VISUAL FIELD BIASES IN 2D AND 3D FACE PROCESSING

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Abstract

The reported upper visual field bias for face processing tends to be small and inconsistent; this may be due to the use of 2D images, that lack the stereoscopic depth information which is typically available in the real world. Here we evaluate the impact of viewing naturalistic stereoscopic 3D face stimuli on face detection and recognition, as a function of location in the visual field. A series of studies using low- and high- level tasks (e.g., orientation discrimination and face recognition) were conducted. Photorealistic face stimuli were presented using a mirror stereoscope with and without binocular disparity in the upper and lower visual field. Our results show that previously reported visual field biases for faces are task dependent. Further, we find no significant differences between 2D and 3D viewing, suggesting that 2D face stimuli can be reasonable proxies for natural 3D faces.

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Chapter 1

Introduction

The ability to correctly perceive and identify faces helps foster engagement and interaction with others, which has been important to human survival throughout evolution. Faces are considered distinct from other complex objects (e.g., an apple, a book) and undergo holistic processing, where the configural relationship between facial features results in a better indication of identity than when features are shown in isolation (Tanaka & Farah, 1993; Thompson, 1980). In comparison, this holistic processing does not occur with objects such as houses (Tanaka & Farah, 1993). Faces that differ from normal configural information, such as when faces are scrambled or inverted, lead to significantly poorer recognition than upright faces and inverted objects (Tanaka & Farah, 1993; Yin, 1969). By comparison, inverted object perception is minimally affected, with performance nearly as good as, or even better than, that of upright versions (Busigny & Rossion, 2010; Yin, 1969).

This difference in processing between objects and faces could be due to the specialization of brain areas for faces, such as the fusiform face area (FFA) and occipital face area (OFA). These regions are thought to be important for processing face form information related to identity and expressions (Bernstein & Yovel, 2015). The fusiform face area and occipital face area exhibit greater selectivity for faces compared to objects (Kanwisher et al., 1997; McCarthy et al., 1997; Pitcher et al., 2007). Thus, the visual system facilitates face processing in dedicated brain regions, leading to distinct advantages for faces that should be considered when exploring processing specialization.

1.1 Visual Field Specialization

The location in the visual field also appears to influence the success with which faces are processed. In his landmark paper, Previc (1990) argued that processing asymmetries exist between the upper and lower visual fields, with differences observed in reaction time, distance judgements, eye movements, attentional abilities, and detection thresholds. This segmentation of the visual fields was later linked to distinctive differences in receptive fields located in the dorsal and ventral regions of the early visual cortex (Silson et al., 2018). Using the elliptical population receptive field (pRF) model and fMRI imaging, Silson et al. (2018) successfully mapped the early visual cortex. The mapping revealed that receptive fields from within the upper and lower visual fields corresponded more frequently to the ventral and dorsal brain regions, respectively. The shape and size of these receptive fields were substantially different; ventrally located receptive fields were larger and more elliptical in shape than those located in the early dorsal areas (Silson et al., 2018). Such distinctions support the idea that regions of the visual field can be attuned to detect specific visual features, depending on their location above or below fixation, and may impact how basic visual features are processed into properties of complex images, such as faces, at later stages (e.g., in the middle and higher brain areas).

This finding aligns with Previc's (1990) proposal that the upper visual field is relatively more associated with the ventral visual stream, and the lower visual field is more associated with the dorsal visual stream. The ventral visual stream is thought to be responsible for identifying and recognising objects (e.g., a book vs. an apple) (Goodale & Milner, 1992; Mishkin & Ungerleider, 1982). As mentioned above, faces are also processed in the ventral regions of the brain (e.g. the fusiform face area) (Bernstein & Yovel, 2015)

In contrast, the dorsal visual stream is thought to be responsible for determining the location of objects (e.g., their postion on a desk), acting upon objects (e.g., inserting a peg into a board), as well as processing facial motion (Bernstein & Yovel, 2015; Goodale & Milner, 1992; Mishkin & Ungerleider, 1982). Although this two-visual-stream hypothesis was originally proposed for object processing, it has been applied to faces (Bernstein & Yovel, 2015). Thus, it would be expected that performance on tasks requiring knowledge of shape or identity would be better in the upper visual field due to its connection to the ventral pathway. There is evidence to support this proposal from studies using different categories of objects: in target visual search (Feng & Spence, 2014; Previc & Blume, 1993), letter working memory (Ghafari et al., 2023), and word–nonword discrimination tasks (Goldstein & Babkoff, 2001).

In the case of faces, an upper visual field advantage appears to exist, but the literature is mixed, yielding variable results and generally weak effects. Tsurumi et al. (2023) found that an upper visual field advantage for faces appears to emerge in infants as young as 7–8 months old. Infants perceived faces as more salient and showed greater habituation when presented with faces in the upper visual field compared to the lower visual field. No such effect was found for houses, suggesting a possible innate link between face processing and the upper visual field. A potentially important aspect of this bias is the influence of the 'typical location' of the stimulus. Expectations regarding the spatial location of facial features guide gaze behaviour toward preferential regions such as the eyes and mouth (De Haas et al., 2016). When the eyes and mouth are positioned in their typical upper and lower visual field locations, respectively, recognition improves (De Haas et al., 2016). Royer et al. (2018) argued that the eyes are the most salient feature of the face and are a key factor in face recognition. As the eyes tend to appear in the upper visual field, the processing advantage may extend to the whole face when presented in this region, as perceptual resources could be focused on this location to capture the critical eye information. Studies of eye movement patterns by Felisberti and Currie (2019) appear to support this proposal. That is, they reported that when an observer views multiple face stimuli simultaneously, the first saccade is directed towards the face located in the upper left quadrant. They argued that, in general, there is a preference for faces located in the upper visual field, with longer dwell times and more fixations than those in the lower visual field (Felisberti & Currie, 2019). It should be noted that they also propose an alternate interpretation. The upper visual field advantage for faces may be due to an attentional bias related to scanning behaviour from reading rather than specialized processing driven by the ventral pathway (Felisberti & Currie, 2019; Pomplun et al., 2013). Additionally, the effect of locational expectation is not unique to faces, as it has been observed to impact object salience (Kaiser & Cichy, 2018b; Palanica & Itier, 2017) and object categorisation in the brain based on typically occurring locations (Kaiser et al., 2018; Kaiser & Cichy, 2018a).

There are also reports of an upper visual field advantage for face processing in low-level eye direction detection tasks (Palanica & Itier, 2017) and high-level sex identification tasks (Quek & Finkbeiner, 2014, 2016). However, these effects tend to be weak for high-level tasks (Quek & Finkbeiner, 2014, 2016). Further, a study by Morsi et al. (2024) found the opposite effect, with greater sensitivity to a face's sex in the lower rather than the upper visual field. Overall, the literature has shown inconsistent findings regarding visual field asymmetries in face processing, with reports of an upper right and lower left visual field advantage (Hagenbeek & Van Strien, 2002) and no visual field advantage (Kreichman et al., 2020). As outlined below, one potential reason for the mixed results on the upper visual field advantage for faces could be the use of 2D stimuli in laboratory studies, unlike real faces, which are naturally three-dimensional.

1.2 2D vs 3D Viewing

As alluded to above, most studies evaluating the visual field advantage for faces have used 2D pictures. While these stimuli can create quite realistic images and give the impression of depth through pictorial depth cues (e.g., shadows, perspective, occlusion, texture), they lack the stereoscopic information typically available in the real world (Snow & Culham, 2021). Stereopsis is a binocular depth cue that arises from the slightly different retinal images in each eye that can be used to calculate the relative distance and depth of objects (Foley, 1967; Howard & Rogers, 1996; McKee, 1983; Wheatstone, 1838). In isolation, stereopsis is one of the most precise sources of relative depth information (Bradshaw & Rogers, 1999; Durgin et al., 1995; Rogers & Graham, 1979). Even in natural environments that have many rich cues to depth, the addition of binocular disparity information often improves depth discrimination thresholds (McCann et al., 2018; McKee & Taylor, 2010). Stereoscopic information can also enhance shape perception when presented with shading and texture depth cues (Li & Pizlo, 2011). Although observers are better at identifying shapes presented at different orientations when defined by stereoscopic information than by shading cues alone, there is an added benefit when both shading and stereoscopic cues are present (Lee & Saunders, 2011). Given these findings, it seems likely that the presence of binocular depth information would benefit face processing.

1.3 3D Shape of Faces

Given the effects of 3D stimuli outlined above, it is possible that the presentation of more realistic face stimuli containing stereoscopic depth and shape information could help resolve the discrepancies in the visual field specialization literature. Indeed, there is some evidence that stereoscopic 3D faces are identified more accurately than 2D faces (Burke et al., 2007; Chelnokova & Laeng, 2011; Eng et al., 2017; H. Liu et al., 2020). Based on differences in pupil diameter when viewing 2D and 3D faces, H. Liu et al (2020) proposed that the smaller pupil size when observing 3D faces, compared to 2D faces, is indicative of a lower processing load during retrieval of face information. Others have reported the 3D advantage in socially driven scenarios, such as speed of encoding of facial emotions (happy and fearful expressions) (Wang et al., 2017). Interestingly, in a recent study using noise texture presented stereoscopically, Dehmoobadsharifabadi and Farivar (2016) demonstrated that faces defined only by binocular disparity cues are sufficient to support face identification.

In addition to the perceptual differences between viewing 2D and 3D faces, researchers have reported that presentation mode influences gaze patterns. Several studies have shown that observers tend to fixate significantly longer on the cheeks of 3D faces compared to 2D faces (Akhavein & Farivar, 2017; Chelnokova & Laeng, 2011; H. Liu et al., 2020). These researchers have argued that the cheeks contain rich volumetric information in 3D faces, which is absent in 2D versions of the stimuli. Therefore, it is likely that the 3D cheeks provide some benefit for face processing, as stereoscopic faces used were perceived more accurately than 2D faces (Chelnokova & Laeng, 2011; H. Liu et al., 2020). In computer vision, information about the curvature of the face, such as that of the cheeks, calculated from 3D depth maps of a face can aid in recognition (Gordon, 1991). These differences when appreciating 2D vs 3D face perception may explain why, under 2D viewing conditions, observers are poor at estimating the correct proportion of their own faces (D'Amour & Harris, 2017).

