Exposure in central vision facilitates view-invariant face recognition in the periphery

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The present study investigated the extent to which a face presented in the visual periphery is processed and whether such processing can be influenced by a recent encounter in central vision. To probe face processing, a series of studies was conducted in which participants classified the sex and identity of faces presented in central and peripheral vision. The results showed that when target faces had not been previously viewed in central vision, recognition in peripheral vision was limited whereas sex categorization was not. When faces were previously viewed in central vision, recognition in peripheral vision improved even with the pose, hairstyle, and lighting conditions of these faces changed. These results are discussed with regard to possible mechanisms unpinning this exposure effect.

Keywords: face perception, peripheral vision, recent exposure, identification, sex categorization


Introduction

Face processing in peripheral vision is limited compared to central vision (Hasson, Levy, Behrmann, Hendler, & Malach, 2002; Levy, Hasson, Avidan, Hendler, & Malach, 2001; Loomis, Kelly, Pusch, Bailenson, & Beall, 2008). This is because in peripheral vision spatial acuity is reduced (Anstis, 1974) and there is increased crowding between features (Pelli & Tillman, 2008). These limitations should have a particularly disruptive effect on the process of identifying faces because this process relies on the registration of subtle differences in facial features and/or the configuration of such features. Indeed, it has been demonstrated that identification judgments are impaired in peripheral vision and that this is partly due to reduced spatial acuity (Melmoth, Kukkonen, Rovamo, & Makela, 2000). Furthermore, Martelli, Majaj, and Pelli (2005) have argued that the features of faces in the periphery crowd themselves and so make that face unrecognizable. Based on this, Pelli and Tillman (2008) suggest that faces cannot be recognized unless viewed in (or close to) central vision.

In contrast with the above, the results of a series of recent studies investigating the role of attention in peripheral face processing appear to indicate that detailed face processing is possible from peripherally presented inputs. What has been shown is that both the sex (Bindemann, Burton, & Jenkins, 2005; Finkbeiner & Palermo, 2009; Reddy, Wilken, & Koch, 2004) and identity (Bindemann et al., 2005; McKone, 2004; Reddy, Reddy, & Koch, 2006) of faces can be extensively processed from peripheral vision. For example, McKone (2004) and Reddy et al. (2006) reported good face recognition performance (>80% correct) for faces of less than 5° vertical visual angle at 8–10° eccentricity. Evidence of identity processing in peripheral vision is particularly surprising as it suggests that such processing does not rely on the perception of fine details (whereas the processing of the sex of a face may rely on coarser and/or more global information and thus should not be as adversely affected by reduced spatial acuity in peripheral vision; O’Toole, Abdi, Deffenbacher, & Valentin, 1993; Schyns, Bonnar, & Gosselin, 2002).

The current study aimed to determine what might account for the discrepancy between these two sets of studies. Based on a suggestion by Martelli et al. (2005), we examined whether the processing of faces presented in the periphery could be enhanced by stimulus familiarity. Martelli et al. examined face processing in peripheral vision and showed that crowding had less impact for faces presented at a familiar orientation (upright) than for an unfamiliar orientation (upside down). Martelli et al. interpreted this finding as showing that familiarity with the stimulus lessens the deleterious effects associated with crowding. Rather than use face orientation as a means to vary face familiarity (as this manipulation may also alter

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Experiment 1

Experiment 1 examined sex and identification (fame) judgments in central and peripheral vision to investigate the extent to which these judgments were impaired in peripheral vision (when faces presented in the periphery had never appeared in central vision). A fame judgment task was chosen to index face identification because this task has been shown to involve processing the identity of targets (Ellis, Young, & Flude, 1990). A sex classification task was employed as a comparison measure to the fame judgment task in order to gauge whether the peripheral stimuli afforded some aspects of face processing to be carried out (i.e., in a task that had the same response characteristics as the fame judgment task). That is, for the reasons outlined above (i.e., sex categorization can be made from low spatial frequency information), relatively better performance is expected on the sex classification compared to the fame judgment task and such a finding will confirm that the experiment was sufficiently sensitive to pick up this difference in processing (note that faces were presented at a similar eccentricity and size as previous studies that showed processing of identity and sex information in peripheral vision; Bindemann et al., 2005; Finkbeiner & Palermo, 2009; Lavie, Ro, & Russell, 2003).

Methods

Participants

Sixteen undergraduate students ($M_{\text{age}} = 21$ years, 12 females) participated in exchange for course credit. All reported having normal or corrected-to-normal visual acuity.

