Characteristic fixation biases in Super-Recognizers

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Neurotypical observers show large and reliable individual differences in gaze behavior along several semantic object dimensions. Individual gaze behavior toward faces has been linked to face identity processing, including that of neurotypical observers. Here, we investigated potential gaze biases in Super-Recognizers (SRs), individuals with exceptional face identity processing skills. Ten SRs, identified with a novel conservative diagnostic framework, and 43 controls freely viewed 700 complex scenes depicting more than 5000 objects. First, we tested whether SRs and controls differ in fixation biases along four semantic dimensions: faces, text, objects being touched, and bodies. Second, we tested potential group differences in fixation biases toward eyes and mouths. Finally, we tested whether SRs fixate closer to the theoretical optimal fixation point for face identification. SRs showed a stronger gaze bias toward faces and away from text and touched objects, starting from the first fixation onward. Further, SRs spent a significantly smaller proportion of first fixations and dwell time toward faces on mouths but did not differ in dwell time or first fixations devoted to eyes. Face fixation of SRs also fell significantly closer to the theoretical optimal fixation point for identification, just below the eyes. Our findings suggest that reliable superiority for face identity processing is accompanied by early fixation biases toward faces and preferred saccadic landing positions close to the theoretical optimum for face identification. We discuss future directions to investigate the functional basis of individual fixation behavior and face identity processing ability.

Introduction

Gaze behavior is traditionally studied via investigations emphasizing commonalities among observers. More recent studies, on the other hand, have shifted toward understanding *individual differences*, and they have revealed substantial reliable idiosyncratic patterns across observers. For example, neurotypical observers' oculomotor behavior is characterized by stable interindividual differences in general oculomotor parameters (i.e., saccades, anti-saccades, smooth pursuit) (Bargary, Bosten, Goodbourn, Lawrance-Owen, Hogg, & Mollon, 2017), as well as visual saliency, or fixation biases for distinct semantic categories, such as faces or text (de Haas, Iakovidis, Schwarzkopf, & Gegenfurtner, 2019; Kanan, Bseiso, Ray, Hsiao, & Cottrell, 2015; Linka & de Haas, 2020).

For faces specifically, neurotypical observers also exhibit reliable idiosyncratic fixation biases (i.e., fixation preferences for *specific parts* of the face) (Arizpe, Walsh, Yovel, & Baker, 2017; Mehoudar, Arizpe, Baker, & Yovel, 2014; Stacchi, Liu-Shuang, Ramon, & Caldara, 2019). Interestingly, a Bayesian foveated ideal observer model predicts a location just below the eyes as optimal for sampling identity information from the face (Peterson & Eckstein, 2012), but such face-specific sampling biases nevertheless are not generally predictive of observers' behavioral proficiency. Although most observers fixate close to this optimal location (Peterson & Eckstein, 2012), deviations from this appear to

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reflect *individually* optimal behavior (Peterson & Eckstein, 2013), either reflecting retinotopic tuning biases (de Haas, Schwarzkopf, Alvarez, Lawson, Henriksson, Kriegeskorte, & Rees, 2016; de Haas, Sereno, & Schwarzkopf, 2021; Poltoratski, Kay, Finzi, & Grill-Spector, 2021) or prioritized processing of the facial information that is most diagnostic for a given observer (Stacchi et al., 2019).

Investigations of gaze behavior in special populations, on the other hand, are often characterized by more heterogeneous findings. For example, individuals with autism have been reported to exhibit an abnormally low tendency to fixate faces (Amestoy, Guillaud, Bouvard, & Cazalets, 2015; Constantino et al., 2017), or specific facial features (Tanaka & Sung, 2016). However, developmental changes have also been reported (Fedor, Lynn, Foran, DiCicco-Bloom, Luna, & O'Hearn, 2018), and, more generally, "a large inconsistency in findings" (Tang, Falkmer, Horlin, Tan, Vaz, & Falkmer, 2015, in response to Weigelt, Koldewyn, & Kanwisher, 2012) may be observed. At the same time, investigating the traits of extreme groups can offer significant power advantages over random samples of comparable sizes (de Haas, 2018), and studies of rare neuropsychological cohorts continue to advance our understanding of brain functioning (e.g., Avidan & Behrmann, 2021; Geskin & Behrmann, 2018; Ramon, 2018; Rossion, 2014). A finding of particular interest for the present study is that deviations from the theoretically optimal fixation location on faces do not appear to reflect individually optimal behavior in observers suffering from developmental prosopagnosia (Peterson, Zaun, Hoke, Jiahui, Duchaine, & Kanwisher, 2019). Specifically, a tendency to fixate lower on the face may be detrimental to face perception in these participants.

The present study investigated visual saliency in a unique observer cohort: Super-Recognizers (SRs), individuals with superior skills for processing facial identity information (Ramon, 2021; Ramon et al., 2019; Russell, Bobak, & White, 2009). To date, only one study has compared the gaze behavior of SRs to that of controls and reported reduced visual attention toward bodies and an increased dwell time on inner facial features, especially the nose (Bobak, Parris, Gregory, Bennetts, & Bate, 2016). At the same time, this study reported no significant difference in the overall salience of faces, suggesting that SRs may differ in the *way* they look at faces rather than their tendency to do so overall. We surmised that at present visual saliency in SRs had not been sufficiently addressed for two methodological reasons at least.

First, in the study by Bobak et al. (2016), observers' gaze patterns were determined based on free viewing of only 20 images of social scenes. Recent findings suggest that a minimum of 40 to 100 images are required to establish reliable estimates of individual observers' fixation biases (Linka & de Haas, 2020). Therefore, the study by Bobak et al. (2016) may have lacked the sensitivity necessary to identify stable idiosyncratic fixation biases. Furthermore, previous results have shown a correlation between face recognition performance and the specific tendency of the *first* fixation (the immediate saccade after image onset) to land on faces (de Haas et al., 2019), a measure that was not investigated in the study by Bobak and is particularly dependent on an adequate number of trials (Linka & de Haas, 2020).

Second, the individuals reported by Bobak et al. (2016) were identified as SRs based on their performance of a well-established measure of face *recognition* (i.e., the ability to locate experimentally learned among novel identities). That is, establishing their SR status did not include formal and isolated assessment of potentially superior face *perception* (i.e., simultaneous matching of face images portraying the same vs. discrimination from other identities). This may have reduced the sensitivity to find differences compared with controls for the following reason: Superiority in face recognition could reflect (domain-specific or -general) mnemonic capacities that need not necessarily coincide with superior perceptual skills. Therefore, it remains to be determined whether SRs that present with superiority in face perception, or face perception *and* recognition, exhibit atypical biases in visual salience toward faces.

