Atypically heterogeneous vertical first fixations to faces in a case series of people with developmental prosopagnosia

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ABSTRACT

When people recognise faces, they normally move their eyes so that their first fixation is in the optimal location for efficient perceptual processing. This location is found just below the centre-point between the eyes. This type of attentional bias could be partly innate, but also an inevitable developmental process that aids our ability to recognise faces. We investigated whether a group of people with developmental prosopagnosia would also demonstrate neurotypical first fixation locations when recognising faces during an eye tracking task. We found evidence that adults with prosopagnosia had atypically heterogeneous first fixations in comparison to controls. However, differences were limited to the vertical, but not horizontal, plane of the face. We interpret these findings by suggesting that subtle changes to face-based eye movement patterns in developmental prosopagnosia may underpin their face recognition impairments, and suggest future work is still needed to address this possibility.

Keywords: Prosopagnosia; face recognition; eye tracking; first fixations;

1. INTRODUCTION

People with developmental prosopagnosia (henceforth prosopagnosia) suffer lifelong impairments in face recognition in the absence of neurological damage (e.g. Behrmann & Avidan, 2005; Galaburda & Duchaine, 2003; Bate & Tree, 2017; Towler & Tree, 2018). While such cases are purported to have face-specific problems, they also suffer some non-face difficulties (Burns, Taylor & Bukach, 2019), coupled with largely intact low-level visual and intellectual functions (Jones & Tranel, 2001). Further, there is evidence of a genetic basis for the condition (see Grueter, et al., 2007), which could explain a strong familial link (e.g. Behrmann, & Avidan, 2005; Bentin, et al., 1999; de Haan, 1999; Duchaine, 2000).

Why these individuals have difficulties with faces is at present unclear, however, there is growing evidence to suggest that these problems are due to deficits in holistic processing, that is, perceiving a face as a unitary whole (e.g. Van Belle, De Graef, Verfaillie, Busigny, & Rossion, 2010). The disorder has been attributed to a failure to develop dedicated facial recognition mechanisms necessary for successful face recognition (Susilo & Duchaine, 2013). In order to understand how prosopagnosia develops, researchers have traditionally viewed the face-processing system as a sequential and hierarchical multi-process system where impairments can occur at a variety of stages (Bruce and Young, 1986) with particular research focus on the latter stages (e.g., Bate & Cook, 2012; Bate, Haslam, Jansari, & Hodgson, 2009; Bennetts, Butcher, Lander, Udale, & Bate, 2015; Duchaine et al., 2007; Lee, Duchaine, Wilson, & Nakayama, 2010; Jackson, Counter & Tree, 2017). However, it is also possible that the impairments occur at a much earlier stage of processing (e.g. Nemeth, et al., 2014) and may involve mechanisms that direct visual attention (specifically, eye movements) to faces. This, therefore, leads to an intriguing hypothesis: is failure to recognise faces a result of inappropriate allocation of attention towards faces?

Successful face recognition may only require one or two fixations (Hsiao & Cottrell, 2008), and is thought to be largely driven by attention toward the eye region (Gilad, Meng, & Sinha, 2009; Sormaz, Andrews, & Young, 2013). It is unclear whether this behaviour is merely a by-product of the social importance of looking someone in their eyes (e.g. Parkington & Itier, 2018; Hills et al. 2013) or if it has a functional role in face recognition. In other words: is an attentional bias toward the eye region experience based or innate (see Gomez, Natu, Jeska, Barnett, & Grill-Spector, 2018; Arcaro, Schade, Vincent, Ponce, & Livingstone, 2017; Luo et al., 2017)? Previous research has indicated the importance of the eye region for early face recognition (e.g. Parkington & Itier, 2018; Hills et al. 2013). Hills, Cooper and Pake, (2013) suggest that the attentional bias towards the eye region may maximise the perception and extraction of basic social cues. Attention to, and use of, eye information has indeed been shown to improve face identity, gender, and emotional expression judgements (Haig, 1985; Hills, Cooper, & Pake, 2013; Schyns, Bonnar, & Gosselin, 2002; Vinette, Gosselin, & Schyns, 2004). Therefore the social importance of attending to the eyes seems clear.

However, the importance of attention for the eyes may not be entirely for social cognitive processes. Peterson and Eckstein (2012) looked at the optimal first fixation location for identifying faces. They observed that the human visual system optimises face identification performance by guiding eye movements towards a location just below the eyes, slightly left of the centre-point between the eyes. From this location the recogniser is able to see perceptually rich information in their fovea and peripheral vision. Therefore fixations toward the eye region seem to have a functional role for face recognition, as well as being important for social cognitive processes (e.g. Parkington & Itier, 2018; Hills et al. 2013). The eye region may represent an area of the face where optimum face recognition can occur because it may enable the parallel processing of multiple salient facial features parafoveally i.e. the eyes, nose, mouth, and the distances between them are processed in parallel as an integrative whole. This would be important as subtle differences in the spatial relations between features (i.e., distances between eyes and mouth) are thought to be necessary for face recognition (Verfaillie, et al., 2014). Fixations to a central region of the face may therefore enable holistic processing, as multiple features could be processed within one fixation and processed as an integrative whole. However, the link between fixations and holistic processing is speculative. Galton's (1883) work over a century ago led to the hypothesis that "a face is perceived as an undecomposed whole, rather than as a collection of individual features" (Verfaillie, et al., 2014, p504), therefore, a first fixation to a central region may aid this process. Although note, the bias toward the eyes rather than directly in the centre of the face may be because the eye region contain the most rich information. Therefore, there appears to be an important distinction between the eyes and the eye region. The eyes are an important feature for social cognitive processes, whereas the eye region may be an optimum area for maximising the potential for holistic processing. However, separating the two may be difficult to measure and beyond the scope of the current paper. Indeed, the first fixation within this region may be a result of both processes. Overall, it would appear that the centre-point between the eyes is the most perceptually rich area for optimal face identification – at least, this is the case for those with intact face recognition. Would adults with prosopagnosia also therefore show the same bias for the optimal face identification location as those with neurotypical face recognition abilities?