Materials

Forty-two images of famous singers or actors and forty-two images of amateur models were selected from the internet. Amateur models were chosen to ensure comparability in attractiveness and age range with the famous faces to ensure that these features could not be used in the fame judgment task. Half of the famous and amateur model faces were female and half male. Care was taken to avoid well-known, iconic images of famous individuals to ensure that the famous stimuli were not associated with any preexisting detailed memories that might assist recognition in peripheral vision.

Images were cropped to include only the face region and the hairline (Figure 1). The luminance and contrast of each image was equalized by setting the distribution of pixel intensities of the face region to a mean of 127 and a standard deviation of 50. Subsequently, the luminance and contrast of the hair was altered until there were no subjective differences between the face and hair. Image size was set so that the stimuli subtended 5° visual angle vertically from a distance of 67 cm.

Procedure

Participants were seated in a dimly lit booth. Head position was stabilized with a chin rest 67 cm from the monitor that had a refresh rate of 85 Hz. Each participant
completed two tasks: a sex categorization task and a fame judgment task. In the sex categorization task, participants decided whether faces were female or male and, in the fame judgment task, whether faces were famous or non-famous. The same stimuli appeared as targets in each task. In each trial, a face appeared in one of three locations: in the center of the screen, 5° to the left of center, or 5° to the right of center (Figure 1). Order of task completion and the location of each face were counterbalanced across participants. Each face appeared in the same location across tasks, to ensure that centrally presented faces did not later appear in peripheral vision.

Each task consisted of 72 trials presented in random order. Trials were evenly divided between the target types (female/male; famous/non-famous), resulting in eighteen trials for each of the four target types. Each of the four target types appeared equally in the three locations (center, left, and right). This meant that, for each task, the three presentation conditions contained 12 trials of each target type relevant to that task. Faces were preceded by a spatial cue to indicate the target location on each trial (Figure 1). Participants responded by pressing either the right (female/famous) or left (male/non-famous) control key on the keyboard. Trials appeared in four blocks of eighteen trials. Before each task, participants were familiarized with the eye tracking procedure and the task instructions with 12 practice trials.

Eye position was monitored with an Eyelink II, sampling at 500 Hz. Trials were considered invalid whenever a participant’s gaze drifted more than 1.5° from the fixation cross during presentation of the target. Calibration was performed at the start of each block and was accepted when at least one eye was tracked with an average error of less than 0.5°. The eye tracked with the lowest average error was the one monitored for that block. Drift correction was performed before each trial to correct for minor changes in headband position.

Results

Three out of the 16 participants were excluded because they obtained less than 80% accuracy on the fame judgment task in the central location. Another participant was excluded because more than 50% of trials in one of the conditions were invalid due to excessive eye movements. Table 1 presents mean accuracy for the sex categorization and fame judgment tasks for each target type and in each location. There was no significant difference in accuracy between the left and right periphery for either task ($t$s $< 1$), and so these conditions were collapsed for the remaining analyses. Planned comparisons revealed that mean accuracy (collapsed across target type) was higher for centrally presented faces than peripherally presented faces in the fame judgment task ($t_{(11)} = 8.67$, $p < 0.001$, $M = 87.9\%$ vs. $M = 61.2\%$), but there was no difference in mean accuracy for centrally and peripherally presented faces in the sex categorization task ($t_{(11)} = 1.57$, $p > 0.05$). This pattern of results indicates that presenting stimuli in peripheral vision impaired the perception of identity, not sex. To examine whether target type had an effect on performance, mean accuracy was calculated for each target type and target location and analyzed in two
separate ANOVAs for each task. The main effect of target type was not significant for either the fame judgment task ($F_{(1,11)} = 2.5, p > 0.05$) or the sex categorization task ($F_{(1,11)} = 0.1, p > 0.05$), and this factor did not interact with presentation location ($Fs < 1$).

To measure the extent to which identification was limited in peripheral vision, fame judgment accuracy was compared to chance level performance by conducting one-sample $t$ tests. Mean accuracy for peripherally presented faces in the fame judgment task was significantly greater than chance performance for famous targets ($t_{(11)} = 3.3, p < 0.01, M = 66.4\%$) but not for non-famous targets ($t_{(11)} = 1.3, p > 0.05, M = 56.0\%$). This suggests that recognition in peripheral vision was possible for familiar targets. However, it is also possible that higher accuracy for famous targets reflects a biased responding strategy, that is, participants might have slightly favored “famous” responses for peripherally presented targets. To control for response bias, accuracy was pooled over both famous and non-famous targets. An additional one-sample $t$ test revealed that pooled accuracy was significantly greater than chance performance ($t_{(11)} = 3.95, p < 0.01, M = 61.2\%$).

