The wide window of face detection

Orit Hershler Department of Neurobiology, Hebrew University, Jerusalem, Israel

Tal Golan Department of Psychology, Hebrew University, Jerusalem, Israel

Shlomo Bentin Department of Psychology and ICNC, Hebrew University, Jerusalem, Israel

Shaul Hochstein Department of Neurobiology and ICNC, Hebrew University, Jerusalem, Israel

Faces are detected more rapidly than other objects in visual scenes and search arrays, but the cause for this face advantage has been contested. In the present study, we found that under conditions of spatial uncertainty, faces were easier to detect than control targets (dog faces, clocks and cars) even in the absence of surrounding stimuli, making an explanation based only on low-level differences unlikely. This advantage improved with eccentricity in the visual field, enabling face detection in wider visual windows, and pointing to selective sparing of face detection at greater eccentricities. This face advantage might be due to perceptual factors favoring face detection. In addition, the relative face advantage is greater under flanked than non-flanked conditions, suggesting an additional, possibly attention-related benefit enabling face detection in groups of distracters.

Keywords: face, detection, attention, flankers, visual search

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Introduction

Faces are a category of enormous interest to researchers and laymen alike. Converging lines of evidence indicate that this interest is paralleled by the special position faces occupy in the brain (Kanwisher & Yovel, 2006). Brain-imaging studies have uncovered a cortical region dedicated to faces, named the Fusiform Face Area or FFA (e.g. Kanwisher, McDermott, & Chun, 1997); faces elicit an early-occurring EEG signal, known as the N170 effect (Bentin, McCarthy, Perez, Puce, & Allison, 1996); and face-selective neurons have been found in the macaque inferior temporal visual cortex, superior temporal sulcus, orbitofrontal cortex and the amygdala (e.g. Perrett, Rolls, & Caan, 1982; Rolls, 2007). A special neuronal face processor is also indicated by prosopagnosia, a condition which greatly impairs face recognition but leaves intact recognition of other objects (e.g. Avidan & Behrmann, 2009; Bodamer, 1947).

Face processing stretches along a continuum from face detection, the categorization of a presented stimulus as a face, to face identification, the recognition of a presented face as being of a specific individual (Nestor, Vettel and Tarr, 2008; Tanaka, 2001). Face processing has been studied extensively and there is ample evidence that it involves domain specific computations (e.g. Carmel & Bentin, 2002; Tanaka & Farah, 1993; Tanaka, 2001). In addition, faces may also be particularly conspicuous in tasks requiring the detection of faces within the visual field, and this is the focus of the present study. When two scenes are presented side-by-side, scenes containing people are fixated more often than scenes without people present, a preference that is evident from the first fixation (Fletcher-Watson, Findlay, Leekam, & Benson, 2008; Yarbus, 1967). The preference for faces remains when highly schematic upright face images are presented next to identical, but inverted faces (Tomalski, Csibra, & Johnson, 2009). Face detection is aided by factors such as context (Bentin, Sagiv, Mecklinger, Friederici, & von Cramon, 2002) and hindered by blurring, obscuring the eye region, or inverting luminance (Lewis & Edmonds, 2003; Tomalski et al., 2009). Finally, newborn infants show a face preference, for both photographic and schematic images (Morton & Johnson, 1991; Nelson & Ludemann, 1989; Valenza, Simion, Cassia, & Umiltà, 1996, but see Simion, Cassia, Turati, & Valenza, 2001).

There is ongoing debate regarding the question of whether rapid face detection stems from the uniqueness of faces as a perceptual category, whether genetic or experience based, or from low-level factors which happen to favor face detection. In a visual search study by

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Hershler and Hochstein (2005), face photographs were detected rapidly among heterogeneous distracters, with search slopes characteristic of parallel or efficient search (Treisman & Gelade, 1980; Wolfe, Cave, & Franzel, 1989). Although there has been an attempt to attribute the rapid visual face search to a single "low-level" factor difference between the faces and surrounding distracters, namely a Fourier amplitude spectrum distinctive to faces (VanRullen, 2006), this account is conflict with the empirical impossibility of locating face Fourier amplitudes in a field of Fourier amplitudes of distracter images (Hershler & Hochstein, 2006). The preference for highly schematic upright faces over identical inverted stimuli when both are presented side-by-side (Tomalski et al., 2009) can also not be explained by Fourier amplitudes. Additional evidence that the tendency to fixate faces is not caused by bottom-up saliency comes from a computational vision study (Cerf, Harel, Einhäuser, & Koch, 2008). In this study, a face detection unit was added to a low-level saliency model, dramatically improving its ability to predict human scan paths.