While there are nuances to this literature, in sum it appears that 3D faces are perceived and processed differently from 2D faces, and previous studies that used 2D stimuli may not have fully captured the perceptual information available during naturalistic 3D face processing.

1.4 Present Study

As outlined above, the focus of the current work is to better understand face processing, specifically how stereopsis contributes to performance, particularly in relation to the upper visual field bias. To our knowledge, no studies have attempted to explain the variability in upper-lower visual field asymmetries in face processing. In the current study, we address one possibility that this variability is related to a lack of realistic stereoscopic depth. Our hypothesis is that stereopsis provides critical depth and shape information that is lacking in 2D images and may interact with the known upper-field advantage to boost sensitivity to faces. In a series of psychophysical experiments, we evaluated the processing of 2D and stereoscopic 3D faces, and how this depth information modulates visual field effects. The potential difference between 2D and stereoscopic 3D faces was evaluated using a novel visual search paradigm, face-matching, and face-recognition tasks. By systematically varying the depth information and the location of the faces, we evaluated 1) the robustness of the visual field effects and 2) whether the presence of 3D information enhances these biases.

Chapter 2

General Methods

2.1 Observers

Participants were recruited from the undergraduate research pool or the York University community, all of whom possessed normal or corrected-to-normal vision. To be included in the study, observers had to have stereoacuity of at least 40 seconds of arc on the Randot™ stereoacuity test. Additionally, observers who performed below 50% accuracy in at least half of all conditions were excluded. The research protocol was approved by the York University Research Ethics Board.

2.2 Stimuli

The stimuli were custom-generated photorealistic faces presented in 2D and stereoscopic 3D. These avatars were designed to capture population diversity, including males and females of different ethnic backgrounds and ages. A total of twenty-six human avatars (12 female, 14 male) were rendered in Blender as 3D models using Reallusion™ software. The upper body mesh, including the head and neck regions of the avatar, was isolated from the full-body models. Stereoscopic pairs of these head models were then created using the dual camera feature in Blender. The cameras were positioned 74 cm from the front of the face and separated 63 mm to match the average human interpupillary distance (Dodgson, 2004; Murray et al., 2017).

2.3 Apparatus

Stimuli were displayed using a Wheatstone mirror stereoscope, as illustrated in Figure 1. This stereoscope consisted of two DELL U2412M LCD monitors (1920 x 1200 pixels) with a refresh rate of 60 Hz. The monitors were positioned 74 cm from the observer, with a fixed chinrest positioned between the screens to minimize head movement. In the 3D condition, stereopairs of images were used, in which the images had a slight positional difference, and when viewed simultaneously, created a perception of depth. In 2D trials, the left-eye image of the stereo pair was presented to both eyes. The stimulus array was presented within a grey circle located at the centre of the display and surrounded by a greyscale Voronoi texture pattern. The experiment was conducted using PsychoPy (2023.2.2), supported by Python 3.10 software.

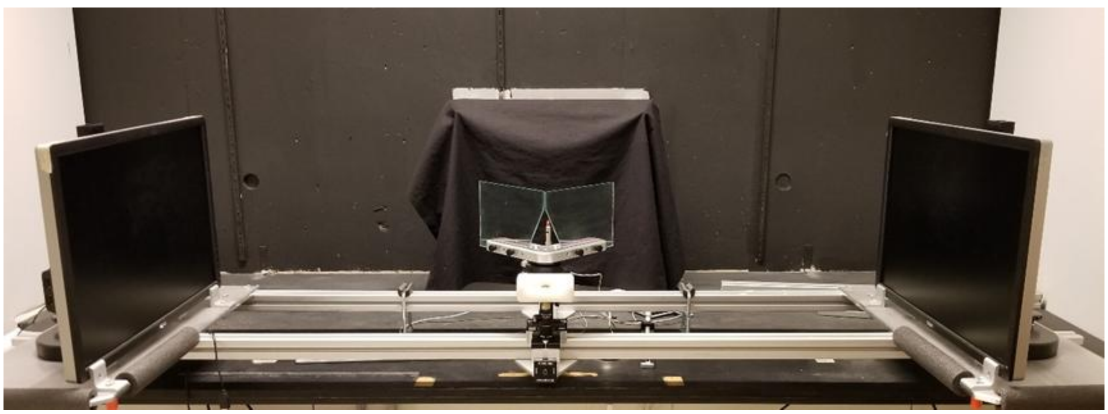

Figure 1. Mirror stereoscope with two DELL U2412M monitor displays (1920 x 1200 pixels) and chinrest.

2.4 Procedure

Before the start of each experiment, the interpupillary distance of each participant was measured using a Richter digital pupil distance meter™, and stereoacuity was assessed with the Randot™ test. Prior to the main task, observers completed a brief practice session. At the beginning of each trial, a Nonius fixation cross appeared in the centre of the display for 100 ms. After this, the stimulus was presented. Observers could respond only by key press once the test face(s) disappeared, allowing them sufficient time to appreciate the stereoscopic depth information. They were asked to maintain fixation on the cross throughout the trial. The target face (specific to a given experiment) was present for 50% of the trials. Modality (2D and 3D) was presented in separate blocks and counterbalanced across participants. Signal detection theory was used to analyze the data and compute sensitivity (d') (Green & Swets, 1966). In cases of extreme performance (100% proportion correct), an adjustment of (N-0.5)/N was applied, where N equals the number of trials (Macmillan & Kaplan, 1985).

Additionally, reaction time was recorded from the moment the test face(s) disappeared until the response was made. Only the trials in which the target was present were analyzed (Nevard et al., 2023). In some cases, the reaction time data were skewed by large outliers due to spontaneous breaks that participants took between trials. To address this, the observer's average reaction time and standard deviation were calculated for each condition. If a reaction time on an individual trial exceeded the mean by three standard deviations, that reaction time value was replaced by the mean value for that condition (Barkhuysen et al., 2008; C. Brown & Hagoort, 1993).

Chapter 3

Experiment 1: Face Orientation Detection Visual Search

3.1 Introduction

As outlined in the Introduction, there may be an advantage in processing faces in the upper visual field. However, these findings are mixed, and we propose that the lack of stereoscopic depth in these studies may explain the variable results. The use of 3D volumetric faces could provide additional information that may facilitate face processing and reduce the variability seen in the visual field asymmetry literature. To our knowledge, no studies have explored the combined impact of stereoscopic vision and the upper visual field advantage on face processing. To address this, we designed a face orientation detection task using a visual search paradigm. The objectives of Experiment 1 were to i) reproduce the upper visual field advantage observed in the literature using the novel task and ii) determine whether binocular disparity enhances the effect.

3.2 Stimuli

In Experiment 1, six faces (3 female, 3 male) were used. The faces were matched in height (2.00° visual angle), although their widths varied across individuals (range: 1.34° – 1.48° visual angle). The maximum disparity ranged from 3.76 to 7.52 arcmin. To eliminate shoulders present in the original images, an oval mask was applied to the faces. The edges of the stimuli created by the mask were blurred to reduce sharpness and visibility of the variation in neck shape. On each trial, one of the six faces was presented as the stimulus. In the 3D condition, the ears were aligned with the fixation plane, thus positioning the faces slightly in front of the plane. The faces had approximately 200 arcseconds of depth from the fixation plane to the end of the nose. The faces were presented on the grey background circle (diameter 3.34° of visual angle) located on the fixation plane.

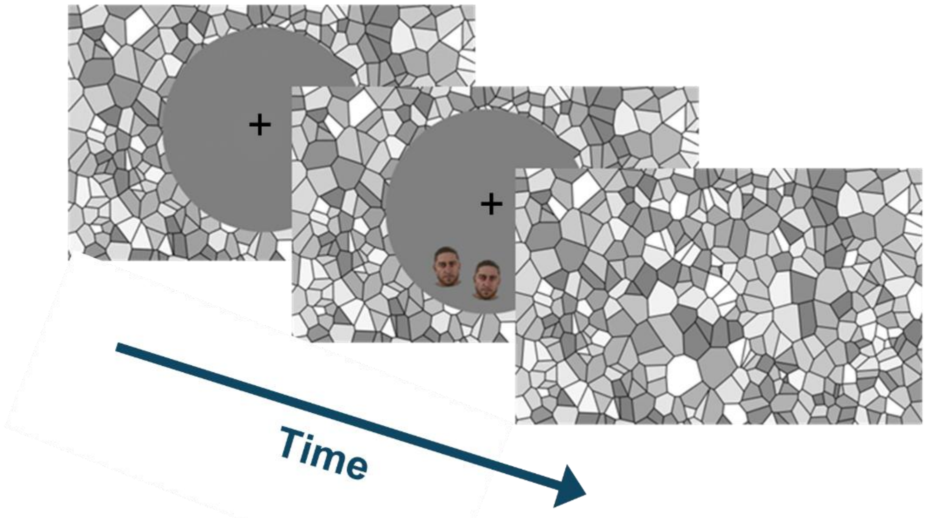

Figure 2. Time series of a single trial in Experiment 1 showcasing initial fixation phase, test array presentation and response phase.

3.3 Procedure

Participants were instructed to identify a target face that was rotated 5° (either to the left or right) among the distractors. The distractor faces had the same identity as the target face but were tilted 5° in the opposite direction (see Figure 2). The rotation of the target was counterbalanced between observers. To modulate task difficulty across trials, the number of faces in the test array was varied from 2 to 5, including both target and distractor faces. Stimuli were restricted to either the upper or lower visual field, equidistant from the central fixation point.