Bobak, et al., (2017) found that adults with prosopagnosia spent less time than controls looking at the eye region. Further, acquired prosopagnosia cases also demonstrate a similar pattern of facial examination (e.g. Caldara et al., 2005; de Xivry, et al., 2008), whilst developmental cases may also have a preference for more external features during facial examination (see Schwarzer et al., 2007). In general, it would appear that adults with prosopagnosia make fewer fixations and demonstrate reduced regional sampling for famous (known) compared to novel faces (Bate, et al., 2008), spend more time examining the mouth and less time examining the eyes when compared to controls (e.g. Bate et al., 2015; cf. Lee, Corrow, Pancaroglu, & Barton, 2019), potentially because adults with prosopagnosia are less well tuned to contrast information from the eye region (Fisher, Towler, & Eimer, 2016), and may be impaired in holistic processing of the eye region but not the mouth region (DeGutis, et al., 2012).

Increased dwell time for the mouth region of the face is unlikely to enable holistic processing as this is not the optimal location for first fixations. For example, Peterson & Eckstein (2012) found that forcing participants to maintain first fixation gaze points away from the optimal point of fixation degraded perceptual performance. This implies that failure to automatically orient toward this perceptually rich optimal area could lead to poorer performance. It may also suggest that adults with prosopagnosia may be impaired in directing the first fixation location, thus leading to degraded perceptual performance. Indeed, interventions designed to improve holistic processing lead to improved face recognition in people with prosopagnosia (DeGutis, Cohan, & Nakayama, 2014). If an atypical first fixation for face stimuli plays a role in disrupting face recognition performance, we might expect to see atypical first fixation locations in prosopagnosia. This is the primary focus of the present work. Although, note, a recent study by Peterson et al. (2019) found that people with prosopagnosia and controls were analogous in first fixation patterns for a famous faces task, an unfamiliar face emotional judgment task, and a restricted fixation unfamiliar face identification. However, whether people with prosopagnosia are analogous to controls on an unrestricted unfamiliar face identification task with neutral expressions is still an open question.

A secondary focus of the current work is to examine whether first fixations are impaired when under different viewing conditions, which are designed to force either holistic or analytic processing.

Van Belle et al (2010; 2014) used a gaze-contingent paradigm to explore whether adults with prosopagnosia process faces holistically or analytically. Their paradigm manipulated the manner with which participants can match faces, by guiding the processing of features in either an analytic or holistic manner. During the experiment, a two-alternative forced choice paradigm was used, with face stimuli. During a third of the trials, participants could freely process the faces in full. However, in the remaining two thirds of trials, participants' eye movements were used to limit perception of the faces in one of two ways, which were designed to simulate either analytic or holistic processing (see Figure 1). During analytic-type trials, a gaze-contingent window revealed only a small area of the face (such as one facial feature) whilst the face falling outside the window was masked. Whereas for holistic-type trials, a mask replaced the window, so that features could not be focussed upon. This forced participants to rely on the whole face beyond just the fixated feature.

Van Belle and colleagues' found that face recognition expertise was not the product of sequential featural processing, but instead, may be the product of the ability to view individual features of the face all at once. These results indicated that holistic processing aids face recognition, and this may be disrupted in impaired face processing; i.e. in prosopagnosia. However, for the current study we were primarily interested in the first fixation on a face. We used the Van Belle et al (2010) paradigm so that we could explore whether different viewing conditions could affect performance within-subjects (condition: full, window, mask), but also between-groups (prosopagnosia and controls). Also, this design would allow us to discover whether first fixations could be linked to face recognition, but also whether it was disrupted by holistic or analytic gaze-contingent manipulations. This is the secondary focus of the current study. Van Belle et al (2010) found that a foveal mask was more disruptive to face recognition than a peripheral mask. Based on this result, they argued that participants employed a more holistic approach to face recognition. Therefore, by using the same viewing conditions, we could explore whether holistic processing begins with a first fixation to an optimal area. Relative to controls, we predicted that prosopagnosia cases will be atypical in first fixations, and that these fixations will also be atypically affected by the different viewing conditions, with particular impairment on the foveal mask trials (cf. Van Belle et al, 2010).

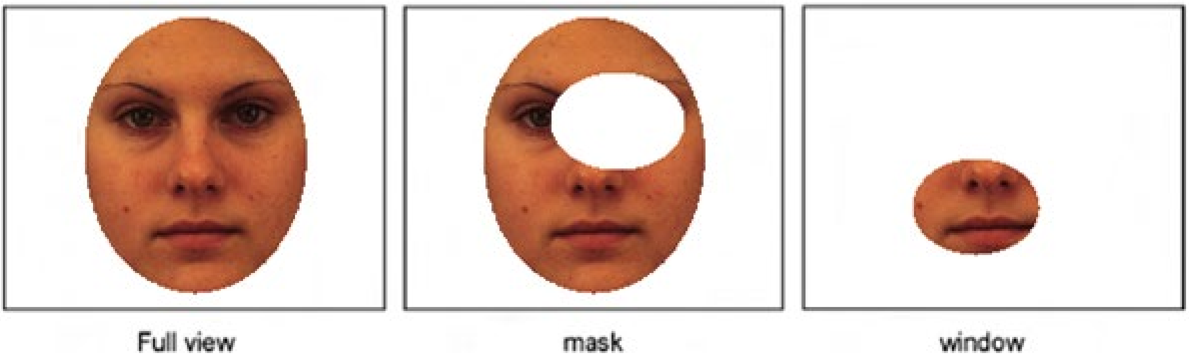

Figure 1. Illustration of the different viewing conditions in the experiment. The size of the window/mask was adjusted to reveal/cover roughly one main internal feature of the face at a time only. The position of the mask/window was synchronised with the observer's fixation position.

