From the Corner of My Eye: The Role of Extrafoveal Recognition Processing in Search Performance

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Data, code and pre-registrations are openly available at the project's Open Science Framework page (https://osf.io/86ky4/?view_only=bbe8698ea4b64c83bf49c8009454936b) Brief description of the results was presented in a talk at the 2022 European Conference on Eye Movements, University of Leicester, United Kingdom. We have no conflicts of interest to disclose.

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Word count: 7010

Abstract

There has been broad consensus that effective visual search relies on comparing the visual input with an active representation of the target's features stored in working memory, known as the search template. However, recent findings challenge this notion by indicating that efficient search can occur even without a search template. That is, individuals could locate a familiar face faster than chance, even when unaware of the specific person they were searching for. If a search template is not mandatory, what could be the guiding mechanism of efficient search? Two experiments suggest that focusing on extrafoveal abilities holds the key to this question. Specifically, we demonstrate that recognition processes, encompassing familiarity and recollection, can take place through extrafoveal vision. Moreover, the capacity to determine whether a face is familiar emerges as a significant predictor of search performance. These findings contribute to our understanding of visual attention models and highlight individual differences in extrafoveal visual processing capabilities.

Public Significance Statement

Visual search is a common, everyday task with potentially life-saving implications, such as a radiologist scanning for a tumor in a CT scan or a lifeguard searching for a drowning person. This study delves into the underlying mechanisms governing search and emphasizes the role of peripheral processing in guiding attention. Notably, we demonstrate that when exposed to a face in the periphery of the visual field, observers can discern whether this face is familiar and detect the identity of the depicted person. Crucially, this ability correlates with search efficiency: individuals with better peripheral processing could find a familiar person faster, even without knowing specifically who they were looking for. These findings challenge traditional search theories and leverage individual differences in extrafoveal vision processing capabilities to explain variations in search performance.

Keywords: visual search; memory-guided attention; extrafoveal vision; individual differences; familiarity and recollection

Introduction

Whether you are reading this paper at your office, home, or library, you are currently surrounded by an abundance of perceptual information that surpasses the limited capacity of your cognitive system. To address this challenge, only a portion of the visual information is attended to at any given moment. To ensure the efficiency of this selective process, attention cannot be directed to all potential bits of visual information; instead, it must be guided toward the most relevant ones (Wolfe & Horowitz, 2017). Deciphering the nature of these guiding mechanisms is at the heart of massive research efforts in the domain of visual attention.

The study of guiding mechanisms in the laboratory often employs the paradigm of visual search. While multiple versions of this task exist, the fundamental concept remains consistent across all variations: the objective is to locate a target within a set of distractors (Eckstein, 2011). By manipulating the properties of the search array and the targets, researchers can examine which factors impact the efficiency of search, enabling them to isolate elements capable of directing attention toward the target. The Guided Search model (Wolfe, 1994, 2021; Wolfe et al., 1989; Wolfe & Gray, 2007) has synthesized these findings into a unified framework based on a priority map, which represents the locations in the visual field that are likely to contain the target. Attention will be deployed to the most active location on the map. While various sources contribute to the priority map in different versions of the model, top-down activation has consistently played a role in all of them.

The idea of top-down guidance is that attention is directed to locations that align with the current goals of the observer. In the realm of visual search, this type of guidance was often conceptualized as the search template (Wolfe, 2020). To illustrate the idea of a search template, think, for example, that you are looking for the television's remote control. In this case, specific features of the target (e.g., “black”, “rectangle”) can guide your search towards probable locations of the target. This template is believed to be maintained in an active state in working memory (Carlisle et al., 2011; Woodman & Arita, 2011) and to be constantly compared to the visual sensory input to direct attention towards probable locations of the target (e.g., black rectangular objects). Since the theoretical formulation of the search template over 30 years ago (Duncan & Humphreys, 1989), extensive research has shown that attention is indeed guided towards locations that resemble the low-level characteristics of the template (Alexander et al., 2019; Bahle et al., 2018; Findlay, 1997; Motter & Belky, 1998), even if the target is not present (Tavassoli et al., 2009). There are indications that facilitation by the search template does not rely solely on the visual properties of the template. Series of studies, for example, showed that search is facilitated when the search template is familiar, such as with known words (Flowers & Lohr, 1985) or familiar faces (Dunn et al., 2018; Kramer et al., 2020).

Remarkably, the facilitation of search by familiarity may be even unrelated to the search template. Qin and colleagues (2014), for instance, showed that search is faster for familiar logos, even when a picture of the target was constantly presented on the screen. Consequently, the performance boost due to familiarity was evident even when participants did not need to actively retain what they were seeking. While one could argue that, in this case, a search template was still constructed, our recent study illustrates that familiarity can enhance performance even when a search template is highly implausible (Lancry-Dayan et al., 2021). In this study, participants saw arrays of five faces (one familiar and four unfamiliar) and were asked to look for the familiar face without knowing the identity of the person that they are looking for. Measures of gaze behavior indicated that observers found the familiar face faster than expected by unguided search. Since statistical models estimate that a person knows hundreds of people (Gelman, 2013; Gurevitch, 1961; McCormick et al., 2010) it is highly unlikely that in this type of search a person can merge the visual properties of all familiar faces into a single, or even a handful of search templates. If a search template is improbable in this case, what could be the mechanism behind the facilitation of search by familiarity?

The key to unraveling this question may lie in the capacity to perceive information through peripheral vision. Although the importance of extrafoveal vision to guide search has already been acknowledged, it has been conceptualized only with regard to an active search template (for a recent review see Lleras et al., 2022). However, if objects can indeed be recognized through extrafoveal vision, the peripheral signal might be adequate to guide search even in the absence of an active search template. To assess this possibility, two crucial pieces are missing in the puzzle: (1) the feasibility of executing recognition processes through extrafoveal vision and (2) the relationship between peripheral recognition processes and search performance.

There is a growing body of evidence suggesting that individuals can extract a wealth of information even from their peripheral vision, including saliency (e.g., color; Abramov et al., 1991; Hansen et al., 2009; Tyler, 2015), object detection (e.g., faces; Devue et al., 2012), emotional indicators (e.g., emotional expressions; Calvo et al., 2010) and even semantic information (Becker & Rasmussen, 2008; Cimminella et al., 2020; LaPointe & Milliken, 2016; Loftus & Mackworth, 1978; Nuthmann et al., 2019; Underwood & Foulsham, 2006). In certain research domains, such as reading, peripheral vision has been shown to be crucial for normal performance (Rayner, 1975; Schotter et al., 2012).

In the realm of face recognition, which is specifically pertinent to our focus, studies have indicated that when a face is presented in the periphery of the visual field, participants can successfully differentiate between two possible identities of that face (McKone, 2004), make decisions about whether it aligns with a given identity (Reddy et al., 2006), or determine whether the depicted person is famous or not (Harry et al., 2012). While these findings significantly contribute to our understanding of face recognition capabilities in the periphery, some caveats should be noted. These studies involved a relatively simple form of face recognition, relying on a binary decision task (e.g., fame discrimination; Harry et al., 2012). In studies that included some form of identity processing (albeit again, with two-forced choice tasks), the identity of the familiar face was cued before the block and enabled observers to construct an active representation of the face. Consequently, it remains unclear to what extent the identity of a person can be processed through extrafoveal vision and whether these processing capabilities necessitate some priming, or an active representation, of the target face.

