than things that help us tell them apart, but this is now partly offset by the highly salient unique features in the Thatcherized faces and, instead, we learn the latter features rapidly. This makes it hard to discriminate upright Thatcherized faces. In the case of discriminating normal upright faces when intermixed with

Thatcherized faces, our tendency to learn more about commonalities is retained, but still result in poor recognition for normal upright faces. This reduction in performance for normal upright faces is reflected in the smaller net result of the inversion effect for Thatcherized faces in literature where tDCS is not applied (Civile, Cooke, et al., 2020; Rakover 1999; Maurer et al., 2002; Talati et al., 2010). The underlying reason for this result is because Thatcherized faces generalized onto normal faces. The answer to how this occurs is as follows: as stated earlier, Thatcherized faces still contain the common features of normal faces, but they are now difficult to predict and highly salient. If we are learning more about the commonalities than the unique features, then here, we are learning the unpredictable features from the Thatcherized faces, and generalize them onto normal upright faces. This is how recognition performance for normal upright faces decrease, and consequently lead to a reduced inversion effect. The direct evidence of this was provided by Experiment 2a and 2b of the current study where Thatcherized faces indeed generalized onto normal faces, yielding a reduced inversion effect in sham, but this did not occur when normal faces were presented with checkerboards. The tDCS effect on the combination of normal and Thatcherized faces may appear counter-intuitive in contrast to its effect on normal faces, where the tDCS behaviorally reduced the inversion effect by reducing performance on upright faces (Civile, McLaren, et al., 2018; Civile, Waguri, et al., 2020; Civile, Quaglia, et al., 2021). This occurs because the *common* features become nearly as salient as the *unique* features, and so reduces discrimination between upright faces, which is termed in the MKM model as the loss in error-driven modulation of salience. Normally we would expect a reduction in the inversion effect, because *the common features* and *unique features* would now have more equal salience, making performance on upright faces worse. However, with Thatcherized faces intermixed with normal faces, this decrease occurs because the harmful generalizations posed from the Thatcherized faces is removed by the tDCS, which results in the increased performance of upright, normal faces and the enhanced inversion effect. A detailed explanation of the effects of tDCS on Thatcherized faces in terms of the model of activation/salience can be found in Chapter 7.

6.5.2 Overall conclusion and future research implications

The two large studies reported here provided strong evidence that provided novel information of how stimuli are represented according to the MKM model, and the effects the tDCS procedure has on the face inversion effect and perceptual learning. Experiment 1 provided a novel understanding of the N170 ERP index of face recognition. The tDCS modulation on the N170 waveforms showed that its latencies may index the changes on feature salience modulation, and its amplitude may index generalization. Experiments 2a and 2b strengthened the generalization account, as the sham groups in both experiments showed that normal faces intermixed with Thatcherized faces significantly reduced the inversion effect in normal faces, compared to when normal faces are intermixed with checkerboards. The additional analysis that compiled the behavioral data from Experiment 2a and Experiment 1 confirmed the notion that anodal tDCS removes the harmful generalization Thatcherized faces posed on normal faces, which resulted in the reinstated inversion effect for normal faces to typical proportions. The additional analysis for Experiment 2b demonstrated this is not the case when normal faces are intermixed with stimuli that would not generalize onto them, because here, the anodal tDCS reduced the inversion effect for normal faces by increasing generalization.

Future research could aim to directly bridge the current findings with the claims from previous studies regarding the existence of both a special and expertise mechanism in face recognition. Specifically, if generalization can occur between normal faces and Thatcherized faces, but not between normal faces and checkerboards, could this be indicative of something parallel with how the tDCS cannot abolish the inversion effect in faces but can with checkerboards; i.e., anything that resembles a face adopts some face specific mechanism, while also sharing a general recognition mechanism that is in the territory of expertise that includes faces and expert objects. Future studies should also investigate how other types of stimuli could influence the inversion effect at baseline in normal faces.

Chapter 7: General Discussion

This marks the final chapter, and has the aim of summarizing and collating the key findings from all the experiments discussed in all the chapters of this thesis. Its implications will be discussed in relation to the key debates in face recognition as outlined in Chapter 1: **i)** How much of face processing is special and not special, especially in the context of the specificity vs expertise debate? **ii)** Could configural/holistic processing be the face specific mechanism? They will also be discussed in relation to the research and the MKM model that preceded these experiments. Finally, this chapter will conclude with suggestions for further research directions.

7.1 Key findings in the context of the face specificity vs expertise debate

7.1.1 Specificity 'vs' Expertise, or Specificity 'and' Expertise?

The prominent debate in the face recognition literature is the specificity or expertise debate. Are faces processed due to underlying mechanisms that are specific to faces (e.g., Yin, 1969) or are they due to our life-long experience and expertise with faces (e.g., Diamond & Carey, 1986)? The experiments from Chapter 2 maintain the notion that expertise via perceptual learning plays an important role as one of the underlying mechanisms for face recognition, which was first put forth by McLaren (1997) with prototype-defined checkerboards then later consolidated by Civile, Zhao, et al., (2014) by demonstrating a robust inversion effect in these checkerboards, and Civile, Verbruggen, et al., (2016) with tDCS. In addition to this perceptual learning component, Chapter 2 entertained the possibility of a face specific mechanism playing a role as well, and thereby, going against the grain of the specificity vs expertise debate, and rather, considered the possibility of *both* specificity and expertise. This stemmed from the findings between two studies, one by Civile, Verbruggen, et al., (2016), which showed that tDCS at Fp3 would eliminate the checkerboard inversion effect, by affecting performance for familiar upright checkerboards, while the other by Civile, McLaren, et al., (2018) showed that the very same tDCS procedure could only (significantly) reduce the inversion effect in faces. Crucially, the inversion effect found in checkerboards behaviorally (Civile, Zhao, et al., 2014) and in sham group was smaller than the typical face inversion effect (Civile, Verbruggen, et al., 2016; Civile, McLaren, et al., 2018). The immediate assumption of this was the difference in the level of expertise between the two stimuli, in the sense that lab-trained experience with checkerboards is inequivalent to the lifetime expertise, and that checkerboards are simply more difficult than faces. By using a matching task, which is easier than the old/new recognition task to control for this potential difficulty between the two stimuli, we were able to obtain the same anodal tDCS-induced reduction in the inversion effect for faces (Experiment 1a) and the abolished inversion effect in checkerboards (Experiment 1b). No main effect of *tDCS Stimulation* was found, thereby, confirming previous suggestions (e.g., Civile, Verbruggen, et al., 2018) that the tDCS does not simply reduce overall performance. Moreover, our Bayesian analyses indicated the results were in line with previous experiments that showed the anodal tDCS reduction of both face and checkerboard inversion effect relied mainly on the reduced recognition performance of upright stimuli (Civile, Verbruggen, et al., 2016; Civile, McLaren, et al., 2018). These are important findings that refute the explanation that the difference in the inversion effect size is due to checkerboards being more difficult than faces. Firstly, recognition performance for upright faces and checkerboards in the anodal group have similar level of performance which reflects an equally sufficient level of expertise for the two stimuli at baseline. The second reason reinforces this because there were no significant differences in the additional analyses across the experiments that directly compared the inversion effect in sham group for faces and checkerboards. Finally, in the additional analyses conducted across the experiments we found no significant differences between the overall recognition performance in Experiment 1a vs the overall recognition performance in Experiment 1b. Given these findings, we reject the argument that these results are due to different levels of expertise and in turn, allow us to reach the position that that the results rather indicate faces are both special, and not special (i.e., face-specific *and* expertise mechanisms are at play).

7.1.2 Implications for face inversion studies

7.1.2.1 Expertise account (e.g., Diamond & Carey 1986; Gauthier & Tarr, 1997)

The findings from Chapter 2 allows us to depart from the conventional debate where the specificity and expertise accounts are in contention, and it now opens the possibility of accepting both notions. This would mean that the narrative that expertise plays a role does not vary. We can say that the findings support Diamond and Carey's (1986, Experiment 3) notion, where expertise plays a role, as we have consistently obtained the inversion effect in checkerboard stimuli. Although in Diamond and Carey's (1986) case, dog images and dog experts were used to determine that an inversion effect that is as comparable to faces can be obtained in non-face stimuli. Gauthier and Tarr's (1997) experiments with Greebles would be more fitting in comparison with our inversion effect of artificial checkerboard stimuli, given that they have demonstrated an equally robust inversion effect with artificial stimuli. However, both authors (as well as others in favor of the expertise account) infer that the observation of expertise playing a role automatically invalidates the possibility of the face specific mechanisms be involved; this is where our findings depart with the expertise notion. More importantly, our findings provide support for the specific process of expertise, which is perceptual learning.

7.1.2.2 Expertise account - perceptual learning (McLaren, 1997; Civile, Zhao, et al., 2014; Civile, Verbruggen, et al., 2016; Civile, McLaren et al., 2018; Civile, Quaglia, et al., 2020)

The findings from Chapter 2 remain consistent with the notion that perceptual learning facilitates one to become an expert in a class of stimuli, and is therefore, reliant on this ability when recognizing faces and distinguishing non-face stimuli that are closely similar to each other (e.g., checkerboards). This was first put forth by McLaren (1997) through 2 experiments using prototype-defined checkerboards, showing that experience with exemplars of a category represented by a prototype (and have second order relational structure as a result of their variation about that prototype) leads to an increased ability to discriminate between members of that category. This improvement is lost when the stimuli are presented in an inverted orientation. Civile, Zhao, et al., (2014) later strengthened the analogy of perceptual learning with face recognition by demonstrating a robust inversion effect with checkerboards, but this time using the old/new recognition task, which is commonly employed in face recognition research. This was taken further by Civile, Verbruggen, et al., (2016) when tDCS at Fp3 was added to this task, which revealed that anodal tDCS abolishes the inversion-effect in checkerboards, by selectively affecting performance on familiar upright exemplars, and provides evidence for a reversal of enhanced generalization or perceptual learning. Similarly, Civile, McLaren, et al., (2018) showed that the same procedure but with face stimuli resulted in a significant reduction in the face inversion effect in comparison to sham control, due to the reduced performance in upright face stimuli (this has been replicated in their Experiment 2). Given that tDCS can provide some causal evidence, the findings from both Civile, Verbruggen, et al., (2016) and Civile, McLaren, et al., (2018) shows that this tDCS procedure modulates perceptual learning and recognition in terms of feature-salience modulation, which in turn, reduce the inversion-effect elicited by faces and checkerboards (after gaining expertise). Our findings from Chapter 2 are therefore, consistent with Civile, Verbruggen et al., (2016) and Civile, McLaren et al., (2018), and supports the interpretation that anodal tDCS induces the reduction of the inversion effect, by specifically impairing recognition performance in upright stimuli.

7.1.2.3 Specificity account (e.g,. Yin ,1969; Valentine & Bruce, 1986, 1988; Yovel & Kanwisher, 2005)

Crucially, the findings of Chapter 2 allow us to regard the specificity account as a coinciding mechanism alongside the expertise account. Going back to Yin's (1969) set of experiments, specifically, Experiment 1 demonstrated that face stimuli were poorly recognized compared to other classes of stimuli, which was suggested to be an inference of an underlying mechanism that is specific to processing faces. This was further confirmed with other stimuli such as houses and planes (Valentine & Bruce, 1986, 1988; Yovel & Kanwisher, 2005), which strengthened the face 'specificity' account. If we take a look at Chapter 2, consider that the tDCS procedure eliminates perceptual learning (i.e., expertise). The tDCS was able to reduce the inversion effect to the point of abolishment in checkerboards (experiment 1b) and not in faces (experiment 1a), given that core of the training and recognition for checkerboards is perceptual learning/expertise. Based on the assumption that people are already experts in faces, we did not train them in this category, however, the tDCS still significantly reduced the inversion effect in these faces. If perceptual learning is acquired as a strategy for recognizing faces, then this has been abolished with the tDCS, but the inversion effect still remains. This is where we can return to Yin's (1969) claim, where there is, perhaps a face specific component, as the tDCS can only abolish the inversion effect in a non-face class of stimuli. However, this also does not refute the *other* (i.e. expertise) account. Moreover, the specificity account does not explicitly put forth a particular mechanism that explains the recognition process other than its broad relation to an innate mechanism, or the FFA at most. This left us with the question: what components of the face processing mechanism is specific to faces, leaving others to be reliant on expertise? This will be discussed in the next section below.

7.1.3 Holistic processing – the face specific component and residue of the tDCS reduction on inversion effect

Chapters 3 and 4 consisted of a two-part investigation on whether holistic processing was the face specific component involved in face recognition, alongside the expertise/perceptual learning component. The possibility of holistic processing being face specific was indicated by Civile, McLaren, Milton, et al's., (2021) study, which reported that the same tDCS procedure used in Chapter 2 was unable to significantly modulate the composite effect (index of holistic processing). The experiments reported in Chapters 3 and 4 aimed to further investigate Civile, McLaren, Milton, et al's., (2021) finding, in checkerboard stimuli based on the assumption that if holistic processing was indeed the component the tDCS procedure was unable to modulate, the same outcome of no significant composite effect should be obtained with the checkerboard stimuli. This opened the question of are non-face, checkerboard stimuli fundamentally susceptible to the composite effect?

7.1.3.1 Perceptual learning and the composite effect (index of holistic processing)

Investigating whether the composite effect can be obtained from the checkerboard stimuli also provided the opportunity to explore if perceptual learning is involved in this effect. This also posed implications on whether perceptual learning is something related to or independent of holistic processing. Chapter 3 demonstrated a significant component of the composite effect, which was the congruency effect in the checkerboard stimuli. However, Chapter 4 showed that despite the significant congruency effect in Chapter 3, the composite effect could not be obtained with the checkerboard stimuli. This led to the conclusion that holistic processing is not subject to perceptual learning and expertise mechanisms, and that it rather signifies face specific mechanisms. Crucially, these findings provide supporting evidence for Civile, McLaren, Milton, et al's., (2021) results. This also allows us to agree with Tsao and Livingstone's (2008) study that suggested the composite effect is an index of specificity based on the findings when composite faces are aligned and shown in an upright orientation, the perception of the intact facial arrangement would permit access to face-specific processing, which is responsible for this composite effect.