In contrast to evidence attesting to a face advantage in detection, several studies found no special face benefit over other objects in some detection tasks. In an RSVP go–no go paradigm there was virtually no rapid categorization advantage for face over animal scenes or close-ups (Rousselet, Macé, & Fabre-Thorpe, 2003). Using a flicker paradigm, Palermo and Rhodes (2003) found that changes to objects among faces were actually easier to detect than changes to faces. Ro, Russell, and Lavie (2001) could find no advantage for singly presented faces in a change blindness study. Counter-evidence, however has been reported in an attentional blink paradigm (Awh et al., 2004) as well as using RSVP (Landau & Bentin, 2008).

How is rapid face detection achieved? Evidence suggests that faces are fixated earlier and more often than non-faces (Cerf et al., 2008; Yarbus, 1967), leading to the hypothesis that faces may have a special advantage over other objects prior to fixation, in peripheral vision. This suggests that the detection advantage would be especially evident in conditions where the initial fixation is **not** on the face. In line with this assumption, Hershler and Hochstein (2009) compared visual search time maps and cumulative search time histograms in search for everyday objects, objects belonging to categories of expertise, and faces. Faces and objects of expertise were detected faster over wider areas of the visual search array, with faces enjoying an especially wide window of detection; 80% of a visual search array of about 160° was covered in a timespan allowing only one or two fixations, suggesting that faces do not have to be fixated directly to be detected.

Yet, there is ample evidence suggesting that face processing is superior in the fovea than in the periphery (e.g. Mäkelä, Näsänen, Rovamo, & Melmoth, 2001), as is the case with other visual processing tasks (Carrasco, Evert, Chang, & Katz, 1995); however, this does not indicate whether the face detection advantage over other objects may be more pronounced in peripheral than in foveal vision. The present study directly investigates whether faces have a relatively greater detection advantage over other objects in the periphery, by placing face targets or control targets (cars, dog faces, and clock faces) at different eccentricities relative to the central point of fixation, while keeping exposure times limited to preclude the possibility of eye movements.

Peripheral stimuli may be at a disadvantage for a number of reasons. One disadvantage stems from the close correlation between attention and fixation (e.g. Sheliga, Riggio, & Rizzolatti, 1994), so that stimuli that are not currently fixated are likely to receive less attention. Another disadvantage of peripheral stimuli is that such stimuli suffer from the lower retinal acuity of the peripheral visual field. In addition, the crowding range, the space needed between stimuli to enable accurate perception, is known to increase with eccentricity (e.g. Pelli & Tillman, 2008), decreasing detection ability in flanked displays. Finally, visual performance decreases with eccentricity (Carrasco et al., 1995).

Faces may be able to overcome some or all of these disadvantages. Faces may attract or retain attention better than do other objects, as evidenced by a study in which a go/no go signal for an unrelated line detection task was superimposed on faces, inverted faces and objects. When the signal was superimposed on an upright face, response times were significantly delayed in comparison with each of the other background stimulus categories, indicating that it was harder to fully attend the go/no go signal in the presence of an irrelevant face (Bindemann, Burton, Hooge, Jenkins, & de Haan, 2005). Faces may be capable of capturing attention when in competition with other non-face objects (Langton, Law, Burton, & Schweinberger, 2008), although counter-evidence shows that faces may not serve as more valid attentional cues in a Posner paradigm (Bentin, unpublished data). Attentional guidance to faces also seems to be under a certain amount of voluntarily control (Bindemann, Burton, Langton, Schweinberger, & Doherty, 2007). It may also be possible to detect face targets, but not other objects, within a crowded display of heterogeneous distracters (Hershler & Hochstein, 2006, 2009). In addition, processing on the basis of lower spatial frequencies may suffice for face detection and not for other objects (Goffaux & Rossion, 2006; Harel & Bentin, 2009; but see Cheung, Richler, Palmeri, & Gauthier, 2008), and face detection may be relatively robust to the attenuation of high spatial frequency information (e.g. Halit, de Haan, Schyns, & Johnson, 2006), leading to an extra-foveal face advantage.