In this study, we investigated natural information sampling in a group of SRs recently identified using a novel and conservative diagnostic framework (Ramon, 2021). Contrary to previous studies that identified SRs based on a performance on a single test of face (re)cognition (e.g., Bobak et al., 2016; Phillips et al., 2018), the cases reported by Ramon (2021) excelled across a number of highly challenging tests of face identity processing (assessing perception and recognition). Recent findings suggest that SRs identified in this manner utilize the same bandwidth of spatial frequency information for identity matching as typical observers but do so more consistently (Nador, Zoia, Pachai, & Ramon, 2021). Moreover, they encode novel facial identities in a viewpoint-invariant manner that facilitates later (surreptitiously solicited) recognition in a more consistent manner (Nador, Vomland, Thielgen, & Ramon, 2022), and regardless of face memorability (Nador, Alsheimer, Gay, & Ramon, 2021).

The present study sought to answer three main questions. First, we aimed to determine whether SRs show enhanced visual preference for faces compared to other observers. To this end, we compared the gaze behavior of SRs and controls exhibited during free-viewing of 700 complex scenes (with detailed metadata for visual object categories) (Xu, Jiang, Wang, Kankanhalli, & Zhao, 2014) using a paradigm that provides highly reliable estimates of individual saliency

biases for various semantic dimensions including faces (de Haas et al., 2019). Second, we specifically investigated potential fixation differences for first fixations after image onset (i.e., landing position of the first saccade), which are thought to be dominated by bottom–up processing and more difficult to suppress than immediate saccades directed toward other stimulus categories (Crouzet, Kirchner, & Thorpe, 2010; de Haas et al., 2019). Third, and finally, using enhanced annotations for facial features in the stimuli (Broda & de Haas, 2022), we investigated observers' face fixations in greater detail to compare the *way* in which SRs and controls fixate faces. Specifically, we compared groups regarding their distance between (first) face fixations and the face region just below the eye, which is optimal for face identity processing according to a foveated Bayesian ideal observer model (cf. Peterson et al., 2019).

To preview our findings, SRs showed a significantly stronger tendency to fixate faces and significantly reduced fixation tendencies for text and objects being touched. These biases were already present for first fixations. Furthermore, SRs showed a tendency to fixate faces differently than controls, as they devoted a significantly smaller proportion of their face fixations toward mouths and fixated closer to the theoretically optimal landing point just below the eyes.

Methods

Observers

In total, 53 healthy observers with normal or corrected-to-normal vision took part in this study. All observers provided written informed consent, and all research procedures were approved by the respective local ethics committees (approval nos. 473 and 486, University of Fribourg; approval no. 2018-0051, University of Giessen) and adhered to the tenets of the Declaration of Helsinki.

SRs ($n = 10$; $M_{age} = 36.10$ years; $SD = 7.28$; one left-handed; five females) (Table 1) were recruited from a larger, recently assembled cohort of SR individuals (Ramon, 2021) and received no reimbursement for participation. SR status was ascertained according to the criteria and cut-offs defined recently by Ramon (2021). In brief, the superior face identity processing abilities of SRs were determined via achievement of high scores in at least two of three demanding tests probing processing of facial identity: the 40-item long form of the Yearbook Test (YBT) (Bruck, Cavanagh, & Ceci, 1991; Fysh, Stacchi, & Ramon, 2020; Stacchi et al., 2020) and the Facial Image Card Sorting Test (FICST) (Fysh et al., 2020; Jenkins, White, Van Montfort & Burton, 2011; Stacchi et al., 2020) as measures of face perception (i.e., matching), and the 102-item version of the Cambridge Face Memory Test (CFMT+) (Russell, Duchaine, & Nakayama, 2009) as a measure of face recognition (i.e., learning and memory).

The control sample ($n = 43$; $M_{age} = 23.37$ years; $SD = 4.19$; three left-handed; 33 females) was comprised of observers who were recruited at Justus-Liebig University Giessen (Germany) and were compensated with course credit or received payment (7€/hr) for participation. Control observers were recruited as pairs of friends and completed several other questionnaires and tasks that were unrelated to the present study (for which the pairing was also irrelevant).

	Demographics			Face perception			Face fixation bias	
Code	Gender	Age (y)	Handedness	FICST score (piles + errors – 2) (Max: 0)	YBT long raw score (Max: 35)	Face recognition CFMT+ raw score (Max: 102)	Dwell time (%)	First fixations (%)
UC1	M	42	R	0	20	92	30	37
FW1	M	32	R	1	22	97	30	44
NC1	F	41	R	7	17	92	42	35
PT1	F	33	R	0	17	78	50	52
MB2	F	45	L	0	18	96	32	42
AM1	F	31	R	0	17	99	36	46
VZ1	M	24	R	6	21	90	32	36
MB1	M	34	R	0	20	97	38	43
GP1	M	47	R	7	15	99	32	40
CB1	F	32	R	2	20	87	31	42

Table 1. Demographics and performance of recruited Super-Recognizers. The table provides information on demographics (gender, age, and handedness) and scores for three tests of face cognition, as well as fixation biases toward faces. SRs were recruited based on the diagnostic framework proposed by Ramon (2021).

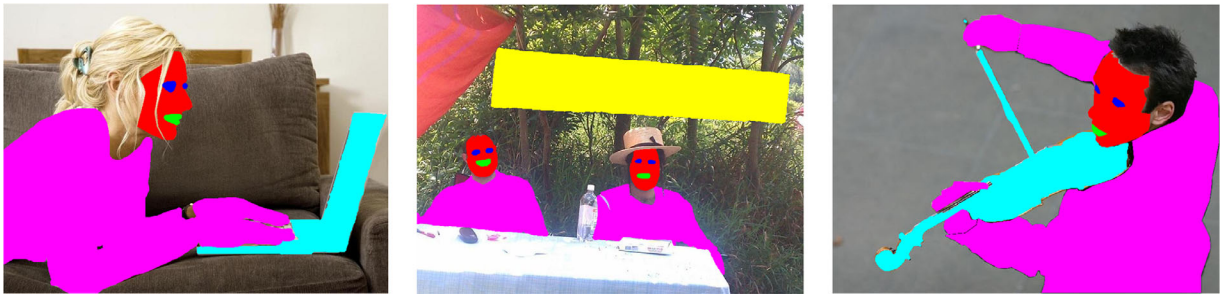

Figure 1. Example stimuli with pixel masks. Example stimuli with overlaid pixel masks for objects of the semantic categories: *Faces* (red), *Eyes* (blue), *Mouths* (green), *Bodies* (violet), *Touched* (cyan), and *Text* (yellow). All images were presented without pixel masks.