2. METHOD

2.1 Participants

There were 22 participants in the study: 5 people with developmental prosopagnosia (mean age = 27.33; 3 males) and 17 non-prosopagnosia controls (mean age = 21.28; 3 males). All participants were Swansea University students and all were British Caucasians to avoid any potential other race effects (Burns et al., 2019; Bate et al., 2018; Estudillo et al., 2019). Participants with prosopagnosia were paid for their time and control participants received subject-pool participation credit. All adults with prosopagnosia confirmed their regular difficulties with faces, a fundamental trait of prosopagnosia, in a short interview with one of the authors in addition to neuropsychological testing (see Table 1); FFT (Famous Faces Test; Duchaine & Nakayama, 2005); CFPTu/i (Cambridge Face Perception Task upright / inverted; Duchaine et al., 2007); CFMTu/i (Cambridge Face Memory Task upright / inverted; Duchaine & Nakayama, 2006b); RMT-f (Recognition Memory Test-faces; Warrington, 1984); Eyes (Reading the Mind in the Eyes task; Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997); AQ (Autism Spectrum Quotient;

Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001); GNT (Graded Naming Test; McKenna & Warrington, 1980); BORB (Birmingham Object Recognition Battery; Riddoch & Humphreys, 1993 – two difficult subtests used from test 10, 64 objects in total), RMT-w (Recognition Memory Test–words; Warrington, 1984). Norms for these tests are reported in Table 1 and were taken from the aforementioned papers or from data collected by our own lab. To be classed as impaired, we required our adults with prosopagnosia to be impaired more than 2 standard deviations away from the control mean on the FFT and CFMT as per prior work (Bate et al., 2014; Burns et al., 2018; Burns et al., 2014; Burns et al., 2017a, Burns et al., 2017b). The controls did not complete the neuropsychological battery of tests, but all had to confirm no trouble recognising faces (the fundamental trait of prosopagnosia): e.g., difficulties not recognising celebrities, having problems recognising familiar people they should identify, such as friends, co-workers and family members.

Table 1. Developmental prosopagnosia case scores on neuropsychological test battery.

	DP1	DP2	DP3	DP4	DP5	Cut-off, for impairment
Age	20	38	20	21	34	
Sex	F	M	M	F	M	
Face testing						
Famous Faces Test	10/35	12/35	22/35	13/35	24/35	< 29/35
CFPTu	64/144	84/144	60/144	48/144	53/144	> 65/144
CFPTi	52/144	74/144	60/144	40/144	48/144	> 92/144
CFMTu	28/72	28/72	40/72	37/72	36/72	< 42/72
CFMTi	16/72	34/72	30/72	39/72	37/72	< 28/72
RMT-f	35/50	28/50	34/50	34/50	36/50	< 36/50
Autism Screening						
Eyes	29	22	26	25	26	< 19/25
ASQ	24	28	25	25	12	> 32/50
Non-face testing						
GNT	16/30	19/30	20/30	25/30	22/30	< 12/30
BORB	52/64	53/64	56/64	62/64	51/64	< 23/64
RMT-w	36/50	47/50	46/50	41/50	45/50	< 35/50

FFT (Famous Faces Test; Duchaine & Nakayama, 2005); CFPTu/i (Cambridge Face Perception Task upright / inverted; Duchaine et al., 2007); CFMTu/i (Cambridge Face Memory Task upright / inverted; Duchaine & Nakayama, 2006b); RMT-f

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2.2 Stimuli

Both the stimuli and the face recognition task were obtained from Van Belle et al. (2010) and followed the same protocol. The task involved the delayed matching of photographs of unknown adult faces: a face was presented followed by a side-by-side presentation of photographs of two faces; one of which was the target that previously appeared in the trial, the other a foil. Note that the matching faces, were photographed at different moments in time, so were slightly different. The participant’s task was to identify the target face.

Stimuli were displayed on a 22” CRT computer monitor at a viewing distance of 55cm with a spatial resolution of 1280 by 1024 pixels and a refresh rate of 100Hz. The height of the faces was 15°, the distance between the inner borders of the faces was approximately 10°, and the elliptical window and mask subtended 8.5° horizontally by 6.5° vertically. The stimulus set contained 10 male and 10 female faces (KDEF database; Lundqvist, Flykt, & Öhman, 1998), each of which had external features cropped, but head shape largely preserved. The faces were randomly combined in pairs of two males or two females. Stimulus display and response registration were handled by an Intel Pentium 4 PC. Eye movements were recorded using SR Research EyeLink 1000 eye tracker at a sampling rate of 1000 Hz and with gaze position error smaller than 0.75°. Eye movements were recorded monocularly, with the dominant eye being determined using the Miles test (Roth, Lora & Heilman, 2002). Head movement was restricted by a chin rest.

2.3 Procedure

The trial procedure is presented in Figure 2. A drift correction with a central fixation cross was followed by the presentation of a blurred face, which was the grey-scale average image of all faces, indicating the position of the reference face and a fixation cross on the left of that face. Participants were instructed to fixate on the fixation cross. Upon steady fixation by the participant, the cross disappeared. From the moment the participant fixated on the blurred face, it changed into the reference face, which participants were instructed to memorise for 4 seconds. After this the participant was prompted to return their gaze to the centre of the screen and two faces were then presented, one on each side of the screen. The participant could freely explore both faces during an unrestricted time period.