7.1.3.2 Gauthier and Tarr (2002); Wong, Palmeri, et al., (2009)

While Chapter 4's findings were in line with Civile, McLaren, Milton, et al., (2021), they also contradicted with the results of Gauthier and Tarr (2002), and Wong, Palmeri, et al., (2009), where both studies demonstrated that a composite effect could be obtained from non-face stimuli (i.e., Greebles and Ziggerins). The problems with employing a partial design as opposed to a complete composite effect design has been considered, and our results demonstrated that by using the complete design, it does indeed test the composite effect, given that Experiment 2 (control) of Chapter 4 found a robust composite effect in faces. Instead, we shift the focus onto the difference in the checkerboard categorization training task used in our Experiment 1 in comparison to Gauthier and Tarr (2002) and Wong, Palmeri, et al's., (2009) training task, where they utilized individuation training. The key difference is that individuation particularly emphasizes subordinate level training as opposed to basic-level by categorization. Wong, Palmeri et al., (2009) have demonstrated a systematic comparison in extracting a composite effect in non-face, artificial stimuli between participants who underwent basic-level categorization and individuation training with Ziggerins, which was a variation of Gauthier and Tarr's (2002) individuation training with Greebles. Wong, Palmeri, et al., (2009) were able to show that undergoing individuation training does result in a composite effect with Ziggerin stimuli, as opposed to participants who underwent the categorization task.

7.1.3.3 Humanization and Top-down mechanism in face recognition

In a similar vein to individuation, Civile, Colvin, et al., (2019) have suggested humanization to affect the inversion effect, in the sense that an inversion effect could not be obtained in participants who viewed face images that were labeled as individuals with autism, as opposed to face images without this label. The inversion effect was re-established only after providing humanizing information. Moreover, a recent study by McCourt et al., (2021) directly showed that holistic information is involved in the face inversion effect. They investigated the inversion effect when the faces were manipulated to disrupt configural information, in terms of the spatial relationships among the main facial features, and when holistic information was disrupted by manipulating the face outline. In an old/new recognition task, scrambled faces were employed to index the disruption of configural information, and scrambled but no-contoured faces were used in addition for disrupting both configural information and face outline. The results revealed that there was a significant inversion effect found in scrambled faces, but not in scrambled non-contour faces. This provided the first direct evidence that holistic information plays a significant role in the inversion effect. Simultaneously, this shows that an inversion effect can be obtained in configurally disrupted faces. All of this would indicate that there is an element of personification/humanization, and a top-down manipulation of humanization by Civile, Colvin et al's., (2019) that can affect face processing, and specifically in the case of Chapter 4, this may affect the manifestation of the composite effect. In line with Civile, McLaren, Milton et al., (2021), all of this put together suggests that there may be an additional component other than lower-level perceptual processes, such as holistic processing, involved in face processing. Therefore, in terms of the specific vs expertise debate, Chapter 4 confirms Chapter 2's indication that in recognizing faces, expertise is a component and there is another component that is more specific to faces. Chapters 3 and 4 indicated that this face-specific component is in the domains of holistic processing, and that perceptual learning is not involved in holistic processing.

7.1.3.4. Other frameworks suggesting both specificity and expertise are at play.

Chapters 2, 3 and 4 of this thesis puts forth the notion that both specificity and expertise are involved in face recognition unlike the conventional debate where specificity and expertise are opposing. How would this fit with other frameworks that also suggest that face recognition processing is not distinctly one or the other? Other authors have demonstrated the possibility of both specificity and expertise are involved in face recognition, or have at the very least acknowledged the possibility that the debate is not a clear divide as it was initially perceived.

Zhou et al., (2010) suggests the integration of the two hypotheses of specificity and expertise. The authors investigated the role of specificity in face processing without awareness, to investigate if specificity is still involved when faces are not as deliberately processed in comparison to the typical face recognition tasks that instruct participants to fixate and remember faces. The authors employed a binocular rivalry task with upright and inverted faces or houses on either the left or right fixation point by blending the images with a dynamic noise pattern. One group viewed the stimuli binocularly (nonrivalry) and the other viewed dichopitcally. The results revealed that for invisible upright faces, noise suppression was broken faster than its invisible counterparts. No difference was found for invisible upright and inverted house stimuli, suggesting that face processing without awareness is also specific. The authors highlight that because expertise was not manipulated in their experiments, its limitation is the lack of ability to fully rule out expertise. They speculate that while faces are special and houses are not, when expertise with non-face objects increase, there is the possibility of its processing to become closer to face processing, however, it will never reach the equivalence of face processing which has a specificity component. While this does imply that there is the consideration among researchers regarding the possibility of joining the two hypotheses, the caveat with Zhou et al's., (2010) suggestion is that the authors had not tested this speculation, and its inference is not derived from actual experimentation they have conducted within their experiment, nor is it clarified what literature they based the strong claim that face processing will never be as equal to face processing.

Weiner and Zilles (2016) have also pointed to the possibility that both specificity and expertise are possible. The authors reviewed the literature regarding the fusiform gyrus and highlighted that there may be a co-occurrence of cortical folding patterns and cytoarchitectonical (the cellular composition of the central nervous system tissues), which provide a meaningful function in the fusiform gyrus. Weiner and Zilles (2016) argued that this would imply that both face perception and expertise processing would rely on different combinations of neurons across cortical layers within face-selective regions. Similarly, Spunt and Adolphs (2017) proposed that domain specificity and expertise can be dynamic and context sensitive. More specifically, they suggest a possibility of a connectivity profile of a brain region together with experience of a specific domain. Based on the authors' previous neuroimaging study (Spunt & Adolphs, 2015), the authors explain in the context of face recognition in social situations, there appears to be a computational function of a component that is experience-dependent which results in domain specificity.

More concrete inferences of expertise and specificity mechanisms working in relation to each other were highlighted by Gauthier, Tarr, Anderson et al's., (1999) study. This study was initially discussed in Chapter 1. In contrast to research suggesting that the fusiform gyrus is specialized for human face perception, their findings suggested that the activation of the middle fusiform area can also be activated for viewing upright greebles compared to inverted ones which participants were experts in as opposed to novices. While the results suggest a strong expertise effect in the fusiform area, the authors emphasize that expertise is not the sole factor that contributes to the specialization of the middle fusiform gyri for face processing. They draw this interpretation by taking into consideration of research in FFA that suggest the specificity plays a role, as well as their previous research with Greebles. Other authors have demonstrated that the difference in recognizing faces and categories of objects is that faces are recognized to the specific level in terms of identity, while objects are recognized less specifically. Moreover, higher activation is found for faces than objects even when participants select objects from a single category (McCarthy et al., 1997) or when participants are required to discriminate similar looking objects (Kanwisher, McDermott et al., 1997). The authors posit that this would suggest that categorization level is not the only factor that determines specialization of the middle fusiform gyri, but neither does it exclude some role for categorization level. The authors refer to two of their previous studies, Gauthier, Anderson, Tarr et al., (1997) and Gauthier, Tarr, Moylan et al., (1998), which revealed that when recognizing non-face familiar objects at a more specific level (i.e., pelicans rather than simply birds), this leads to activation of the face-selective part of the middle fusiform gyri. Activation for passive viewing of faces minus objects as opposed to specific non-face object recognition, showed that the magnitude for faces was comparable and fell within range of specific-object recognition, although this was much more focused. Based on this, the authors summarized that there is still the possibility for an interaction between the two factors of specialization and expertise, because the level of categorization may constitute a broad specialization in the middle fusiform gyri, and with expertise for the subordinate-level recognition would compound and lead to further specialization and therefore, more focused activation. This slightly touches on the individuation categorization from Chapters 3 and 4, where expertise with the subordinate-levels of a category is what leads to a comparable performance to faces. Although, this was specific to the composite effect, therefore, it would be interesting to further explore this in terms of passive viewing of checkerboards vs faces, as well as the inversion effect and our tDCS procedure; referring back to the suggestion from Chapters 2, 3, and 4 regarding the possibility of both specificity and expertise (i.e., perceptual learning) playing a role, it might as well be that perceptual learning is involved that leads to expertise and builds on the already specialized mechanism, but more research is needed to determine how perceptual learning may or may not differ at category level training and subordinate level training.

Interestingly, Bukach et al., (2010) suggested that perceptual expertise in a particular class would not generalized onto distinct subclasses, by showing that modern-car experts discriminate with high accuracy and demonstrate holistic processing with modern cars, but not with antique cars, despite the fact that both categories are cars. Because there are limitations in generalization of expertise among various subclasses within faces and non-face objects, the authors suggest that there are implications for a category specificity system as well. However, that does not rule out any generalizations between face and non-face objects. For instance, in Tanaka et al's., (2005) study, it was suggested that perceptual expertise with birds requires individuation experience, and this individuation training was also shown to improve recognition for subclasses in face recognition and reduce the other-race effect (Lebrecht et al., 2009). Considering that this was not the case with modern car experts with antique-cars, the authors posed the question of whether a modern-car expert acquiring expertise with antique-cars differ than expertise with birds. This would also be an interesting avenue for future research to observe if there are any transference of expertise skills between checkerboards and faces, and how this fits into the framework of unifying the specificity and expertise accounts.

Extending on the interaction of category types with specificity and expertise, Gauthier, Skudlarski et al., (2000) showed that categorization and expertise determines the specialization of the FFA. Specifically, the authors investigated the fusiform gyri and the occipital lobe and how expertise with unfamiliar objects (i.e., Greebles) recruit these supposedly face selective areas of the brain. They tested bird and car experts with fMRI during tasks with faces, familiar objects cars, and birds. Categories that were homogeneous activated the FFA more than familiar objects, and the right FFA and OFA showed significant expertise effects.

Developmental studies have also highlighted the possibility of a face-specific process as well as some domain-specific processing that facilitates face recognition. It has been demonstrated that domain specificity in face recognition, or at least the pattern of face-specific processing is only observed after a particular age (after the age of ten years; Aylward & Meltzoff, 2005;

Golarai et al., 2015; Hills & Lewis, 2018). From the ages of nine and ten years, an increase in face-recognition expertise has been observed (Hills & Lewis, 2018). On the other hand, there has been a suggestion that face memory increases as domain-specific (Weigelt et al., 2013) as it has been observed that in children across the ages of 5 to 18, the hit rate for upright faces increased, unlike memory for inverted faces (Hills & Lewis, 2018). Future research may investigate the interaction between domain-specific components of face memory and expertise/perceptual learning in face recognition.

In sum, the aforementioned studies show how other frameworks, or different combinations of frameworks also suggest the notion that both specificity and expertise processing are at play, although there is still a lack of understanding in the specific mechanism of how the two processing function together and whether one processing is more dominant than the other. Future research may investigate how the perceptual learning and face recognition literature may fit in with the other proposed frameworks.

7.1.3.5 Order of trials effect and the composite effect

In addition to uncovering holistic processing as a face specific component, Chapters 3 and 4 also revealed that during the matching task, the order of the trials affected recognition performance. Presenting incongruent trials first, followed by congruent trials resulted in both the congruency effect (Chapter 3, and only in novel checkerboards in Chapter 4) and the composite effect in faces, but neither were extracted when the trial orders were reversed. This was the first evidence in the literature where the order of the congruent and incongruent trials was revealed to be modulating the congruency effect. A potential explanation was that generalization occurred from the categorization phase when congruent trials were presented before incongruent trials. This seemed to be primarily affecting familiar stimuli on congruent trials, which potentially led to finding of the trial order effects in both familiarity and congruency factors in the analysis. This is because for congruent trials the generalization leads to the different stimuli to seem more recent in the familiar category case. We further investigated this in Chapter 4 to ascertain if this order of trials effect can be replicated and if it would also determine the extraction of the composite effect with faces. Here, it was confirmed that the order of trials presented does indeed affect both the congruency and composite effect in novel checkerboards, and the composite effect in faces. The interpretation regarding this order of trials effect was that it could be attributed to *proactive interference*.

A question that may come to mind here is, why we counterbalanced the matching task to begin with, and what is the necessity of doing so in investigating the composite effect? It can be argued that opting to randomize congruent and incongruent trials would be beneficial to prevent any biases from occurring. Our intention behind counterbalancing the trials in the first place was so that we could corroborate the composite effect results of the checkerboard stimuli with the composite faces, particularly with previous studies within the lab investigating the composite effect in faces, which also had an experiment involving the counterbalancing of trial orders (among other combinations of trials). This finding of the order of trials effect/proactive interference, was also crucial for us to revisit our procedures when investigating the *inversion effect*, which is what Chapter 5 set out to do (this will be discussed in detail below). That being said, the experiments from Chapters 3 and 4 does lack a comparative approach, for instance, directly comparing the effects of counterbalanced presentation of the trial order, and with trials that are randomized. Future research should investigate this further, as well as comparing methods that may break the buildup of proactive interference, for instance, by investigating this is to conduct the old/new recognition task with checkerboards, where one group of participants have a break between the categorization task and study phase, while the other group would not have a break.

7.1.4 tDCS on the inversion effect: Proactive interference vs perceptual learning

The finding of proactive interference when investigating the composite effect led to the concern of whether the same interference was affecting the checkerboard and/or face inversion effect in the experiments of Chapter 2, and potentially the previous inversion effect studies, which put the perceptual learning interpretation of the tDCS into question (e.g., McLaren, 1997; Civile, Zhao, et al., 2014; Civile, Verbruggen, et al., 2016; Civile, McLaren, et al., 2018). Based on the behavioral findings from Chapter 5, we can infer that the tDCS is not inducing this effect of order/proactive interference with the face inversion effect, given that the tDCS affected recognition performance only in upright faces, whereas proactive interference affected overall performance of both upright and inverted faces. This confirms three things from Chapter 2: i) the difference in the tDCS-effects on the checkerboard inversion compared to the face inversion effect is perhaps due to the difficulty of the old/new recognition task when performing a checkerboard task when performing a checkerboard task; ii) Chapter 2 was able to fix this by opting for an objectively easier matching task; iii) The tDCS does modulate perceptual learning, which affects the inversion effect by worsening recognition for upright stimuli. Taking everything together, proactive interference appeared to affect the congruency effect and/or familiarity, but not the inversion effect.