The faces were positioned along an imaginary semi-circle at pseudo-randomly assigned positions in the upper (18°, 54°, 60°, 90°, 126°) and lower (198°, 235°, 270°, 306°, 342°) visual fields, at an eccentricity of 3.34° of visual angle from the centre of the stimuli to the centre of the display. Face positions were constrained to ensure there were no more than two empty positions occurred between adjacent faces, helping limit possible eye movements. The face arrays were presented for 600 ms before disappearing, leaving only the background pattern. The presentation time was selected based on pilot trials to minimize eye movements away from centre fixation while still allowing sufficient time for observers to appreciate the stereoscopic depth information.

Observers were instructed to respond quickly and accurately by pressing a key to indicate the presence or absence of the target. A brief practice session, using two novel faces, was completed prior to the experiment. Responses were allowed only after the faces disappeared and following each response, the fixation cross reappeared at the centre of the screen. The full experiment consisted of two blocks (2D and 3D) each containing 16 conditions (number of stimuli, upper/lower visual field, target present/absent) with 24 trials each, for a total of 768 trials.

3.4 Results & Discussion

A total of four observers were excluded from the analysis based on the exclusion criteria described in the General Methods; one of these observers reversed the response buttons. As a result, data from the remaining 28 participants were considered in the final analysis. Descriptive statistics indicated that the data were sufficiently normally distributed. Therefore, we conducted a secondary analysis using a repeated-measures ANOVA. Mauchly's test of sphericity was performed for conditions with three or more levels and revealed that the assumption of sphericity was violated for modality × number of stimuli and visual field × number of stimuli interactions (see Appendix A Table A.1 for results of Mauchly's test of sphericity). To compensate for this, the Greenhouse-Geisser correction was applied to these interactions. A 2 (modality) × 2 (visual field) × 4 (number of stimuli) repeated-measures ANOVA was conducted to investigate the effect of modality (2D vs 3D) and visual field (upper vs lower) on face orientation sensitivity across different levels of task difficulty (number of stimuli). In addition, a Bayesian repeated-measures ANOVA was conducted to evaluate the strength of evidence in favour of the null hypotheses. Bayes factors were calculated for main effects and interactions of interest that did not reach significance as indicated by the repeated-measures ANOVA. Means and standard deviation not reported in the text are provided in Appendix B Table B.1.

The ANOVA revealed no significant interaction between modality and visual field location on sensitivity to faces, $F(1, 27) = 0.06$, $p = 0.82$, $\eta^2 = 0$. Bayesian analysis revealed moderate evidence ($BF_{10} = 0.30$) for the null hypothesis regarding this interaction. Main-effect analysis showed no significant difference in sensitivity to face orientation between the 3D ($M = 2.74$, $SD = 0.91$) and the 2D ($M = 2.65$, $SD = 0.91$) faces, $F(1, 27) = 0.05$, $p = 0.82$, $\eta^2 = 0$. For this main effect, Bayesian analysis revealed weak evidence ($BF_{10} = 0.21$) in support of the null hypothesis indicating that modality do not impact face sensitivity. Additionally, there was no consistent pattern of influence of the number of stimuli (task difficulty) on visual field location.

There was a significant main effect of visual field location, $F(1, 27) = 6.14$, $p = 0.02$, $\eta^2 = 0.01$. That is, observers were more sensitive to faces presented in the upper visual field ($M = 2.75$, $SD = 0.89$) compared to the lower visual field ($M = 2.60$, $SD = 0.96$), irrespective of modality and the number of stimuli. Since there was no effect of modality or interaction between modality and visual field location, we collapsed the data across the 2D and 3D conditions to highlight the upper visual field advantage (see Figure 4).

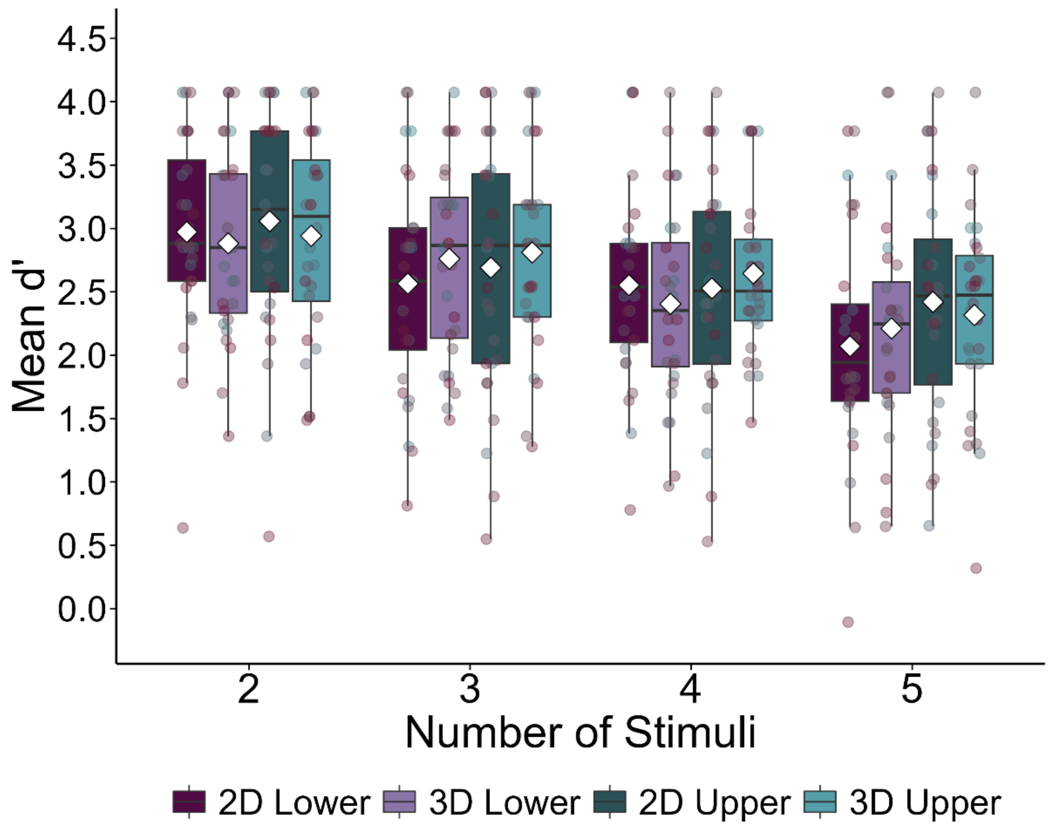

Figure 3. Boxplot show the average d' (n = 28) for 2D lower (dark purple), 3D lower (light purple), 2D upper (dark teal) and 3D upper (light teal) conditions across the number stimuli presented. White diamonds represent the group mean, the bolded horizontal line boxes represent the median, the box indicates the interquartile range, and whiskers show the upper and lower 25% of values, excluding outliers that are outside this range. Coloured dots represent a single individual's average score.

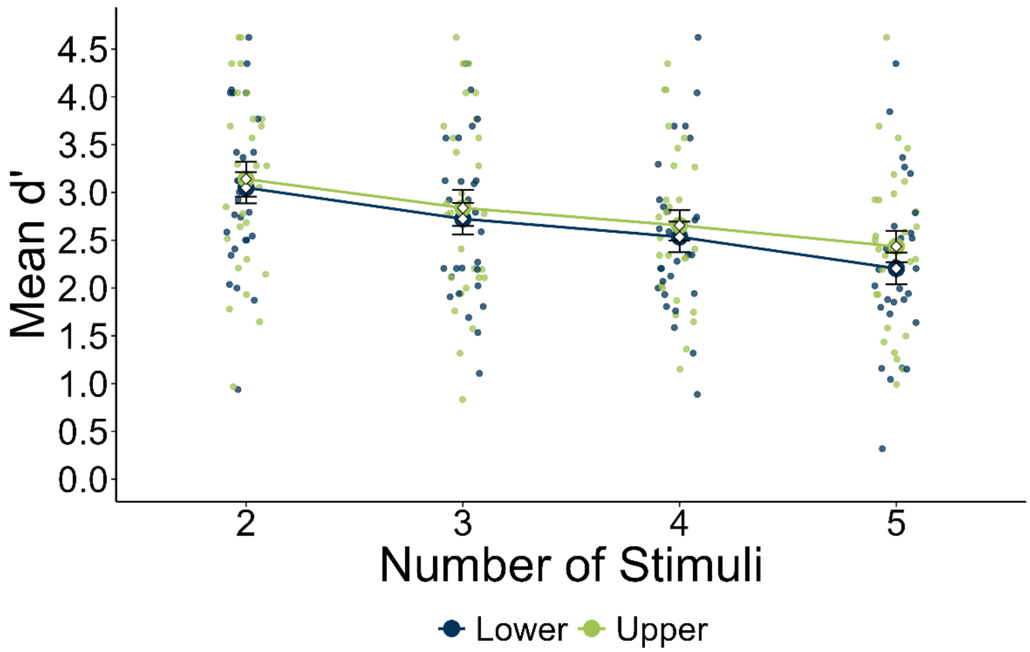

Figure 4. The line graph shows the average d' (n = 28) upper (green) and lower (blue) visual field location across the number of stimuli presented. White dots represent the mean. Colored dots represent a single individual's score in the upper (green) and lower (blue) condition. Error bars indicate the standard error of the mean.

There was also a significant main effect of the number of stimuli, $F(3, 81) = 43.35$, $p < .001$, $\eta^2 = 0.25$. Holm-corrected post hoc comparisons revealed that mean sensitivity significantly decreased as the number of stimuli increased (see Appendix C). Additionally, there was no interaction between modality × number of stimuli, $F(2.14, 57.90) = 2.24$, $p = 0.11$, $\eta^2 = 0.01$; visual field × number of stimuli, $F(2.28, 61.60) = 0.71$, $p = 0.51$, $\eta^2 = 0$; or modality × visual field × number of stimuli, $F(3, 81) = 1.97$, $p = 0.13$, $\eta^2 = 0.01$.