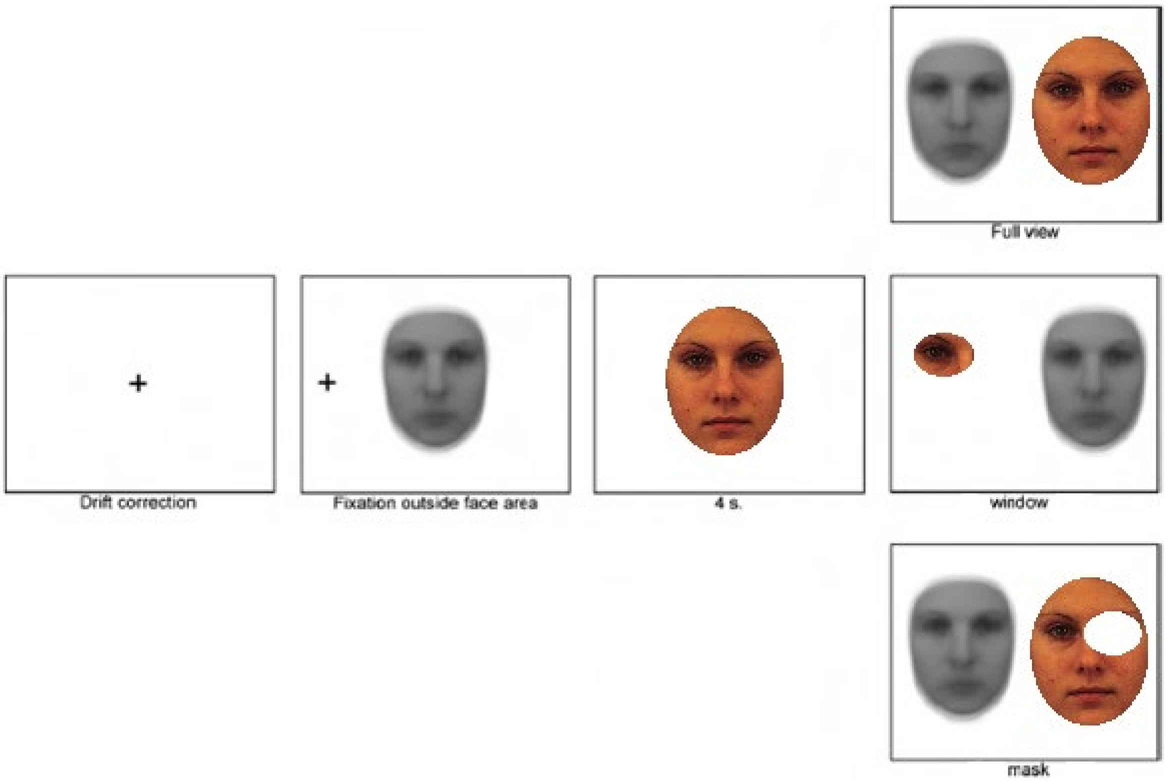

Figure 2. Procedure of a trial. The greyscale face displayed is the average of all faces, this is displayed when the observer does not fixate on the face. In all conditions, the non-fixated face was always replaced by the blurry average face. In the mask and window, the fixated face was covered by the window or mask.

In one third of the trials, the faces were completely visible (full view). In another third of the trials, a gaze-contingent mask covered the fixated feature in the central part of the visual field (mask condition). In the remaining third of the trials, only the fixated feature in the central part of the visual field was visible through a limited spatial window (window condition). The mask/window covered/revealed roughly one feature of the face at a time (eye, nose, or mouth), although it was large enough to cover/reveal the whole eye–eyebrow combination in the mask/window conditions, respectively.

During the exploration of the pair of faces, the face that was not fixated upon by the participant was replaced by the average face (Figure 2), in order to provide a reference frame for saccade planning to the face in all viewing conditions. Furthermore, this way, the amount of information from one face during the exploration of the other face was similar in all three viewing conditions. The matching response was provided by pressing the left or right keyboard key.

The experiment was subdivided into 9 blocks, each consisting of 27 trials, 9 for each of the 3 viewing conditions (for 81 trials/condition in total). The order of the viewing conditions within each block was randomised and the participant was unaware of the type of viewing condition during the exploration of the reference face.

3. RESULTS

Our primary interest was the first fixation made on each face within each of the trials i.e. the first fixation on the left face and then the first fixation on the right face. There were three trial-types (Full, window, and mask). Each trial was preceded by a reference face. Therefore, we obtained first fixation information for four different types of faces. For each of the faces we computed the x and y coordinates of the centre-point between the eyes. We measured in degrees (°) how far the first fixation was from the centre-point between the eyes, along x and y coordinates. We were then able to compare these x and y coordinates to the first fixation on the face made by each participant.

We predicted that the control participants would consistently make a first fixation toward the optimal face recognition location on the face, despite the viewing condition (in terms of average first fixation location and variation in first fixation location: see Peterson & Eckstein, 2012). However, we anticipated that people with prosopagnosia would make first fixations on the face in an atypical manner. Note, as would be expected, people with prosopagnosia and controls differed significantly on the task in terms of accurately recognising the faces (F(1,20)=18.822; p<.005) and reaction time (F(1,20)=18.162; p<.005: see Table 2). However, of primary interest was the first fixation toward each face.

Table 2. Accuracy and reaction time (seconds) data for the three trial types for controls and people with prosopagnosia. Parenthesis contain the standard deviation.