7.1.4.1 Future directions to test proactive interference in checkerboards

One could argue that in Chapter 5 we did not directly test proactive interference on the inversion effect for checkerboards. Testing this effectively in checkerboard stimuli involves many considerations, because any paradigm involving the checkerboard stimuli would require the additional process of training/learning the classes of checkerboards to reach expertise before being able to test the inversion effect, let alone the effects of proactive interference for the checkerboard inversion effect. If altering the trials is not a valid option for testing the effects of proactive interference with the checkerboards in an old/new recognition task, then implementing methods that may alleviate proactive interference within the task would be of interest for future research, as any differences (i.e., improvement) in recognition performance would indicate that proactive interference had been affecting the old/new recognition task with checkerboards. Typically, providing a break, whether this is in the form of an inter-trial break or an unrelated task relative to the experiment is implemented after the learnt materials, would reduce the effects/build-up of proactive interference (e.g., May et al., 1999; Lustig et al., 2001; Blalock & McCabe, 2011). However, these breaks could counteract the learning required for participants to become experts in the checkerboard stimuli, which is crucial for extracting a robust inversion effect. This was shown in a recent pilot study within our lab, which investigated whether a long break (15 minutes) consisting of a composite effect task would alleviate the proactive interference between a checkerboard categorization task and a study/recognition task with checkerboard. The results revealed poor performance in the study/recognition task, and this was attributed to the fact that the 15-minute interval task with composite faces was too long, and that the learning, which participants experienced from the categorization task had been forgotten. In terms of the current study, if we were to test proactive interference on the checkerboard inversion effect, the expected solution would be is to have participants train in the categorization task of faces or checkerboards (between-subjects) and undergo the old/new recognition task with upright or inverted checkerboards (within-subjects), with perhaps shorter inter-trial breaks, while another group undergoes the same task but without the inter-trial breaks.

Other methods of alleviating proactive interference have been suggested, such as testing memory when learning a list of words (Szpunar et al., 2008; Darley & Murdock, 1971; Pastötter et al., 2011). However, the old/new recognition task is already testing memory. It could be argued that the memory test could be inter-trial, and higher in frequency within the old/new recognition task, but then this would defeat the purpose of the old/new recognition task and would result in an inaccurate measurement of the inversion effect, therefore, the use of inter-trial testing would be redundant. Alternatively, opting for a cued-recall paradigm could be a potentially feasible method in alleviating the build-up of proactive interference, or at least a variation of it. The widely used A-B, A-C paradigm (Underwood, 1957) is often employed to research retroactive and proactive interference by employing repeated cues to test whether learning one cue-target associations impairs learning of a subsequent association of the same cue with a different target. However, this would require some tweaking if we were to use it for the checkerboard stimuli. Weinstein et al., (2011) used a variation for face-name learning research, A-B, C-D unique cue-target association because every cue would be a unique face. This decision was based on the classic response competition explanation where unique cues should eliminate proactive interference (i.e., McGeoch, 1942). However, the results revealed that this was not the case, and in fact, this negatively impacted with the buildup of proactive interference. Consequently, testing after participants learnt each list counteracted proactive interference as it served as a “reset”. When it comes to implementing this in between the categorization/training phase and old/new recognition with checkerboards, on the one hand we have the problem with inter-trial testing, and on the other hand, the use of the unique cued-recall paradigm would be something one may hesitate from using for preventing proactive interference. Especially if we consider that checkerboard exemplars are individually unique, a similar result to Weinstein et al., (2011) could be anticipated. However, a key difference is that checkerboards are categorized and do not require to be named individually, therefore, this may be of interest for future studies to look into, or perhaps investigate a variation of this unique cue-target paradigm so that it could be implemented to test the role of proactive interference in the checkerboard inversion effect.

There are also some unanswered questions from the current study, one particularly being why proactive interference significantly affected the congruency effect and not the old/new recognition task (i.e., face inversion effect). At first glance, we can speculate that perhaps, the task from Chapters 3 and 4 (i.e., matching task) is fundamentally different to the current old/new recognition task, however, the prime problem is not the inability to find proactive interference in the old/new recognition task testing the inversion effect, but rather, how this was possible to manifest in the matching task testing the congruency effect. Once again, the results defy the notion that providing breaks would prevent the build-up of proactive interference, however, in Chapters 3 and 4, both tasks employed a keyboard training task between the study phase and matching task, which should serve as a break, yet the results showed otherwise (i.e., proactive interference affected the congruency effect). Addressing this is beyond the face recognition paradigm, and it enters the domain of the proactive interference paradigm, but this would also be a direction for future research to elucidate.

7.1.5 The inversion effect, generalization, and the N170

Finally, Chapter 6 explored the converse effect of the tDCS effect observed in Chapter 2 (reduced upright face recognition and inversion effect). Here, we investigated the effects when tDCS improves recognition for upright faces. This was a crucial investigation in strengthening the generalization and features salience modulation theory accounted by the perceptual learning theory, establishing a technique that allowed the *enhancement* of face recognition, as well as uncovering what the amplitude and latency of the N170 ERP component indicate.

7.1.5.1 Civile, Cooke, et al., (2020)

The findings from Chapter 6 confirmed the results of Civile, Cooke, et al., (2020), which was the first to demonstrate the selective improvement in upright faces, when upright and inverted Thatcherized faces were intermixed in the same procedure as Civile, McLaren, et al., (2018) of engaging participants in an old/new recognition task with upright and inverted normal, while tDCS was administered. Chapter 6 was able to replicate this robustly. Importantly, Civile, Cooke, et al., (2020) proposed an explanation that the anodal tDCS-induced enhancement was potentially due to the elimination of harmful generalizations between Thatcherized and normal faces. Experiments 2a and 2b directly tested and confirmed the notion that Thatcherized faces generalize onto normal faces sufficiently, and therefore reduce the inversion effect. Such generalization and reduction in the inversion effect could not be observed when normal faces were presented with checkerboards, which was further confirmed upon additional analysis. The latter finding indicated that the anodal tDCS procedure produces the effect of significantly reducing the inversion effect, which is consistent with previous literature (Civile, Verburggen, et al., 2018; Civile, Waguri, et al., 2020; Civile, Cooke, et al., 2020; Civile, McLaren, Waguri, et al., 2020; Civile, McLaren, Milton, et al., 2021; Civile, Quaglia et al., 2021). This indirectly reinforces the findings in Chapter 5, where it was shown that including a checkerboard categorization task with an old/new face recognition task would not significantly affect the inversion effect (albeit, the checkerboard stimuli were not intermixed like Chapter 6, Experiment 2b). Altogether, the findings support the MKM model of perceptual learning and its role in face recognition as initially posited by Civile, Cooke, et al., (2020).

7.1.5.2. Civile, Waguri, et al., (2020)

Here, we investigated the effects of the behavioral modulation of the inversion effect and its correspondence to the electrophysiological modulation of the N170 ERP component, by adopting concurrent tDCS and EEG (Civile, Waguri, et al., 2020). The literature regarding the N170 lacks consensus as to what the amplitudes and latency convey, and findings from Civile, Waguri, et al., (2020) added to this ambiguity, where the N170 responses dissociated for the tDCS-induced effects on the inversion effect. For the *latencies*, the tDCS reduced the usual face-inversion-effect (delayed N170 in response to inverted vs. upright faces) compared to sham, thus reflecting the behavioral results.

Contrary to this, the same tDCS procedure increased the inversion effect seen in the *amplitudes* by increasing the negative deflection for the inverted faces than for the upright faces. The tDCS effects on the latency were analogous to the behavioral results, and also fit the narrative of the N170 literature where there is better consensus regarding the latency (more so than the amplitude, which posits that the delay could be attributed to the longer response in inverted faces due to the disruption of configural information (Eimer, 2011). In light of this dissociation, Civile, Waguri, et al., (2020) initially proposed that the amplitude and latency may index different mechanisms; the discrepancy between the increased amplitude and decreased behavioral performance points away from behavioral indices, and rather, suggests that the N170 amplitudes could be an index of increased generalization, as induced by the tDCS procedure. The increase in generalization reduces recognition performance, which in turn, reduces the N170 latency. Experiment 1 of chapter 6 offered the full picture by investigating the N170 latencies and amplitudes when the inversion effect was enhanced. This time, despite the tDCS-induced improvement in the inversion effect and upright face recognition, the N170 latencies were reduced as observed in Civile, Waguri, et al., (2020) when upright face recognition was reduced by tDCS. However, the amplitude showed the opposite outcome to Civile, Waguri, et al., (2020) and this time, there was a reduction in the amplitude. This suggests that anodal tDCS at Fp3 will always significantly reduce the inversion effect on the N170 latency, whether the behavioral inversion effect for normal faces is enhanced or reduced. Regarding the anodal tDCS effects on the N170 amplitudes, this confirmed Civile, Cooke, et al's., (2020) interpretation of the tDCS effects on the N170 ERP upon inversion. This may explicate the unclear amplitudes in other N170 studies, such as Rossion, Kung, et al., (2004), which investigated the effects of perceptual training with Greebles on the N170 in comparison to faces to test potential confounding facts such as attention and perceptual competition. The method is of key importance here: In each training trial, a Greeble appeared as fixation for 600ms, then a face was added in either the left or right visual hemifield. Participants had to report which side the face was presented. The results revealed that while the ERPs before and after training revealed that the N170 was affected by perceptual training, the amplitudes here were reduced for lateral faces after training with greebles. Given that greebles are somewhat face-like, this may be an indication that at first, facial features generalized onto greebles, however through the course of training where participants had more exposure to the greebles, the two stimuli no longer generalized. However, more research should be conducted to test the role of generalization outside the context of the inversion effect.

7.1.5.3 Limitations

One limitation, as well as an avenue for future research is that Chapter 6 did not have a baseline comparison between regular faces and checkerboards with intermixed Thatcherized faces. That being said, there is the difficulty of emulating this with checkerboards, given that Experiment 2b (and Chapter 5, experiment 1b) showed that checkerboards do not generalize onto faces, therefore, the converse of faces (let alone Thatcherized faces) generalizing onto checkerboards is unfeasible. One possible solution is to emulate the Thatcherized effect in the checkerboard stimuli, however, careful considerations must be made. Thatcherization in face stimuli involves the facial features to be inverted. Checkerboards are non-mono-orientated, and do not have ‘features’ alike faces. Manipulating similar to facial configurations may result in the checkerboard to become face-like, therefore, randomizing or selecting certain sections of the checkerboard stimuli to be inverted may be plausible, although, this should also be systematically tested.

7.2 MKM-Theory (McLaren, Kaye, et al., 1989)

The MKM model has been the core theory used as guidance in researching the role of perceptual learning in face recognition in this thesis. The MKM model explains perceptual learning as discrimination between AX and BX, by which pre-exposure facilitates X elements to become better predicted (giving them lower salience) and increase relative salience for the unique A and B elements, due to their high error. This is because according to the MKM model, activation of an element/unit according is a function of how much input it receives. Salience modulation by error, operates by providing a boost to the input that an element receives that depends on its error. This is how initially near indistinguishable stimuli of the same category (e.g., faces, checkerboards) are recognized. Upon inversion, this is lost as there is no pre-exposure to the inverted stimuli. The role tDCS plays in modulating face recognition has been explained in the context of the MKM model in Civile, Verbruggen, et al., (2016) and Civile, McLaren, et al's., (2018) studies, which interpreted that the tDCS procedure is in fact changing error-based modulation of salience to the point that its typical operation no longer occurs. Specifically, the usual logic of high error producing high salience is now reversed by the tDCS procedure, and is now reducing/abolishing the modulation of salience by error. This means that predicted elements become more salient than unpredicted, novel elements within a stimulus. Chapter 2 provided consistent support for this interpretation where the tDCS was able to ‘reverse’ perceptual learning in face stimuli (experiment 1a) and checkerboard stimuli (experiment 1b), albeit the reversal was an abolishment with the checkerboard stimuli.

Crucially, Chapter 6 advanced the MKM model of generalization and activation salience with the enhanced inversion effect and recognition for upright faces when normal and Thatcherized faces are intermixed. This was attributed to the loss of harmful generalization between the Thatcherized and normal faces via tDCS. This will be explained in terms of the MKM model of activation/salience. The activation in this context is determined by the total input to the unit or element representing a particular feature, and determines salience. The input is contingent on the modulation by error. High and positive error results in high input and consequently, high activation. Novel features start with high activation and are less predicted/salient. As their predictions increase, which is facilitated by the other elements present, then error, followed by activation, and salience falls. This explains how the common features of a face are perceived; these are represented by elements with lower salience, because they will be well predicted and have lower error than the unique features. This is the how the research with faces and checkerboard have been accounted for in terms of perceptual learning (Civile, McLaren et al., 2014; Civile, McLaren et al., 2016; Civile, Zhao et al., 2014).

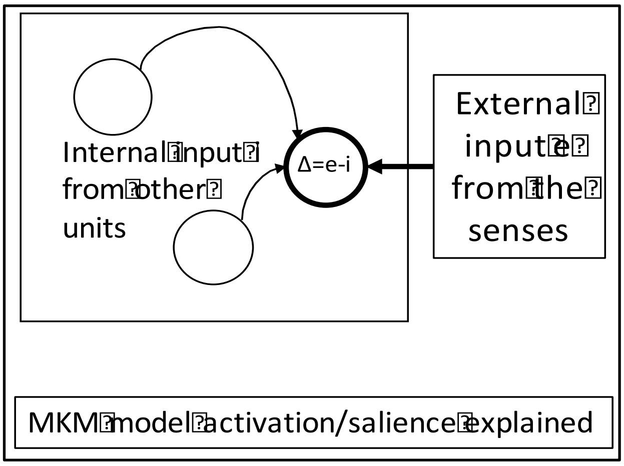

Figure.7.1 Activation (salience) in the McLaren, Kaye and Mackintosh (MKM) model. The activation of a target unit shown in a function of the total input it receives modulated by ∆. Activation depends on e+i+k∆e where k is a large positive constant (e.g., 50). Modulation only occurs when ∆>0. ∆ determines net effect of activation. High error means high activation. However, without modulation, a lower error would mean more activation, because then e+i is greatest. (McLaren, Kaye, et al., 1986).

The impact of anodal tDCS is that it switches off this modulation, and results in the altered salience profile of the features in a given face. The common features now have low error, which results in these features to be the highest in salience. In reference to the equation (see Figure.7.1), this means that *e* and *i* are roughly equal, which amounts to approximately *2e.* For unique/novel features, they have high error, and are therefore, less in activation and salience than the common feature, which gives the input a single *e* because *i* is near zero. As described earlier, the eyes and mouth of the Thatcherized faces are super salient, because the conjured expectation in context to the rest of the face is not met. The predicted features are lacking, and instead, inverted eyes and mouth have taken its place, which stands out. This is how these features are ‘super’-salient; their salience is greater than novel features, as well as the error because incorrect features compound onto the absence of the predicted features. This is represented in the equation as error, $\Delta = 2e$ because the elements representing these feature have an external input of e, but an internal input of $i = -e$. This results in modulation to amount to $100e$, which is high, and embodies the super-salient nature of these features. However, this does not apply upon inversion, because inverted faces have low predictions due to the lack of experience with them. This explains one of the factors involved when perceiving an upright Thatcherized face. This is contrasts with normal faces, which have a higher number of predicted features. This lowers their salience in normal faces, and facilitates the unique features of the face to be relatively salient (unless prediction increases through familiarity), and this helps the discrimination between two faces.

