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The categories, frequencies, and stability of idiosyncratic eye-movement patterns to faces

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The spatial pattern of eye-movements to faces considered typical for neurologically healthy individuals is a roughly T-shaped distribution over the internal facial features with peak fixation density tending toward the left eye (observer's perspective). However, recent studies indicate that striking deviations from this classic pattern are common within the population and are highly stable over time. The classic pattern actually reflects the average of these various idiosyncratic eye-movement patterns across individuals. The natural categories and respective frequencies of different types of idiosyncratic eye-movement patterns have not been specifically investigated before, so here we analyzed the spatial patterns of eye-movements for 48 participants to estimate the frequency of different kinds of individual eye-movement patterns to faces in the normal healthy population. Four natural clusters were discovered such that approximately 25% of our participants' fixation density peaks clustered over the left eye region (observer's perspective), 23% over the right eye-region, 31% over the nasion/bridge region of the nose, and 20% over the region spanning the nose, philthrum, and upper lips. We did not find any relationship between particular idiosyncratic eye-movement patterns and recognition performance. Individuals' eye-movement patterns early in a trial were more stereotyped than later ones and idiosyncratic fixation patterns evolved with time into a trial. Finally, while face inversion strongly modulated eye-movement patterns, individual patterns did not become less distinct for inverted compared to upright faces. Group-averaged fixation patterns do not represent individual patterns well, so exploration of such individual patterns is of value for future studies of visual cognition.

1. Introduction

The classic and ubiquitously reported pattern of fixations during face perception is a T-shaped distribution with peak density over the eyes, especially the left eye (from the observer's perspective), and less fixation density over the nose and mouth (e.g. Althoff and Cohen (1999), Barton, Radcliffe, Cherkasova, Edelman, and Intriligator (2006), Heisz and Shore (2008), Janik, Wellens, Goldberg, and Dell'Osso (1978), Malcolm, Lanyon, Fugard, and Barton (2008), Yarbus (1965)). Deviations from characteristic spatial or temporal eye-movement patterns to faces have been shown to reflect disorders including autism spectrum disorders (Kliemann, Dziobek, Hatri, Steimke, & Heekeren, 2010; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Morris, Pelphrey, & McCarthy, 2007; Pelphrey, Morris, & McCarthy, 2005; Pelphrey et al., 2002; Snow et al., 2011), schizophrenia (Green, Williams, & Davidson, 2003a; Green, Williams, & Davidson, 2003b; Manor et al., 1999; Phillips & David, 1997a, 1997b, 1998; Streit, Wölwer, & Gaebel, 1997; Williams, Loughland, Gordon, & Davidson, 1999), bipolar disorder (Bestelmeyer et al., 2006; Kim et al., 2009, 2013; Loughland, Williams, & Gordon, 2002; Streit et al., 1997), and prosopagnosia (Schwarzer et al., 2007; Stephan & Caine, 2009; Van Belle et al., 2011), among others (Horley, Williams, Gonsalvez, & Gordon, 2003, 2004; Loughland et al., 2002; Marsh & Williams, 2006), and are thought to relate to the social and perceptual deficits associated with such disorders (e.g., see the correlation of eye-region fixations to emotion recognition performance for children with bipolar disorder, but not for healthy control children, reported in Kim et al. (2013)). However, recent studies have uncovered striking deviations from the classic pattern of fixations even within the healthy population. Further, it appears that

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the classic pattern in fact holds largely only when averaging across individual participants' eye-movement patterns (Gurler, Doyle, Walker, Magnotti, & Beauchamp, 2015; Kanan, Bseiso, Ray, Hsiao, & Cottrell, 2015; Mehoudar, Arizpe, Baker, & Yovel, 2014; Peterson & Eckstein, 2013; Peterson, Lin, Zaun, & Kanwisher, 2016). Such idiosyncratic eye-movement patterns have been shown to be highly stable even over the course of at least 18 months (Mehoudar et al., 2014), and thus variation in eye-movement patterns among individuals must be regarded as a largely stable dynamic rather than as variance from other sources. Patterns of individual differences in the laboratory have been reported to have a strong correlation with those in real-world settings (Peterson et al., 2016). Deviation from the classic spatial pattern in the healthy population was not reflected in reduced recognition performance for faces in our prior study (Mehoudar et al., 2014), which is consistent with a prior report showing no difference in the distribution of fixations between high and low face memory groups (Sekiguchi, 2011). Rather, forcing individuals to deviate from their own idiosyncratic fixation patterns has been reported to reduce performance for judgments on faces (Peterson & Eckstein, 2013). Even so, there is also evidence of an association between perception of the McGurk Effect and the degree of an individual's tendency to fixate the mouth of McGurk stimuli (Gurler et al., 2015). Idiosyncratic scanpaths have further been shown to vary across different tasks involving judgment of faces, but to be stable within a given task (Kanan et al., 2015). In addition to these recent findings of idiosyncratic eye-movement spatial patterns to faces, other studies involving temporal measures or other visual perceptual domains have additionally reported individual differences in eye-movements (Andrews & Coppola, 1999; Boot, Becic, & Kramer, 2009; Castelhano & Henderson, 2008; Poynter, Barber, Inman, & Wiggins, 2013; Rayner, Li, Williams, Cave, & Well, 2007). These surprising findings shed light on an intriguing phenomenon of individual differences in eye-movements and raise questions of how these individual differences relate to perceptual mechanisms and performance.