Nevertheless, to generalize extrafoveal vision capabilities as a potential underlying guiding mechanism for search in the absence of a template, it is imperative to demonstrate whether peripheral recognition capabilities are indeed correlated with search performance. To establish the link between extrafoveal recognition processes and search efficacy, an individual differences approach can be used. This approach has been recently exploited by Veríssimo and colleagues (2021) who examined whether individual differences in susceptibility to crowding (i.e., the ability to discriminate properties of a peripherally presented object when it is surrounded by distractors) are related to search performance. This study has shown that limitations in extrafoveal processing (i.e., higher susceptibility to crowding) are correlated with less proficient search (i.e., longer reaction times and more fixations during search). Although the focus of the current study is different (i.e., guidance of search by long-term representations), the Veríssimo and colleagues (2021) work still shows the potential of an individual differences approach to examine extrafoveal processing capabilities as an explanatory factor of search. Here we adopt this method to find the required link between extrafoveal vision and guidance of search in the absence of a template.

In essence, the current study aims to investigate the hypothesis that representations in long-term memory can effectively guide search through extrafoveal vision, even in the absence of an active search template. This objective is pursued through a two-step design. The first step seeks to establish that recognition processes can indeed be carried out through extrafoveal vision. To advance our understanding of recognition processes in the peripheral visual field, we focus on two aspects of recognition: (1) familiarity, representing the sense that an object or event has been previously experienced, and (2) recollection, reflecting the ability to retrieve details about the recognized object or event (Yonelinas, 2002). The second step is to examine whether individual differences in the ability to conduct extrafoveal recognition processes can predict the efficiency of search guidance.

Thus, each experiment in this study includes two parts. The first part examines the ability to recognize a familiar face that is presented at the periphery of the visual field. This ability is explored along two dimensions: (1) distance: how far the familiar face is from the fovea and (2) exposure time: for how long the familiar face is displayed. These dimensions are investigated for their impact on familiarity (Experiment 1) and recollection (Experiment 2). The second part of each experiment introduces a search task, where participants are asked to find a familiar face without prior knowledge of the specific individual they are looking for. This part aims to determine whether the measured recognition ability from the first part can predict guidance of search in the second part.

Experiment 1 – Familiarity

Method

Both experiments in this study were approved by the ethics committee of the Faculty of Social Sciences of the Hebrew University of Jerusalem. The target population for all experiments was neurotypical adults.

Participants

40 participants were recruited for the experiment. We removed from further analysis 3 participants with more than 50% disqualified trials (due to the exclusion criteria) and 3 participants due to technical issues. Thus, the final sample included 34 participants (10 men; $M = 24.27\ years$).

To determine the sample size we focused on achieving adequate statistical power to detect a main effect size in a repeated-measures ANOVA. With an alpha level of 0.05, our analysis indicated that a sample size of 34 participants would be sufficient to detect a medium effect size (Cohen's f of 0.25, which is equivalent to $\eta_p^2 \approx 0.06$) with power of 0.8. Power calculations were performed using G*Power (Faul et al., 2007). While previous studies on peripheral recognition processes did not provide effect size estimates, we opted to follow Cohen's conventions suggested by GPower, despite recent criticisms of these thresholds (Correll et al., 2020).

Our primary focus for sample size calculation was on the ANOVA analysis, as it serves as the main statistical test for evaluating the extrafoveal recognition task, which is the novel paradigm in our study. Yet, another key aspect of our research is the correlation between extrafoveal recognition performance and search performance. Based on our prior hypothesis that better recognition ability will be associated with better search performance, we conducted a post-hoc power analysis based on our sample size and a one-tailed test. This analysis showed that 34 participants are sufficient to detect effect size of $|r| = 0.39$ with power of 0.8 and alpha of 0.05.

All participants were native Hebrew speakers with normal or corrected-to-normal vision. They took part in the experiment in return for course credits or payment (40 Shekels). Similar to our previous study (Lancry-Dayan, Gamer, et al., 2021) participants received an extra payment (10 Shekels) for adequate performance in the search task: starting the search on time, finding the familiar face quickly (under 1500 ms on average) and correctly recognizing which face was the familiar one.

Apparatus and Stimuli

The stimuli were displayed on a 24" monitor, with a 1920 × 1080 screen resolution and a 120-Hz refresh rate. Monocular gaze position was tracked at 1000 Hz with a tower-mounted EyeLink 1000+ system (SR Research Ltd., Mississauga, ON, Canada). The distance from the center of the screen to the participants' eyes amounted to 53 cm.

The face stimuli were adopted from Lancry-Dayan et al., (2021). This stimuli set includes 500 faces of 100 Israeli celebrities, 100 German celebrities and 300 unfamiliar individuals, collected via Google images. All images were cropped, resized and transformed into black and white. Amazon Mechanical Turk (M-Turk) questionnaires were used to make sure that (1) the familiar faces were not distinguishable from the unfamiliar faces in factors other than familiarity, (2) the familiarity status of the faces was correct (i.e., no familiar face was mistakenly tagged as unfamiliar) and (3) the Israeli and German familiar faces were not universally familiar. For further details on the processing of the stimuli and the M-Turk questionnaires, see the Supplemental Materials of Lancry-Dayan et al., (2021). Given the introduction of a question about to the occupation of celebrities in Experiment 2 (further details provided below), we aimed to maintain an equal distribution of celebrities across occupation categories. To achieve this balance, we added six images of Israeli celebrities to the dataset. These images were generated in the same manner as described above (but were not part of the M-Turk questionnaire).

Design

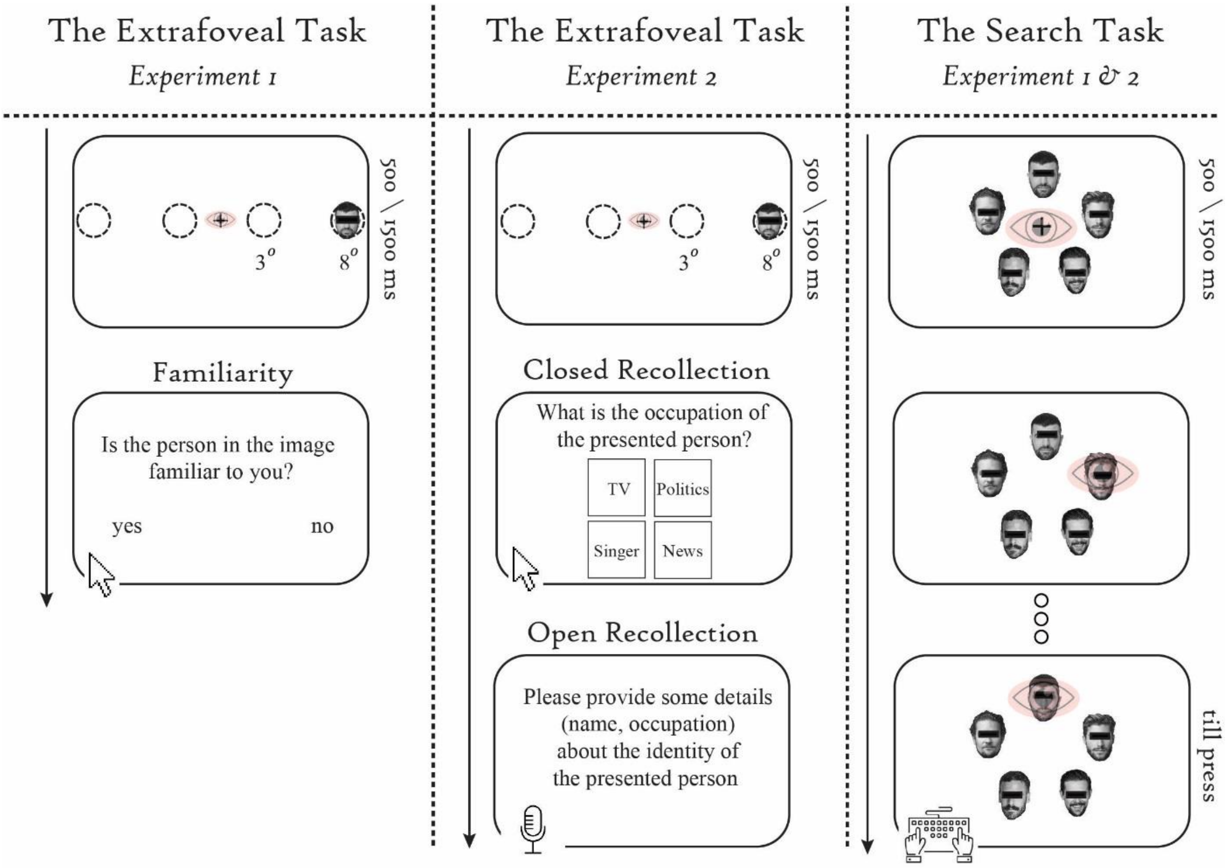
The Extrafoveal Recognition Task (Figure 1). Participants performed a visual recognition task in which they were asked to fixate a central cross and report with the mouse whether a peripherally presented face is familiar or not. If participants moved their eyes from the central cross, they saw a warning message informing them that they had moved their eyes. Since the goal of this part was to examine extrafoveal abilities, in the case participants moved their eyes from the central cross they were not asked to report the familiarity status of the face and the trial was excluded from further analysis.