Next, we explain how all of this affects generalization. When normal faces are intermixed with Thatcherized faces, the tDCS decreases generalization between faces. The net input according to the equation is approximately $e - e = 0$. This means that the features are weakly represented. For the heightened salience of the features common to both Thatcherized and normal faces, this will also reduce lower than normal faces, while roughly equal to the salience of novel features (input of e). With the stimulation, the net result is that normal upright faces experience the beneficial effect of reduced generalization that offsets the reduced salience in the unique features in normal faces, and ultimately result in an increased inversion effect for normal faces.

7.2.1 Can other perceptual learning theories explain these findings?

7.2.1.1 The delta rule (Δ) or error term: McClelland and Rumelhart (1985) vs MKM (McLaren, Kaye et al., 1986)

The MKM model is one out of many perceptual learning theories. Is there the possibility for other theories or models of perceptual learning to explain/predict the findings of the current thesis, as well as the previous literature regarding perceptual learning and face recognition (e.g., Civile, Zhao et al., 2014; McLaren 1997)? We will first revisit McClelland and Rumelhart's (1985) theory, which was discussed briefly in Chapter 1 of this thesis to explain the foundations of the MKM theory. The key difference between the MKM (McLaren, Kaye et al., 1986) and McClelland and Rumelhart's model (1985) is the delta rule (*Δ*), or error term. McClelland and Rumelhart's (1985) delta rule is employed based on the framework of connectionist network that denotes distributed stimulus representation for modelling categorization learning and recognition. In this case, the learning algorithm in combination with the activation function leads to higher salience in features that are frequently co-activated. As a result, it is the common features of a stimulus that forms the strongest links. If we apply this to the checkerboard studies, this would mean that the common features between the exemplars and the category prototype is the most salient, meaning, individuals pre-exposed to prototype-defined categories of stimuli, such as checkerboards, would become worse at discriminating new exemplars drawn from the familiar categories. Consequently, generalization would be increased instead of the perceptual learning effect that has been observed throughout the thesis and in previous literature. For this reason, the MKM can arguably explain the findings of this thesis better in accuracy.

7.2.1.2 Explaining the disadvantage in recognizing inverted exemplars drawn from that category: Honey and Hall (1989); McLaren (1997), McLaren, Kaye et al., (1986)

Next, we will focus on the explanation of how the familiarity with a prototype-defined category leads to the disadvantage in recognizing inverted exemplars drawn from that category. McLaren (1997) suggested that this is related to the finding of participants capability in categorizing exemplars even when they are inverted. This was revealed by several tests that had been administered at the end of the experiments in McLaren's (1997) study, which showed that participants were able to classify with above-chance accuracy of the correct categories inverted exemplars belonged to for both prototype-defined categories and shuffled categories. Civile, Zhao et al., (2014) highlighted two possible mechanisms that may explain the disadvantage for inverted exemplars drawn from a familiar category. One of them is the "learned distinctiveness" effect and "learned equivalence" effect put forth by Honey and Hall (1989). Learned distinctiveness refers to the notion that the various labels attached to each exemplars would aid in discriminating said exemplars. It is suggested that this occurs when discriminating between an exemplar from one category (e.g., "A") and an exemplar from the other (e.g., "B"). On the other hand, learned equivalence effect can be expected when the discrimination is within category, which is when generalization enhances between the stimuli and makes discrimination more difficult. This effect can be expected for both upright and inverted exemplars drawn form a familiar category, however, Civile, Zhao et al., (2014) argues that the perceptual learning benefit with the upright exemplars would compensate for this effect. It is when this compensatory effect disappears upon inversion, where learned equivalence manifests as a cost which may explain why the familiar inverted exemplars are poorly recognized compared to novel exemplars. This notion is plausible with supportive evidence, however, such effect has not been observed with the shuffled stimuli in Civile, Zhao et al's., (2014) Experiments 1B and 3B, nor in McLaren's (1997) Experiment 1b, which is where this effect should have manifested because it is not dependent on a category being prototype-defined. The second possible mechanism is predicted by the MKM theory, and depends on category structure. The ability to categorize inverted exemplars with prototype-defined categories suggest that features within these exemplars can form some mental representation of the structure of its category, which corresponds to the upright, prototypical structure experienced during the training phase. The MKM theory suggests that this ability facilitates the manifestation of differential salience of the unique elements of an exemplar for better learning and memory. With inverted exemplars drawn from a familiar category, the disadvantage in discriminating them emerges because the predictions made by retrieving prototypical structures will be incorrect as they do not correspond to the layout of the black and white squares of the inverted exemplar. Now, the elements that become differentially salient are randomly determined, particularly with the element common across most exemplars due to the higher occurrence of them. This overshadows the unique elements and simultaneously add unwanted noise for discrimination, resulting in the disadvantage for inverted exemplars drawn from a familiar category.

7.2.1.3 The comparison process vs the MKM model

An alternative process of perceptual learning was put forth by Mundy, Dwyer et al., (2006), Mundy, Honey et al., (2007), Dwyer and Vladeanu (2009), and Mundy, Honey et al., (2009) through studies involving human participants who were presented with face stimuli, which showed that simultaneous or alternated presentation of a similar stimuli leads to better discrimination during a subsequent test phase. They posit that this is indicative of a “comparison process”, which refers to stronger perceptual learning lead by the comparison of stimuli that are required to be discriminated later, which is otherwise not observed for those who are equally exposed to these stimuli but are not provided the opportunity for comparison. Let us apply this interpretation to our results as well as Civile, Zhao et al., (2014) and McLaren (1997). In the categorization phase, the participants successively compare each exemplars that are either between and within categories. Assuming that this generalizes onto new exemplars, participants would eventually be better at discriminating both within and between categories, and consequently, this predicts an advantage in later recognition for upright exemplars drawn from familiar category. This is also referred to as a “blocked schedule of exposure”, and the refined MKM model, the MKM-APECS hybrid model by McLaren, Forrest et al., (2012). This prediction of the comparison process account aligns with the observations of our findings and previous lines of experiments conducted by Civile, Zhao et al., (2014) and McLaren (1997), and this has the capacity to predict that upon inversion, there would be a loss of perceptual learning. However, if we consider the other findings where the inversion of exemplars drawn from a familiar category leads to worse recognition performance than novel exemplars, this is not something that can be explained by the comparison account. Another issue with the comparison account is explicating the shuffled stimuli in Civile, Zhao et al., (2014), where they showed that the shuffled stimuli does not lead to perceptual learning. Following the logic of the comparison account, if people are able to learn to categorize the shuffled stimuli, then they should benefit the same comparison process as when they are exposed to prototype-defined exemplars, however, this was not the case. Therefore, to my knowledge, it seems that the MKM-based models may be the only theories capable of explaining these aspects fully.

7.2.1.4 Perceptual learning or just strategic fixation on a location of the stimuli?

Another concern for whether we can attribute our findings to perceptual learning is in terms of how participants perceive the stimuli. It has been suggested that under some conditions of perceptual learning, participants may simply learn where they should look on the stimulus to discriminate, which would not imply a general enhancement in discrimination by perceiving the content of stimulus (Jones & Dwyer, 2013; Wang, Lavis et al., 2012). This would imply that rather than perceptual learning taking place across the categorization phase for discriminating faces/checkerboards, the obtained results, such as the inversion effect, is due to participants learning a particular location on each stimulus during the categorization phase, and use this strategy successfully during the recognition phase for upright familiar exemplars, but not for inverted familiar exemplars. This is indeed a plausible strategy, however, in the experiments of this thesis and prior studies (e.g., Civile, Zhao et al., 2014), learning to fixate on one location cannot be fully relied on. This is because the checkerboards used in these experiments are all randomly generated, which results in no particular region that can be focused on for detecting a discriminating feature. While the categorization training can encourage participants to look for particular regions on a stimulus that individuate them as either exemplars for Category A or B, this cannot be applied for discriminating exemplars within each category. This was ensured and tested in the recognition phase by using only one of the familiar categories from the categorization phase during the study/recognition phase.

This way, improved recognition performance is not entirely reliant on any enhanced ability in distinguishing between categories via experience. Finally, Civile, Zhao et al., (2014) argue that in their experiment with shuffled stimuli, given that these stimuli were more easily categorized, and if this is to be taken as an index of success in learning the necessary strategy, the inversion effect should have been larger in Experiment 1B rather than nonexistent, but this was not the case. Considering all the explanations above, it is to my knowledge that the MKM is better able to explicate the findings of this thesis.

7.3 Interpreting the effects of tDCS empirically

One common, yet justifiable argument is that the effects of tDCS can be unclear at times. Much of this thesis' chapters and background literature that scaffolds each experiment in the chapters heavily rely on results from tDCS-induced performance, therefore, addressing this is crucial. The typical expectation is that anodal stimulation excites the cortical neurons, and therefore improve performance, and cathodal stimulation results in the vice-versa effect. However, this is not always the case. How this is sometimes deviated was briefly mentioned when discussing Ambrus et al's. (2011) findings in Chapter 1. It is known that anodal and cathodal stimulation can have varying results based on the region of stimulation, duration, polarities, and intensity. However, this remains an obscure effect reported by many studies (for a review, see Jacobson et al., 2012) with little clarity.

7.3.1 Interpreting tDCS-induced effects on performance in motor learning studies

Many of the tDCS studies that exhibited this opposite effect or at times obscure effects were obtained from research that involved stimulating the motor cortex, M1 region, to investigate motor learning (Nitsche, Schauenburg, et al., 2003; Stagg et al., 2011). Some studies have suggested that the timing of delivering stimulation would affect performance differently. Administering tDCS on the M1 during a task will yield the expected result of enhanced performance/learning (Kuo, Unger, et al., 2008), whereas stimulation *before* the task will either have no significant effect (Kuo, Paulus, et al., 2008), or worsen performance (Stagg et al., 2011; Amadi et al., 2015). The latter effect was also found to affect action semantic word processing (Birba et al., 2020). A potential explanation is that this is attributed to the physiological process of homeostasis. Our body is constantly regulated by homeostatic mechanisms, which means that the body constantly sends signals to either increase or decrease excretion of hormones and excitability of neurons to maintain a stable, equilibrium range for the body to usefully operate and avoid destabilization. Motor learning is suggested to be explained in terms of the Hebbian synaptic plasticity mechanisms, along the likes of Long-Term Potentiation (LTP) effect (e.g., Muellbacher et al., 2002; Ziemann et al., 2004). In detail, this is operated by positive feedback, which has the potential to destabilize established networks, which results in unregulated cortical activity and will prevent further dynamic modulations (Abraham, 2008). This means that motor learning neurons are prone to destabilization, therefore, to avoid this and maintain neural activity for motor learning, it is suggested that homeostatic mechanisms operate, by which an already increased level of cortical excitability will be reduced; this is the

Bienenstock-Cooper-Munro model (Bienenstock, Cooper, et al., 1982). If we apply this to the findings from the tDCS studies, anodal stimulation delivered before a task highly excites cortical activation, and by the time stimulation ends and participants start a task that would also increase the same neural activity, homeostasis 'kicks-in' to decrease the already increased neural activation caused by the stimulation to prevent it from any further escalation. This decrease that is almost overcompensating, results in poor performance.

7.3.2 Similar anodal tDCS-induced reduction in performance at DLPFC

It is surprising to find similar patterns of reverse tDCS effects of stimulating the M1 and DLPFC. Ambrus and colleagues' (2011) argued that while the LTP-like effect may explain impaired performance during the actual task (post-stimulation), this model implies cathodal stimulation should increase performance, which had no effect statistically in their study. The authors draw on another previous study from their lab, where the opposite, but similar effects were found. In a study investigating visuo-motor coordination, Antal, et al., (2004) revealed that cathodal tDCS of the V5 region increased task performance, while no effect was found in the anodal group. It was postulated that overall, cortical excitability was decreased by cathodal stimulation, by which it lowered the activation state of neuronal patterns that are, presumably, suboptimal to the task. This lowered activation leads to below-threshold of execution, leaving the optimal pattern above threshold. Based on this logic, Ambrus et al., (2011) posited that anodal tDCS increased cortical excitability and elevated the suboptimal neuronal patterns that ultimately raised the chance of implementation of incorrect responses. However, a review conducted by Jacobson et al., (2012) would argue that tDCS effects on cognitive tasks are more susceptible to results that depart form the anodal excitatory and cathodal inhibitory assumption due to external noise from the variety of measures of the task (e.g., reaction times, accuracy), as opposed to tDCS motor effect research that use a standardized motor evoked potentials (MEP) measure.

However, it could also be argued that identifying these varying tDCS results as external noise is too simplistic. Zmigrod et al., (2014) demonstrated that both anodal and cathodal tDCS stimulation on the right DLPFC reduced control of stimulus-response binding. The same procedure on the left DLPFC did not yield significant results. A similar case of both polarities inducing the same effect was observed by Dockery et al., (2009), who reported that both anodal and cathodal stimulation on the DLPFC enhanced planning ability. Looking at the varying effects from different studies and angles, as of now, it could be said that this is perhaps a reflection of how any stimulation (either positive or negative currents) on a particular region induce cognitive disruption in healthy individuals when performing certain tasks.

7.3.3. Anodal tDCS at DLPFC/Fp3 – LTP or modulating perceptual learning?

With the effects of tDCS in general being unclear at times, this is no surprise when the same is observed when interpreting anodal tDCS delivered on the DLPFC (for a recent review see Tremblay et al., 2014). To name a few examples, anodal tDCS delivered at DLPFC showed elimination of prototype distortion effect, hence reduced categorization learning (Kincses et al., 2004), decreased performance in working memory (Fregni et al., 2005), risk-taking behaviors (Beeli et al., 2008), negative emotion perception (Boggio et al., 2009), and cognitive flexibility (Plewina et al., 2013). However, other studies have also shown anodal stimulation over the left DLPFC to increase working memory performance (Ohn et al., 2008), positive emotion processing (Nitsche, Koschack, et al., 2012), performance on verbal tasks, (Fertonani et al., 2010), learning (Javadi & Walsh, 2012), and mental flexibility: problem solving, planning, and inhibition (Elmer et al., 2009; Jeon & Han, 2012).