Reaction time was also analyzed using a 2 (modality) × 2 (visual field) × 4 (number of stimuli) repeated-measures ANOVA to assess the effect of these variables on face orientation detection speed (see Appendix D Table D.1 for results). Mauchly's test of sphericity was conducted for conditions with three or more levels and indicated that the assumption of sphericity was not met for the number of stimuli, modality x number of stimuli and modality x visual field x number of stimuli (see Appendix A Table A.2 for full results of the Mauchly's test of sphericity). Thus, the Greenhouse-Geisser correction was applied to this main effect and interactions. Overall, there were no significant interactions. The only significant main effect for reaction time was the number of stimuli; as task difficulty increased, reaction time also increased. Holm-corrected post hoc comparisons revealed that reaction times were significantly longer for five face stimulus trials compared to two face stimulus trials (see Appendix D Table D.2).

We predicted that in the 3D upper visual field condition, there would be enhanced face processing. However, our results indicate that no such interaction occurred in low-level orientation face detection tasks. An upper visual field advantage was observed, demonstrating the effectiveness of our paradigm and extending the previously reported bias in the literature to this novel visual search orientation task. However, this effect was not reflected in reaction time. The lack of a significant effect of modality is surprising, as noted in the Introduction, since stereoscopic information has been shown to support face processing in other studies. One possible explanation for this lack of effect is that the task was too easy, as evidenced by the fact that some individuals achieved 100% accuracy, and the average d′ values were very high. This lack of difficulty may have limited the potential contribution of stereoscopic information.

Chapter 4

Experiment 2: Sequential Matching Visual Search

4.1 Introduction

In Experiment 1, the visual search paradigm was validated as an effective method for examining the upper visual field advantage in a low-level face orientation detection task. With the goal of making the task more difficult, in Experiment 2 we adapted the visual search to create a higher-level face-matching task requiring observers to match faces based on identity. This task is both more challenging and more reliant facial identity information that may benefit from volumetric depth and enhanced structural definition of facial feature. Therefore, the objectives of Experiment 2 were to i) replicate the upper visual field advantage seen in Experiment 1 using a high-level task and ii) determine whether the lack of a modality effect in Experiment 1 was due to task characteristics and/or insufficient task difficulty.

4.2 Stimuli

The target face was selected from a set of eight faces (4 female and 4 male). The faces were the same height, had the same maximum disparity range, and underwent the same preprocessing (e.g., masking, smoothing) as those in Experiment 1, as shown in Figure 5. However, because additional faces were used in Experiment 2, the widths of the faces range from 1.34° to 1.71° visual angle. To increase task difficulty, distractor faces were different identities and were pseudo-randomly selected from a pool of 15 face identities (as opposed to the same identity in Experiment 1).

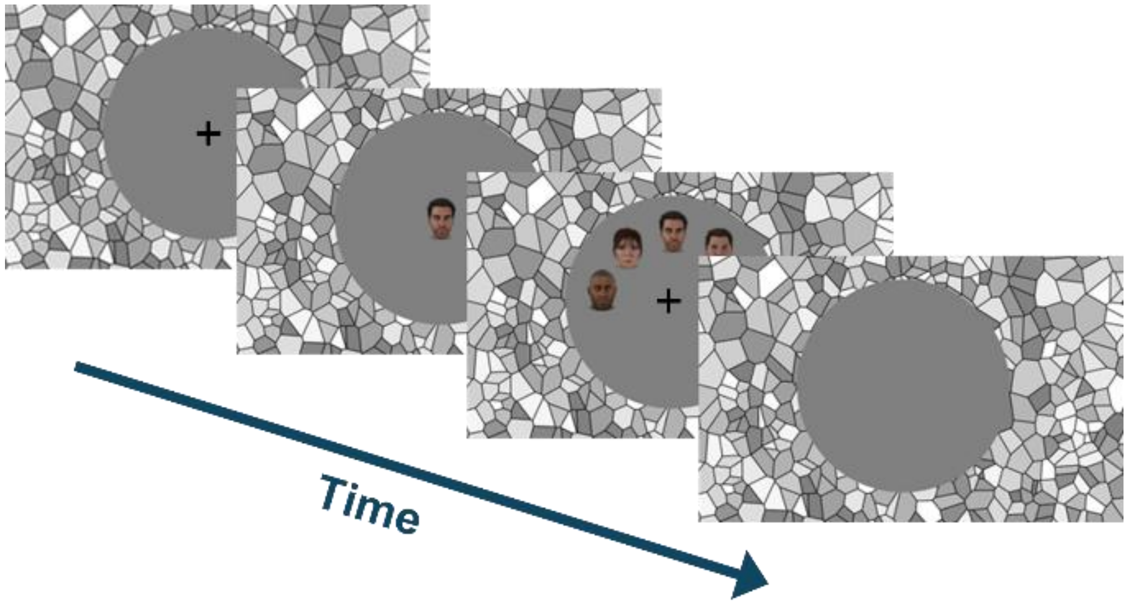

Figure 5. Time series of a single trial in Experiment 2 show initial fixation phase, target face presentation, test array presentation and response phase.

4.3 Procedure

Aside from the changes outlined below, the procedure and analysis followed those described for Experiment 1. A brief practice session consisting of 24 randomly selected trials was completed at the start of the session. In the full experiment, the reference target face was first shown briefly (400 ms), followed by a test array of pseudo-randomly selected faces of different identities Observers indicated whether the target face was present or absent in the test array. To further limit opportunities for eye movements and to increase task difficulty, the viewing time for the test array was reduced to 400 ms. Additionally, to shorten the study duration, the number of stimuli in the search array was reduced to 3 and 6 faces. Each 2D and 3D block consisted of 8 conditions with 42 trials each for a total of 672.

4.4 Results and Discussion

A total of 22 observers participated in Experiment 2. Descriptive statistics indicated that the face sensitivity data were sufficiently normally distributed, as shown in the boxplot in Figure 5. Therefore, a 2 (modality) × 2 (visual field) × 2 (number of stimuli) repeated-measures ANOVA was conducted to assess the effect of modality (2D, 3D), visual field location (upper, lower), and number of stimuli (3, 6) on face-matching sensitivity. A Bayesian repeated-measures ANOVA was also conducted. For means and standard deviation not reported in the text see Appendix B Table B.2. The ANOVA revealed no significant interaction between modality and visual field location, $F(1, 21) = 0.01$, $p = 0.76$, $\eta^2 = .00$. The Bayesian analysis also found no evidence supporting the null hypothesis ($BF_{10} = 0.09$, error = 2.79%).

Main-effect analysis of modality and location revealed no significant difference in sensitivity between 2D ($M = 2.64$, $SD = 0.72$) and 3D ($M = 2.66$, $SD = 0.70$) face presentations, $F(1, 21) = 0.12$, $p = 0.72$, $\eta^2 = .00$, and between upper ($M = 2.71$, $SD = 0.75$) and lower ($M = 2.64$, $SD = 0.67$) visual field presentations, $F(1, 21) = 0.65$, $p = 0.43$, $\eta^2 = 0$. Bayes factors indicated weak evidence in favour of the null hypothesis for modality ($BF_{10} = 0.27$), and moderate evidence in support of the null hypothesis ($BF_{10} = 0.32$) for visual field location. Therefore, this study provides no support for an upper visual field advantage or 3D advantage in face processing.

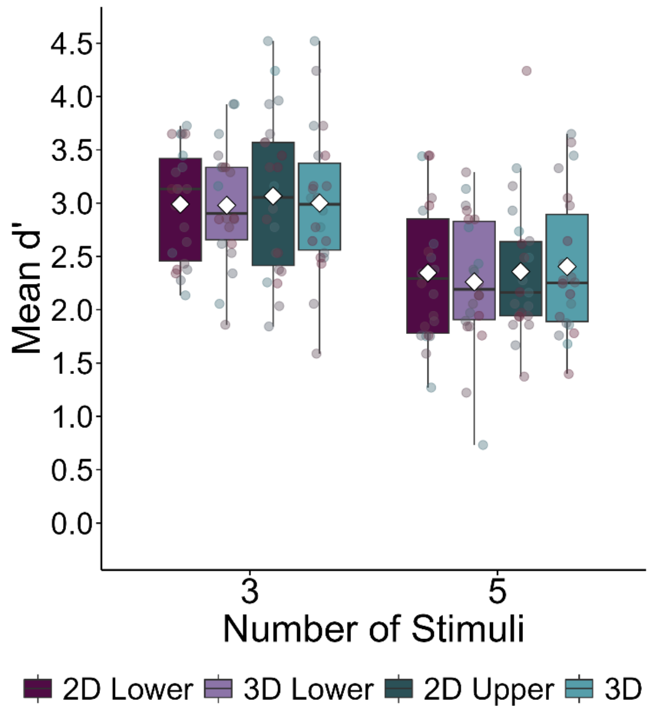

Figure 6. Average d' (n = 22) for the different face presentation conditions: 2D lower (dark purple), 3D lower (light purple), 2D upper (dark blue purple) and 3D upper (light blue) across the number of stimuli. The boxplot uses the same conventions outlined in Figure 3.

A significant main effect of the number of stimuli was found, $F(1, 21) = 95.60$, $p < 0.01$, $\eta^2 = 0.38$. Observers showed greater sensitivity when three stimuli ($M = 3.01$, $SD = 0.62$) were present compared to when five stimuli ($M = 2.34$, $SD = 0.63$) were shown. However, there was no interaction between modality × number of stimuli, $F(1, 21) = 0.02$, $p = 0.89$, $\eta^2 = 0$; visual field × number of stimuli, $F(1, 21) = 0.05$, $p = 0.82$, $\eta^2 = 0$; or modality × visual field × number of stimuli, $F(1, 21) = 0.57$, $p = 0.46$, $\eta^2 = 0$.

Additionally, reaction time on target-present trials was assessed using a 2 (modality) × 2 (visual field) × 2 (number of stimuli) repeated-measures ANOVA. The analysis showed no significant interactions or differences in reaction time between 2D and 3D faces, or between upper and lower visual field presentations. However, there was a significant main effect of the number of stimuli, with observers taking significantly longer to respond when the test array contained five faces compared to three faces (see Appendix D Table D.3 for results).