Apparatus

The free-viewing task was created and implemented with Psychtoolbox 3.0.12 (Kleiner, Brainard, Pelli, Ingling, Murray, & Broussard, 2007; Pelli, 1997) in MATLAB R2019a (MathWorks, Natick, MA). Controls saw the stimuli presented on an ultra-high-definition monitor (3840 × 2160 resolution; LG Corporation, Seoul, South Korea) and SRs on a SyncMaster 2233RZ 3D liquid-crystal display monitor (1680 × 1050 resolution; Samsung Electronics, Suwon-si, South Korea). Eye tracking data from the left eye were measured with a tower-mounted EyeLink 1000 (SR Research, Kanata, Ontario, Canada) at a frequency of 1 kHz.

Stimuli and procedure

The free-viewing task included 700 images of everyday scenes, each showing multiple potentially dominant objects (Xu et al., 2014). Most of the scenes contained objects of multiple semantic dimensions. The images were displayed at a resolution of 1200 × 900 pixels and 31.5 × 23.6 degrees of visual angle (DVA), with a viewing distance of 62 cm (SR sample), and at a resolution of 2400 × 1800 pixels and 34.3 × 25.7 DVA, with a viewing distance of 55 cm (control sample). Semantic metadata for the full stimulus set included binary pixel masks for 5551 objects and corresponding labels for 12 semantic dimensions (OSIE dataset) (Xu et al., 2014), as well as the additional 6365 masks and labels for 10 semantic labels that came with the $OSIE_{Person}$ dataset (Broda & de Haas, 2022) (see Figure 1 for example pixel masks). To reduce overlap between labels, the *Smell* label was removed from all objects with the label *Text*, the labels *Operable* and *Gazed* were removed from all objects with the *Touched* label, and the *Watchable* label was removed from all objects with the label *Text* (cf. de Haas et al., 2019; Linka & de Haas, 2020).

After completing a nine-point calibration and validation procedure, participants were instructed to freely view seven blocks of 100 images each. Each image was presented for 2 seconds before a self-paced fixation cross appeared. The appearance of the next image could then be initiated by the participant by pressing the spacebar. The order of image presentation was identical across groups and participants.

Analysis

Data processing

Statistical analyses were performed with MATLAB R2019a. To ensure that only object-specific fixations were included, all onset fixations and fixations that could not be assigned to an object label were disregarded. Following de Haas et al. (2019) and Linka & de Haas (2020), fixations that fell within ~0.5 DVA from a labeled object were assigned the respective attribute label. When a fixation fell within ~0.5 DVA between two or more labeled objects, we assigned all respective object labels. Fixations were defined using the standard settings of the EyeLink parser, and fixations with a duration below 100 ms were removed (following the manufacturer's recommendations). Data and code allowing the reproduction of all presented results and figures can be downloaded from the Open Science Framework (https://osf.io/bdafk/).

Bootstrapping

To test group differences between SRs and the control group, we applied a nonparametric bootstrapping approach. This method maximizes statistical power and controls the risk of type 1 errors for unequal group sizes. In each iteration, we pooled individual fixation data across all 53 observers and drew a random subsample of $n = 10$ from the pooled sample. After this, we calculated the statistic of interest from the given fixation data. This procedure was repeated 10,000 times, resulting in a sampling distribution consisting of 10,000 bootstrap estimates. Under the null hypothesis (no systematic difference between SRs and controls), the SR sample

characteristic is not expected to be extreme relative to this bootstrapped null distribution. Therefore, the *p* value for the observed statistic of interest for the SR group was calculated as the proportion of random draws from the pooled groups that lay below or above that value.

Visual saliency across four semantic dimensions

We investigated group differences in visual saliency along four semantic dimensions: *Faces* to test the hypothesis of altered face saliency in SRs; *Text* and *Touched*, because they have previously shown a strong anti-correlation with individual face saliency (de Haas et al., 2019); and *Bodies*, for which Bobak et al. (2016) reported reduced fixation behavior in SRs. Note that most scenes included objects of multiple semantic categories; hence, fixations toward specific dimensions can lead to fewer fixations toward objects of competing semantic categories. Nevertheless, some dimensions of semantic salience have been found to correlate positively with each other for these images (de Haas et al., 2019). We first computed individual cumulative fixation times across fixations toward all labeled objects. The proportion of time spent on a given semantic attribute (cumulative dwell time ratio) was then determined for each subject. Additionally, we computed the proportion of *first fixations* toward objects of a given semantic dimension after image onset for each individual (first fixation ratio). To test group differences, we then pooled participants across groups and bootstrapped a null distribution of mean fixation ratios, against which we compared the observed value for SRs (see above). This was repeated for each dimension, and the corresponding *p* values were adjusted for the four semantic attributes using the Holm–Bonferroni correction (Holm, 1979).

Differences in fixation behavior toward inner face regions

Tendency to fixate eyes and mouths

To test whether SRs and control participants differed in their tendency to fixate Eyes and Mouths (Bobak et al., 2016), we first excluded all faces with an eye-to-mouth distance below 2.5 DVA. This was done to avoid inconclusive assignments of fixations to both eyes and mouths (due to the margin of tolerance), as well as false positives due to calibration inaccuracy. After that we calculated the cumulative fixation time on faces for each participant to then determine the individual proportion of this face fixation time spent on Eyes and Mouths. Further, we computed the individual proportions of fixations toward Eyes and Mouths among the first fixations landing on a given face (note that here we analyzed first fixations toward each observed face in a scene). Again, group differences were tested for statistical significance by bootstrapping the group mean for random samples drawn from all participants and comparing the observed mean for SRs against this null distribution (see above). Again, *p* values for Eye and Mouth fixations were adjusted using the Holm–Bonferroni correction (Holm, 1979).

Deviation from optimal fixation location for face identity processing

To investigate whether SRs tend to fixate closer to the ideal fixation location for identification just below the eyes, as predicted by a foveated Baysian ideal observer model (cf. Peterson & Eckstein, 2012), we first again removed all fixations with an eye to mouth distance of below 2.5 DVA. We then calculated the approximate optimal fixation point for each fixated face by calculating the point that lay at a height of 70% along the direct line connecting the centroids of mouth and eyes (Peterson & Eckstein, 2012, figure 5B). Finally, we projected each face fixation of each observer onto this connecting line and calculated its distance from the optimal location along this line normalized as percentages from the distance from the respective mouth centroid to the ideal fixation point. We then compared the resulting mean distances for each observer across groups, again bootstrapping the group mean for random samples drawn from all participants, and we compared the observed mean for SRs against this null distribution. We applied the Holm–Bonferroni correction (Holm, 1979) to adjust *p* values for first fixations and all fixations.