Other than LTP-like effect put forth by the Bienenstock-Cooper-Munro model (Bienenstock, Cooper, Munro, 1982) alternative explanations were sparse and unclear. Recently, Civile, McLaren, Waguri, et al., (2020) investigated whether the tDCS procedure in the old/new recognition task used in prior studies (e.g., Civile, Verbruggen, et al., 2016; Civile, McLaren et al., 2018) would result in *immediate* behavioral effects on the inversion effect, or if it needed time to build up. To test this, participants underwent stimulation, either during the *study phase* of the old/new recognition task, or during *recognition phase,* in comparison to sham. Incidentally, this also provided some insight on whether the timing of the stimulation does indeed reflect an LTP-like process as suggested by previous studies investigating the effects of tDCS on learning. Interestingly, it was revealed that anodal stimulation decreased recognition performance in <u>both</u> stimulation conditions (study phase and recognition phase) and confirms an immediate tDCS effect on the face inversion effect. This rules out the Bienenstock-Cooper-Munro model, at least for stimulation on the left DLPFC in combination with the old/new recognition task of faces. It also does not reflect activation of suboptimal neural patterns as suggested by Ambrus et al., (2011) as that would imply the stimulation effects to be erratic, which is not the case here as there is a specific reduction in performance for upright faces only, and this clearly demonstrates the disruption of perceptual learning <u>and</u> feature salience upon recognition for familiar upright faces (predicted by the MKM model on a separate occasion). In light of these results, it should be highlighted that while tDCS findings can be difficult to interpret, as demonstrated by the abundant studies that produced converging results in so many ways, it should not take away from findings that are consistent as demonstrated with this particular tDCS procedure for face recognition/perceptual learning. To properly interpret the results of tDCS, a clear a priori hypothesis based on a theoretical background is necessary if we are to be able to interpret the results. Also, careful technical (e.g. stimulation intensity and duration) and methodological considerations (e.g. double-blind procedure) are mandatory to obtain further insights into the impact of tDCS on cognitive functions and related behavioral effects. Nevertheless, the countless experiments that consistently showed tDCS applied at Fp3 reduces the inversion effect (e.g., Civile, Verbruggen, et al., 2016; Civile, McLaren, et al., 2018; Civile, Waguri, et al., 2020; Civile, Cooke, et al., 2020; Civile, McLaren, Waguri, et al., 2020) establishes this procedure as reliable in modulating perceptual learning, as none show otherwise.

7.3.4. Underlying brain networks when stimulating the frontal cortex (DLPFC) and its effect on the parietal/posterior/occipital areas (PO8/N170 ERP)

As mentioned above, several research has shown that the DLPFC is involved in certain executive functions and administering stimulation on this brain region can either impair or improve these functions. However, this opens the question of why stimulating the DLPFC affects the recognition of faces and objects of expertise (Civile, Verbruggen et al., 2016; Civile, McLaren et al., 2018; Civile, Quaglia et al., 2021) and specifically, why stimulating this area indirectly affects the N170 neuro-correlates recorded from parietal/posterior/occipital regions (e.g.,PO8) as observed in Chapter 6 of this thesis, and in previous literature (e.g., Civile, Cooke et al., 2020; Civile, Waguri et al., 2020). This is particularly interesting considering that when direct stimulation is administered on the PO8 site (where a strong N170 is also often recorded), there are inconsistent reports of its effect on face recognition performance (e.g., Civile, McLaren, Milton et al., 2021 with composite faces). Barbieri et al., (2016) demonstrated that 20 minutes of tDCS at 1.5mA intensity on the PO8 results in higher face and object recognition performance. However, Experiment 1 of Willis et al., (2019) failed to replicate Barbieri et al's., (2016) findings and instead, found that when anodal tDCS was delivered over the right occipitotemporal cortex (PO8), object or facial expression perception did not differ to baseline performance (although the authors highlight this difference in findings could be attributed to their reduction in the number of task trials). Similar inconsistencies regarding the effects of PO8 stimulation on face recognition performance have been observed in the composite face paradigm, which was discussed in Chapter 3 and 4 of this thesis (e.g., can influence face recognition skills indexed by the composite effect; Yang et al., 2014, vs no influence; Renzi et al., 2015; Civile, McLaren, Milton et al., 2021). The current thesis follows prior interpretations from Civile, Verbruggen et al., (2016), Civile, McLaren et al., (2018), Civile, Waguri et al., (2020), and Civile, McLaren, Waguri et al., (2020) that tDCS at Fp3 site/DLPFC modulating the N170 recorded at PO8 implies that i) Fp3/DLPFC is involved in categorization/perceptual learning; ii) perceptual learning is involved in face recognition, and therefore, potentially suggests that Fp3/DLPFC is an area that is involved in face processing and recognition. However, this needs to be substantiated with a robust investigation, perhaps involving fMRI to localize the specific regions involved and understand the neural networks of these regions when tDCS is applied and faces/objects of expertise are recognized.

Some research suggest an overlap of the frontal lobe/prefrontal cortex and occipital/parietal lobe when faces/objects are processed. In a neuroimaging study, Heekeren et al., (2004) investigated the mechanism involved in perceptual decision-making. Specifically, the authors explored whether similar mechanisms are involved for both simple and complex decisions within the human brain and ascertain its localization. Participants underwent a categorization task that required them to indicate if the presented image is a face or a house. The task difficulty was determined by the noise proportions of the image stimuli, where the stimuli in the easier task included low noise proportion, while the harder task had high noise proportion. fMRI results demonstrated higher activity in the left DLPFC when processing easy decisions compared to difficult decisions, which covaried between face- and house-selective regions (ventral temporal cortex). Interestingly, several regions related to attentional networks, including the parietal regions (i.e., intraparietal sulcus) showed greater activation when the task increased in difficulty.

Minamoto et al., (2012) demonstrated that in a face working memory task with face distractors as a time filler, both the dorsal frontal cortex and inferior parietal lobe are involved in encoding long-term memory. Participants were first presented with the face working memory task, followed by a surprise recognition task in the MRI scanner. The behavioral results revealed that the recognition accuracy was higher and faster for distractors than for novel stimuli. Neuroimaging results demonstrated less activation in the middle and superior frontal regions and lateral inferior parietal lobe for distractors that were remembered than the ones participants had forgotten. The authors concluded that the dorsal frontal cortex regulates attentional control, while the inferior parietal lobe plays a role in the reorientation of attention, and that insufficient engagement of these regions is indicative of the process of goal-irrelevant information “tapping into” the working memory, resulting in the encoding of long-term memory.

Further evidence of parietal and frontal mechanisms parallel contributions to competitive visual processing have been provided by Peers et al., (2005). In Part 2 of their study, the authors investigated attentional allocation between high attentional weight (competitors processed well and poses strong interference with others) vs low attentional weight (poorly processed imposing less interference with others). Two groups of participants, either with frontal lesion or parietal lesion, were presented with three or six letters (black or white; targets or non-targets), which participants were asked to identify as many target letters as possible in left or right visual fields. The results revealed that overall, both groups of patients did not demonstrate impairments in top-down control, however, both exhibited correlations between the lesion volume and top-down control scores with significant impairment for patients with larger lesions in frontal and parietal regions. This suggested that both the frontal and parietal regions are involved in attentional weighting.

Other than the notable N170 and face processing/recognition, the occipital lobe has been connected with visual consciousness (Koch et al., 2016; Boly et al., 2017), which is manifested by a negative ERP of visual awareness at ~200ms onset of stimulus, named the “visual awareness negativity” (VAN). Using the inattentional blindness paradigm, which refers to suppressed conscious awareness of an unexpected stimuli due to attentional engagement to a different task, it has been suggested that responses from VAN and the N170 covaried (Rossion, 2014). In a simultaneous EEG-fMRI study, Dellert et al., (2021) investigated the roles of consciousness and task relevance in face perception and the activations of brain regions and N170 recordings. Participants were presented with an inattentional blindness task with three different phases. Phase 1 involved a distractor task where line drawings of faces and the control stimuli were presented at the center, which resulted in some participants to spontaneously notice the faces, while others where inattentionally blind to them. Subsequently, in Phase 2, participants continued the distractor task but were informed of the task-irrelevant faces. Finally, in Phase 3, the faces became task relevant. There was a strong association of conscious face perception with activation of the fusiform gyrus and the N170 and VAN, and acute awareness effects were found in the occipital and prefrontal cortex. Task-relevant processing resulted in strong and prolonged activation of the occipitotemporal, frontoparietal, and attentional networks.

Considering that the aforementioned research suggest some parallel network activity between the frontal and parietal lobes for face recognition, perceptual decision making, visual processing, working memory, and attentional weighting, future research should explore the brain networks in the context of perceptual learning playing a role in face recognition, and investigate the effects of the tDCS at Fp3 and PO8 in a neuroimaging study.

7.3.5 Manipulating the face stimuli – the effect of cropping hair and validity of data in face recognition

In line with previous studies of face recognition and perceptual learning (i.e., Civile, Verbruggen et al., 2016; Civile, Waguri et al., 2020; Civile, Quaglia et al., 2021), the face stimuli utilized throughout this thesis' experiments underwent several adjustments to standardize them and remove distracting features. One of the adjustments was cropping out the hair and removing the hairline. This follows the assumption that the hair is an external feature on the head that distracts/interferes with the internal processing of the faces particularly when hair is susceptible to change in different occasions and should, therefore, be removed so that the data directly reflects the recognition performance of internal facial features (Abudarham, Shkiller et al., 2018). However, this is subject to debate. Given that external facial features can also be identified independently from the face, the extent to which these features dictate the identification of a face, and how they vary in interference with different recognition tasks that measure different processing (e.g,. holistic/featural/part-based) lacks consensus in the literature.

Toseeb et al., (2012) demonstrated that if the hair for each face stimuli remained consistent throughout the experiment, there is no difference in recognition performance compared to recognition performance for faces without hair. However, switching the hair on a face stimuli from test phase (after learning phase) showed a decline in recognition accuracy as opposed to the trials where the hair remained the same across trials. The authors attributed this to a disruption in holistic processing of the face.

On the other hand, a recent systematic study by Olderbak et al., (2022) argues that basic face recognition abilities should not be attributed to whether the employed face stimuli had included external features (i.e., hair) or cropped external features, and would remain the same across different face recognition tasks. The authors investigated this by putting to three varying hypotheses to test. Their first hypothesis was in favor of a general face recognition ability that does not involve an additional ability (i.e., recognizing external features). This was derived from research that utilized different stimuli or tasks. Herzmann et al., (2008), investigated a series of face cognition studies to test the efficacy of various tasks measuring face-perception, -learning, -recognition, and emotional expressions. Notably, participants were shown different face stimuli in the face-perception tasks. Here, participants were shown a three-quarter view of a face as a target, whereas the test phase required the participants to select one out of two morphed, front-facing faces that most matched the target face. A strong single factor for face perception was obtained with high accuracy rates in perception despite the difference in angles and morphed features.

The authors tested a second hypothesis that outlines external features such as hair (Frowd et al., 2012) and non-face objects such as glasses, which the fusiform face area appears to be sensitive to, (Axelrod & Yovel, 2010) can decrease face recognition performance. These external features can also be processed independently from internal features. This suggests that there are two separate processing abilities that processes the external features with the internal features, as well as the ability to ignore the external features, which the second hypothesis set out to test. The third hypothesis extends on the premise of the second hypothesis, and poses a third additionally processing ability in recognizing faces the same person, but with different photographs. This was derived from Burton et al's., (2010) research addressing real-world scenarios such as forensic setting, where live individuals need to be identified based on a photograph such as driver's license or a security camera photo, which are taken with different devices that produce varying qualities of photographs (i.e., phone or high-tech camera), which would require some form of adaptability in recognizing individuals with different sources of face images.

These hypotheses were tested by employing a modified version of three face recognition tasks from Herzmann et al's., (2008) and Wilhelm et al's., (2010) BeFaT measuring Acquisition Curve, Eyewitness Testimony, and Decay Rate.

The overall results revealed that the basic face recognition ability was not negatively impacted by the varying face stimuli and use/lack of external features.

Ascertaining whether there are any differences in including or cropping the hair and hairline, and whether or not cropping yields the assumed benefit of reduced distraction, future studies may conduct a comparative study to investigate the role of perceptual learning when employing cropped vs non-cropped face stimuli, as well as in non-face stimuli. However, the latter poses a challenge in designing the stimuli, and how faces with and without external features can be analogous to objects of expertise. Particularly in the case of checkerboards, which technically do not possess external features, it can be argued that the stimuli used in the current thesis and prior experiments (e.g., Civile, Zhao et al., 2014) serve as an appropriate stimuli for comparing perceptual learning processes with face stimuli that have cropped hair. In order to investigate the effects of external features/hair on faces in comparison with the checkerboard stimuli and to test how this applies to the MKM model, an immediate proposal is to equally add external features onto the checkerboard stimuli, however, this opens several other questions (or perhaps concerns), such as what constitutes as an external feature for object stimuli, and would adding external features make the object stimuli deviate from its nature as an object and lean towards humanistic features.

7.4. Further research

Several areas of interest have emerged for future research to investigate regarding face recognition. A few have been indicated above and/or in previous chapters, but we will revisit them once more below for completeness.

7.4.1 Emotional valence/individuation training and Social factors

In Chapter 4, there was a clear difference in the training task between our Experiment 1 (checkerboards) and those of Greebles/Ziggerins (Gauthier & Tarr, 2002; Wong, Palmeri, et al., 2009), is utilizing a categorization task or individuation training. Both are aimed to train participants in becoming experts, but it is nuanced in the sense that individuation particularly emphasizes subordinate level training as opposed to basic-level by categorization. While there is much debate as to what it exactly promotes and whether subordinate level can indeed increase holistic processing strategies, Wong, Palmeri, et al., (2009) have demonstrated that individuation training (i.e., learning and identifying individual Ziggerins) similar to Gauthier and Tarr (2002) does yield a composite effect in artificial stimuli as opposed to categorization training (class level expertise). This would indicate that there is a top-down effect of personification/humanization affecting the manifestation of the composite effect. Therefore, there may be an additional component other than lower-level perceptual processes (e.g., holistic) that influences face processing, which has also been suggested by Civile, McLaren, Milton, et al., (2021). Humanization has been shown affect the inversion effect, in the sense that an inversion effect could not be obtained in participants who viewed face images that were labeled as individuals with autism. The inversion effect was re-established only after providing humanizing information. After providing humanizing information, this inversion effect was re-established (Civile, Colvin, et al., 2019). However, future research should directly investigate this factor in the composite effect. Other top down factors or motivations shown to affect the composite effect should also be considered (e.g., task relevancy vs irrelevancy, Liu et al., 2020; occupational status, Ratcliff et al., 2011, Experiment 3). Furthermore, our Experiment 2 did not have novel face stimuli, as opposed to Experiment 1 with novel checkerboards. While the novelty of faces may be disparate compared to checkerboards (i.e., life-time experience), future studies should incorporate novel face stimuli for an apt comparison. These social factors could also be considered for further investigating the inversion effect to explore how social factors play a role with perceptual learning.