One aim of this study was to increase task difficulty, and participants reported that the use of different identities did make the task challenging. Further, response times were overall longer, consistent with increased task difficulty. However, despite this, there was no benefit to viewing 3D faces. Furthermore, the upper visual field advantage observed in Experiment 1 was not seen here. It is possible that the visual field effect in Experiment 1 is limited to low-level tasks; however, further research is needed to confirm this.

Chapter 5

Experiment 3: Degraded Single Face Sequential Matching Task

5.1 Introduction

Given that observers performed very well in Experiments 1 and 2 (despite reporting that the task was difficult), we designed Experiment 3 to be even more challenging. Furthermore, to favour the use of stereoscopic information, the face stimuli were enlarged by 27%, which in turn increased the amount of disparity between facial features. The objectives were the same as those in Experiment 2, just under a new experiment paradigm.

A sequential single-face matching paradigm was used, in which a same-different comparison was made between a target and test face. To ensure that the task was not too easy, target faces were degraded by reducing contrast and applying pixelation. The amount of pixelation and contrast was determined through a series of pilot studies to ensure an accuracy rate near 75%. We hypothesized that, as the task became more challenging and disparities increased, observers would be more likely to use stereoscopic information to aid face perception. Additionally, to verify that observers were not relying on feature-based processing, but instead using holistic face processing, inverted versions of the stimuli were also tested. If holistic face processing was indeed occurring, performance would be expected to be significantly worse in the inverted face condition due to the face inversion effect (Tanaka & Farah, 1993; Yin, 1969).

5.2 Stimuli

In Experiment 3, there were 10 possible target faces (5 female, 5 male). The images of the target faces were degraded by adjusting the image contrast through clipping the original contrast range—for example, altering it from 0–1 to 0.2–0.8—resulting in a stimulus with 60%

of the original contrast. The faces were pixelated by averaging across every 15 pixels to form a single large pixel. To avoid introducing stereoscopic matching noise (caused by differences in pixelation between the two eyes) all target faces were shown in 2D, and viewing modality was only manipulated for the test faces. The test faces (not pixelated) had either the same identity as the target or a different identity (distractor). The distractor faces were randomly selected from a pool of 19 possible identities, including faces from the target pool that were not designated as the target on the given trial. For the between-subjects orientation condition, faces were either presented upright or inverted (see Figure 7). All face stimuli were converted to greyscale, with luminance normalized to the average luminance value of the set of faces. An oval mask was also applied to each face to remove or minimize non-facial features such as ears, neck, and hair. Additionally, the image size was increased relative to the faces used in Experiments 1 and 2, with a height of 4.74° (the width varied with identity 3.16 °- 3.59° visual angle). Increasing face size in turn increased the range of binocular disparities, with maximum disparity ranging from 12.55 to 20.07 arcmin, across face identities. The target face was presented in the centre of the display, and the test face was presented above or below the fixation cross at an eccentricity of 3.78° from the centre of the cross to the centre of the face. The size of the grey background area was increased to a diameter of 5.01° to accommodate the increase in face size. For the 3D face condition, test faces (non-degraded) were presented with their noses at the fixation plane.

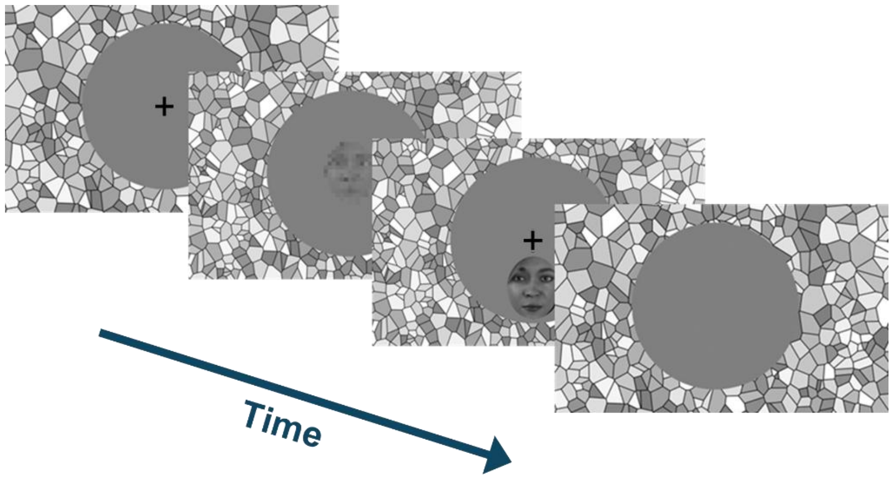

Figure 7. Time series of a single trial in Experiment 3 show initial fixation phase, target face presentation, test face presentation and response phase. The inverted face condition follows the same protocol, except for the change in face orientation.

5.3 Procedure

The apparatus and analyses followed those described in the general methods. A sequential face-matching task, similar to the one used in Experiment 2, was employed, except that only a single face was presented during the test phase. Observers were assigned to either the upright or inverted face orientation condition and completed 24 practice trials before the start of the experiment. In both modality conditions, the degraded target face was displayed at the centre of the screen for 300 ms, followed by presentation of a single non-degraded test face above or below the fixation cross for 300 ms. The observers' task was to indicate whether the target and test faces had the same identity. Responses were made after the test face was removed. The subsequent trial started automatically following an inter-trial interval of 100 ms. In 50% of the trials, the test and target faces were the same. Each test block (2D and 3D), contained 4 conditions (visual field location, target presentation) with 80 trial each, for a total of 640 trials across all blocks.

5.4 Results and Discussion

Two observers from the upright face condition and five from the inverted face condition were excluded from the analysis because they met the exclusion criteria outlined in the General Methods. As a result, 52 observers (26 in the upright face condition and 26 in the inverted face condition) were included in the analyses. Figure 8 shows these observers' face-matching performance (d′) for both modalities in the inverted and upright conditions. Preliminary statistics confirmed that the data were normally distributed and met assumption of homogeneity of variance (for Levene's test see Appendix A Table A.3). Face sensitivity (d′) was analyzed using a 2 (modality) × 2 (visual field) × 2 (orientation) mixed-factorial ANOVA, with orientation (upright, inverted) as the between-subjects variable and modality (2D, 3D) and visual field (upper, lower) as the within-subjects variables. A mixed-model Bayesian ANOVA was also used to evaluate the strength of null findings for conditions that did not reach significance with the mixed-factorial ANOVA. Means and standard deviations not reported are provided in Appendix B Table B.3.

The ANOVA results indicated no interaction between modality and visual field, $F(1, 25) = 0.13$, $p = 0.72$, $\eta^2 = 0$. The Bayesian model indicated moderate evidence ($BF_{10} = 0.30$) in favour of the null hypothesis, again suggesting that, stereoscopic vision and visual field location do not influence each other. Further analysis revealed no main effect of modality, $F(1, 25) = 3.64$, $p = 0.06$, $\eta^2 = 0.01$, or visual field, $F(1, 25) = 0.71$, $p = 0.41$, $\eta^2 = 0.03$. Bayes factors confirmed the lack of effect, with only weak evidence for the alternative hypothesis for modality ($BF_{10} = 1.28$) and the null hypothesis for visual field ($BF_{10} = 0.23$).

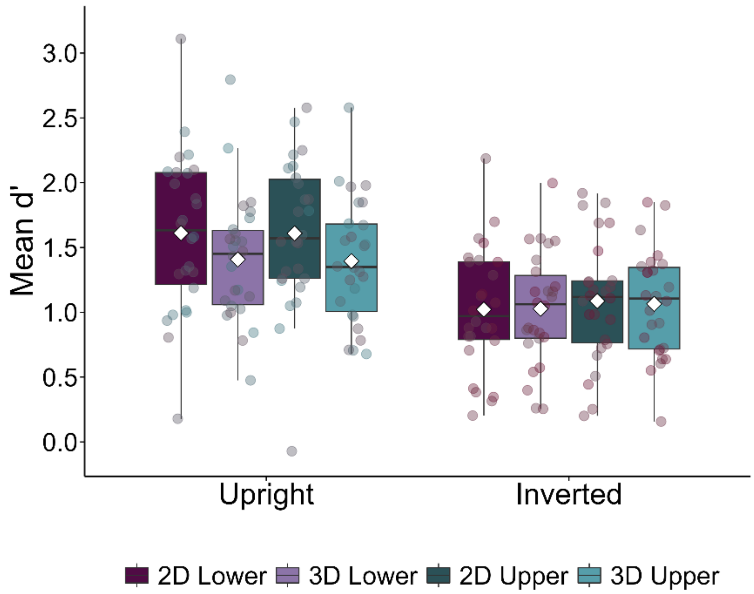

Figure 8. Average d’ (n = 26) for 2D lower (dark purple), 3D lower (light purple), 2D upper (dark blue purple) and 3D upper (light blue) face presentation. The boxplot conventions are the same as those described in Figure 3.

The between-subjects effect of orientation was significant, $\chi^2(1, 50) = 14.29$, $p < 0.001$, $\eta^2 = 0.18$, indicating that observers were more sensitive to upright faces (M = 1.48, SD = 0.48) than inverted faces (M = 1.03, SD = 0.37). No other interactions reached significance: modality × orientation, $F(1, 50) = 3.11$, $p = 0.08$, $\eta^2 = 0.01$; visual field × orientation, $F(1, 50) = 1.29$, $p = 0.26$, $\eta^2 = 0$; modality × visual field × orientation, $F(1, 50) = 0.02$, $p = 0.89$, $\eta^2 = 0$.

Reaction times on target-present trials during the single face-matching task were evaluated using a 2 × 2 × 2 mixed-factorial ANOVA, examining the effects of modality, visual field, and orientation. A Levene’s test (see Appendix A Table A.4) confirmed the assumption of homogeneity of variance. There was a significant effect of visual field, with observers responding faster when the test faces were presented in the upper visual field than in the lower visual field. All other main effects and interactions did not reach significance (Appendix D Table D.4).