Results

Salience differences across object categories

First, we tested whether SRs would show higher cumulative dwell time and first fixation ratios for *Faces* than controls and reduced dwell time and first fixation ratios toward *Text*, *Touched* objects, and *Bodies*. Figure 2 shows individual gaze tendencies for each SR (red lines), superimposed on raincloud plots (Allen, Poggiali, Whitaker, Marshall, van Langen, & Kievit, 2019) of the distribution for controls. Figure 3 shows the bootstrapped null distributions of random sample means drawn from all participants (pooled across groups), with the observed mean of the SRs superimposed as a red line.

Bootstrap analyses confirmed that SRs spent more time fixating *Faces* than did the controls ($p_{FWE} < 0.01$). Further, SRs showed lower cumulative dwell-time ratios for the dimension *Text* ($p_{FWE} < 0.05$) and *Touched*

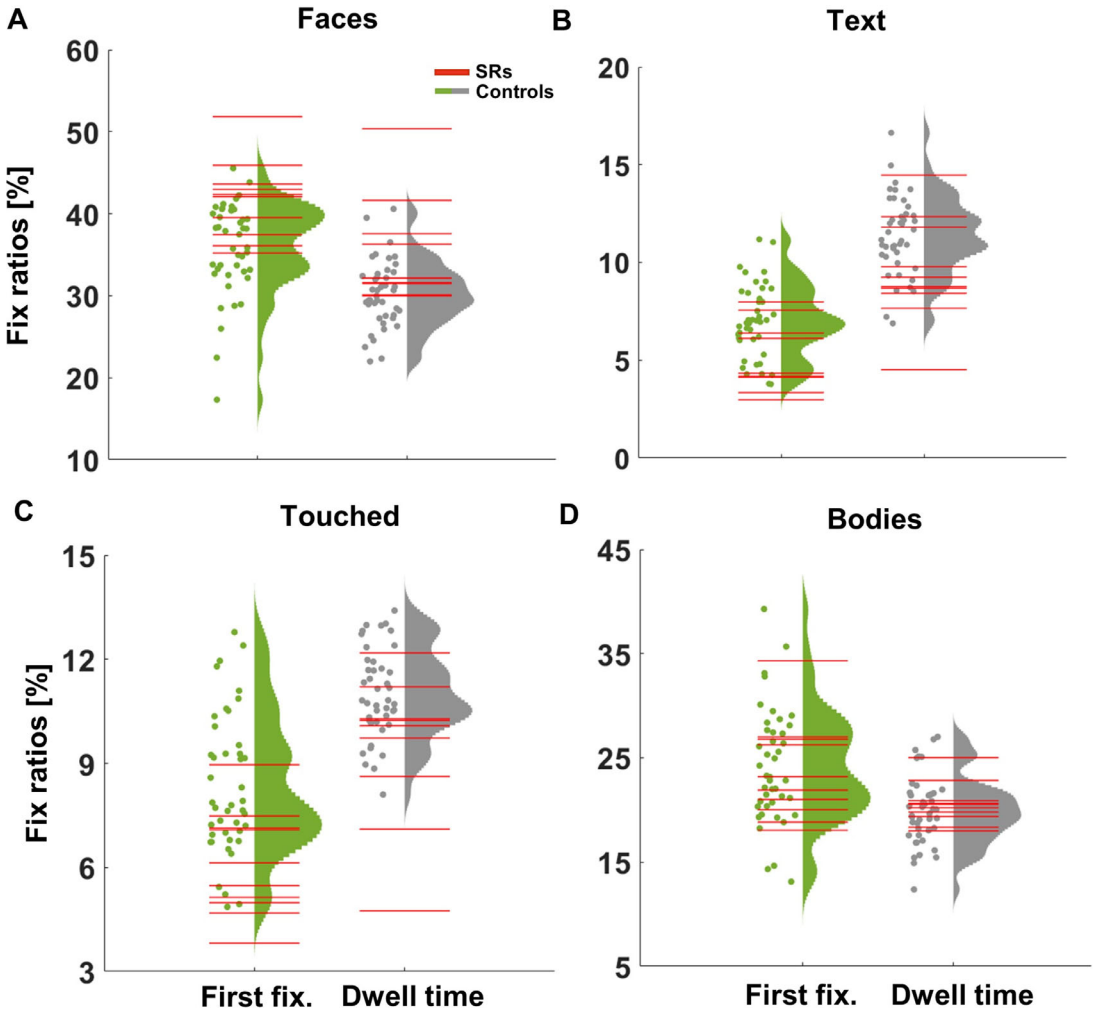

Figure 2. Individual gaze tendencies toward four semantic dimensions. (A–D) Right-hand leaves show the distributions of the control group for percent first fixations (green) and percent cumulative dwell time (gray) along each semantic dimension. Dots depicted in the left-hand raincloud plots indicate the corresponding individual data for each control subject. Superimposed red lines refer to the fixation ratios for each SR.

($p_{FWE} < 0.01$) compared with the control group. Further, SRs and controls did not differ in dwell time proportion toward *Bodies* ($p_{FWE} = 0.27$). Similar results were found for analyses testing group differences in the proportion of first fixations; SRs spent a significantly larger proportion of first fixations on *Faces* than did the control group ($p_{FWE} < 0.01$). Further, SRs directed a smaller proportion of first fixations toward *Text* ($p_{FWE} < 0.01$) and *Touched* objects ($p_{FWE} < 0.01$) compared with the control group. SRs did not differ from controls in the proportion of first fixations toward *Bodies* ($p_{FWE} = 0.42$).

Correlations between face cognition performance and visual saliency

Previous research has shown a correlation between the tendency to direct first fixations toward faces and CFMT performance in controls (de Haas et al., 2019). To test whether variance in face saliency is also associated with enhanced face cognition performance within the group of SRs, we computed two Pearson's correlations: (1) between observers' face cognition performance composite scores (across CFMT+, YBT long, and FICST) (cf. Nador et al., 2022) and percent dwell time toward faces, and (2) between their composite score and percent first fixations toward faces. The results show no significant correlation between face cognition performance and percent dwell time (if anything a negative trend; $r = -0.63$, $p_{FWE} = 0.10$) or percent first fixation ($r = -0.07$, $p_{FWE} = 0.85$). Note, that the limited sample size of SRs ($n = 10$) and the reduced variance in this group implied an extremely limited sensitivity of our design for this exploratory analysis.