Faces appeared either to the left or to the right of the central cross, at varying distances from the cross (3/8 degrees of visual angle; DVA) and for different durations (500/1500 ms). Since the distance and time variables included two levels each, counterbalancing between these variables required each face to appear four times. Thus, we created four blocks of 80 trials (half familiar and half unfamiliar), resulting in 320 trials overall. The order of blocks and the order of trials within blocks were randomized between participants. Beyond the counterbalancing of time and distance, each face was presented equally on both sides of the screen.

The Search Task (Figure 1). Participants completed a visual search task in which they were asked to look for a familiar face among five faces. The area of each face was scaled into a circle with a radius of 4 DVA. The center of each face was 9 DVA away from the center of the screen. The distance between the center of each pair of adjacent faces and each pair of non-adjacent faces was 10.6 and 17.1 DVA, respectively. After a drift correction procedure, an array of five faces with a central cross appeared. Participants were asked to fixate the cross and start the search only when it disappeared (after 500 or 1500 ms). In case they moved their eyes from the cross before it disappeared, an error sound was played and the trial continued as usual (although these trials were later excluded from the analysis). Participants were asked to find the target and press the space bar when they were looking at it. If participants pressed the space bar without fixating on the target, a message appeared on the screen informing them that they did not look at the target when they responded. Overall, this task included 100 trials, each presenting a different set of five faces. The location of the familiar face and the duration of central fixation cross were counterbalanced across trials.

Figure 1

Illustration of the Experimental Paradigm of the Two Experiments



Note. Each experiment included two tasks: the extrafoveal task (left and center) and the search task (right). In the extrafoveal task participants fixated on a central cross while a face was presented to the left or right of the cross. After the presentation of the face, participants reported whether the presented person was familiar to them (experiment 1) or provided details about his\her identity (experiment 2). In the search task participants were asked to fixate on a central cross, circled by an array of five faces (one of which is an Israeli celebrity). Once the cross disappeared, participants had to find the familiar face, look at it and press the space bar. Black bars were added to the faces in the figure for privacy reasons (participants saw the unmodified image).

In order to familiarize participants with the search task, a color block was carried out prior to the main task. In this block, the five stimuli were not faces, but four circles of one color and a single target circle of another color (colors switched across trials). This block included 10 trials that were repeated until participants completed more than 70% of them correctly (that is, moving gaze only once the cross had disappeared and responding when looking at the target). Following this training, participants also performed four training trials with faces, prior to the initiation of the main block. The faces in the training procedure did not appear in the main task.

Procedure

After signing the consent form, participants completed the extrafoveal task and the search task. At the beginning of each task, as well as in the middle of the search task, participants went through the standard 9-point calibration and validation procedures provided with the eye tracker (SR Research Ltd., Mississauga, Ontario, Canada). After a short training in each task, the experimenter left the room and the task begun. In both tasks, each trial was proceeded by a drift correction allowing a deviation of only 2 DVA (extrafoveal task) or 1 DVA (search task) between the predicted gaze position and the actual fixation point. Once participants completed the two tasks, they filled a questionnaire to validate their familiarity with the celebrities. In each question participants saw a single face and were asked to report whether it is familiar to them or not. If their answer was yes, they were asked to provide further details about the person in the image (e.g., name, occupation, etc.). The questionnaire included only images of familiar faces.

Exclusion criteria

In the extrafoveal task trials were excluded when at least one of the following conditions was met: (1) participants moved their gaze from the central cross and (2) the trial depicted a face that was not recognized in the final debriefing. Trials in the search task were excluded when meeting at least one of the following conditions: (1) participants moved their gaze from the central cross before it disappeared, (2) participants pressed the space bar without looking at the familiar face and (3) bad quality of eye tracking (more than 25% of the eye samples were missing). If more than 50% of participant's trials were disqualified in one of the tasks, the data of that participant was removed from further analysis. Based on these criteria, the average of excluded trials per participant was 17.62% and 27.58% for the extrafoveal and search tasks, respectively. Due to the relatively high rate of exclusions we also report in the Supplementary Materials the results for the full sample (all participants and all trials). As can be seen in this analysis, the results pattern is overall robust to exclusions.

Transparency and openness

We followed JARS (Kazak, 2018) guidelines for qualitative research (Appelbaum et al., 2018) and reported above how we determined the sample size, all data exclusions, all manipulations and all measures in the study. All data and analysis codes are available at https://osf.io/86ky4/?view_only=bbe8698ea4b64c83bf49c8009454936b. Other research materials will be provided upon request. Data were analyzed using R, version 4.2.1 (R Core Team, 2022) and the packages: (1) dplyr, version 1.1.1 (Wickham et al., 2022), (2) reshape2, version 1.4.4 (Wickham, 2007), (3) lsr, version 0.5.2 (Navarro, 2013), (4) psycho, version 0.6. (Makowski, 2018), (5) DescTools version 0.99.46 (Signorell et al., 2019), (6) effectsize, version 0.7.0.5 (Ben-Shachar et al., 2020), (7) cocor, version 1.1-4 (Diedenhofen & Musch, 2015), (8) confitr, version 0.2.0 (Mayer, 2023) and (9) ggplot2 version 3.4.2 (Wickham, 2016).

This study's design, hypotheses and analysis plan were preregistered: https://osf.io/86ky4/registrations?view_only=bbe8698ea4b64c83bf49c8009454936b. Data was collected during 2022.