7.4.2 Eye-tracking and face recognition/N170

Extending on holistic processing, Hills, Cooper, et al., (2013) demonstrated that longer fixation on a face right between the eyes have been linked to holistic coding, where upright faces were better recognized when the fixation cue was placed above the nose bridge and between the eyes, as opposed to the mouth region. Importantly, the authors found the inversion effect to be smaller when eyes were cued compared to cue on the mouth region and no cue. This was also found subsequently by Hills (2018). Crucially, Hills (2018) demonstrated through a series of experiments comparing adult scan-paths to children, that children adopt the adult-like refined coding of longer fixation on the eyes in processing familiar (their own) faces, as opposed to unfamiliar faces, which showed that fixation in processing faces change developmentally. Developing the adult-like (configural) processing has been suggested to occur after the age of 9 (Hills and Lewis, 2018).

Importance of eye-fixation have also been indicated in defining the N170 peak amplitude. Itier, Alain, et al., (2007)'s work suggests that the N170 peak amplitude is increased by additional recruitment of eye-specific cells by inverted faces. Hence, the disruption of configural information induced by inversion would result in extra salience of the eyes as features which would then lead to an increased N170. Moreover, Nemrodov, et al., (2014) used eye tracking and EEG and demonstrated how a larger N170 can be found when fixation was enforced on the eyes compared to fixation on the forehead, nasion, nose, or mouth.

Future studies should aim to combine tDCS and eye tracking to study first how the tDCS procedure influences the typical scan-paths associated with face recognition for upright faces (e.g. many saccades between the eyes and fewer to the nose and mouth, Althoff & Cohen, 1999) and for inverted ones by comparison. If the eyes are linked to the N170 amplitudes, this would provide additional explanation to the N170 amplitude explanation in Chapter 6, which was attributed to changes in generalization. In this case, perhaps the eyes could be a large contributing element in becoming perceptual-experts with faces, which facilitates encoding features that are unique to humans (hence, a more in-depth understanding of how both expertise and specific mechanisms are employed). On a similar note, the specificity (Bentin et al., 1999; Valentine & Bruce, 1988; Valentine, 1988) and expertise (Tarr & Gauthier, 2000; Rossion, Gauthier, et al., 2002; Busey and Vanderkolk, 2005) accounts should be revisited for the N170 and examine if there are indications of both accounts involved.

7.4.3 fMRI- FFA and holistic/individuation

Another direction for future research is to investigate whether holistic processing can be observed in neuroimaging studies. Given that the FFA has been indicated as a brain region specific to face recognition (e.g., Kanwisher, McDermott et al., 1997; Kanwisher, Tong et al., 1998), it would be of interest in investigating if our findings from Chapters 2 to 4 regarding holistic processing being face-specific have any associations with the FFA. Considering that the specificity vs expertise debate also surrounds the FFA as well (e.g., Gauthier et al., 1999 with Greebles), it would be plausible to re-examine the localization of face recognition with neuroimaging such as fMRI in order to test what extent the FFA is responsible for face specific and expertise face recognition mechanism.

7.4.4 tDCS-induced reduction and enhancement of upright face recognition and inversion effect – corroborating with prosopagnosia literature.

Prosopagnosia is a disorder of the inability to recognize individual faces that is usually acquired due to brain damage, and is not an impairment attributed to intellectual deficiency or related to visual problems (Schwarzer et al., 2007). A notable study using the matching task with prosopagnosic patients is by Farah et al's., (1995) study. They extended Yin's (1969) findings of the inversion effect, and investigated this in a prosopagnosic patient named 'LH'. For prosopagnosics, it is common that alongside 'face-blindness', they demonstrate a slight difficulty with recognizing common objects, however, not at the magnitude of their inability to recognize faces. The debate of specificity vs domain-general mechanism of face processing is manifested here, where on the one hand it is suggested that a specialized face processor is damaged, and on the other hand, it there is a mild to moderate damage of a general-purpose object recognition system. The authors aimed to investigate this by using inverted faces as a non-face control stimulus, as it was argued that these stimuli are not processed the same way as normal upright faces (e.g., Valentine, 1988). Instead of a recognition task, a matching task was used which was deemed simple enough for those with prosopagnosia to perform above chance, and the participant was able to successfully match upside-down faces better than upright faces. This task involves participants to sequentially see face stimuli, followed by a brief interstimulus interval, and then another face, to which they have to respond if this face is the same as or different to the face before the interstimulus interval. These were the matching tasks used in Chapters 2, 3 and 4. Considering that our tDCS procedure induces prosopagnosia-like effects, it would be interesting for future research to investigate potential analogies between the prosopagnosia disorder and the recognition impairments induced in healthy participants by the tDCS procedure. Furthermore, extending a modified method of the tDCS procedure in Chapter 6 of enhancing recognition for upright faces would pose clinically beneficial implications. More research is needed in realizing this.

7.5. Overall summary

To conclude, this thesis investigated the classic face specificity (e.g., Yin, 1969) vs expertise (e.g., Diamond & Carey, 1986) debate of face-recognition through a different lens by questioning to what extent face recognition relies on mechanisms that embody specificity and expertise. The approach to a different angle was offered by a recent line of studies demonstrating the link between a particular process of expertise named perceptual learning and face recognition through the comparative investigations of face and checkerboard stimuli (McLaren, 1997; Civile, Zhao, et al., 2014; Civile, Verbruggen, et al., 2016; Civile, McLaren, et al., 2018). The main findings are as follows: 1) Face recognition is reliant on both perceptual learning and face specific mechanisms; 2) One of the face specific mechanisms can be attributed to holistic processing, and in this case, it was observed that perceptual learning is not involved in holistic processing, however, this open for further investigation using different categorization tasks; 3) Proactive interference affects the composite effect and congruent effect paradigms, but not the inversion effect paradigm, which implies that the tDCS modulates perceptual learning; 4) Generalization, as per the MKM model, occurs between Thatcherized and normal faces, which the tDCS removes and result in an increased recognition for upright faces, and consequently the inversion effect; 5)The N170 amplitude and latency may index different mechanisms that may not directly be in reference to recognition performance as once though; N170 amplitudes could be an index of generalization, while latencies may index the changes on feature salience modulation.

REFERENCES:

Abraham, W. C. (2008). Metaplasticity: tuning synapses and networks for plasticity. *Nature Reviews Neuroscience*, *9*(5), 387-387.

Abudarham, N., Shkiller, L., & Yovel, G. (2019). Critical features for face recognition. *Cognition*, *182*, 73-83.

Alonso-Prieto, E., Caharel, S., Henson, R. N., & Rossion, B. (2011). Early (N170/ M170) face-sensitivity despite right lateral occipital brain damage in acquired prosopagnosia. Frontiers in Human Neuroscience, 5, 138.

Althoff, R. R., & Cohen, N. J. (1999). Eye-movement-based memory effect: a reprocessing effect in face perception. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*(4), 997.

Amadi, U., Allman, C., Johansen-Berg, H., & Stagg, C. J. (2015). The homeostatic interaction between anodal transcranial direct current stimulation and motor learning in humans is related to GABAA activity. *Brain stimulation*, *8*(5), 898-905.

Ambrus, G. G., Zimmer, M., Kincses, Z. T., Harza, I., Kovács, G., Paulus, W., & Antal, A. (2011). The enhancement of cortical excitability over the DLPFC before and during training impairs categorization in the prototype distortion task. *Neuropsychologia*, *49*(7), 1974-1980.

Anderson, M. C., & Neely, J. H. (1996). Interference and inhibition in memory retrieval. In *Memory* (pp. 237-313). Academic Press.

Antal, A., Nitsche, M. A., Kruse, W., Kincses, T. Z., Hoffmann, K. P., & Paulus, W. (2004). Direct current stimulation over V5 enhances visuomotor coordination by improving motion perception in humans. *Journal of cognitive neuroscience*, *16*(4), 521-527.

Axelrod, V., & Yovel, G. (2010). External facial features modify the representation of internal facial features in the fusiform face area. *Neuroimage*, *52*(2), 720-725.

Aylward, E. H., Park, J. E., Field, K. M., Parsons, A. C., Richards, T. L., Cramer, S. C., & Meltzoff, A. N. (2005). Brain activation during face perception: evidence of a developmental change. *Journal of cognitive neuroscience*, *17*(2), 308-319.

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.

Beeli, G., Casutt, G., Baumgartner, T., & Jäncke, L. (2008). Modulating presence and impulsiveness by external stimulation of the brain. *Behavioral and Brain Functions*, *4*(1), 1-7.

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.

Bentin, S., & Deouell, L. Y. (2000). Structural encoding and identification in face processing: ERP evidence for separate mechanisms. *Cognitive neuropsychology*, *17*(1-3), 35-55.

Bienenstock, E. L., Cooper, L. N., & Munro, P. W. (1982). Theory for the development of neuron selectivity: orientation specificity and binocular interaction in visual cortex. *Journal of Neuroscience*, *2*(1), 32-48.

Birba, A., Vitale, F., Padrón, I., Dottori, M., de Vega, M., Zimerman, M., ... & García, A. M. (2020). Electrifying discourse: Anodal tDCS of the primary motor cortex selectively reduces action appraisal in naturalistic narratives. *Cortex*, *132*, 460-472.

Blalock, L. D., & McCabe, D. P. (2011). Proactive interference and practice effects in visuospatial working memory span task performance. *Memory*, *19*(1), 83-91.

Bodamer, J. (1947). Die prosop-agnosie. *Archiv für Psychiatrie und Nervenkrankheiten*, *179*(1), 6-53.

Boggio, P. S., Zaghi, S., & Fregni, F. (2009). Modulation of emotions associated with images of human pain using anodal transcranial direct current stimulation (tDCS). *Neuropsychologia*, *47*(1), 212-217.

Boly, M., Massimini, M., Tsuchiya, N., Postle, B. R., Koch, C., & Tononi, G. (2017). Are the neural correlates of consciousness in the front or in the back of the cerebral cortex? Clinical and neuroimaging evidence. *Journal of Neuroscience*, *37*(40), 9603-9613.

Bötzel, K., & Grüsser, O. J. (1989). Electric brain potentials evoked by pictures of faces and non-faces: a search for “face-specific” EEG-potentials. *Experimental Brain Research*, *77*(2), 349-360.

Bötzel, K., Schulze, S., & Stodieck, S. R. (1995). Scalp topography and analysis of intracranial sources of face-evoked potentials. *Experimental brain research*, *104*(1), 135-143.

Bruce, V. (1982). Changing faces: Visual and non-visual coding processes in face recognition. *British journal of psychology*, *73*(1), 105-116.

Bruce, V., & Young, A. (1986). Understanding face recognition. *British journal of psychology*, *77*(3), 305-327.

Bukach, C. M., Phillips, W. S., & Gauthier, I. (2010). Limits of generalization between categories and implications for theories of category specificity. *Attention, Perception, & Psychophysics*, *72*(7), 1865-1874.

Busey, T. A., & Vanderkolk, J. R. (2005). Behavioral and electrophysiological evidence for configural processing in fingerprint experts. *Vision research*, *45*(4), 431-448.

Carmel, D., & Bentin, S. (2002). Domain specificity versus expertise: factors influencing distinct processing of faces. *Cognition*, *83*(1), 1-29.

Civile, C., Cooke, A., Liu, X., McLaren, R., Elchlepp, H., Lavric, A., ... & McLaren, I. P. L. (2020). The effect of tDCS on recognition depends on stimulus generalization: Neuro-stimulation can predictably enhance or reduce the face inversion effect. *Journal of Experimental Psychology: Animal Learning and Cognition*, *46*(1), 83.

Civile, C., Elchlepp, H., McLaren, R., Galang, C. M., Lavric, A., & McLaren, I. P. L. (2018). The effect of scrambling upright and inverted faces on the N170. *Quarterly Journal of Experimental Psychology*, *71*(11), 2464-2476.

Civile, C., McLaren, R., & McLaren, I. P. (2016). The face inversion effect: roles of first and second-order configural information. *The American Journal of Psychology*, *129*(1), 23-35.

Civile, C., McLaren, R., & McLaren, I. P. L. (2018). How we can change your mind: Anodal tDCS to Fp3 alters human stimulus representation and learning. *Neuropsychologia*, *119*, 241-246.

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.

Civile, C., McLaren, R., Waguri, E., & McLaren, I. P. L. (2020). Testing the immediate effects of transcranial Direct Current Stimulation (tDCS) on face recognition skills. In *CogSci*.

Civile, C., Quaglia, S., Waguri, E., Ward, M., McLaren, R., & McLaren, I. P. L. (2021). Using transcranial Direct Current Stimulation (tDCS) to investigate why faces are and are not special. *Scientific reports*, *11*(1), 1-11.

Civile, C., Verbruggen, F., McLaren, R., Zhao, D., Ku, Y., & McLaren, I. P. L. (2016). Switching off perceptual learning: Anodal transcranial direct current stimulation (tDCS) at Fp3 eliminates perceptual learning in humans. *Journal of Experimental Psychology: Animal Learning and Cognition*, *42*(3), 290.

Civile, C., Obhi, S.S., & McLaren, I. P. L. (2019). The role of experience-based perceptual learning in the Face Inversion Effect. *Vision Research, 157*, 84-88.

Civile, C., Waguri, E., A, Cooke., R, McLaren., & I. P. L. McLaren, (under review). Using transcranial Direct Current Stimulation (tDCS) to selectively modulate the face inversion effect and N170 Event-Related Potentials. *Journal of Experimental Psychology : Animal and Learning.*

Civile, C., Waguri, E., Quaglia, S., Wooster, B., Curtis, A., McLaren, R., ... & McLaren, I. P. L. (2020). Testing the effects of transcranial direct current stimulation (tDCS) on the face inversion effect and the N170 event-related potentials (ERPs) component. *Neuropsychologia*, *143*, 107470.