### Discussion

Fame judgment accuracy was severely impaired in peripheral vision, whereas sex categorization judgments were not. These results can be explained by two straightforward proposals. First, that peripheral vision is associated with encoding limitations (e.g., Levi, 2008; Pelli & Tillman, 2008), as this would explain why face identification that requires relatively detailed face processing was impaired. Second, that sex categorization is based on global, spatially distributed features; this would explain why the accuracy of sex categorization was largely maintained, since these features are less likely to be adversely affected by reduced spatial acuity (O’Toole et al., 1993; Schyns et al., 2002), at least at 5° eccentricity.

The current finding that face recognition was impaired when a face (which has not previously been seen in central vision) was presented in peripheral vision contrasts with previous results in which fame judgment performance was better than 80% accuracy with faces presented as far as 10° in the periphery (McKone, 2004; Reddy et al., 2006). It should be pointed out that current identification performance in peripheral vision was better than chance; however, this result appeared to be largely driven by better performance on famous targets. Better performance for famous faces is consistent with studies that have shown that familiarity assists recognition under degraded conditions (Bruce, Henderson, Newman, & Burton, 2001; Watier & Collin, 2009) and that the identification of famous individuals can withstand degradations to image quality (Harmon & Julesz, 1973; Yip & Sinha, 2002).

One reason why performance on peripherally presented stimuli was good in these previous studies is that participants may have unintentionally viewed the stimuli in central vision. Indeed, such a possibility is hinted at in the current results where the fame judgment task was associated with higher rates of involuntary eye movements than the sex categorization task (suggesting that simply having to judge the identity of faces presented in peripheral vision increases the likelihood of involuntary eye movements to the periphery). Additionally, some of these previous studies involved making distinctions between only a few individuals (e.g., McKone, 2004; Reddy et al., 2006) and this might have lead to better performance on peripheral stimuli than in the current experiment that called for distinguishing between larger sets of individuals. However, it is also possible that accuracy for peripherally presented faces reported previously was due in part to these studies having presented faces both in central vision and in peripheral vision. Thus, **Experiment 2** investigated whether recent exposure in central vision improves identification in peripheral vision.

This experiment examined whether recent exposure to faces in central vision can facilitate recognition judgments for faces presented in peripheral vision. Participants were first exposed to a set of famous and non-famous faces presented in central vision, followed by a test phase where participants recognized exposed and unexposed faces that were presented in peripheral vision. In addition to this, the present study also investigated whether any learning associated with recent exposure was image specific or whether it would generalize to new images of the exposed faces. To test for the generalization of learning, the experiment included two test conditions; in one condition, the target faces were the same images as those presented in the exposure phase, whereas in the other condition, the target faces were new images of the exposed faces (i.e., pose, hairstyle, and lighting conditions were changed). If recent exposure involves learning features that are specific to the images presented during the exposure phase, then new images of trained faces should not be judged more accurately than unexposed control images. However, if

<table>
<thead>
<tr>
<th>Location</th>
<th>Sex categorization</th>
<th>Fame judgment</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Center</td>
<td>100 (0)</td>
<td>98.47 (1.0)</td>
</tr>
<tr>
<td>Left</td>
<td>97.64 (1.7)</td>
<td>97.85 (1.5)</td>
</tr>
<tr>
<td>Right</td>
<td>96.93 (1.7)</td>
<td>97.71 (1.2)</td>
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</tbody>
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Table 1. Mean percentage of correct responses for each task, target type, and target location. *Note:* Standard errors are in parentheses.
recent exposure involves learning features that are specific to the facial features of the individuals themselves, then new images of trained faces should be recognized more accurately than unexposed control images.

Methods

Participants

Another sixteen graduate and undergraduate students ($M_{\text{age}} = 25$ years, 8 females) participated in exchange for payment. All reported having normal or corrected-to-normal visual acuity.

Materials

Two images each of thirty-two famous singers or actors and thirty-two amateur models were selected from the internet. The hairstyle, lighting conditions, and pose varied across the two images of the same famous or non-famous face. All other aspects of image preparation were the same as Experiment 1.

Procedure

Exposure phase in central vision

Participants were presented only one of the four subsets of 16 famous and 16 non-famous faces during the exposure phase (Figure 2). These stimuli were presented in a face judgment task where targets appeared in central vision. On each trial, a fixation cross appeared for 500 ms at the center of the screen followed by a randomly selected target for 1800 ms or until the participant responded. Participants received visual feedback after each response. If the participant did not respond before the target disappeared, the trial was recorded as incorrect. Participants repeated the task until it was completed on three consecutive blocks without error. Participants returned at least 1 day later and repeated the task until they had completed three consecutive blocks without error. Participants progressed to the test phase after a short break. Each subset of stimuli was presented equally across the participants. Participants were not informed that they would later view the stimuli in peripheral vision.