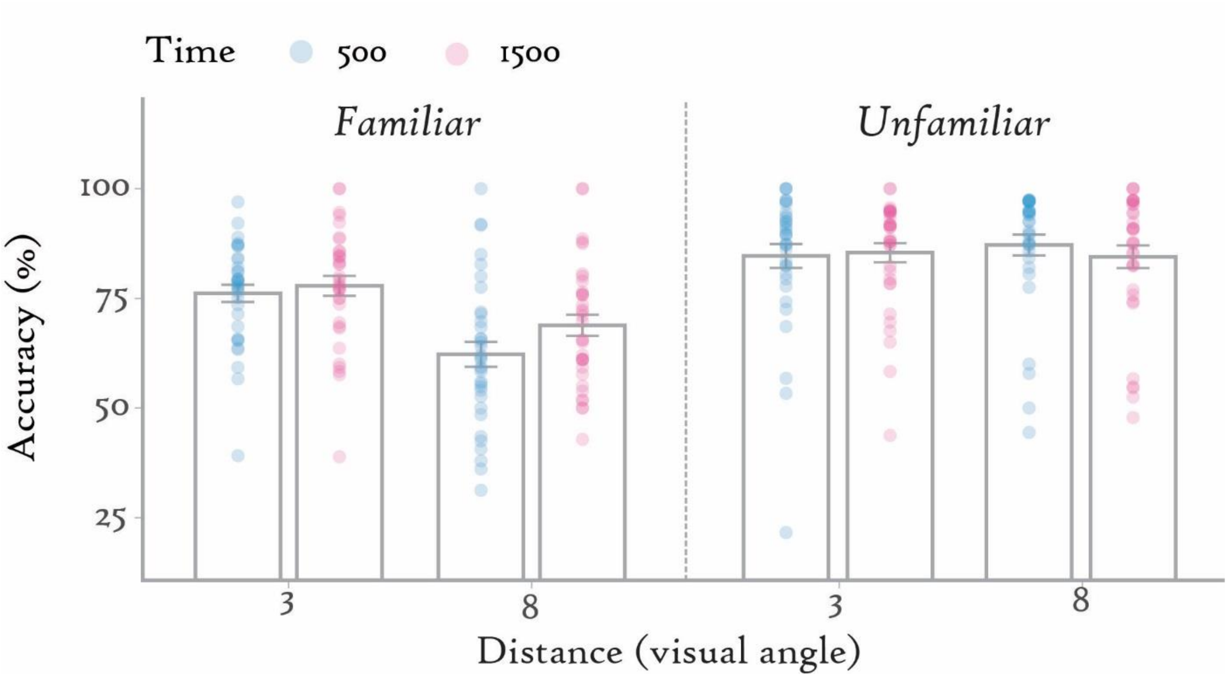
Results

Extrafoveal Familiarity Task

When participants were exposed to a familiar face through extrafoveal vision, the ability to classify this face as familiar or unfamiliar was higher than the 50% chance level (mean accuracy: 78.65%, $t(33) = 22.693, p < .001, d = 3.89, 95\%\ CI = [2.89, 4.88]$). To further characterize this ability we conducted a repeated measure ANOVA with three factors: face-familiarity (familiar\unfamiliar), exposure duration (500\1500 ms) and distance (3\8 DVAs). Performance was significantly better for unfamiliar faces ($F(1,33) = 15.76, p < .001, \eta_p^2 = .32, 95\%\ CI = [0.08, 0.52]$), closer faces ($F(1,33) = 36.79, p < .001, \eta_p^2 = .53, 95\%\ CI = [0.3, 0.67]$) and faces presented for a longer duration ($F(1,33) = 4.46, p = .042, \eta_p^2 = .12, 95\%\ CI = [0, 0.33]$). In addition, the results indicated that the influence of distance and exposure duration on accuracy is different between familiar and unfamiliar faces, as illustrated by a significant interaction between all factors ($F(1,33) = 8.01, p = .007, \eta_p^2 = .2, 95\%\ CI = [0.01, 0.04]$) as well as significant interactions between face-familiarity and distance ($F(1,33) = 48.55, p < .001, \eta_p^2 = .6, 95\%\ CI = [0.35, 0.72]$) and between face-familiarity and exposure duration ($F(1,33) = 8.18, p = .007, \eta_p^2 = .2, 95\%\ CI = [0.02,\ 0.41]$).

Figure 2.

Results of the Extrafoveal Task in Experiment 1



Note. Mean accuracy rates are depicted separately for familiar (left) and unfamiliar faces (right), exposure duration (500\1500 ms) and distance (3\8) conditions. Each dot represents the accuracy rate of one participant in one of the conditions. Error bars indicate ± 1 standard error.

To further explore the nature of these interactions we conducted for each level of face-familiarity (familiar\unfamiliar) a separate repeated-measure ANOVA with two factors of exposure duration (500\1500 ms) and distance (3\8). The analysis of unfamiliar faces did not reveal an effect of distance ($F(1,33) = 0.76, p = .391, \eta_p^2 = .02, 95\%\ CI = [0, 0.19]$) or exposure duration ($F(1,33) = 0.76, p = .389, \eta_p^2 = .02, 95\%\ CI = [0, 0.19]$). Reporting a familiar face as such however, was significantly better for closer faces ($F(1,33) = 57.71, p < .001, \eta_p^2 = .64, 95\%\ CI = [0.41, 0.75]$) and for those exposed for longer durations ($F(1,33) = 11.36, p = .002, \eta_p^2 = .26, 95\%\ CI = [0.04, 0.47]$). The interactions between distance and exposure durations did not reach a significant level in both analyses of familiar and unfamiliar faces ($F < 4.11, p > 0.051$). Figure 2 shows these results.

The effect of face familiarity demonstrated that participants were more accurate at identifying unfamiliar faces than familiar ones. This pattern of results suggests that participants tended to reject faces as familiar, regardless of their real familiarity status. To dive deeper into this tendency we adopted the bias and d-prime measure from the signal detection theory (Green & Swets, 1966; Macmillan & Creelman, 2004). The bias reflects the tendency of participants to say 'no' or 'yes'. A score of 1.0 reflects unbiased behavior; as the bias towards 'no' responses increases the score goes beyond 1.0 on an open-ended scale (Makowski, 2018; Pallier, 2002). While there was indeed a bias to report faces as unfamiliar (mean bias 2.22, $t(33) = 4.65, p < .001, d = 0.8, 95\%\ CI = [0.41, 1.18]$), this bias was not affected by the distance of the presented face ($F(1,33) = 0.69, p = .409, \eta_p^2 = .02, 95\%\ CI = [0, 0.18]$), its exposure duration ($F(1,33) = 1.07, p = .309, \eta_p^2 = .03, 95\%\ CI = [0, 0\ .2]$) or the interaction between these two factors ($F(1,33) = 0.98, p = .328, \eta_p^2 = .03, 95\%\ CI = [0, 0.2]$). The sensitivity to recognize a familiar face, however, was higher at closer distances ($F(1,33) = 18.14, p < .001, \eta_p^2 = .35, 95\%\ CI = [0.1, 0.54]$) but not significantly affected by either the exposure duration to the face ($F(1,33) = 1.56, p = .221, \eta_p^2 = .05, 95\%\ CI = [0, 0.23]$) nor by the interaction between distance and exposure duration ($F(1,33) = 0.01, p = .943, \eta_p^2 = .0002, 95\%\ CI = [0, 0.06]$).