Differences in the tendency to fixate eyes and mouths

Given that SRs exhibited a stronger tendency to fixate faces compared with controls, we next probed whether SRs and control participants differed in *how*

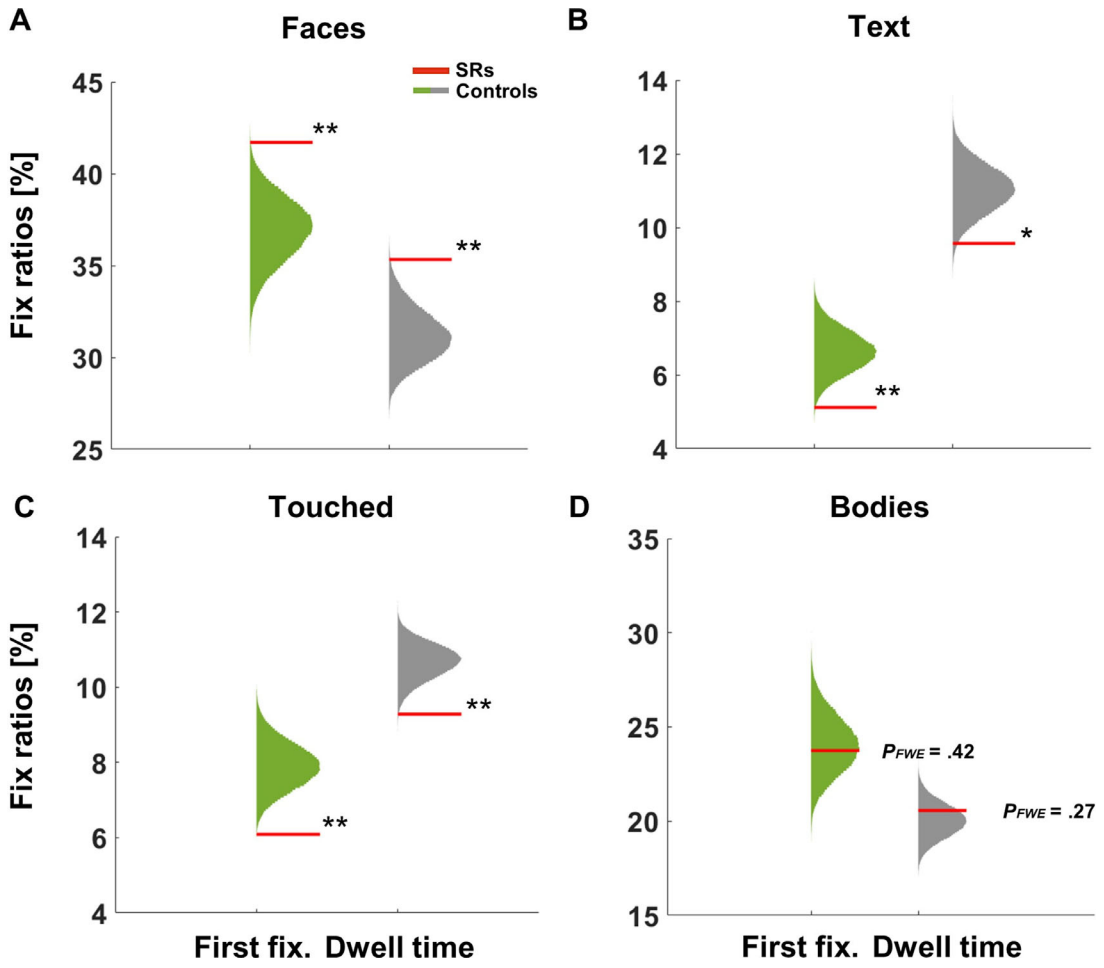

Figure 3. Group difference in gaze tendency across four semantic dimensions. (A–D) Bootstrapped null distributions of 10,000 random sample means drawn from all participants (pooled across groups) for percent first fixations (green) and percent of cumulative dwell time (gray). The superimposed red lines refer to the observed mean percent first fixations and mean percent cumulative dwell time of SRs for each given semantic dimension. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ (Holm–Bonferroni corrected; see Methods).

they fixated faces. We first tested group differences in the proportion of cumulative fixation time spent on faces that was directed toward Eyes and Mouths. Figure 4 shows bootstrapped mean distributions and the respective observed mean values from SRs for mean cumulative dwell-time ratios and first fixation ratios toward Eyes and Mouths. SRs spent significantly less time fixating Mouths when looking at a face than did controlse ($p_{FWE} < 0.05$). This was also true when considering the proportion of first fixations toward faces ($p_{FWE} < 0.01$). SRs and controls did not differ in percent dwell time ($p_{FWE} = 0.30$) and percent first fixation ($p_{FWE} = 0.33$) spent on Eyes.

Differences in face fixations toward the theoretical optimal fixation point

To test whether SRs compared with controls fixate closer to the optimal fixation point for identification, as predicted by an ideal Bayesian foveated observer model (Peterson & Eckstein, 2012), we computed the mean distance between (first) face fixations and the respective estimated optimal landing point for each observer. Compared with controls, SRs fixated significantly closer to the estimated optimal fixation point ($p_{FWE} < 0.01$). This also held for first fixations toward a given face ($p_{FWE} < 0.01$). Figure 5 shows the distribution of first fixations and all fixations toward faces for SRs and control subjects, as well as the average distance from the ideal fixation point for SRs and controls.