In addition to ascertaining whether a face detection advantage over other objects is more pronounced at further eccentricities, the present study investigates possible sources of the hypothesized face advantage. Our first experiment checks the hypothesis that faces have an extra-foveal advantage even if task-dependent and exogenous

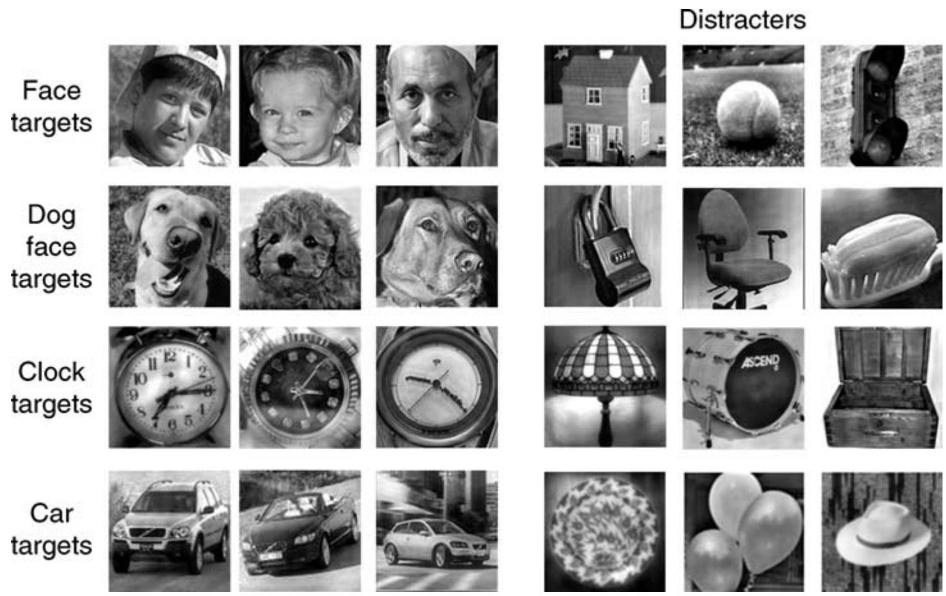

Figure 1. Examples of target and distracter stimuli. Targets were faces, cars, dog faces and clocks, distracters comprised a variety of objects. These images are equalized for luminance and Fourier amplitude (see Methods section).

attention factors are similar for faces and other objects by presenting faces and control targets as single targets at varying eccentricities in a face/non-face categorization task, and minimizing the possibility of eye movements by limiting exposure time. We found no detection advantage for face stimuli under these conditions. The second experiment forced subjects to spread attention over the visual field by the simultaneous presentation of single stimuli at differing eccentricities on both sides of a central fixation point. In addition, these stimuli were masked. Results show a significant detection advantage for faces over all control targets. Relatively, this face advantage over controls grows with eccentricity. An additional condition in this experiment presented the same targets under the same conditions, but now surrounded by flanking distracters. A comparison of the two conditions indicated that faces have a larger relative advantage over the control targets in the flanked than in the single condition. In a third experiment, we investigated the face advantage in visual search displays under conditions of greater target location uncertainty, and again found that faces are more easily detected than the control targets; the relative face advantage once again grows with eccentricity.

It is notoriously hard to define adequate controls in any study concerning face processing (Hershler & Hochstein, 2006; Kanwisher, 2001). Face stimuli are special in various ways, including their being biologically and sociologically relevant and perhaps the face category being quite homogenous relative to other categories—e.g. they all share a canonical structure including two eyes, a nose and a mouth, symmetrically located relative to the long axis of an oval contour (though not all of these are evident from all viewpoints). In the present study, we used three control categories, selected to be either animate and shaped similar to faces (dog faces), non-animate and shaped similar to faces (clock faces) or non-animate and not similar in shape to faces (cars). In both experiments, non-target distracters were taken from the same image collection. Examples of target and distracter displays are shown in Figure 1. Note that the term "faces" alone is used only for human faces.

If, indeed, faces have a peripheral detection advantage, the relative detection advantage for faces over other objects should increase with eccentricity. Furthermore, a comparison of the detection performance of faces with performance for the control targets should give some indication regarding the underlying cause for a possible face advantage; for example, a robust detection of clock targets presented in the periphery would indicate that for faces, too, the round shape probably aids detection, while a more robust dog face detection would indicate that faces in general have an advantage over the round shape.

Experiment 1

Methods

Participants

A total of 24 subjects, ranging in ages from 20 to 27, (average: 23) participated in Experiment 1. Four subjects were males. Subjects were recruited from among the student body of the Hebrew University—16 participated as part of the requirements for undergraduate studies, and were paid only for correct performance (see Procedure section), the remaining subjects were paid for both participation and performance. All subjects had normal or corrected-to-normal vision. They provided prior written consent to participate in the experiment according to the requirements of the Hebrew University IRB committee.