	Accuracy		Reaction Time	
	Control	DP	Control	DP
Full	1 (.02)	.89 (.23)	1.71 (.58)	3.0 (1.51)
Mask	.97 (.04)	.85 (.30)	2.25 (.77)	5.32 (3.10)
Window	.91 (.07)	.74 (.44)	3.32 (1.15)	7.17 (3.39)

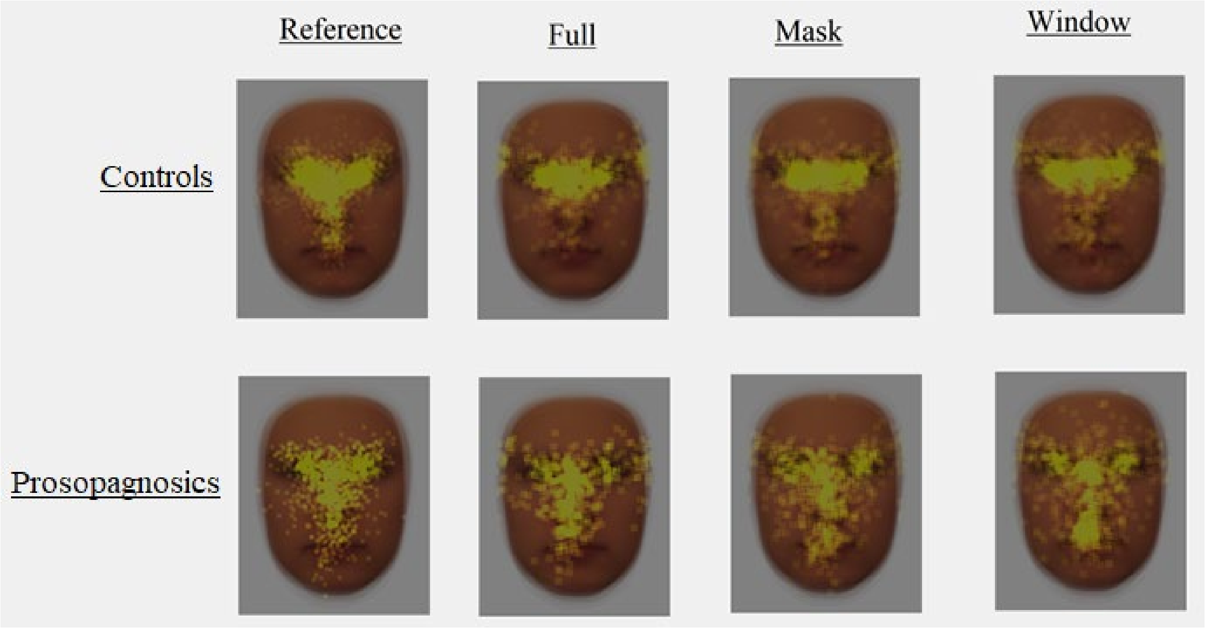

Figure 3. Heatmaps of all first fixation points. Control participant (N=17) first fixations are on the top, and prosopagnosia participants (N=5) are on the bottom. The prosopagnosia participants are more heterogeneous in where their first fixations land, particularly on the y axis. The face-types are all presented separately.

Figure 3 demonstrates the heat maps of first fixations across all trials, with Figure 4 illustrating the mean first fixations for the control participants and each of the adults with prosopagnosia. Across the different conditions, the control participants were consistently making first fixations within the eye region and nose-bridge region, closer toward the centre-point between the eyes. However, the prosopagnosia group's first fixations were much less focussed. Although, the prosopagnosia cases' first fixations do appear similar to controls in terms of the horizontal plane, it appears that there is a larger spread of first fixations along the vertical plane. We therefore analysed x and y coordinates separately.

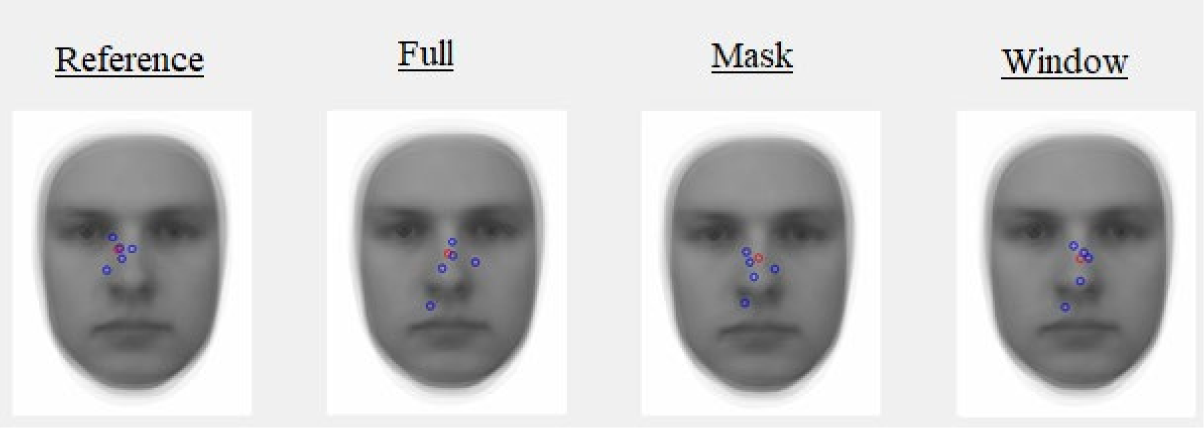

Figure 4. Average first fixation points from all trials for controls (red) and the individual people with prosopagnosia (blue). The face-types are reference, full, mask and window.

As first fixations in the adults with prosopagnosia could have been atypically above or below the centre-point from the eyes, it may be inappropriate to average our participants' data together (i.e., Figure 4). This is because we would not be able to recognise the consistency, or inconsistency, with which the adults with prosopagnosia are initially fixating upon the faces (i.e., the trial by trial fixation variability). It may be more appropriate to instead look at the variance within each participant for first fixation y coordinates, as this would crudely index the heterogeneity with which they first looked at a face. For example, if control participants are highly consistent in their first fixations, they will have very little variance. Prosopagnosia cases may first fixate in an incredibly heterogeneous fashion, thereby suggesting that they do not have a consistent pattern with which to initially focus on a face or be distracted by other features. This is borne out by inspection of Figure 3.