Discussion

Previous studies revealed that neurotypical observers exhibit reliable idiosyncratic gaze biases toward specific semantic stimulus categories and that their tendency to immediately fixate a face within a scene is correlated with face recognition ability (de Haas et al.,

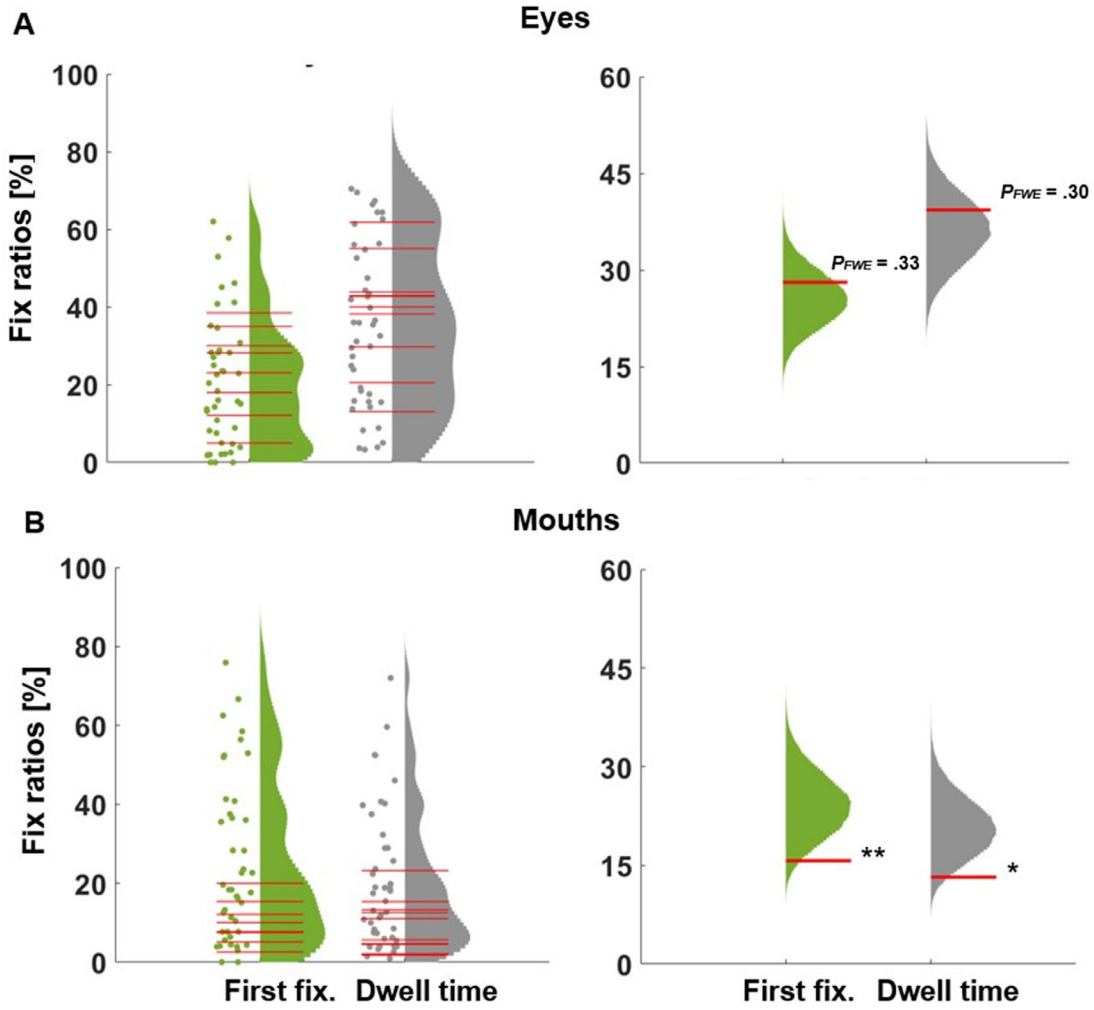

Figure 4. Fixations toward eyes and mouths. (A, B) Left-hand sides show the distributions of the control group for percent first fixations (green) and percent cumulative dwell time (gray) for fixations toward (A) eyes and (B) mouths relative to the amount of time spent looking at faces. Dots depicted in the left-hand raincloud plots indicate the corresponding individual data for each control subject and red lines indicate the fixation ratios for each SR. Right-hand sides show bootstrapped null distributions of 10,000 random sample means drawn from all participants (pooled across groups) for percent first fixations (green) and percent of cumulative dwell time (gray), respectively, for fixations toward (A) eyes and (B) mouths. The superimposed red lines refer to the corresponding observed mean of SRs. $*p < 0.05$, $**p < 0.01$, $***p < 0.001$ (Holm–Bonferroni corrected; see Methods).

2019). Extending this work, here we examined visual saliency in Super-Recognizers (SRs), individuals with exceptional face identity processing skills (Ramon, 2021; Ramon et al., 2019; Russell et al., 2009). To this end we registered oculomotor behavior of 10 SRs and 43 controls. Observers freely viewed 700 unique naturalistic scenes, depicting over 5000 objects, which were individually annotated by manually created pixel masks (Xu et al., 2014).

First, we tested whether SRs show enhanced dwell time proportions toward faces relative to objects of other semantic categories. Our findings show that SRs spend a significantly larger proportion of their dwell time fixating faces and a significantly smaller proportion of time fixating touched objects and text compared with controls. SRs and controls did not differ in proportion of dwell time spent on bodies.

We sought to further scrutinize these observations through a targeted analysis focusing on the proportion of first fixations executed after image onset. This revealed that, compared with controls, SRs showed a significantly stronger tendency to fixate faces immediately after image onset and directed a significantly lower proportion of initial fixations toward touched objects and text. In line with the findings for overall dwell time, again there was no group difference in fixations toward bodies.

Moreover, we did not find a significant correlation between the SRs' face cognition performance and their tendency to (first) fixate faces; if anything, the opposite