As found in Experiment 2, observers' face sensitivity was consistent across the visual field; no upper visual field advantage was seen. Again, we were unable to replicate the upper visual field advantage observed in Experiment 1. However, we did find that faces were processed faster when presented in the upper visual field; a result that was not seen in Experiment 1. These results highlight the unreliable nature of visual field effects for face stimuli. Further, despite the increased task difficulty and additional disparity information, no performance benefit was observed for 3D faces compared with 2D faces. In fact, there was a suggestion of a *2D advantage*; however, this trend did not reach significance and was likely due to the use of 2D target faces in both the 2D and 3D conditions.

Chapter 6

Experiment 4: Viewpoint Face Recognition Task

6.1 Introduction

In the previous experiments, our goal was to assess the interaction between modality and visual field, and we hypothesised that stereopsis would enhance the upper visual field bias. However, none of these studies showed any interaction between visual field location and 3D viewing. We were only able to successfully reproduce the upper visual field bias for face sensitivity in Experiment 1 and for reaction time in Experiment 3. Given the surprising a lack of a 3D face advantage, in this final study, we focus on the impact of binocular disparity on face processing and try to replicate the 3D face advantage reported in the literature. In addition, we tried to increase the likelihood that observers would use stereoscopic information.

To do so, we generated 45° angled versions of the faces (both to the left and right). Due to the change in viewpoint, the noses partly obscured other facial features, thereby increasing the relative disparity. Similar to Experiment 3, a sequential face recognition paradigm was used, but with faces presented both frontoparallel and angled relative to the viewer. In this task, encoding the structural information of the faces is crucial for recognizing them across viewpoint changes and reflects "true" face recognition ability (Bruce & Young, 1986).

6.2 Stimuli

A total of 14 face identities were used in the experiment, comprising 7 male and 7 female faces. As mentioned above, to maintain task difficulty between face comparisons, the stimuli included frontoparallel and 45° angled faces. The angled faces were created by positioning the 3D rendering camera at a 45° angle from the front-facing virtual head models, other aspects of the viewing geometry (e.g. distance) were the same as those described in the General Methods. Each face identity was rendered from three viewpoints: frontoparallel, angled 45° to the right, and to the left, as depicted in Figure 9. Hair and facial hair were removed, the face images were cropped at the neck to remove the shoulders, and the images were adjusted as described in Experiment 3 to equate luminance and colour. All faces were the same height and aligned with the fixation plane in the same manner as those in Experiment 3. As face were rotated, the widths of faces (range: 3.32° to 3.99° visual angle) and maximum disparity (range: 6.27 – 12.55 arcmin) varied from those in Experiment 3.

Face identities were selected and paired into target–distractor groups based on similarity, as determined in a pilot study. A group of 10 volunteers ranked the similarity of each of the 26 frontoparallel target faces relative to four 45° rotated distractor faces. The top 12 ranking target–distractor pairs were chosen and six novice observers then performed the main experimental task with these selected face pairs. The results showed that one pair had a proportion-correct rate over 90%, while another pair had a proportion-correct rate below 50%. Consequently, these two pairs were excluded, resulting in 10 unique pairs that exhibited a high degree of similarity, for a total of 20 potential target–distractor pairs.

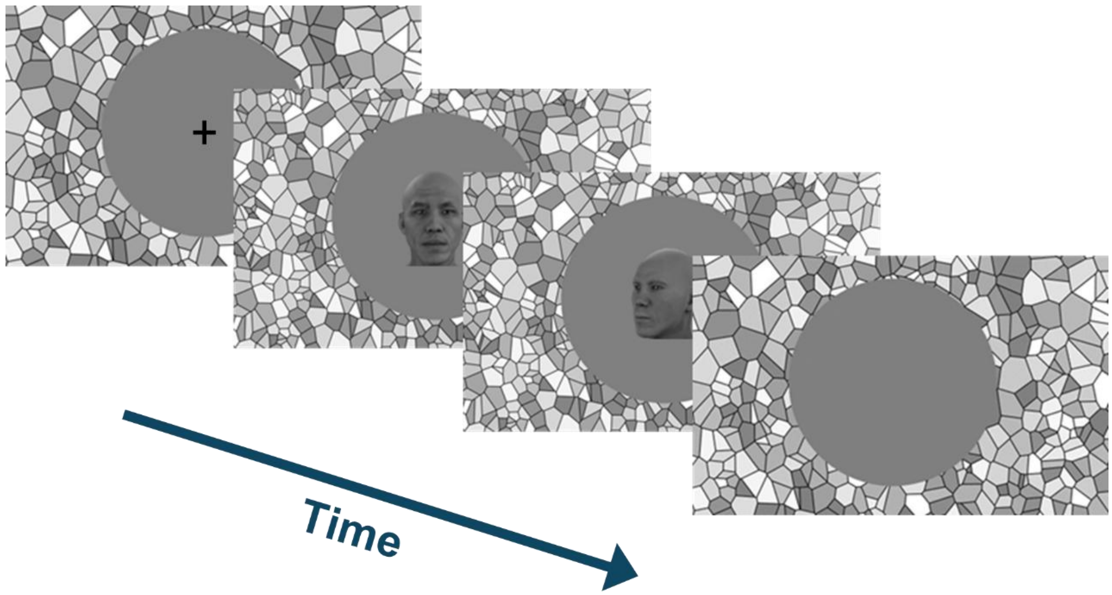

Figure 9. Time series of a single trial in Experiment 4 show initial fixation phase, target face presentation, test face presentation and response phase.

6.3 Procedure

Experiment 4 followed a similar procedure to Experiment 3, with two key changes: pixelated face was replaced with faces presented at different viewpoints, and both the target and test faces were presented at the centre of the screen for 300 ms. The target was either a frontoparallel or a rotated 45° face, and the test face always presented at an alternate viewpoint (e.g., frontoparallel to 45° or vice versa). Rotation direction (left or right) was balanced across trials and was tested pseudo-randomly. The test face either had the same or different identity from the target. After the test face was removed, observers were asked to indicate if its identity was the same or different compared to the target face. Observers completed 10 practice trials followed by a total of 640 experiential trials in two counterbalanced blocks (2D vs. 3D, 320 per condition).

6.4 Results and Discussion

Two observers met the exclusion criteria outlined in the General Methods; data analysis was conducted using the remaining 26 observers. Observers' recognition performance is illustrated in Figure 10 for both 2D and 3D faces, aggregated across the target viewpoint. Although some deviations from normality were observed, the assumptions of the paired t-test were sufficiently met. The t-test showed no significant difference between the two modalities (3D: M = 2.32, SD = 0.72; 2D: M = 2.27, SD = 0.74), $t(25) = –0.39$, $p = 0.70$. The effect size ($d = 0.16$) indicated a small effect. A follow-up Bayesian paired t-test confirmed that there was only weak evidence for the alternative hypothesis ($BF_{10} = 0.22$). A paired t-test also confirmed that there was no significant difference in reaction time between the 2D (M = 0.97 s , SD = 0.17 s) and 3D (M = 0.96 s, SD = 0.22 s) face presentations, t(25) = -0.12, p= 0.91, d =-0.02.

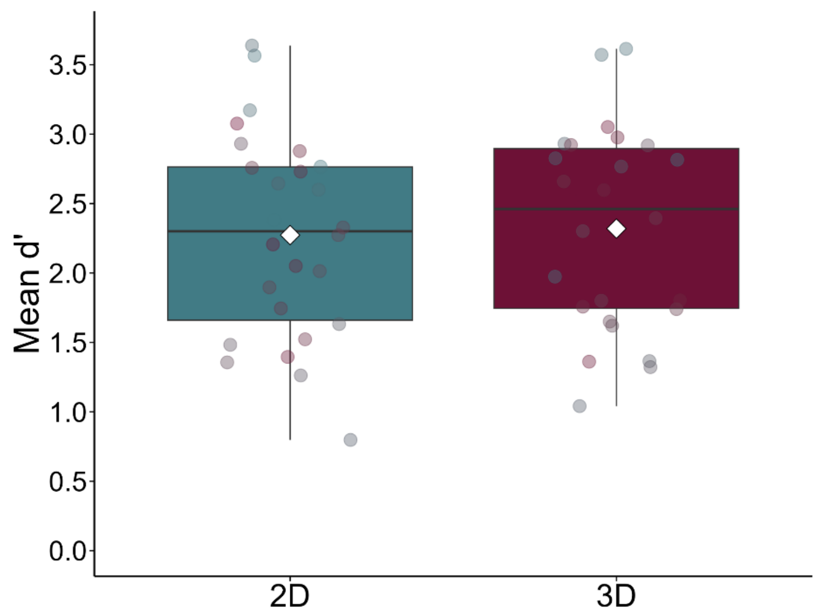

Figure 10. Average d' (n = 26) for 2D (blue) and 3D (purple) face presentation. The boxplot conventions are the same as those described in Figure 3.

The results of Experiment 4 show that 3D viewing does not improve face recognition or speed of responses, even though face stimuli were viewed centrally and relative disparity was maximized. Our results again show that under these conditions, the visual system does not rely on stereoscopic information for face recognition. Similarly, response time did not differ significantly between 2D and 3D faces suggesting that similar processing is performed despite the differences in modality.

Chapter 7

Discussion

7.1 Summary

The primary goal of this thesis was to examine how stereoscopic depth information and visual field location interact to influence sensitivity and speed in face processing. As outlined in the Introduction, previous work on visual field asymmetries has relied exclusively on 2D face stimuli, and these flat images lack the volumetric depth present in real faces, which could explain inconsistent findings in the literature. Because several studies report that 3D faces can facilitate recognition performance (Burke et al., 2007; Eng et al., 2017; Wang et al., 2017), we expected that stereoscopic depth cues might strengthen the upper visual field advantage.

In Experiment 1, participants showed better detection of face orientation in the upper visual field, replicating some earlier findings. However, we found no evidence that stereoscopic presentation improved face orientation judgments or enhanced the visual field effect. We hypothesized that this null result is likely related to the low-level nature of the task (orientation judgment), as estimating face orientation does not require access to the three-dimensional structure of the face. Identity-based judgments, which depend more heavily on 3D feature layout, were therefore assessed in Experiment 2.