To examine any possible group differences in this heterogeneity, we performed a 2 x 4 repeated measures ANOVA on participants' first fixations' standard deviations of the y-axis coordinates in degrees (°) from the centre point between the eyes, using factors of Group (developmental prosopagnosia: DP & control) and Face-type (reference, full, mask, window). Levene's test indicated equal variances (all p's > .05). Importantly, we found a main effect of Group [F(1,20) = 14.131; p = .001]. This latter effect was driven by prosopagnosia cases' increased variability along the y axis for their first fixation (see Figure 5). There was also a significant interaction between Face-type and Group [F(3,60) = 4.420; p = .007]. Subsidiary comparisons showed that prosopagnosia cases' y co-ordinate standard deviations (mean = 2.08°; SD =.55) were found to vastly differ from the control participants' (mean = 1.23°; SD =.41) for full trials [t(20) = -3.842; p = .001], window trials (DP mean = 2.36°; SD =.68; Control mean = 1.38°; SD =.49; t(20) = -3.595; p = .002], and mask trials (DP mean = 2.17°; SD =.50; Control mean = 1.48°; SD =.57; t(20) = -2.428; p = .025]. By contrast, no group differences were found in the reference condition (DP mean = 1.02; SD =.21; Control mean = .86; SD =.21; t(20) = -1.514; p = .146]. However, Bayesian analysis suggested that this result may have been due to a lack of power, rather than due to the absence of an effect (BF_{10} = .906).[1]

Note, we also performed 2 x 4 repeated measures ANOVA on the standard deviations of the x-axis coordinates in degrees (°), using factors of Group (DP, control) and Face-type

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[1] Note, we explored the effect of age and sex. Age was not found to be associated with y coordinate SD in either the controls (reference: r(15)=.240;p=.354; full: r(15)=.450;p=.07; window: r(15)=.385;p=.127; mask: r(15).240;p.354) nor prosopagnosia (reference: r(3)=.003;p=.989; full: r(3)=.404;p=.50; window: r(3)=.330;p=.588; mask: r(3)=.058;p=.927). Similarly, males and females did not differ in performance on the task in terms of accuracy or y coordinates (p>.05). Further, we conducted a series of t-tests between a group of age-matched controls (which included the five oldest controls) compared to the five prosopagnosia cases. These groups were found not to differ in terms of age (t(8)=.580;p=.578). However, the groups did differ in terms of y coordinate variance for the full condition (t(8)=2.448;p=.040), window condition (t(8)=2.332;p=.049), and marginally the mask condition (t(8)=1.996;p=.081) and reference (t(8)=1.719;p=.124). This suggests that there is strong evidence that age and sex did not affect performance.

(reference, full, mask, window). Levene's test indicated equal variances (all p's > .05). It was observed that there was a main effect of Face-type [F(3,60) = 21.154; p < .0005]. However, we did not observe a significant main effect of Group [F(1,20) = .007; p = .936; $BF_{INCLUSION} = .34$] nor significant interaction [F(3,60) = .921; p = .436 $BF_{INCLUSION} = .39$]. This demonstrates that adults with prosopagnosia did not demonstrate increased variability for x axis co-ordinates and this interpretation is supported by the Bayesian analysis.

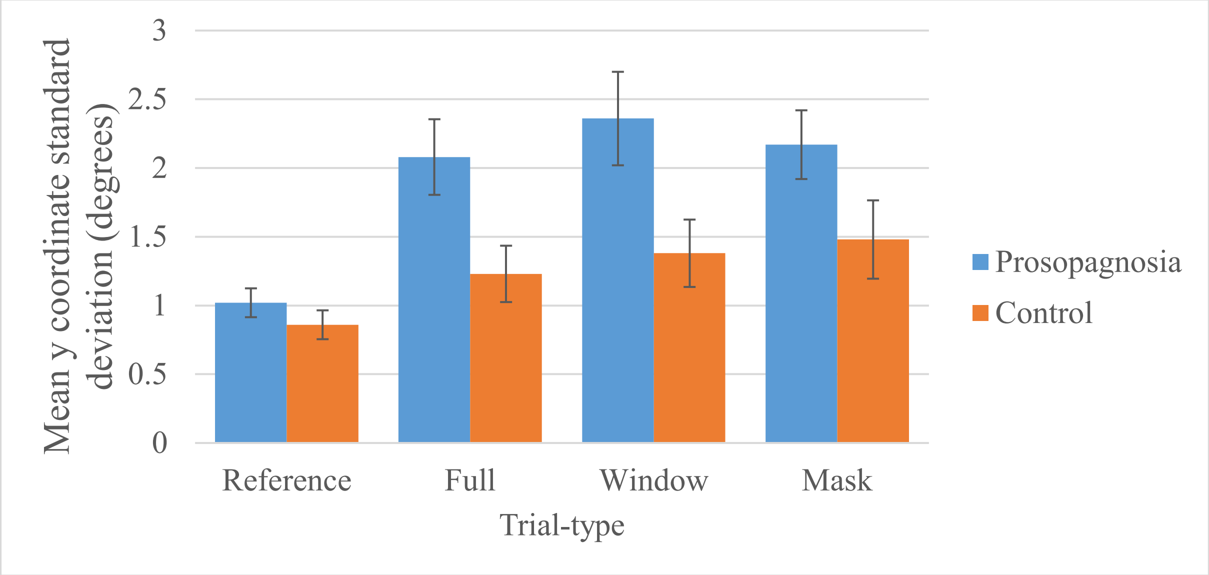


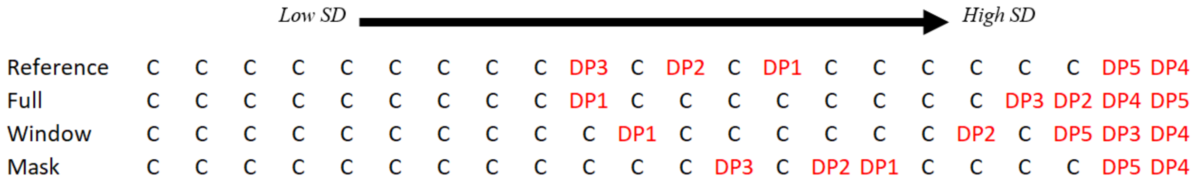
Figure 5. The average first fixation standard deviations of the y axis coordinates in degrees (°) for controls (orange) and the people with prosopagnosia (blue) for each trial-type reference, full, mask and window. The prosopagnosia group were atypically heterogeneous as to where their first fixations landed on faces' vertical planes in all conditions barring the Reference condition (i.e., left-most bars) where they were memorising the face. Error bars show standard error.