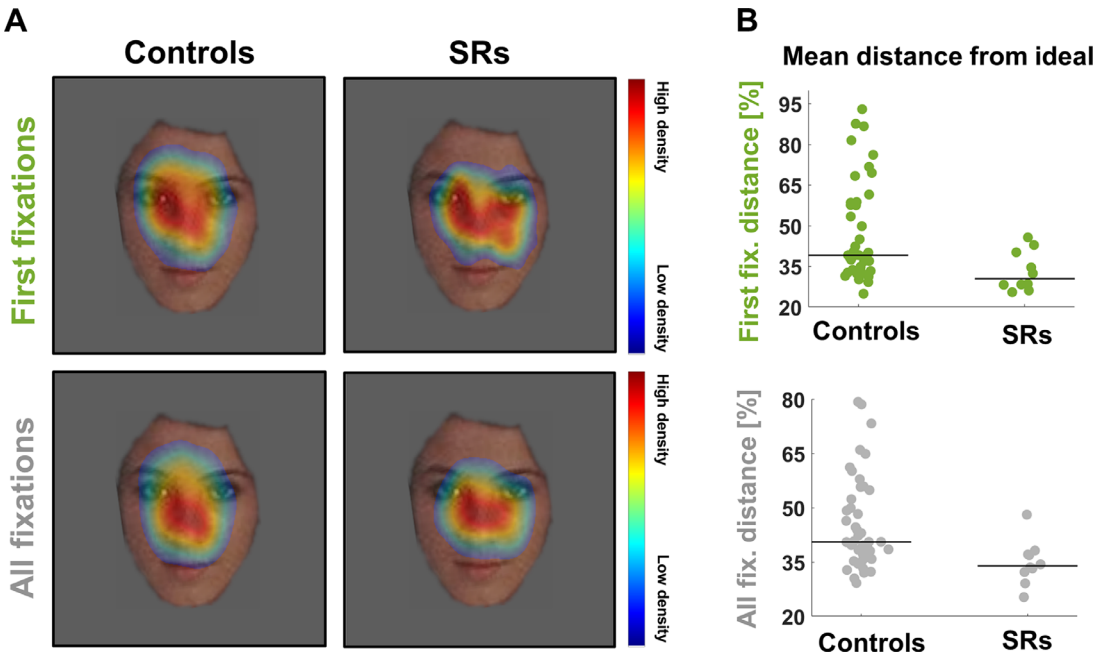

Figure 5. Results for the stimulus category *Faces*. (A) Heatmaps showing the distribution of first fixations (top row) and all fixations (bottom row) on all observed faces with an eye-to-mouth distance > 2.5 DVA superimposed over an example image (selected from one stimulus used in the free-viewing task). The heatmap was horizontally compressed to match the example face. Heatmaps on the left-hand side show fixation data from controls, maps on the right-hand side show fixations from SRs. All face fixation coordinates were normalized to the horizontal (*X*) and vertical (*Y*) extent of the respective observed face. Warmer colors indicate higher density of fixations. (B) Average of relative distances from ideal fixation point for first fixations (top row) and all fixations (bottom row) toward faces with an eye to mouth distance >2.5 DVA for each observer. Distances from the ideal fixation point just below the eyes (Peterson & Eckstein, 2012) were calculated for each face and fixation, normalized as percentages from the distance from the respective mouth centroid to the ideal fixation point and then averaged for each observer. The resulting mean distances for controls are shown on the left-hand side, those for SRs on the right-hand side. See Methods for further details.

trend for dwell time was observed. Importantly, however, these results must be interpreted with caution. We acquired data on face processing abilities only from SRs, and the small size of this group ($n = 10$) together with reduced variance within this group implies a lack of statistical power and a high probability of type 2 errors. Thus, although our data provide strong evidence for heightened face salience in SRs compared with controls, it cannot provide reliable evidence regarding the question of associations between face salience and recognition performance *within* this group. Together, our results indicate that SRs show characteristic fixation biases that differ from those shown by neurotypical controls.

Atypical saliency in relation to previously reported fixation behavior in SRs

Our findings differ from and extend the results from the only previous study on natural scene viewing in SRs in several important ways. Most strikingly, we found a significantly enhanced gaze tendency toward faces in SRs than control subjects, whereas no such effect was reported in the previous work (Bobak et al., 2016). These seemingly contradictory findings may be explained by procedural differences between studies.

First, the present study involved a more sensitive measurement (700 vs. 20 images in Bobak et al., 2016); recent findings suggest that a minimum of 40 to 100 images are necessary to reliably capture salience biases toward complex scenes (Linka & de Haas, 2020). Additionally, the SR individuals tested here were identified using a more stringent diagnostic framework (Ramon, 2021), which involves the use of a combination of the most challenging tests of face perception *and* recognition (vs. a single recognition test, as in Bobak et al., 2016).

Further, we analyzed overall dwell time, as well as first fixations. We report increased proportions of first fixations toward faces in SRs versus controls. These findings match recent evidence reported by de Haas et al. (2019) showing that individual differences in the proportion of first fixations toward faces correlate with face recognition performance in typical observers,

pointing to potential differences in bottom–up salience processing.

Finally, Bobak et al. (2016) found that SRs spent a significantly lower proportion of dwell time fixating bodies. We investigated further types of objects known to be highly salient and found no group difference for bodies but a significant tendency for SRs to fixate text and touched objects less. This is in line with the anti-correlation between individual saliency for faces, on the one hand, and text and objects being touched, on the other, which has been described for controls (de Haas et al., 2019). The general nature of this push–pull mechanism may point to SRs being at the extreme end of a general and continuous space of individual saliency, rather than showing a gaze behavior that is qualitatively different from controls.

SRs and the continuous spectrum of face salience

Together with previous work, the present findings draw a heterogenous picture of visual salience biases in the population. Across neurotypical observers, there seems to be large variability in the tendency to attend faces (de Haas et al., 2019). Certain cohorts, such as patients with autism spectrum disorder (ASD) (Wang, Jiang, Duchesne, Laugeson, Kennedy, Adolphs, & Zhao, 2015) or developmental prosopagnosia (DP) (Bobak et al., 2016), show reduced visual salience toward social stimuli such as faces, already in infancy (Constantino et al., 2017), as well as large deficits in face identity processing (Bowles et al., 2009; Griffin, Bauer, & Scherf, 2021). Notably, although most patients with ASD or DP show atypical gaze behavior toward faces, the extent can vary idiosyncratically across individuals (Pantelis & Kennedy, 2017). Here, we show that the superior face identity processing skills of SRs (Ramon, 2021; Ramon et al., 2019; Russell et al., 2009) can go along with enhanced salience for faces. However, we also observe large individual differences in gaze biases among SRs. Moreover, our preliminary findings show no significant association between fixations tendency toward faces and face processing ability within the group of SRs. This suggests that enhanced face salience is a common but most likely neither necessary nor sufficient ingredient for superior face identity processing skills. Taken together, on a population level, individual face salience seems to fall on a wide spectrum, with specific groups showing a tendency to cluster at either end rather than differing qualitatively from controls. This resembles the large individual differences reported for face identity processing skills (e.g., Bobak, Jones, Hilker, Mestry, Bate, & Hancock, 2022; Fysh & Bindemann, 2018; Fysh & Ramon, 2022; Fysh et al., 2020; Stacchi et al., 2020; Stantić et al., 2021; Stantić, Ichijo, Catmur, & Bird, 2022; Wilmer, 2017).