Test phase in peripheral vision

Participants completed a fame judgment task in the test phase where all targets were presented in peripheral vision. This phase of the experiment consisted of two tests: the Recent Exposure Test and the Generalization Test (see Figure 2). The Recent Exposure Test involved presenting the subset of 16 famous and 16 non-famous faces that participants were exposed to during the Exposure Phase as well as an additional subset of 16 famous and 16 non-famous unexposed faces that served as control stimuli. The Generalization Test involved presenting the subset of faces that consisted of the same 16 famous and 16 non-famous individuals as the exposed set, but the pose, hairstyle, and lighting conditions were changed. Another subset of 16 famous and 16 non-famous unexposed images were also presented in this task as control stimuli. The subset of control stimuli presented in each test was always from the same set (either set A or set B in Figure 2) as the test stimuli. The
Recent Exposure Test and the Generalization Test were blocked and order of task completion was counterbalanced so that half of the participants completed the Recent Exposure Test first. Before each test, participants were instructed that half of the targets were famous and half non-famous and that half of the targets (both famous and non-famous) would depict individuals presented in the exposure phase. Trial structure was the same as Experiment 1 except that targets only appeared either 5° to the left or 5° to the right of center. Participants were given short breaks every 16 trials during which the eye tracker was recalibrated. Eye position was monitored in the same manner as in Experiment 1.

Results and discussion

Table 2 presents mean accuracy across target type (famous, non-famous), test (Recent exposure test, Generalization test), and exposure condition (exposed/changed, control). Preliminary analysis of the Recent Exposure Test and the Generalization Test showed a significant response bias for the control targets in the Recent Exposure Test \( t(15) = 3.7, p = 0.002 \) with participants responding “non-famous” on 62.7% of the trials. A similar trend toward biased responding was also observed for the control targets in the Generalization Test \( t(15) = 1.9, p = 0.081 \) with participants responding “non-famous” on 55.7% of the trials. In order to remove the effect of response bias from the control conditions, accuracy was pooled over both target types for the control conditions of the Recent Exposure and Generalization Tests and used as the baseline in testing whether preexposed faces were recognized.

A paired samples \( t \) test demonstrated that recognition of the exposed faces was significantly better than the unexposed control images \( t(15) = 13.6, p < 0.001, M = 96.2\% \) vs. \( M = 66.4\% \), collapsed over target fame) even when the pose, hairstyle, and lighting conditions were changed \( t(15) = 3.4, p < 0.01, M = 72.7\% \) vs. \( M = 60.8\% \), collapsed over target fame). This indicates that there was some transfer of learning from exposed images to new unexposed images of the same individuals, i.e., recent exposure did not merely involve learning specific images. These results suggest that this learning also assisted the recognition of new images of the individuals presented during the exposure phase, indicating that the improved recognition for exposed targets was not entirely due to learning the specific images. It is possible of course that the improved performance for famous, changed pose targets was not driven by perceptual learning per se but was due to the participants learning which famous individuals might have appeared later in the test phase. However, two paired samples \( t \) tests revealed that accuracy was higher for both famous \( t(15) = 3.4, p < 0.01, M = 76.1\% \) vs. \( M = 60.8\% \) and non-famous targets \( t(15) = 2.2, p < 0.05, M = 69.4\% \) vs. \( M = 60.8\% \) when compared against the unbiased accuracy composite score for the control stimuli in the Generalization Test. The finding of improved performance for non-famous, changed pose targets can only be the result of exposure to images of these individuals (even though the images were not the same).

Two 1-sample \( t \) tests revealed that recognition of control targets was significantly better than chance performance in the Recent Exposure Test \( t(15) = 3.95, p < 0.01, M = 66.8\% \) and in the Generalization Test \( t(15) = 4.4, p < 0.001, M = 60.9\% \). This is consistent with the results of Experiment 1 that showed that faces could be identified more accurately than chance when presented in peripheral vision.

<table>
<thead>
<tr>
<th>Target Type</th>
<th>Recent Exposure Test</th>
<th>Generalization Test</th>
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<tbody>
<tr>
<td></td>
<td>Exposed</td>
<td>Control</td>
</tr>
<tr>
<td>Famous</td>
<td>95.7 (1.8)</td>
<td>53.7 (4.4)</td>
</tr>
<tr>
<td>Non-famous</td>
<td>96.7 (1.2)</td>
<td>79.1 (3.6)</td>
</tr>
</tbody>
</table>

Table 2. Mean percentage of correct responses for exposed, changed pose, and control images for famous and non-famous targets by task. Note: Standard errors are in parentheses.