Search Task

To evaluate the proficiency of search guidance we extracted the scanning order of the faces array in each trial. Thus, in each trial we generated the ordinal number in which the familiar face was initially fixated upon. Then we averaged across trials the ordinal number of all familiar faces. Importantly, under the null hypothesis that there is no guidance of search the expected value of the ordinal number should be three (i.e., the expected value of a discrete uniform distribution with a probability of 0.2 for each possibility). A one-sample t-test showed that the mean ordinal number of the familiar face was significantly lower than the expected value under the null hypothesis ($t(33) = -8.27, p < .001, d = 1.42, 95\%\ CI = [0.93, 1.89]$), with 32 participants (out of 34) having a mean ordinal number lower than three (see figure 3).

A comparison between the two exposure durations of the search array (500 ms and 1500 ms), showed that the mean ordinal number was lower when participants were exposed to the array of faces for a longer duration ($t(33) = -8.45, p = .02, d = 0.55, 95\%\ CI = [0.06, 1.03]$). Yet, guidance of search was evident also under the short exposure condition (i.e., the mean ordinal number was lower than three, $t(33) = -5.49, p < .001, d = 0.94, 95\%\ CI = [0.53, 1.34]$). Thus, these results provide another indication that search can be guided towards a familiar target face even though its identity is not known in advance.

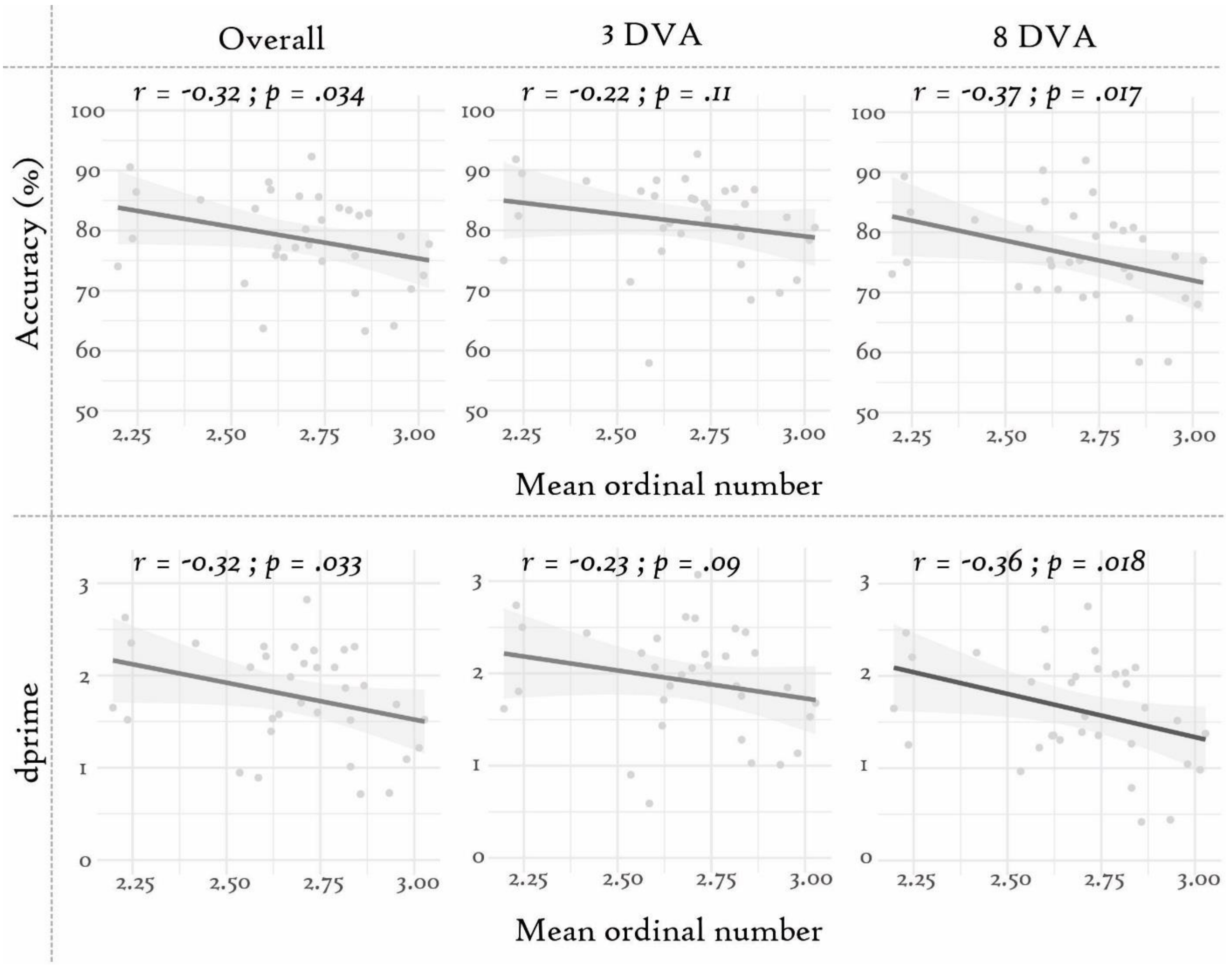
Relationship Between Extrafoveal Recognition and Search

To examine whether search performance can be predicted by extrafoveal processing abilities we correlated individuals' mean ordinal number of the familiar face in the search task with individuals' performance in the extrafoveal processing task (figure 3). Since a lower mean ordinal number in the search task indicates a more efficient search, we expected that participants with better extrafoveal abilities would have a lower mean ordinal number. Thus, as described in the pre-registration, a link between search performance and extrafoveal processing would be reflected in a significant *negative* correlation. This a-priori hypothesis enables us to use a one-tailed test to increase the statistical power. As expected, the Pearson correlation between accuracy and search performance was negative and significant ($r = -0.32, t(32) = -1.89, p = .034, 95\%\ CI = [-1, -0.03]$). Due to the bias to respond "unfamiliar" in the extrafoveal task, we also looked at the correlations with the signal detection measures. We found a negative and significant correlation with sensitivity ($r =$

$-0.32, t(32) = -1.91, p = .033, 95\%\ CI = [-1, -0.035]$) but not with bias ($r = 0.09, t(32) = 0.5, p = .31, 95\%\ CI = [-1, 0.37]$).

Figure 3.

Correlations Between Participants' Search Performance and Extrafoveal Familiarity Processing in Experiment 1



Note. Each dot in the scatter plots reflects the participant's mean ordinal number in the search task (x axis) and the mean accuracy (top) or sensitivity measure (bottom) in the extrafoveal task (y axis). Scatter plots are displayed across distance conditions (left) or separately for the 3 DVA (middle) and 8 DVA (right) conditions. The solid line is the regression line and the grey shadow is its confidence interval.

Since the influence of extrafoveal processing on search might be more pronounced in larger distances from the fovea, we also examined the correlation between the mean ordinal number and overall accuracy in the extrafoval task separately for the two distances of 3 and 8

DVA. Along with this rationale, we found that the correlations were significant for the larger distance condition ($r = -0.37$, $t(32) = -2.22, p = .017, 95\%\ CI = [-1, -0.088]$) but not for the smaller distance condition ($r = -0.22$, $t(32) = -1.27, p = .11, 95\%\ CI = [-1, 0.07]$). A similar pattern was observed also for correlations with sensitivity (8 DVA: $= -0.36$, $t(32) = -2.19, p = .018, 95\%\ CI = [-1, -0.081]$; 3 DVA: $r = -0.23$, $t(32) = -1.36, p = .09, 95\%\ CI = [-1, 0.057]$). However, it should be noted that the difference between the correlations of the larger distance and the smaller distance was not significant in a Fisher-Z test ($p > .53$).