The aim of the current study was to establish natural categories of individual eye-movement patterns to faces and to estimate the frequencies of such categories within the normal healthy population. As in prior studies, we additionally probed how individual eye-movement patterns might relate to recognition performance. Finally, we investigated how time into a trial and face inversion each modulated individual spatial patterns of eye-movements to faces in terms of both relative distinctiveness and consistency. We found a strikingly variable distribution of individual differences in the spatial pattern of eye-movements in our participants, which reflected a rather continuous distribution. Nevertheless, four natural clusters were discovered in the spatial distribution of the peaks in the spatial density of eye-movements across participants. Approximately 25% of our healthy participants' peaks clustered over the left eye region (observer's perspective), 23% over the right eye-region, 31% over the nasion/bridge region of the nose, and 20% over the region spanning the nose, philthrum, and upper lips. As in prior studies, we could not find evidence that individuals' eye-movement patterns related to recognition performance, suggesting that idiosyncratic eye-movements that preferentially deviate from the "classic" T-shaped pattern do not result in reduced facial recognition. We also found evidence that idiosyncratic eye-movement patterns early into a trial were more stereotyped than those later into a trial, that such patterns evolved with time into a trial, and that while face inversion modulated individuals' eye-movement patterns, inversion did not modulate the distinctiveness of those eye-movement patterns among participants.

2. Materials and methods

2.1. Ethics statement

All participants gave written informed consent and were compensated for their participation. The study was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and was approved (protocol # 93-M-0170, NCT00001360) by the Institutional Review Board of the National Institutes of Health, Bethesda, Maryland, USA.

2.2. Sources of data

The eye-movement data for the current study were obtained from two prior published eye-tracking studies that were equivalent or highly comparable across many aspects of the stimuli and design. In the first study (Arizpe, Kravitz, Yovel, & Baker, 2012), Face Orientation and pre-stimulus Start Position were manipulated. In the second study (Arizpe, Kravitz, Walsh, Yovel, & Baker, 2016), Race of Face and pre-stimulus Start Position were manipulated. Though all details of these studies are contained in the respective papers, for completeness a detailed re-description of the stimuli, design, and procedure for these studies are included in the Supplementary Materials.

Concisely, both studies involved a study phase in which participants studied a unique face in each trial and a test phase in which participants viewed a face on each trial and responded as to whether the face was recognized as one observed during the study phase (old/new task; Fig. 1). Participants were allowed to advance study phase trials in a self-paced manner (up to 10 s per trial, self-terminating trials with a button press). The test phase began immediately after the study phase. In each trial of the test phase, participants viewed a face for a limited duration (one second only) and were instructed to respond within two seconds following stimulus onset, as soon as they thought they knew the answer. Each stimulus was a grayscale frontal view of a young adult's face scaled to have a forehead width subtending 10° visual angle. At the start of each trial, participants were required to maintain brief fixation on a pre-stimulus fixation location ("start position") that was either to the right, to the left, above, or below the upcoming centrally-presented face stimulus. An additional central start position condition existed for the first (i.e., Face Orientation) study.

2.3. Participants

50 individuals, who were residing in the greater Washington D. C. area, participated. Of those, 30 (11 male) participated in the experiment in which Race of Face and Start Position were manipulated. From that group, one participant's data was excluded from analysis due to partial data corruption. The remaining 20 individuals (12 male) participated in the experiment in which Face Orientation and Start Position were manipulated. From that group, one participant's data was excluded from analyses requiring test phase eye-movement data or recognition performance data because they did not complete the test phase. All participants were Western Caucasians because eye-movement differences have been reported among different races/cultures of observers (e.g. Blais, Jack, Scheepers, Fiset, and Caldara (2008), though see Goldinger, He, and Papesh (2009)) and we were interested in individual difference measures that could not be explained by this effect.