Experiment 2 required observers to discriminate a target identity from distractors with different identities. Again, stereoscopic information offered no measurable benefit and did not provide an upper visual field advantage. Efforts to increase task difficulty by using a higher-level task were only partially successful: while somewhat reduced, d’ remained high, suggesting that the task was still too easy.

In Experiment 3, stimulus size was increased to enhance disparity signals, and the target faces were altered to make them more difficult to recognize. An inverted condition was added to assess holistic processing. Although we observed a clear face inversion effect, showing that the engaged holistic processing, stereoscopic information did not improve performance. A reaction-time advantage for upright faces in the upper visual field was seen in this study, but sensitivity did not differ across test locations. This aligns with existing reports that upper-field effects are highly variable across tasks and measures (Carlei et al., 2017; Felisberti & Currie, 2019, 2019; Tsurumi et al., 2023).

Given the consistent absence of stereoscopic benefits across Experiments 1–3, we rejected our hypothesis that lack of 3D viewing was responsible for the inconsistency of reported visual field biases in face processing. In Experiment 4 we focused on the apparent lack of effect of 3D viewing. As stereoscopic cues may be particularly useful for cross-viewpoint recognition (Burke et al., 2007), we conducted a 3D vs 2D recognition task. Even under these 'optimized' conditions, we found no benefit of 3D viewing.

7.2 Revisiting the Visual Field Biases for Faces

In the series of experiments reported here, we found, very limited support for the upper-field advantage in face processing. This is consistent with the broader literature, where findings are mixed and often difficult to replicate. Only Experiments 1 and 3 produced significant upper-field effects, but these effects were weak and observed across different measures (discrimination vs. reaction time), underscoring that the phenomenon is not robust and depends on the specific paradigm. The influence of paradigm type on visual field biases for faces is illustrated by studies of the fat-face illusion, which show a face-specific *lower* visual field effect: faces appear closer and larger only when located in the *lower* visual field (Sun et al., 2012).

Given the small effect sizes in both our work and prior studies (Burke et al., 2007), some reported advantages may reflect high variability. Moreover, a well-documented publication bias in psychology may inflate reported evidence of visual field differences for faces while downplaying null results (Francis, 2012).

Our results are consistent with Carlei et al.'s (2017) proposal that the upper visual field advantage may not be specific to faces. These researchers examined specialization of visual fields using a visual search task in which 2D face stimuli simultaneously appeared in each quadrant of the visual field, and participants identified a target based on eye gaze. Reaction times were faster for both upright and inverted faces in the upper visual field. If this advantage were related to face-specific processing, it should have diminished for inverted faces; however, it did not, suggesting that the bias was driven by general object processing (Carlei et al., 2017). Additionally, the upper visual field bias only emerged for lower-salience targets, suggesting that task difficulty may play a role (Carlei et al., 2017).

Unlike Carlei et al. (2017), in Experiment 3 we found faster response times in upper visual field for upright face, but not inverted faces. If object processing was indeed associated with a general upper visual field advantage, it should have been seen in both inverted and upright face stimuli, but this was not the case. One possible explanation for this discrepancy between our studies is that the upper visual field advantage may be task dependent. Both Experiment 1 and Carlei et al. (2017) focused on low-level feature detection (orientation for our study and eye gaze for theirs), which does not require a configural understanding of facial layout. Although, we could not confirm that the greater sensitivity to faces in the upper visual field in Experiment 1 would also transfer to inverted face as only upright faces were used. Such low-level tasks may engage object-based processing mechanisms rather than face specific mechanisms and may explain the visual field effect observed in Experiment 1. Similarly, Tsurumi et al. (2023) who demonstrated an upper visual field bias for faces in infants, argued in a more recent paper that this effect is not exclusive to faces, but also applies to basic 2D shapes (Tsurumi & Kawahara, 2023). Overall, the faster response time for the upright faces in the upper visual field in Experiment 3 remains difficult to explain. Because reaction time was highly variable across all experiments, it is possible that the effect found in Experiment 3 is a false positive, especially given that measures of reaction time tend to be less precise and influenced by exogenous factors (Dodonova & Dodonov, 2013).

7.3 The Role of Location Expectation

As outlined above, evidence suggests that the reported upper visual field bias for faces reflects a broader bias towards objects recognition that can be influenced by objects' occurrence in their typical locations (Kaiser & Cichy, 2021). For instance, in one of their studies, observers' expectations about an object's everyday location lead to increased brain connectivity when objects occurred in their typical location (e.g., a hat in the upper visual field) compared to an atypical location (e.g., a hat in the lower visual field) (Kaiser & Cichy, 2018a). These expectation biases are also evident in visual search tasks. Objects are more salient when they appear in their typical locations rather than atypical positions (Kaiser & Cichy, 2018b). Further, individuals tend to search for objects at expected locations, based on everyday locational occurrence probabilities, in both real-world and laboratory search tasks (Nakayama & Martini, 2011).

Locational expectations may account for the upper visual field bias in infants as they typically experience faces in their upper visual field (Tsurumi et al., 2023), however, it could be argued that this is not the case for adolescents and adults. Individuals usually direct their gaze to the other person's eyes or just below, and maintain this gaze, bringing the face into the centre of the visual field (Peterson & Eckstein, 2012). As a result, faces are more often located in the center of the visual field, which should diminish any 'typical location' effect for faces.

7.4 2D vs 3D Faces

7.41 Face Viewpoint

As outlined in the Introduction, the brain is highly specialized for processing faces, and under some conditions, for example when understanding emotional expressions (Wang et al., 2017) or recognizing faces (Eng et al., 2017) it has been shown that there are advantages to viewing stereoscopic versions of face stimuli. These are the only studies that have reported evidence of a stereoscopic advantage for frontoparallel faces. Other evidence indicates that stereopsis only may support face processing primarily when faces are viewed across multiple viewpoints (e.g. frontal vs angled) (Chelnokova & Laeng, 2011). For example, Burke et al. (2007) found that face matching performance between frontoparallel faces was the same for 2D and 3D views. Binocular disparity information only improved matching accuracy over that of 2D faces when comparing frontoparallel faces to 45º or 90º rotated faces. Stereoscopic faces may be more viewpoint invariant than their 2D representations (Deng et al., 2024). Similarly, H. Liu et al. (2020) found an advantage of 3D faces over 2D faces when using different viewpoints for target and test face, but this effect was limited to target faces at 0º (front-facing) or 22.5º (rotated). Structural information of the face derived from binocular disparity may be more valuable under specific conditions that rely on this knowledge, such as viewpoint transformations. These viewpoint-specific effects for 3D faces may explain the lack of 3D advantage in our experiments, as comparisons were only made between frontoparallel faces in Experiment 1 to 3. However, even in Experiment 4, when observers evaluated faces across different viewpoints (frontal to angled 45º faces, or vice versa) no effect of modality was seen.

Thus, our results show that the 3D benefit observed in the previously described studies is not broadly generalizable.

7.4.2 No Stereoscopic Advantage for Face Processing

Across all our experiments, stereoscopic depth failed to provide any performance benefit, even under the viewing conditions in Experiment 4 which should have favoured the use of stereoscopic depth information. Some behavioural studies likewise report minimal differences between the use of 2D and 3D faces (C. H. Liu & Ward, 2006; H. Liu et al., 2020). 3D faces located on the same fixation plane (i.e., the same perspective), as was used in our studies, did not provide any advantage; benefits from 3D faces emerged only when comparing faces at different distances from the observer (C. H. Liu & Ward, 2006). In these cases the important factor may be vergence, as vergence changes with fixation distance and is known to help scale depth from stereopsis (Bradshaw & Rogers, 1999). In our studies, we controlled vergence by providing a consistent fixation plane across trials and limiting the exposure duration.

Overall, our results suggest that even when disparity information is available, the visual system does not make use of it for face processing. Recent neuroimaging evidence supports this interpretation, as specialized face-processing areas of the brain, such as the occipital face area (OFA), fusiform face area (FFA), and posterior superior temporal sulcus (pSTS), do not show differential activation in response to viewing 3D vs. 2D faces (Deligiannis et al., 2025). Even during higher-level assessments of facial emotion, that are socially important, binocular disparity information does not result in a change in EEG decoding signals relative to that of 2D faces for both expressions and face identity (Klotzsche et al., 2025).

Interestingly, although Hong Liu et al. (2006) found that binocular disparity did not impact memory recognition of faces, they found that when the test and target faces had incongruent modalities (e.g. 3D test face and 2D target face) performance was significantly worse than when comparisons were between faces of the same modality. This is very similar to the effect observed in Experiment 3, with a trend towards a 2D advantage for upright faces. In this experiment, the target faces were always presented in 2D so, in the 2D condition, this information would be congruent, and incongruent in the 3D condition. In turn, the 3D face condition may have led to an increased perceptual load, and it would be expected that no 3D advantage would occur. However, in Experiments 1, 2, and 4, the target and test faces had the same modality, and sensitivity to 2D and 3D was the same, thus changes in modality between faces do not explain the lack of stereoscopic benefit overall.

7.4.3 Monocular Depth Cues and Top- Down Face Processing

Under our test conditions, it appears that participants relied on monocularly available information about the structure and shape of faces to detect and identify them. While counter to our hypotheses, this result is consistent with other literature showing a strong dependence on 2D depth information. For instance, in the case of the hollow-face illusion, a concave face mask or pseudoscopy in which disparities are inverted, faces are perceived as a ‘normal’ convex face as pictorial depth cues override stereoscopic information (Matthews et al., 2011). Van Den Enden and Spekreijse (1989) proposed that the texture perspective cues, unaffected by disparity reversal, are relied on more by observers for face depth and create the convex appearance, because when texture information is removed by applying a neutral texture mask, the hollow-face illusion disappears. This highlights the visual system’s preference to exploit monocular depth cues, even though texture defined faces have been shown to lead to poorer face identification than binocular disparity defined faces (Akhavein & Farivar, 2017). It is likely that other depth cues, such as shading ,that have lower face identification accuracy than binocular disparity defined faces are also favored during face processing (Van Den Enden & Spekreijse, 1989). This aligns with our findings, as the presence of disparity information along with pictorial depth cues included in photorealistic face stimuli had the same performance as when pictorial cues were alone. Although, it has been argued that the hollow face illusion is caused by higher-level processing, such as expectation of face shape rather than low level sensory information (Schneider et al., 1998). Only when cognitive functioning is impaired (individuals with severe alcohol intoxication or moderate withdrawal) face depth is perceived based on binocular disparity information, even though monocular depth cues are still present (Schneider et al., 1998).