Next, we used the Crawford adjusted single-samples t-test (Crawford & Garthwaite, 2002) in order to compare each prosopagnosia participant separately to the controls. Table 3 demonstrates that four of the five people with prosopagnosia had atypical y coordinate first fixation standard deviations in degrees (°) during the Full trials-types, which likely reflects their typical strategies when viewing a face. This suggests the majority of prosopagnosia cases might have subtle problems in performing optimal first fixations, and contrasts with other eye tracking data which suggests it is only the most severe of prosopagnosia cases that have atypicalities in face-viewing behaviour (Bobak et al., 2017).

These atypicalities were less present in the other conditions, with only three impaired cases in the Mask condition and two cases in the Window condition atypical. To explore this further, we considered where people with prosopagnosia fell on a continuum which included controls ranging from the lowest SD to the highest SD (see figure 6). Control y coordinates for the reference faces ranged from .55° to 1.2°, for full face trials from .53° to 1.97°, for window face trials from .68° to 2.19°, and mask face trials from .56° to 2.63°. Therefore, some of the control participants had a higher y coordinate SD than some of the prosopagnosia participants (see figure 6). This indicates that the first fixation location is not always optimum in control participants too. But the prosopagnosia cases' (particularly DP4 and DP5) first fixations were typically amongst the furthest away from the optimum location.

Table 3. The standard deviation of first fixations y-coordinates away from the centre-point between the eyes for individual prosopagnosia cases (z-score), and the average of the standard deviation for all control participants (SD). Note that these are degrees away from the centre-point and not degrees away from the optimal place of slightly to the left of the centre-point, as observed by Peterson & Eckstein (2012). Also note, * denotes <.05 level of significance; ** denotes Bonferroni corrected level of significance of <.013

	Reference	Full	Window	Mask
Control (SD)	.86 (.21)	1.23 (.41)	1.38 (.49)	1.48 (.57)
DP1 (z-score)	.91 (.21)	1.15 (-.2)	1.40 (.04)	2.02 (1.0)
DP2 (z-score)	.87 (.05)	2.28** (3.2)	2.18 (1.6)	1.85 (2.0)
DP3 (z-score)	.84 (-.1)	2.09* (2.1)	2.72** (2.7)	1.59 (.20)
DP4 (z-score)	1.25* (1.9)	2.39** (2.9)	3.23** (3.8)	2.73* (2.2)
DP5 (z-score)	1.25* (1.9)	2.51** (3.2)	2.26* (1.8)	2.64* (2.0)



Reference C C C C C C C C C DP3 C DP2 C DP1 C C C C C C DP5 DP4
Full C C C C C C C C C DP1 C C C C C C C C DP3 DP2 DP4 DP5
Window C C C C C C C C C C DP1 C C C C C C DP2 C DP5 DP3 DP4
Mask C C C C C C C C C C C C DP3 C DP2 DP1 C C C C DP5 DP4

Figure 6. The standard deviation continuum of y coordinates for people with prosopagnosia and controls on the different face-types.

4. DISCUSSION

Previous research has found that just to the left of the centre of the face is the optimal location for first fixations during face recognition (Hsiao & Cottrell, 2008; Peterson & Eckstein, 2012). It has been speculated that this position may be the optimal place for holistic processing of the entire face to occur (Hsiao & Cottrell, 2008; Peterson & Eckstein, 2012). Evidence suggests that people with prosopagnosia are impaired in holistic processing (Avidan, Tanzer, & Behrmann, 2011; Jansari et al. 2015). Indeed, interventions designed to improve holistic processing can lead to improved face processing in some people with prosopagnosia (DeGutis, Cohan, & Nakayama, 2014). Bobak et al. (2017) observed that the nose (a region broadly analogous to the optimal place for holistic processing) had decreased dwell time within prosopagnosia cases potentially indicating decreased capability for holistic processing. However, only two fixations may be required for face recognition (Hsiao & Cottrell, 2008) so dwell time may not be the most precise measure of holistic-type processing.

Here, we instead looked at first fixations and found evidence that people with prosopagnosia, as a group, exhibit atypically heterogenous first fixations when landing on a face's vertical plane. This occurred when asked to recognise a face, and also when face recognition was disrupted by our gaze contingent manipulation. While the first fixations were not significantly atypical on the reference faces (i.e., during memorising), two of five of our prosopagnosia cases were severely impaired. Moreover, none of the prosopagnosia cases were homogenous in their first fixations much above the mean of the control group, in the reference condition or any other. This suggests that while some prosopagnosia cases can perform within the control range, as a group, they may never attain levels of consistency beyond the control group's midrange. This is remarkably similar to the perceptual deficits that prosopagnosia cases as a group exhibit: even though many can score within the bottom half of the control range, they never perform to any great extent beyond the neurotypical mean (Biotti, Gray & Cook, 2019).