To ensure that these correlations are not derived by any outliers, we report in the Supplementary Materials a Spearman correlation analysis (which is less sensitive to outliers) and the Pearson correlations after the removal of outliers (observations that are more than 2 standard deviations above or below the mean). In both analyses, we observe a similar pattern of correlations as discussed above. Finally, since both tasks might be influenced by the general ability of a participant to recognize celebrities (i.e., if someone is highly familiar with famous people, he\she might do well on both tasks), we also discuss in the Supplementary Materials the correlations between the performance of each task and the scores in the debriefing questionnaire. Interestingly, the debriefing scores were only correlated with the extrafoveal task performance indicting that the correlation between the tasks is not a by-product of how celebrity-minded the participants are.

Experiment 2 – Recollection

Method

Transparency and openness, apparatus, stimuli and procedure were identical to experiment 1 and will not be further described.

Participants

47 participants were recruited, 7 participants were removed from further analysis as more than 50% trials were disqualified (due to the exclusion criteria elaborated below) and 5 participants due to technical issues. Thus, the final sample included 35 participants (8 men; $M = 23.08\ years$). Sample size considerations were identical to experiment 1, resulting in a pre-registered sample size of 34 participants. Inclusion criteria and payment\course credits were identical to the other experiments.

Design

The Extrafoveal Recollection Task (Figure 1). Participants fixated on a central cross while a face appeared to the left or to the right at varying distances (3\8 DVA) and for different durations (500\1500 ms). Once the face disappeared, participants had to recall information about the presented face in two ways: (1) a closed forced choice recollection question – participants were asked to choose an occupation out of four possibilities (politics, TV and entertainment, singers and news anchors), (2) an open recall question – participants were asked to report the name of the person in the image or to provide another identifying information. If participants moved their eyes from the central cross, a warning message appeared, informing them that they had moved their eyes. Since the goal of this part was to examine extrafoveal abilities, in the case participants moved their eyes they were not asked to recall the identity of the presented person and the trial was excluded from further analysis.

This task included 40 familiar faces (the same as experiment 1), 10 for each occupation category in the closed recollection question. To counterbalance over time and distance, as in experiment 1, each face had to be presented four times. Thus, the task included four blocks of 40 trials each, resulting in an overall of 160 trials. The order of blocks and the order of trials within blocks were randomized between participants.

The Search Task (Figure 1). Identical to experiment 1.

Exclusion Criteria

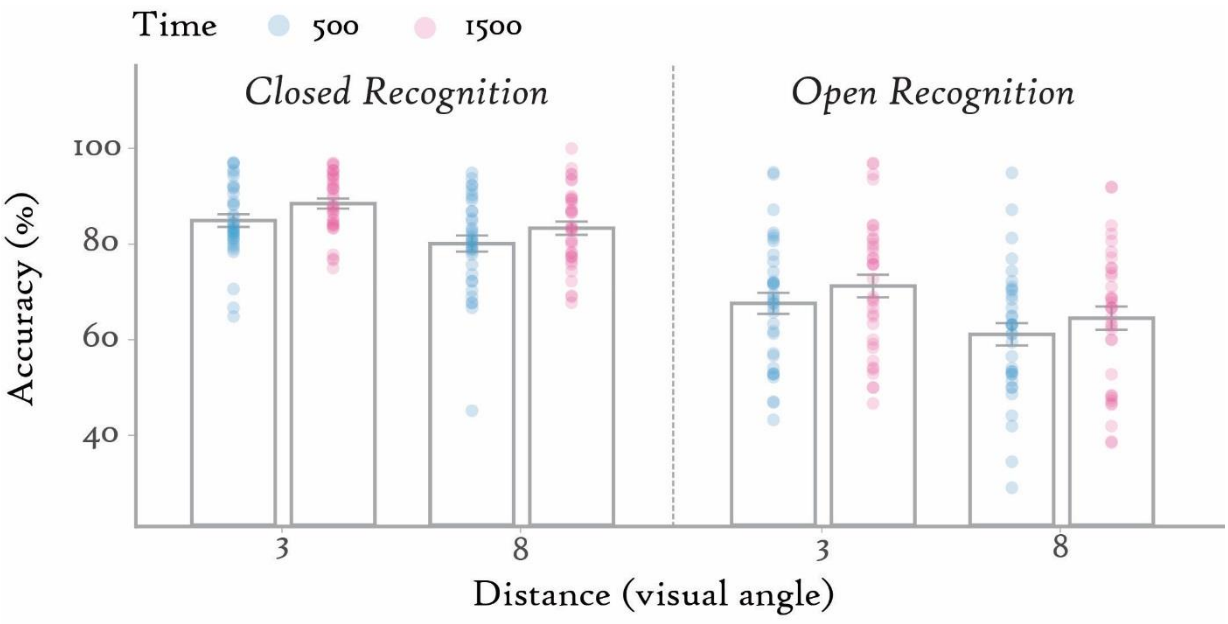
Identical to experiment 1. Based on these criteria, 18.46% and 23.2% of the trials were excluded, on average, from the extrafoveal and search tasks, respectively. Yet, the following results were robust to exclusions (i.e., a similar pattern was observed when analyzing the dataset without removing participants or trials). For further details see the Supplementary Materials.

Results

Extrafoveal Recollection Task. Two aspects of recollection were examined in the current experiment. The first aspect referred to the ability to report the occupation of the presented face out of four possibilities (closed recollection). Repeated-measure ANOVA with two factors: distance (3\8 DVA) and exposure durations (500\1500 ms) demonstrated that closed recollection was better for closer faces ($F(1{,}34) = 27.07, p < .001, \eta_p^2 = .44, 95\%\ CI = [0.19, 0.61]$) and faces that were presented for longer durations ($F(1{,}34) = 14.62, p < .001, \eta_p^2 = .3, 95\%\ CI = [0.07, 0.5]$). There was no significant interaction between the two factors ($F(1{,}34) = 0.03, p = .858, \eta_p^2 < 0.001, 95\%\ CI = [0, 0.09]$). The second aspect refers to the ability to freely retrieve information. Since the occupation of the presented person was primed in the closed question, a correct answer to the open question was coded only if the participant reported the correct name of the presented person. Repeated-measure ANOVA with the same two factors of distance (3\8 DVA) and exposure durations (500\1500 ms) showed the same pattern of significant effects of distance ($F(1{,}34) = 37.35, p < .001, \eta_p^2 = .52, 95\%\ CI = [0.27, 0.67]$) and exposure duration ($F(1{,}34) = 17.56, p < .001, \eta_p^2 = .34, 95\%\ CI = [0.1, 0.53]$) without a significant interaction effect ($F(1,34) = 0.018, p = .895, \eta_p^2 = .0005, 95\%\ CI = [0, 0.07]$). These results are presented in figure 4.

Figure 4.

Results of the Extrafoveal Task in Experiment 2



Note. Mean accuracy rates are depicted separately for closed (left) and open (right) recollection questions, exposure duration (500\1500 ms) and distance (3/8) conditions. Each dot represents the accuracy rates of one participant in one of the conditions. Error bars indicate ± 1 standard error.

Search Task. Replicating the findings of the previous experiment, a one-sample t-test showed that the mean ordinal number of the familiar face was lower than 3 ($t(34) = -10.45, p < .001, d = 1.77, 95\%\ CI = [1.23, 2.29]$), with 34 (out of 35) of the participants showing this trend. Guidance of search was more prominent in the longer exposure duration ($t(34) = -3.94, p < .001, d = 0.92, 95\%\ CI = [0.43, 1.41]$), but was nevertheless evident also when analyzing only trials in the 500 ms condition ($t(34) = -6.19, p < .001, d = 1.05, 95\%\ CI = [0.63, 1.45]$).