It should be noted that the depth cues are not essential to face processing as cartoon faces that do not contain information related to 3D structure cause activation in the FFA (Tong et al., 2000). In fact, simplified drawings of faces containing only the outline of features can even lead to higher face matching accuracy than using photographs of faces (V. Brown et al., 1997). It is thought that face processing in general is related to holistic processing and configural face information, as long as faces have this information, such as drawings of faces, which be negatively impacted by inversion (Day & Davidenko, 2019). Faces represented by the most basic configural information, three white dots indicating the eyes and mouth within an oval, can trigger a face distortion aftereffect (Vakli et al., 2012). It is important to note that in our experiments, perceived depth (2D *or* 3D) was not essential to performing the tasks. That is, as outlined above, the relative positions of facial features and facial shape could have informed observers' judgements and we cannot say with certainty that depth played a role.

Overall, while our results show that the availability of stereopsis did not improve performance, we are not saying that stereopsis is not used under some conditions. For example, as mentioned in the Introduction, it has been found that binocular disparity on its own, presented in random dot patterns, can support face identification (Akhavein & Farivar, 2017; Dehmoobadsharifabadi & Farivar, 2016). Just because the visual system is capable of using binocular defined faces to determine face identity does not mean that under normal conditions that stereoscopic information is relied upon for face processing.

7.5 Considerations

7.5.1 Eccentricity

One possible reason why we did not observe a difference between 2D and 3D faces in Experiments 1 to 3 is that the faces were positioned in the parafoveal region. While this was necessary in order to evaluate face processing specialization across the upper and lower visual field, stereoacuity thresholds rapidly decrease outside of the fovea (Blakemore et al., 1970; Siderov & Harwerth, 1995). Additionally faces are more easily and quickly detected at the fovea than at other eccentricities (Kreichman et al., 2020). Thus, both the binocular disparity information and face processing ability may have been weakened for these experiments and may explain the null findings. However, in Experiment 4, faces were presented at the center of the visual field, and we still found no difference between 2D and 3D faces. It is unlikely that eccentricity is the cause of the lack of stereoscopic advantage.

7.5.2 Eye movements

One potential limitation of our study is the restriction of eye movements. Natural face viewing involves active scanning, and eye movements are often important for encoding identity

(Henderson et al., 2005). Studies comparing free-viewing of 2D and 3D faces show systematic differences in fixation patterns (Burke et al., 2007; H. Liu et al., 2020). Because our tasks required central fixation, participants were unable to use naturalistic scanning strategies, which may have reduced the potential value of stereoscopic cues. Studies that rely on recognition may be disproportionately impacted by the restriction of eye movements. Although stereoscopic stimuli provide depth cues similar to real-world faces (or objects) the use of a stereoscopic display introduces some inherent depth conflicts that are not present in the real world. For example, under natural viewing, size varies with distance but we did not change size (perspective) with changing disparity. Additionally, real faces are substantially larger, have greater variation in disparity, and can be acted upon. The affordance of objects has been shown to impact recognition ability between 2D pictures and physical objects (Holler et al., 2019). It is possible that these factors may have limited observers' reliance on stereoscopic information in these studies.

7.6 Conclusion

Taken together, these findings show that the variability of upper visual field advantages reported in the literature cannot be attributed to the absence of stereoscopic depth cues. Across multiple tasks varying in complexity, stereoscopic information failed to improve performance or alter visual field asymmetries. Although stereopsis can support some forms of face recognition under specific conditions (Burke et al., 2007; Eng et al., 2017; C. H. Liu & Ward, 2006), our results indicate that such benefits do not generalize well. These outcomes complement recent neuroimaging evidence suggesting that face-processing regions do not differentiate strongly between 2D and 3D faces (Deligiannis et al., 2025; Klotzsche et al., 2025). Overall, high-quality

2D images appear sufficient for studying most aspects of face perception, and stereoscopic presentation does not confer meaningful advantages for the tasks examined here.

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Appendices

Appendix A: Assumption Checks

Table A.1

Mauchly's Sphericity Test for Face Sensitivity from Experiment 1

	X^2	df	p	Greenhouse-Geisser ε
Number of Stimuli	9.54	5	0.09	0.84
Modality x Number of Stimuli	0.57	5	0.01	0.72
Visual Field x Number of Stimuli	0.64	5	0.04	0.76
Modality x Visual Field x Number of Stimuli	0.91	5	0.78	0.94

Table A.2

Mauchly's Sphericity Test for Reaction Time from Experiment 1

	X^2	df	p	Greenhouse-Geisser ε
Number of Stimuli	12.64	5	0.03	0.75
Modality x Number of Stimuli	21.56	5	<.001	0.65
Visual Field x Number of Stimuli	8.85	5	0.12	0.83
Modality x Visual Field x Number of Stimuli	46.94	5	<.001	0.50

Table A.3

Levene's Test of Equality of Variance from Experiment 3 for Face Sensitivity Across Conditions

	F(1,50)	p
2D Upper Visual Field	0.83	0.37
2D Lower Visual Field	1.56	0.28
3D Upper Visual Field	0.45	0.51
3D Lower Visual Field	0.13	0.72

Table A.4

Levene's Test of Equality of Variance from Experiment 3 for Face Reaction time Across Conditions

	F(1,50)	p
2D Upper Visual Field	2.83	0.10
2D Lower Visual Field	2.24	0.14
3D Upper Visual Field	0.91	0.35
3D Lower Visual Field	2.37	0.13

Appendix B: Means and Standard Deviations

Table B.1

Mean and Standard Deviation of Face Sensitivity for Number of Stimuli and Modality x Visual Field from Experiment 1

	Condition	M	SD
Number of Stimuli	2	2.96	0.80
	3	2.71	0.85
	4	2.53	0.71
	5	2.25	0.86
Visual Field x Modality	Upper Visual Field – 2D	2.67	0.95
	Upper Visual Field – 3D	2.68	0.78
	Lower Visual Field – 2D	2.54	0.88
	Lower Visual Field – 3D	2.56	0.78

Table B.2

Mean and Standard Deviation of Face Sensitivity for Modality x Visual Field from Experiment 2

		Visual Field			
		Upper		Lower	
		M	SD	M	SD
Modality	2D	2.71	0.78	2.67	0.67
	3D	2.70	0.73	2.62	0.68

Table B.3

Mean and Standard Deviation of Face Sensitivity for Conditions from Experiment 3

	Condition	M	SD
Visual Field	Upper	1.29	0.56
	Lower	1.27	0.56
Modality	2D	1.33	0.60
	3D	1.22	0.48
Visual Field x Modality	Upper Visual Field – 2D	1.35	0.58
	Upper Visual Field – 3D	1.23	0.47
	Lower Visual Field – 2D	1.32	0.62
	Lower Visual Field – 3D	1.22	0.50

Appendix C: Experiment 1 Post Hoc Tests for Number Stimuli Face Sensitivity

Table C.1

Experiment 1 Post Hoc Tests Sensitivity Number Stimuli for Face Sensitivity

		t	Pholm	Cohen's d
2	3	4.01	<.001	0.31
	4	6.73	<.001	0.52
	5	11.07	<.001	0.56
3	4	2.72	0.01	0.21
	5	7.06	<.001	0.55
4	5	4.34	<.001	0.34

Note. P-value adjusted for comparing a family of 6. Results are averaged over the levels of: Modality, Visual Field.

Appendix D: Reaction Time Analysis

Table D.1

Experiment 1 Reaction Time ANOVA Results

Variable	df	F	p	η^2
Modality	1	0.07	0.79	0
Visual Field	1	0.08	0.78	0
Number of Stimuli	2.24	2.96	0.05	0
Modality x Visual Field	1	0.17	0.67	0
Modality x Number of Stimuli	1.94	0.23	0.79	0
Visual Field x Number of Stimuli	3	0.17	0.91	0
Modality x Visual Field x Number of Stimuli	1.49	1.18	0.31	0.01

Table D.2

Experiment 1 Post Hoc Tests Number Stimuli for Reaction Time

		t	Pholm	Cohen's d
2	3	-1.82	0.36	-0.13
	4	-1.76	0.36	-0.13
	5	-2.95	0.03	-0.21
3	4	0.06	0.95	0.00
	5	-1.13	0.72	-0.08
4	5	-1.18	0.72	-0.09

Note. P-value adjusted for comparing a family of 6. Results are averaged over the levels of: Modality, Visual Field.

Table D.3

Experiment 2 Reaction Time ANOVA results

Variable	df	F	p	η^2
Modality	1	0.20	0.66	0.01
Visual Field	1	1.45	0.24	0.01
Number of Stimuli	1	44.92	<.001	0.10
Modality x Visual Field	1	0.84	0.37	0
Modality x Number of Stimuli	1	0	0.97	0
Visual Field x Number of Stimuli	1	0.02	0.88	0
Modality x Visual Field x Number of Stimuli	1	1.20	0.29	0

Table D.4

Experiment 3 Reaction Time ANOVA results

Variable	df	F	p	η^2
Modality	1	0.42	0.52	0
Modality x Orientation	1	0.12	0.73	0
Visual Field	1	5.37	0.03	0
Visual Field x Orientation	1	0.33	0.57	0
Modality x Visual Field	1	1.35	0.25	0
Modality x Visual Field x Orientation	1	0.94	0.34	0
Orientation	1	0.40	0.53	0.01