Atypical heterogeneity of first fixations in developmental prosopagnosia may be due to a number of different problems that these individuals suffer from. One such hypothesis is that impaired holistic perception may result in the atypical viewing patterns we observed. This interpretation is based upon the possibility that an optimal first fixation just below the eyes may enable the parallel processing of multiple facial features parafoveally, i.e. the eyes, nose, mouth, and the distances between them are processed in parallel as an integrative whole. If their ability to utilise holistic perception is non-existent, or at least quantitatively impaired, then there is little motivation to consistently land within this narrow vertical plane where holistic perception is most efficiently utilised. Instead, prosopagnosia cases may fixate more frequently on broader features present within the face, to aid whatever residual face processing abilities they have; i.e., picking up on whatever distinctive cues they can detect (Burns et al., 2014), and/or utilising featural processing more frequently as a remedial technique. Alternatively, they could have a problem at landing first fixations consistently within this ‘optimal’ vertical window, which then leads to a failure to effectively utilise holistic perception. Future work will be required to explore these possibilities.

In addition, our data supported the findings of Peterson & Eckstein (2012), in that participants without face recognition problems made a first fixation toward the eye region during face recognition. This was observed despite our experimental attempts at disrupting face recognition by using two different gaze contingency trial-types (mask or window: Figure 3). Note Van Belle et al (2010) found that foveal mask was more disruptive to face recognition than the peripheral mask. Based on this result, they argued that participants employed a more holistic approach to face recognition. Within the current study we observed that the scanning patterns of the individuals with developmental prosopagnosia were equivalent across the three conditions.

Therefore, it is not clear to what extent we can infer whether they were employing holistic and/or non-holistic strategies. However, the equivalence between the conditions may indicate that holistic and/or non-holistic strategies for face perception occurs in subsequent fixations rather than first fixations.

The paper extends the work by Peterson & Eckstein (2012) in two ways: [1] because of the use of two new conditions to disrupt face recognition: window and mask – with the largest degree differences away from the centre region of the eyes (i.e. poorer performance) were found for the restricted viewing conditions for controls. [2] The results also indicate that prosopagnosia is associated with viewing faces at sub-optimal locations. Because participants impaired in face recognition demonstrate different first fixation locations, this may imply that a failure to develop an automatic orientation to this location could be contributing to poorer face recognition. The results imply that first fixation differences in face recognition could either be a cause or effect of prosopagnosia, and thus our findings indicate the need for further exploration of these divergences in eye fixation patterns in cases of prosopagnosia. Peterson & Eckstein (2012) found that forcing participants to maintain gaze points away from preferred point of fixation degraded perceptual performance. DeGutis, Cohan, and Nakayama (2014) found evidence to suggest that using interventions designed to encourage holistic processing of faces improved face recognition for people with prosopagnosia. Would these findings therefore imply that if people with prosopagnosia were forced to attend to the optimal first fixation location (and therefore encourage holistic processing), their face recognition ability would improve? The implications are striking: could attentional retraining toward optimal face recognition regions improve face recognition performance for prosopagnosia? Peterson and colleagues (2019) found that such forced viewing away from an individual’s own looking preference (e.g., if they prefer to look at the mouth, then they are forced to look at the eyes) results in a decline in face processing performance. This suggests shifting fixations will not necessarily improve face processing abilities in prosopagnosia, however, it might accelerate improvement when a training paradigm such as DeGutis and colleagues' (2013) is employed.

Atypicalities of first fixations were only found along the y plane of the face and not the x plane within the prosopagnosia group. They showed increased variability in terms of the vertical position of their first fixation but not horizontal first fixation position. This may indicate that people with prosopagnosia have intact first fixation positional allocation in terms of limiting eye movement to a notional vertical centre line down the face. However, in terms of their vertical first fixation location, the people with prosopagnosia were more likely to look at features below the centre-point between the eyes, for example, the nose and the mouth, but also more likely to look above the eyes (potentially toward the hairline). This behaviour may represent a viewing pattern for face recognition which involves differentiating faces based upon distinctive features, such as hair styles or distinctive noses or mouths (see Kress & Daum, 2003). These results may therefore imply that when recognising faces, a person with prosopagnosia is more likely to look up and down a face to recognise it rather than left or right. This might be because there may be fewer distinctive features which would aid face identification to be found to the left and/or right side of a face (see Bobak, et al., 2017). There was a degree of overlap between the controls and people with prosopagnosia in terms of the y coordinates. Further, the results imply that some of the control participants had more y variability in first fixations than some of the people with prosopagnosia. Also, there may be individual differences in first fixations within participants (cf Peterson & Eckstein, 2013), so there is no clear cut-off scores between people with prosopagnosia and controls. It is possible that the results represent a continuum of ability to holistically process a face in a single fixation, with control participants typically able to do this, with some people with prosopagnosia consistently less able to do this, whilst there is a grey area in between. Although note, people with prosopagnosia were all typically amongst the participants less likely to fixate toward the neurotypical optimum location. Therefore, the results appear to suggest a qualitative rather than a quantitative shift for the adults with prosopagnosia. It is apparent that further research is required regarding first fixation location.

It is also worth reflecting on why the current results differ so greatly from those reported by Peterson et al (2019). They found no differences in first fixations between people with prosopagnosia and controls, whilst we did find clear differences. This discrepancy in findings may be due to methodological differences between the two studies; for example, they tested prosopagnosia cases with celebrity faces, emotional unfamiliar faces, and cars. By contrast, we used unfamiliar neutral faces. Future work will be required to confirm if emotion and face familiarity can therefore account for these differences. .

In conclusion, it was observed that people with prosopagnosia demonstrate a difference from controls in y coordinates when recognising faces. This difference in orienting of attention may contribute to poorer face recognition abilities. The question of whether this is a cause or effect of prosopagnosia is beyond the scope of this paper, but points to a potential future avenue for further work. In particular, we hope that this research may provide guidance for further work that may focus on utilising attentional retraining to remediate people with prosopagnosia with face recognition.

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