Civile, C., Zhao, D., Ku, Y., Elchlepp, H., Lavric, A., & McLaren, I. P. (2014). Perceptual learning and inversion effects: Recognition of prototype-defined familiar checkerboards. *Journal of Experimental Psychology: Animal Learning and Cognition*, *40*(2), 144.

Cunillera, T., Brignani, D., Cucurell, D., Fuentemilla, L., & Miniussi, C. (2016). The right inferior frontal cortex in response inhibition: A tDCS–ERP co-registration study. *Neuroimage*, *140*, 66-75.

Cunillera, T., Fuentemilla, L., Brignani, D., Cucurell, D., & Miniussi, C. (2014). A simultaneous modulation of reactive and proactive inhibition processes by anodal tDCS on the right inferior frontal cortex. *PloS one*, *9*(11), e113537.

Darley, C. F., & Murdock, B. B. (1971). Effects of prior free recall testing on final recall and recognition. *Journal of Experimental Psychology*, *91*(1), 66.

Dellert, T., Müller-Bardorff, M., Schlossmacher, I., Pitts, M., Hofmann, D., Bruchmann, M., & Straube, T. (2021). Dissociating the neural correlates of consciousness and task relevance in face perception using simultaneous EEG-fMRI. *Journal of Neuroscience*, *41*(37), 7864-7875.

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of neuroscience methods*, *134*(1), 9-21.

Diamond, R., & Carey, S. (1986). Why faces are and are not special: an effect of expertise. *Journal of Experimental Psychology: General*, *115*(2), 107.

Dienes, Z. (2011). Bayesian versus orthodox statistics: Which side are you on?. *Perspectives on Psychological Science*, *6*(3), 274-290.

Dockery, C. A., Hueckel-Weng, R., Birbaumer, N., & Plewnia, C. (2009). Enhancement of planning ability by transcranial direct current stimulation. *Journal of Neuroscience*, *29*(22), 7271-7277.

Dwyer, D. M., & Vladeanu, M. (2009). Perceptual learning in face processing: Comparison facilitates face recognition. *Quarterly Journal of Experimental Psychology*, *62*(10), 2055-2067.

Eimer, M. (2011). The face-sensitive N170 component of the event-related brain potential. *The Oxford handbook of face perception*, *28*, 329-44.

Eimer, M. (2000). The face-specific N170 component reflects late stages in the structural encoding of faces. *Neuroreport*, *11*(10), 2319-2324.

Elmer, S., Burkard, M., Renz, B., Meyer, M., & Jancke, L. (2009). Direct current induced short-term modulation of the left dorsolateral prefrontal cortex while learning auditory presented nouns. *Behavioral and Brain Functions*, *5*(1), 1-7.

Estes, W. K. (1950). Toward a statistical theory of learning. *Psychological review*, *57*(2), 94.

Farah, M. J., Wilson, K. D., Drain, H. M., & Tanaka, J. R. (1995). The inverted face inversion effect in prosopagnosia: Evidence for mandatory, face-specific perceptual mechanisms. *Vision research*, *35*(14), 2089-2093.

Fertonani, A., Rosini, S., Cotelli, M., Rossini, P. M., & Miniussi, C. (2010). Naming facilitation induced by transcranial direct current stimulation. *Behavioural brain research*, *208*(2), 311-318.

Fregni, F., Boggio, P. S., Nitsche, M., Bermpohl, F., Antal, A., Feredoes, E., ... & Pascual-Leone, A. (2005). Anodal transcranial direct current stimulation of prefrontal cortex enhances working memory. *Experimental brain research*, *166*(1), 23-30.

Frowd, C. D., Skelton, F., Atherton, C., Pitchford, M., Hepton, G., Holden, L., ... & Hancock, P. J. (2012). Recovering faces from memory: The distracting influence of external facial features. *Journal of Experimental Psychology: Applied*, *18*(2), 224.

Gauthier, I., Anderson, A. W., Tarr, M. J., Skudlarski, P., & Gore, J. C. (1997). Levels of categorization in visual recognition studied using functional magnetic resonance imaging. *Current Biology*, *7*(9), 645-651.

Gauthier, I., Skudlarski, P., Gore, J. C., & Anderson, A. W. (2000). Expertise for cars and birds recruits brain areas involved in face recognition. *Nature neuroscience*, *3*(2), 191-197.

Gauthier, I., & Tarr, M. J. (1997). Becoming a "Greeble" expert: Exploring mechanisms for face recognition. *Vision research*, *37*(12), 1673-1682.

Gauthier, I., & Tarr, M. (2002). Unraveling mechanisms for expert object recognition: Bridging brain activity and behavior. *Journal of Experimental Psychology: Human Perception and Performance, 28, 431–446*.

Gauthier, I., Tarr, M. J., Anderson, A. W., Skudlarski, P., & Gore, J. C. (1999). Activation of the middle fusiform 'face area' increases with expertise in recognizing novel objects. *Nature neuroscience*, *2*(6), 568-573.

Gauthier, I., Tarr, M. J., Moylan, J., Anderson, A. W., & Gore, J. C. (1998, March). The functionally defined" face area" is engaged by subordinate-level recognition. In *Cognitive neuroscience abstracts* (p. 35).

Gauthier, I., Williams, P., Tarr, M. J., & Tanaka, J. (1998). Training 'greeble' experts: a framework for studying expert object recognition processes. *Vision research*, *38*(15-16), 2401-2428.

George, N., Jemel, B., Fiori, N., Chaby, L., & Renault, B. (2005). Electrophysiological correlates of facial decision: insights from upright and upside-down Mooney-face perception. *Cognitive Brain Research*, *24*(3), 663-673.

Gibson, E. J., & Walk, R. D. (1956). The effect of prolonged exposure to visually presented patterns on learning to discriminate them. *Journal of comparative and physiological psychology*, *49*(3), 239.

Goffaux, V., & Rossion, B. (2006). Faces are ‘‘spatial” – Holistic face perception is supported by low spatial frequencies*. Journal of Experimental Psychology: Human Perception and Performance, 32*, 1023–1039.

Golarai, G., Liberman, A., & Grill-Spector, K. (2015). Experience shapes the development of neural substrates of face processing in human ventral temporal cortex. *Cerebral Cortex*, *27*(2).

Haxby, J. V., Horwitz, B., Ungerleider, L. G., Maisog, J. M., Pietrini, P., & Grady, C. L. (1994). The functional organization of human extrastriate cortex: a PET-rCBF study of selective attention to faces and locations. *Journal of neuroscience*, *14*(11), 6336-6353.

Heekeren, H. R., Marrett, S., Bandettini, P. A., & Ungerleider, L. G. (2004). A general mechanism for perceptual decision-making in the human brain. *Nature*, *431*(7010), 859-862.

Herzmann, G., Danthiir, V., Schacht, A., Sommer, W., & Wilhelm, O. (2008). Toward a comprehensive test battery for face cognition: Assessment of the tasks. *Behavior Research Methods*, *40*(3), 840-857.

Hills, P. J. (2018). Children process the self face using configural and featural encoding: Evidence from eye tracking. *Cognitive Development*, *48*, 82-93.

Hills, P. J., Cooper, R. E., & Pake, J. M. (2013). First fixations in face processing: The more diagnostic they are the smaller the face-inversion effect. *Acta Psychologica*, *142*(2), 211-219.

Hills, P. J., & Lewis, M. B. (2018). The development of face expertise: Evidence for a qualitative change in processing. *Cognitive Development*, *48*, 1-18.

Hochberg, J., & Galper, R. E. (1967). Recognition of faces: I. An exploratory study. *Psychonomic Science*, *9*(12), 619-620.

Hole, G. J., George, P. A., & Dunsmore, V. (1999). Evidence for holistic processing of faces viewed as photographic negatives. *Perception*, *28*(3), 341-359.

Honey, R. C., & Hall, G. (1989). Acquired equivalence and distinctiveness of cues. *Journal of Experimental Psychology: Animal Behavior Processes*, *15*(4), 338.

Itier, R. J., Alain, C., Sedore, K., & McIntosh, A. R. (2007). Early face processing specificity: it's in the eyes!. *Journal of cognitive neuroscience*, *19*(11), 1815-1826.

Itier, R. J., Latinus, M., & Taylor, M. J. (2006). Face, eye and object early processing: what is the face specificity?. *Neuroimage*, *29*(2), 667-676.

Itier, R. J., & Taylor, M. J. (2004). Source analysis of the N170 to faces and objects. *Neuroreport*, *15*(8), 1261-1265.

Jackson, J. B., Feredoes, E., Rich, A. N., Lindner, M., & Woolgar, A. (2021). Concurrent neuroimaging and neurostimulation reveals a causal role for dlPFC in coding of task-relevant information. *Communications biology*, *4*(1), 1-16.

Jacobson, L., Koslowsky, M., & Lavidor, M. (2012). tDCS polarity effects in motor and cognitive domains: a meta-analytical review. *Experimental brain research*, *216*(1), 1-10.

Javadi, A. H., & Walsh, V. (2012). Transcranial direct current stimulation (tDCS) of the left dorsolateral prefrontal cortex modulates declarative memory. *Brain stimulation*, *5*(3), 231-241.

Jeffreys, D. A. (1989). A face-responsive potential recorded from the human scalp. *Experimental brain research*, *78*(1), 193-202.

Jeffreys, D. A. (1996). Evoked potential studies of face and object processing. *Visual Cognition*, *3*(1), 1-38.

Jeffreys, H. (1939/1961).*The Theory of Probability,* (1st/3rd ed). Oxford University Press.

Jeon, S. Y., & Han, S. J. (2012). Improvement of the working memory and naming by transcranial direct current stimulation. *Annals of rehabilitation medicine*, *36*(5), 585.

Jones, S. P., & Dwyer, D. M. (2013). Perceptual learning with complex visual stimuli is based on location, rather than content, of discriminating features. *Journal of Experimental Psychology: Animal Behavior Processes*, *39*(2), 152.

Jung, T. P., Makeig, S., Humphries, C., Lee, T. W., Mckeown, M. J., Iragui, V., & Sejnowski, T. J. (2000). Removing electroencephalographic artifacts by blind source separation. *Psychophysiology*, *37*(2), 163-178.

Kamin, L. J. (1967, June). Attention-like processes in classical conditioning. In *SYMP. ON AVERSIVE MOTIVATION MIAMI* (No. TR-5).

Kanwisher, N. (2000). Domain specificity in face perception. *Nature neuroscience*, *3*(8), 759-763.

Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: a module in human extrastriate cortex specialized for face perception. *Journal of neuroscience*, *17*(11), 4302-4311.

Kanwisher, N., Tong, F., & Nakayama, K. (1998). The effect of face inversion on the human fusiform face area. *Cognition*, *68*(1), B1-B11.

Kincses, T. Z., Antal, A., Nitsche, M. A., Bártfai, O., & Paulus, W. (2004). Facilitation of probabilistic classification learning by transcranial direct current stimulation of the prefrontal cortex in the human. *Neuropsychologia*, *42*(1), 113-117.

Koch, C., Massimini, M., Boly, M., & Tononi, G. (2016). Neural correlates of consciousness: progress and problems. *Nature Reviews Neuroscience*, *17*(5), 307-321.

Köhler, W. (1940). *Dynamics in Psychology.* New York: Liveright Publishing Co.

Kuo, M. F., Unger, M., Liebetanz, D., Lang, N., Tergau, F., Paulus, W., & Nitsche, M. A. (2008). Limited impact of homeostatic plasticity on motor learning in humans. *Neuropsychologia*, *46*(8), 2122-2128.

Lebrecht, S., Pierce, L. J., Tarr, M. J., & Tanaka, J. W. (2009). Perceptual other-race training reduces implicit racial bias. *PloS one*, *4*(1), e4215.

Liu, C. H., Young, A. W., Basra, G., Ren, N., & Chen, W. (2020). Perceptual integration and the composite face effect. *Quarterly Journal of Experimental Psychology*, *73*(7), 1101-1114.

Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: an open-source toolbox for the analysis of event-related potentials. *Frontiers in human neuroscience*, *8*, 213.

Lubow, R. E. (1973). Latent inhibition. *Psychological bulletin*, *79*(6), 398.

Lubow, R. E., & Moore, A. U. (1959). Latent inhibition: the effect of nonreinforced pre-exposure to the conditional stimulus. *Journal of comparative and physiological psychology*, *52*(4), 415.

Lupyan, G., Mirman, D., Hamilton, R., & Thompson-Schill, S. L. (2012). Categorization is modulated by transcranial direct current stimulation over left prefrontal cortex. *Cognition*, *124*(1), 36-49.

Lustig, C., May, C. P., & Hasher, L. (2001). Working memory span and the role of proactive interference. *Journal of Experimental Psychology: General*, *130*(2), 199.

Maurer, D., Le Grand, R., & Mondloch, C. J. (2002). The many faces of configural processing. *Trends in cognitive sciences*, *6*(6), 255-260.

May, C. P., Hasher, L., & Kane, M. J. (1999). The role of interference in memory span. *Memory & cognition*, *27*(5), 759-767.

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.

McGeoch, J. A. (1942). *The psychology of human learning: An introduction*. New York: Longmans.

McLaren, I. P. L. (1997). Categorization and perceptual learning: An analogue of the face inversion effect. *The Quarterly Journal of Experimental Psychology Section A*, *50*(2), 257-273.

McLaren, R., Civile, C., & McLaren, I. P. L. (2021). Latent inhibition in young children: A developmental effect?. *Journal of Experimental Psychology: Animal Learning and Cognition*, *47*(1), 63.

McLaren, I. P., Forrest, C. L., & McLaren, R. P. (2012). Elemental representation and configural mappings: Combining elemental and configural theories of associative learning. *Learning & Behavior*, *40*(3), 320-333.

McLaren, I.P.L., Kaye, H., & Mackintosh, N.J. (1989). *An associative theory of the representation of stimuli: applications to perceptual learning and latent inhibition.* In R.G.M. Morris (Ed.) Parallel Distributed Processing - Implications for Psychology and Neurobiology. Oxford : OUP.

McLaren, I. P. L., & Mackintosh, N. J. (2000). An elemental model of associative learning: I. Latent inhibition and perceptual learning. *Animal Learning & Behavior*, *28*(3), 211-246.

McClelland, J. L., & Rumelhart, D. E. (1985). Distributed memory and the representation of general and specific information. *Journal of Experimental Psychology: General*, *114*(2), 159.