Functional implications of atypical saliency in SRs

Given the higher face saliency in SRs versus controls reported here, it is tempting to speculate about a potential causal relationship between individual face salience and (superior) face identity processing. Do inherent visual face biases affect face identity processing skills, or vice versa? As mentioned above, the contingency between the two is not perfect, as not all SRs show enhanced face salience and not all individuals with high face salience are SRs. Nevertheless, increased (early) face salience may promote social interaction via mutual reinforcement leading to advanced processing of facial information. This idea is partly consistent with data showing an association between extraversion and individual differences in face identity processing (Li, Tian, Fang, Xu, Li, & Liu, 2010). It also matches theories on learning style that explain difficulties in face processing in autism (Qian & Lipkin, 2011). Future research may investigate whether early tendencies to attend faces develop into corresponding levels of face identity processing abilities.

Recent twin studies in infants and children have shown strong heritability for individual face fixation biases (Constantino et al., 2017; Kennedy, D'Onofrio, Quinn, Bölte, Lichtenstein, & Falck-Ytter, 2017). On the other hand, further twin studies have shown that face identity processing abilities are heritable, as well (Wilmer et al., 2010; Zhu et al., 2010). Some studies provide evidence that face identity processing performance, as well as its genetic component, increases from preschool until adolescence (Germine, Duchaine, & Nakayama, 2011; Zhu et al., 2010). Together with the evidence for heritable gaze biases in infants, this suggests that individual salience biases may be innate and contribute to the later development of face identity processing abilities.

Retinotopic feature-location biases in SR face fixation behavior

To probe the fixation behavior of SRs *within* the semantic category of faces, we compared the proportion of dwell time and first fixations toward eyes and mouths between SRs and controls. We found that when fixating a face, compared with controls SRs fixated mouths significantly less and did not differ in the tendency to fixate eyes. The same pattern of results emerged when only the first fixation toward faces was considered. Moreover, we found that SRs fixated faces closer to

a region just below the eyes, which, according to a Bayesian ideal foveated observer model, is optimal for face identification (Peterson & Eckstein, 2012). This converges with the report by Bobak et al. (2016) of an increased fixation tendency toward noses in SRs versus typical observers (cf. Bennetts, Mole, & Bate, 2017). Interestingly, individual variance around this theoretical optimum has previously been shown to be individually optimal (Peterson & Eckstein, 2013), except for some observers suffering from developmental prosopagnosia (Peterson et al., 2019).

It is tempting to speculate that SRs may have face templates or visual field layouts aligning their individually optimal (and preferred) fixation locations more closely with the theoretical optimum than is the case for neurotypical controls. Further studies using forced fixation paradigms (Peterson & Eckstein, 2013) and more accurate, face-specific Bayesian model predictions of optimal fixation locations are required to test this. Furthermore, the stereotypical gaze behavior of SRs seems aligned with visual field tuning for the recognition of isolated facial features (de Haas & Schwarzkopf, 2018; de Haas et al., 2016) as well as their neural processing (de Haas et al., 2016; de Haas et al., 2021). Future studies should also test whether such feature-location effects are more pronounced in SRs than controls.

It is currently unclear why the individually optimal fixation point of some observers is shifted from the theoretical (and most common empirical) optimal fixation location just below the eyes. One possible explanation is that individual observers may deviate from model assumptions such as symmetric foveation. This could lead to overall detrimental effects on face identity processing performance which could partially be compensated for by altered fixation behavior. Although this remains speculative at present, it is noteworthy that our current results suggest that the fixation behavior of SRs is more tightly clustered around the theoretical optimum predicted by a foveated ideal observer than that of controls. This behavior could reflect increased spatial coverage potentially due to larger population receptive fields enabling more efficient spatial integration of information in face selective areas (Witthoft et al., 2016), or entorhinal cortex (Avidan & Behrmann, 2021).

Limitations and further considerations

One limitation of the present study is that we have no information about face identity processing ability in the control sample. This limits our power to test associations between visual salience and face cognition abilities, because we can only do so in a categorical (rather than graded) manner. Furthermore, to date there is no reliable estimate regarding the prevalence of SRs in the general population. However, note that in a recent study, Nador et al. (2022) reported that five of the final sample of 114 police professionals, whose data were subject to analysis (and six of the original 146 who completed the lab tests) met the SR criteria used here and elsewhere (Ramon, 2021; Nador et al., 2021). Therefore, although we cannot exclude the possibility that our control sample included individuals meeting SR criteria, we would expect their number to be very low.

Although here we show a significant difference in visual salience between SRs and controls, there is considerable overlap between both groups (see Figure 2). This overlap could potentially be driven by control observers located at the upper end of the face identity processing spectrum. Future research may additionally test face identity processing abilities and use regression approaches to exploit individual variance across the whole spectrum.

One could reasonably argue that the present findings could have been impacted by an implicit factor related to the experimental design: SRs who volunteered to participate in the present study were aware of their superior face identity processing skills. Therefore, they may have focused toward faces more often and/or longer, purely because they expected the experiment to address questions related to face cognition.

However, compared with controls, SRs showed stronger differences in their tendency to first fixate faces versus non-face objects than in their allocation of overall dwell time. Previous studies have shown very low latencies for first saccades after image onset directed toward faces. Specifically, observers have a hard time suppressing such face-directed fixations (Crouzet et al., 2010). Thus, it seems unlikely that these effects are significantly impacted by top–down expectancy effects.

Here, we investigated individual differences in fixation behavior during free viewing of complex static scenes containing people and other objects. Such individual differences have been shown to be highly stable over time (de Haas et al., 2019). Furthermore, individual differences in fixation behavior *within* faces has been shown to be extremely stable across lab-based identification tasks and real world free-viewing (Peterson, Lin, Zaun,& Kanwisher, 2016). Nevertheless, at the group level, face fixation behavior varies with task (Buchan, Paré, & Munhall, 2007) and between static and dynamic stimuli (Võ, Smith, Mital, & Henderson, 2012). Future studies will have to determine whether and how individual and group differences vary with task and stimulus modality.

Conclusions

In sum, we find that SRs compared with controls exhibit significantly enhanced gaze biases toward

faces and significantly diminished tendencies to fixate touched objects and text when freely viewing complex scenes. These differences are evident from the first fixation onward, suggesting a substantial bottom–up component in salience processing. However, the distributions of the fixation tendencies of SRs and control observers are overlapping, and the push–pull relationship between different fixation tendencies is seen in both groups. This suggests a continuous space of individual salience in which SRs cluster toward the high face salience end (rather than inhabit a qualitatively different space). Finally, within the category of faces, SRs show a more stereotypical fixation pattern, exhibiting a stronger tendency than controls to preferentially fixate near the theoretical optimum just below the eyes. Further research is needed to probe the developmental and causal relationships between individual gaze behavior and face identity processing skills.

Keywords: super-recognizers, face identity processing, perception and recognition, visual salience, eye movements

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