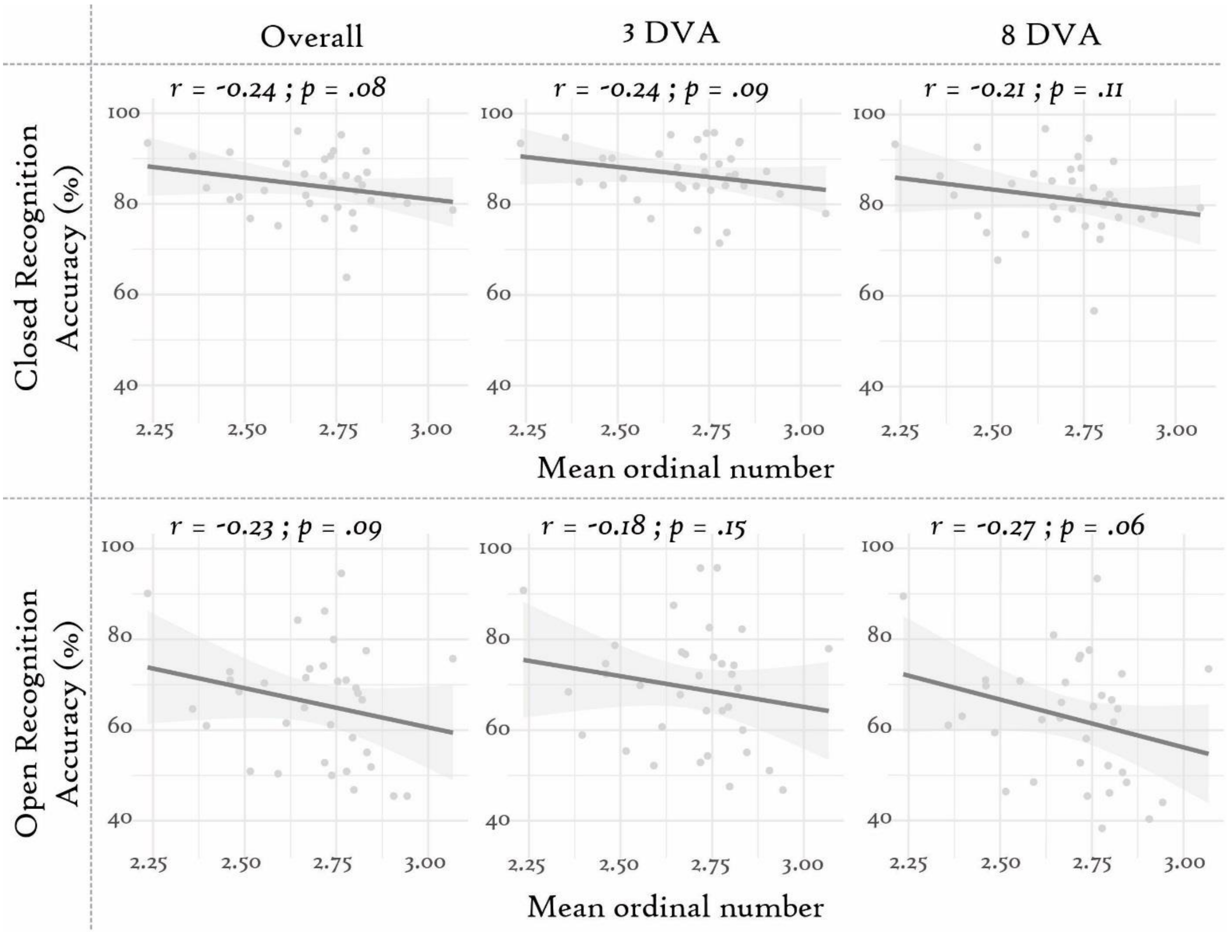
Relationship Between Extrafoveal Recognition and Search. To examine whether the ability to retrieve information about the presented person through extrafoveal vision is related to search performance, we correlated the two accuracy scores in the extrafoveal task with the mean ordinal number of the search task (figure 5). Although the correlations were in the expected direction (i.e., better performance in the extrafoveal task was related to faster detection of the target in the search task), they were insignificant in a one-tailed t-test in the closed ($r = -0.24$, $t(33) = -1.44, p = .08, 95\%\ CI = [-1, 0.04]$) and the open ($r = -0.23$, $t(33) = -1.38, p = .09, 95\%\ CI = [-1, 0.05]$) recollection scores. Note, however, that although the correlations in the first experiment were significant a Fisher's Z-test did not show that the correlations in experiment 1 were significantly stronger than the correlations in experiment 2 ($p > .81$).

As in experiment 1, we examined the correlations separately for the two distances in the extrafoveal task. In this analysis as well, the correlations were not significant for either the closed recollection accuracy (8 DVA: $r = -0.21$, $t(33) = -1.26, p = .11, 95\%\ CI = [-1, 0.07]$; 3 DVA: $r = -0.24$, $t(33) = -1.42, p = .09, 95\%\ CI = [-1, 0.05]$) nor for the open recollection accuracy (8 DVA: $r = -0.27$, $t(33) = -1.63, p = .06, 95\%\ CI = [-1, 0.01]$; 3 DVA: $r = -0.18$, $t(33) = -1.06, p = .15, 95\%\ CI = [-1, 0.11]$).

Finally, we report in the Supplementary Materials the results of the correlation analysis when using methods to examine the impact of outliers (Spearman correlations and removal of scores that have a z-score larger than 2). This analysis yielded a similar pattern of results. Additionally, we examined also in this experiment the correlations between the performances in each task and the final score in the debriefing questionnaire. As elaborated in the Supplementary Materials, there was a significant correlation only with the extrafoveal task, excluding the possibility that the correlation between the tasks is a by-product of how celebrity-minded the participant is.

Figure 5.

Correlations between search performance and extrafoveal recollection in experiment 2



Note. Each dot in the scatter plots reflects one participant's mean ordinal number in the search task (x axis) and the mean accuracy in the closed (top) or open (bottom) recollection questions in the extrafoveal task (y axis). Scatter plots are presented across conditions of distance (left) or separately for the 3 DVA (middle) and 8 DVA (right) conditions. The solid line is the regression line and the grey shadow is the confidence interval.

General Discussion

Even though visual search may seem like a simple task, it has already been acknowledged as one of the cognitive processes that can contribute to the understanding of attentional mechanisms (Wolfe & Horowitz, 2004). Specifically, figuring out how attentional resources are deployed during visual search can shed light on how the cognitive system deals with its limited processing capacity. Throughout the years the dominant view in the field was that attentional resources are deployed to probable locations of the target based on a comparison between the visual input and an active template of the target that resides in working memory (Wolfe, 2020). The goal of the current study was to suggest an alternative guiding mechanism that is solely based on extrafoveal perception of familiar items. Such a mechanism could explain recent findings that show that efficient search can be conducted even in the absence of an active search template (Lancry-Dayan et al., 2021).

The current study advocate for the feasibility of such a mechanism in two main ways. First, it demonstrates that individuals can both determine whether a peripherally presented face is familiar to them and recollect additional information about their identity. Consequently, we extend beyond previous findings (Harry et al., 2012; McKone, 2004; Reddy et al., 2006) by illustrating that the peripheral signal is adequate for a comprehensive identification of the presented person. Second, not only can people execute recognition processes through extrafoveal vision, but this ability (especially the ability to identify whether someone is familiar or not) is predictive of search performance.