McCourt, S., McLaren, I. P. L., & Civile, C. (2021). Perceptual Processes of Face Recognition: Single feature orientation and holistic information contribute to the face inversion effect. In *Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 43, No. 43).

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual review of neuroscience*, *24*(1), 167-202.

Minamoto, T., Osaka, M., Engle, R. W., & Osaka, N. (2012). Incidental encoding of goal irrelevant information is associated with insufficient engagement of the dorsal frontal cortex and the inferior parietal cortex. *Brain research*, *1429*, 82-97.

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.

Muellbacher, W., Ziemann, U., Wissel, J., Dang, N., Kofler, M., Facchini, S., ... & Hallett, M. (2002). Early consolidation in human primary motor cortex. *Nature*, *415*(6872), 640-644.

Mundy, M. E., Dwyer, D. M., & Honey, R. C. (2006). Inhibitory associations contribute to perceptual learning in humans. *Journal of Experimental Psychology: Animal Behavior Processes*, *32*(2), 178.

Mundy, M. E., Honey, R. C., & Dwyer, D. M. (2009). Short Article: Superior Discrimination between Similar Stimuli after Simultaneous Exposure. *Quarterly Journal of Experimental Psychology*, *62*(1), 18-25.

Mundy, M. E., Honey, R. C., & Dwyer, D. M. (2007). Simultaneous presentation of similar stimuli produces perceptual learning in human picture processing. *Journal of Experimental Psychology: Animal Behavior Processes*, *33*(2), 124.

Murphy, J., Gray, K. L. H., and Cook, R. (2017). *The composite face illusion. Psychonomic Bulletin & Review, 24*, 245-261.

Navajas, J., Ahmadi, M., & Quiroga, R. Q. (2013). Uncovering the mechanisms of conscious face perception: a single-trial study of the n170 responses. *Journal of Neuroscience*, *33*(4), 1337-1343.

Neimark, E. D., & Estes, W. K. (1967). *Stimulus sampling theory*. Holden-Day.

Nemrodov, D., Anderson, T., Preston, F. F., & Itier, R. J. (2014). Early sensitivity for eyes within faces: A new neuronal account of holistic and featural processing. *NeuroImage*, *97*, 81-94.

Nitsche, M. A., Koschack, J., Pohlers, H., Hullemann, S., Paulus, W., & Happe, S. (2012). Effects of frontal transcranial direct current stimulation on emotional state and processing in healthy humans. *Frontiers in psychiatry*, *3*, 58.

Nitsche, M. A., & Paulus, W. (2000). Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. *The Journal of physiology*, *527*(3), 633-639.

Nitsche, M. A., Schauenburg, A., Lang, N., Liebetanz, D., Exner, C., Paulus, W., & Tergau, F. (2003). Facilitation of implicit motor learning by weak transcranial direct current stimulation of the primary motor cortex in the human. *Journal of cognitive neuroscience*, *15*(4), 619-626.

Ohn, S. H., Park, C. I., Yoo, W. K., Ko, M. H., Choi, K. P., Kim, G. M., ... & Kim, Y. H. (2008). Time-dependent effect of transcranial direct current stimulation on the enhancement of working memory. *Neuroreport*, *19*(1), 43-47.

Olderbak, S., Pollak, K., Sanchez, J. F., & Hildebrandt, A. (2022). Assessing individual differences in face recognition: No impact of task design features on the structure of this ability. *Psychological Assessment*.

Pastötter, B., Schicker, S., Niedernhuber, J., & Bäuml, K. H. T. (2011). Retrieval during learning facilitates subsequent memory encoding. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(2), 287.

Pearce, J. M. (1987). A model for stimulus generalization in Pavlovian conditioning. *Psychological review*, *94*(1), 61.

Peers, P. V., Ludwig, C. J., Rorden, C., Cusack, R., Bonfiglioli, C., Bundesen, C., ... & Duncan, J. (2005). Attentional functions of parietal and frontal cortex. *Cerebral cortex*, *15*(10), 1469-1484.

Perrett, D. I., Mistlin, A. J., Chitty, A. J., Smith, P. A. J., Potter, D. D., Broennimann, R., & Harries, M. (1988). Specialized face processing and hemispheric asymmetry in man and monkey: evidence from single unit and reaction time studies. *Behavioural brain research*, *29*(3), 245-258.

Plewnia, C., Zwissler, B., Längst, I., Maurer, B., Giel, K., & Krüger, R. (2013). Effects of transcranial direct current stimulation (tDCS) on executive functions: influence of COMT Val/Met polymorphism. *Cortex*, *49*(7), 1801-1807.

Rakover, S. S. (1999). Thompson's Margaret Thatcher illusion: when inversion fails. *Perception*, *28*(10), 1227-1230.

Radman, T., Ramos, R. L., Brumberg, J. C., & Bikson, M. (2009). Role of cortical cell type and morphology in subthreshold and suprathreshold uniform electric field stimulation in vitro. *Brain stimulation*, *2*(4), 215-228.

Ratcliff, N. J., Hugenberg, K., Shriver, E. R., & Bernstein, M. J. (2011). The allure of status: High-status targets are privileged in face processing and memory. *Personality and Social Psychology Bulletin*, *37*(8), 1003-1015.

Renzi, C., Ferrari, C., Schiavi, S., Pisoni, A., Papagno, C., Vecchi, T., ... & 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.

Rescorla, R. A., & Wagner, A. R. (1972). *A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement.* In A. H. Black & W. F. Prokasy (Eds.), Classical conditioning II (pp. 64-99). New York: Appleton-Century-Crofts.

Richler, J. J., & Gauthier, I. (2014). A meta-analysis and review of holistic face processing. *Psychological Bulletin, 140, 1281–1302*.

Robbins, R., & McKone, E. (2007). No face-like processing for objects- of-expertise in three behavioural tasks. *Cognition, 103, 34–79.*

Rondot, P., & Tzavaras, A. (1969). La prosopagnosie après vingt années d'études cliniques et neuropsychologiques. *Journal de Psychologie Normale et Pathologique*, *66*, 133-165.

Rossion, B. (2014). Understanding face perception by means of human electrophysiology. *Trends in cognitive sciences*, *18*(6), 310-318.

Rossion, B., Gauthier, I., Goffaux, V., Tarr, M. J., & Crommelinck, M. (2002). Expertise training with novel objects leads to left-lateralized facelike electrophysiological responses. *Psychological science*, *13*(3), 250-257.

Rossion, B., & Jacques, C. (2008). Does physical interstimulus variance account for early electrophysiological face sensitive responses in the human brain? Ten lessons on the N170. *Neuroimage*, *39*(4), 1959-1979.

Rossion, B., & Jacques, C. (2012). The N170: understanding the time course of face perception in the human brain. In: Steven J. Luc, *The Oxford Handbook of Event-Related Potential Components*, Oxford University Press : (United Kingdom) Oxford 2011, p. 115-142.

Rossion, B., Kung, C. C., & Tarr, M. J. (2004). Visual expertise with nonface objects leads to competition with the early perceptual processing of faces in the human occipitotemporal cortex. *Proceedings of the National Academy of Sciences*, *101*(40), 14521-14526.

Sagiv, N., & Bentin, S. (2001). Structural encoding of human and schematic faces: holistic and part-based processes. *Journal of cognitive neuroscience*, *13*(7), 937-951.

Scapinello, K. F., & Yarmey, A. D. (1970). The role of familiarity and orientation in immediate and delayed recognition of pictorial stimuli. *Psychonomic Science*, *21*(6), 329-330.

Schwarzer, G., Huber, S., Grueter, M., Grueter, T., Groß, C., Hipfel, M., & Kennerknecht, I. (2007). Gaze behaviour in hereditary prosopagnosia. *Psychological research*, *71*(5), 583-590.

Soria Bauser, D. A., Suchan, B., & Daum, I. (2011). Differences between perception of human faces and body shapes: evidence from the composite illusion. *Vision Research, 51, 195–202*.

Spunt, R. P., & Adolphs, R. (2017). A new look at domain specificity: insights from social neuroscience. *Nature Reviews Neuroscience*, *18*(9), 559-567.

Spunt, R. P., & Adolphs, R. (2015). Folk explanations of behavior: A specialized use of a domain-general mechanism. *Psychological science*, *26*(6), 724-736.

Stagg, C. J., Jayaram, G., Pastor, D., Kincses, Z. T., Matthews, P. M., & Johansen-Berg, H. (2011). Polarity and timing-dependent effects of transcranial direct current stimulation in explicit motor learning. *Neuropsychologia*, *49*(5), 800-804.

Szpunar, K. K., McDermott, K. B., & Roediger III, H. L. (2008). Testing during study insulates against the buildup of proactive interference. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(6), 1392.

Talati, Z., Rhodes, G., & Jeffery, L. (2010). Now you see it, now you don't: Shedding light on the Thatcher illusion. *Psychological Science*, *21*(2), 219-221.

Tanaka, J. W., & Curran, T. (2001). A neural basis for expert object recognition. *Psychological science*, *12*(1), 43-47.

Tanaka, J. W., Curran, T., & Sheinberg, D. L. (2005). The training and transfer of real-world perceptual expertise. *Psychological Science*, *16*(2), 145-151.

Tarr, M. J., & Gauthier, I. (2000). FFA: a flexible fusiform area for subordinate-level visual processing automatized by expertise. *Nature neuroscience*, *3*(8), 764-769.

Toseeb, U., Keeble, D. R., & Bryant, E. J. (2012). The significance of hair for face recognition. *PloS one*, *7*(3), e34144.

Tremblay, S., Lepage, J. F., Latulipe-Loiselle, A., Fregni, F., Pascual-Leone, A., & Théoret, H. (2014). The uncertain outcome of prefrontal tDCS. *Brain stimulation*, *7*(6), 773-783.

Tsao, D. Y., & Livingstone, M. S. (2008). Mechanisms of face perception. *Annu. Rev. Neurosci.*, *31*, 411-437.

Underwood, B. J. (1957). Interference and forgetting. *Psychological review*, *64*(1), 49.

Valentine, T. (1988). Upside-down faces: A review of the effect of inversion upon face recognition. *British journal of psychology*, *79*(4), 471-491.

Valentine, T., & Bruce, V. (1988). Mental rotation of faces. *Memory & cognition*, *16*(6), 556-566.

Valentine, T., & Bruce, V. (1986). The effect of race, inversion and encoding activity upon face recognition. *Acta psychologica*, *61*(3), 259-273.

Waguri, E., McLaren, R. P., McLaren, I. P. L., & Civile, C. (2021). Using prototype-defined checkerboards to investigate the mechanisms contributing to the Composite Face Effect. In *Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 43, No. 43).

Waguri, E., McLaren, R. P., McLaren, I. P. L., & Civile, C. (in press). Investigating the Composite Effect in Prototype-Defined Checkerboards vs. Faces. In *Proceedings of the Annual Meeting of the Cognitive Science Society.*

Wang, T., Lavis, Y., Hall, G., & Mitchell, C. J. (2012). Location and salience of unique features in human perceptual learning. *Journal of Experimental Psychology: Animal Behavior Processes*, *38*(4), 407.

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.

Weiner, K. S., & Zilles, K. (2016). The anatomical and functional specialization of the fusiform gyrus. *Neuropsychologia*, *83*, 48-62.

Weinstein, Y., McDermott, K. B., & Szpunar, K. K. (2011). Testing protects against proactive interference in face–name learning. *Psychonomic bulletin & review*, *18*(3), 518-523.

Willems, S., Vrancken, L., Germeys, F., & Verfaillie, K. (2014). Holistic processing of human body postures: evidence from the composite effect. *Frontiers in Psychology*, *5*, 618.

Wilhelm, O., Herzmann, G., Kunina, O., Danthiir, V., Schacht, A., & Sommer, W. (2010). Individual differences in perceiving and recognizing faces—One element of social cognition. *Journal of personality and social psychology*, *99*(3), 530.

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.

Wong, A. C. N., Bukach, C. M., Hsiao, J., Greenspon, E., Ahern, E., Duan, Y., & Lui, K. F. (2012). Holistic processing as a hallmark of perceptual expertise for nonface categories including Chinese characters. *Journal of Vision*, *12*(13), 7-7.

Wong, A. C. N., Bukach, C. M., Yuen, C., Yang, L., Leung, S., & Greenspon, E. (2011). Holistic processing of words modulated by reading experience. *PloS one*, *6*(6), e20753.

Wong, A. C., Palmeri, T. J., & Gauthier, I. (2009). Conditions for facelike expertise with objects: becoming a Ziggerin expert–but which type? *Psychological Science*, 20, 1108–1117.

Yang, L. Z., Zhang, W., Shi, B., Yang, Z., Wei, Z., Gu, F., ... & 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.

Yarmey, A. D. (1971). Recognition memory for familiar “public” faces: Effects of orientation and delay. *Psychonomic Science*, *24*(6), 286-288.

Yin, R. K. (1970). Face recognition by brain-injured patients: a dissociable ability?. *Neuropsychologia*, *8*(4), 395-402.

Yin, R. K. (1969). Looking at upside-down faces. *Journal of experimental psychology*, *81*(1), 141.

Yovel, G., & Kanwisher, N. (2004). Face perception: domain specific, not process specific. *Neuron*, *44*(5), 889-898.

Yovel, G., & Kanwisher, N. (2005). The neural basis of the behavioral face-inversion effect. *Current biology*, *15*(24), 2256-2262.

Zhao, M., Bülthoff, H. H., & Bülthoff, I. (2016). Beyond faces and expertise: Facelike holistic processing of nonface objects in the absence of expertise. *Psychological science*, *27*(2), 213-222.

Zhou, G., Zhang, L., Liu, J., Yang, J., & Qu, Z. (2010). Specificity of face processing without awareness. *Consciousness and cognition*, *19*(1), 408-412.

Ziemann, U., Iliać, T. V., Pauli, C., Meintzschel, F., & Ruge, D. (2004). Learning modifies subsequent induction of long-term potentiation-like and long-term depression-like plasticity in human motor cortex. *Journal of Neuroscience*, *24*(7), 1666-1672.

Zion-Golumbic, E., & Bentin, S. (2007). Dissociated neural mechanisms for face detection and configural encoding: evidence from N170 and induced gamma-band oscillation effects. *Cerebral Cortex*, *17*(8), 1741-1749.

Zmigrod, S., Colzato, L. S., & Hommel, B. (2014). Evidence for a role of the right dorsolateral prefrontal cortex in controlling stimulus-response integration: a transcranial direct current stimulation (tDCS) study. *Brain stimulation*, *7*(4), 516-520.