General discussion

The primary aim of the present study was to determine whether recent exposure to a face would enable that face to be more readily recognized in peripheral vision. The rationale for examining this was twofold. First, finding a recent exposure effect would help reconcile previous disparate findings regarding how accurately faces can be recognized in peripheral vision. Second, such a recent exposure effect is worthwhile investigating in itself, specifically to determine whether it was confined to the same images or whether it generalized to new instances of an exposed face. Experiment 1 showed that the processing of face images presented only in peripheral vision was compromised for identification but not for sex categorization. When, however, participants were first exposed to a set of faces in central vision (Experiment 2), identification judgments of these faces viewed in peripheral vision improved compared to unexposed control face images. This finding is consistent with the results of other studies showing that previous exposure to a stimulus facilitates subsequent recognition under degraded conditions (Bruce & Valentine, 1985; Dolan et al., 1997; Hsieh et al., 2010; James et al., 2000). Moreover, the current findings also showed that the effect of recent exposure generalized to new images of trained faces, indicating that
the priming effect was not confined to features contained in the exposed images.

What mechanism might underpin such a recent exposure effect? Considered broadly, the present results can be described in terms of a priming effect whereby the processing of a previously exposed stimuli (a prime) acts to reduce the amount of perceptual information required to access long-term representations (James et al., 2000; Morton, 1969). However, because the term priming is rather broad, it is important to distinguish the current effect from some of the different forms of priming that have been previously described. Furthermore, in adopting a priming framework, it is important to specify what is being primed and how this process relates to recognizing faces presented in the periphery.

In regard to differentiating the current priming effect from that shown in some other studies, it is worth pointing out that the current results revealed a relatively long-lasting priming effect that occurred for face recognition under degraded conditions. This is in contrast to studies that have shown that faces presented in the periphery can prime recognition of central targets when there is a short lag (<1 s) between prime and target onset (e.g., Bindemann et al., 2005; Cooper, Harvey, Lavidor, & Schweinberger, 2007). It is possible that priming in tasks with a short prime–target interval are due to a type of cuing effect whereby the prime acts to indicate the individual that could appear as the target on each trial (thereby reducing uncertainty). This form of priming should be distinguished from the more incidental form (examined in the present study) that involved blocked prime and target presentation that was separated by a relatively long interval.

As to the matter of what is being primed, the present results suggest that recent exposure alters how different facial properties (e.g., features and configuration) contribute to face recognition. As suggested by the results of Experiment 1, face recognition requires high spatial frequency information that is detailed enough to encode the unique properties of a face. One possibility then is that the priming observed in Experiment 2 involved facilitating the use of low spatial frequency information (available from peripheral vision) to allow a more unique specification of the exposed faces. One way that low spatial frequency information could assist accurate face recognition is if recently exposed faces are stored in a form that permits the ready linkage of low and high spatial frequency information. High and low spatial frequency information has been shown, respectively, to contain the details needed for featural and configural processing (Goffaux, Hault, Michel, Vuong, & Rossion, 2005; Goffaux & Rossion, 2006) and appear to be processed independently (Liu, Harris, & Kanwisher, 2010; McKone, 2004). Thus, priming by recent exposure might act to strengthen the linkage between feature and configural processing that could in turn mediate the recognition of faces viewed in peripheral vision (consisting of low frequency/configural information). Given priming was observed for both famous and non-famous targets, it seems that exposure did not alter long-term representations since only famous targets would be associated with these. Instead, the linkage between featural and configural processing was probably the result of participants creating representations of the exposed images in a short-term store.

The proposal that a representation generated by recent exposure to a centrally presented face enables recognition from low spatial frequency information could also account for why changed pose images were recognized more accurately than control images (where again, priming was observed for famous and non-famous targets). Here, it would need to be the case that the low-frequency information of the centrally exposed face and the changed pose image were sufficiently similar to permit a match. Such a match could plausibly involve the processing of details that are diagnostic for identity and that are available in the low spatial frequency information (e.g., face shape, aspect ratio, configuration). Indeed, it appears that the use of coarse, global details for face matching is experience dependent (Megreya & Burton, 2006). Interestingly, this idea that short-term representations can link coarse inputs of faces to more detailed information would allow a person to keep track of the identity of those in the visual periphery without the need for constantly refixating them in central vision.

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