Understanding which aspects of an item can be processed through extrafoveal vision extends beyond a mere exploration of the visual system's capabilities. It contributes to the ongoing debate about the factors that can govern the deployment of overt attention in visual processing. Two primary approaches characterize this debate (Hayes & Henderson, 2019): the image guidance theory (attention is guided by low-level features of the visual input; Itti & Koch, 2001) and the cognitive guidance theory (attention is guided by prior semantic knowledge about the structure of the visual input; Henderson, 2007). The observed relationship between extrafoveal recognition processes and search efficacy suggests the existence of an intermediate "guidance route”. This route is not purely top-down (as in the cognitive approach) or bottom-up (as in the image approach). Instead, it proposes that certain features of the image can guide attention not because of their visual salience, but due to their connection to high-level factors like long-term memory. Whether this memory-guided attention relies on a top-down, abstract search goal (e.g., looking for something familiar) or is a general phenomenon of attention capture by familiar objects goes beyond the scope of this paper.

It should be mention, however, that previous studies suggest the involvement of at least some top-down control in the process of memory-guided attention. The deployment of visual attention toward familiar items appears to be influenced by the relevance of these items to the current goals of the observer. During neutral tasks (e.g., free viewing) or tasks related to familiar objects (e.g., searching for a familiar object), there are indications that attention is drawn towards familiar items (Lancry-Dayan, Gamer, et al., 2021; Nahari et al., 2019). Yet, when the task goals are unrelated to familiarity (e.g., searching the person who pronounce the vowel "o"), there is no guidance of attention towards the familiar object (Devue et al., 2009; Qian et al., 2015). Finally, in certain cases (e.g., encoding of items), current goals may direct attention away from familiar stimuli (Lancry-Dayan et al., 2018; Lancry-Dayan, Nahari, et al., 2021). Hence, it appears that the cognitive system exhibits flexibility in utilizing familiarity signals to guide attention; this route is employed only when it doesn't interfere with the ongoing task performance.

The idea that representations in long-term memory can guide attention also expands the perspective on which individual characteristics are relevant to search performance. Since previous models of visual search have claimed that the search template is maintained (at least initially) in visual working-memory (Carlisle et al., 2011; Woodman & Arita, 2011), researchers have examined how individual differences in working memory capacity are related to search performance. Specifically, it was hypothesized that participants with a higher working-memory capacity would also have a better performance in the search task. This line of research elicited a mixed pattern of results, with some studies showing a significant positive correlation between visual working-memory capacity and visual search performance (Luria & Vogel, 2011; Shen et al., 2014; Williams & Drew, 2018), while other studies showed this relation under some conditions only (Couperus et al., 2021; Poole & Kane, 2009; Sobel et al., 2007) or failed to demonstrate such a relation at all (Kane et al., 2006).

The current framework suggests that this indecisive pattern of results might indicate that other individual differences are relevant to search performance. Specifically, here we demonstrate that individual differences in extrafoveal processing abilities are predictive of search performance. To the best of our knowledge, a link between individual differences in extrafoveal abilities and search performance was demonstrated only once before (Veríssimo et al., 2021). Our findings generalize this previous work on visual crowding by showing that also individual differences in high-level factors, such as recognition, can explain search performance. Together with the previous study, the current results highlight the potential of extrafoveal processing capacities to explain individual differences in a variety of searches, with or without a guiding template. Thus, using extrafoveal processing capabilities as a core principle of search can release theories from the need to rely on the assumption of a search template.

In a sense, shifting the focus from a search template to extrafoveal processing can unlock the potential of visual search to elucidate visual attention in a broader context beyond the search domain. Notably, while search is a prevalent task, individuals are not exclusively engaged in it during their daily activities. More often, people interact with their visual environment during social interactions, navigation, and various other activities. In these cases, there is no explicit, active "template" signaling to the cognitive system what is currently relevant. Instead, an efficient mechanism would be to draw on prior experience to continually monitor which aspects of the surroundings are relevant and attend to them once detected. The cocktail party effect (Moray, 1959), where people can detect their name even in an unattended channel, is a well-known example of such a mechanism in the auditory domain. In the visual domain, the bottleneck of such a mechanism would be the capacity to process visual information through extrafoveal vision. Once information can be processed and detected as relevant, it can be used to guide attention.

Importantly, the concept of attentional guidance in this context should be clarified. In the early days of attention research, theories referred to a limited set of features (e.g., color, orientation, etc.) that can be detected ‘preattentively’ and capture attention (Treisman & Gelade, 1980). In this cohort of studies, guidance is referred to as an automatic process that, for example, is not effected by the set size of distractors (i.e., the pop out effect; Treisman, 1986). This is, however, not always how guidance of search is manifested when a target template is available. In particular, studies employing complex search templates, such as real objects, indicate that although the search template contributes to an efficient search, reaction times for this search still increase with the set size (Vickery et al., 2005; Yang & Zelinsky, 2009). Therefore, in the context of a search template, guidance does not necessarily involve the automatic direction of attention to the target. Instead, it refers to information that can enhance the efficiency of the search process.

The current study was designed to examine the latter type of guidance, where representations in long-term memory contribute to more efficient search. However, akin to complex search templates, such guidance may not happen instantaneously. Specifically, since recognition processes of faces take time even when the face is presented in the fovea (Barragan-Jason et al., 2015; Caharel et al., 2014), it is reasonable to anticipate that memory-guided effects would not manifest immediately with the onset of stimuli. Thus, we allowed observers first to be exposed to extrafoveal information before initiating their search, simulating a variety of real-life situations where extrafoveal information is constantly available. In this preliminary exploration of the link between search efficacy and extrafoveal vision, we utilized two fixed exposure durations. Future studies could adopt shorter durations, potentially tailored to individual differences, to more precisely refine the timescale of attentional guidance by familiarity.

The chosen exposure durations to the search array might have also masked possible differences between familiarity and recollection processes. Notably, although only the correlation between search performance and familiarity was significant, there is no indication that this correlation is significantly stronger than the correlation of search performance with recollection. While this can be a genuine finding, it can also be related to the relatively long exposure durations. Since familiarity processes are considered to be more rapid (Yonelinas, 2002), their relatively superiority in guidance of attention might be revealed when there is less time to process the array. Hence, shortening the exposure duration to the search array may be a useful pathway to explore the relationship between familiarity and recollection processes. This relationship has been one of the core debates of memory research (Yonelinas, 2002), revolving around the question whether familiarity and recollection are two distinctive processes (dual-process theories) or whether they are two extremes of one continuum that differ only by the strength of memory (single-process theories). A stronger correlation with only one of the processes may support the dual-process theory, while a lack of such a difference may favor the single-process theory. The goal of this study was to characterize people's ability to execute recognition processes through extrafoveal vision, to examine how it changes in time and space and to link it to search performance. As such, our main goal was to provide a proof of concept that such ability does exist and can be predictive of search guidance. Future studies should accurate this ability and better characterize how it differs between individuals. To that purpose, the extrafoveal task should include a larger variation in display durations and distances. This will enable researchers to determine for each participant a recognition threshold and tailor his\her ability. Having a more accurate characterization of individual differences can contribute to a better understanding of differences in search performance and predict who will be a better searcher. Since search is a fundamental part of some occupations, even with life-saving implications (e.g., security guides, radiologists and lifeguards), revealing what leads to individual differences in this ability can be of great value.

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