Stimuli

Stimuli were created from collections of 42 photographs each, of clock faces, dog faces, cars and human faces, and 165 distracter photographs comprised of a wide variety of other objects. Clock, dog face and face photographs were frontal views, car photographs were side or angular views. Photographs were cropped to square images to maintain aspect ratio. Photographs were transformed into gray-scale images. Mean luminance was equalized and RMS contrast was enhanced by clipping the 0.5% brightest and 0.5% darkest intensities and linearly scaling the intensity histogram to full range (Adobe PhotoShop's auto-contrast function). Spatial spectra were equalized over all images by calculating the Fourier amplitude average for each frequency across orientations (rotational average) for each image. Next, we calculated grand averages for each frequency over all images and equated the individual image Fourier amplitudes with the grand averages (Schyns & Oliva, 1994). This means that the overall amplitude spectrum (collapsed upon orientations) is identical across images, while inter-image rotational differences in amplitude spectrum are preserved.

All stimuli contained a single object photograph, measuring 4.4° by 4.4°. Target-present stimuli contained a face, a dog face, a car or a clock face, while target-absent stimuli contained one of the distracter images. Distracter stimuli did not contain any of the potential target objects, even those not used as a current target. Each target or distracter could appear in one of 42 positions, arranged in four concentric circles around the center of fixation. Eccentricities of each ring are shown in Table 1. Note that there is a 6° separation between rings 1, 2 and 3. For simplicity, graphs are plotted with ring number as the abscissa. Targets were placed with equal probability in each ring of the visual search array; this placement was pseudo-randomized so that the target appeared an equal number of times in each position of each ring. Ring 4 has less available positions as the top and bottom half of the 20° circle are outside of the screen.

	Eccentricity	Number of Positions
Ring 1	4°	4
Ring 2	10°	10
Ring 3	16°	16
Ring 4	20°	12

Table 1. Eccentricities and number of positions for the four rings used in Experiments 1 and 2.

Procedure

Subjects were seated in a dark room at a distance of 37 cm from the computer screen. The viewing distance was maintained by a chin rest. Subjects were instructed to fixate the center of the screen, look for the target category and respond as accurately as possible by means of a button press on the keyboard (right side for present target, left side for absent).

At the onset of each trial, four triangles converged from the sides of the screen to the center to ensure proper fixation, followed by a fixation cross. The fixation was followed by the stimulus, which was displayed for 40 msec. The stimulus was followed by a blank screen, which remained until the subject's response.

Stimuli were presented in a blocked-by-target design, 128 trials per block, and instructions appeared at the start of each block, repeating the general fixation and response instructions and informing the subject of the target to be detected in this block (face, dog, car or clock). The order of the blocks was fully counterbalanced across subjects. Note that the experiment was not blocked according to eccentricity, to prevent subjects from focusing on any specific distance from the fixation point. This means that in the d-prime calculations, the false alarm rate for each eccentricity is the global false alarm rate.

To maintain motivation, monetary compensation was promised and given for each correct response (0.10 Israel Shekels, about equal to $0.025, per response). No monetary penalty was given for incorrect responses. Subjects received no feedback about responses until after the entire experiment.

Results and discussion

In Experiment 1, subjects detected single human face, dog face, clock or car targets at differing eccentricities. No surrounding distracters were present. Figure 2 shows the detectability d′ values for the different target categories as a function of eccentricity.

To analyze a possible face advantage, we performed a two-way ANOVA with main factors of category and eccentricity, with d′ as the dependent variable. Violation of sphericity was tested by Mauchly's test and, when necessary, the degrees of freedom were corrected using the Greenhouse–Geisser procedure. There were significant main effects for both factors. Detection performance decreased significantly with eccentricity ($F(1.5, 34.6) = 70.0$, $p < 0.01$, Greenhouse–Geisser corrected at E = 0.5). Post hoc analyses indicated this was true for all target categories (face: $F(3, 92) = 30.0$, $p < 0.01$, car: $F(3, 92) = 16.0$, $p < 0.01$, dog: $F(3, 92) = 12.7$, $p < 0.01$, clock: $F(3, 92) = 21.5$, $p < 0.01$). This pattern is similar to the eccentricity effects on color-orientation conjunction search reported previously (Carrasco et al., 1995). The

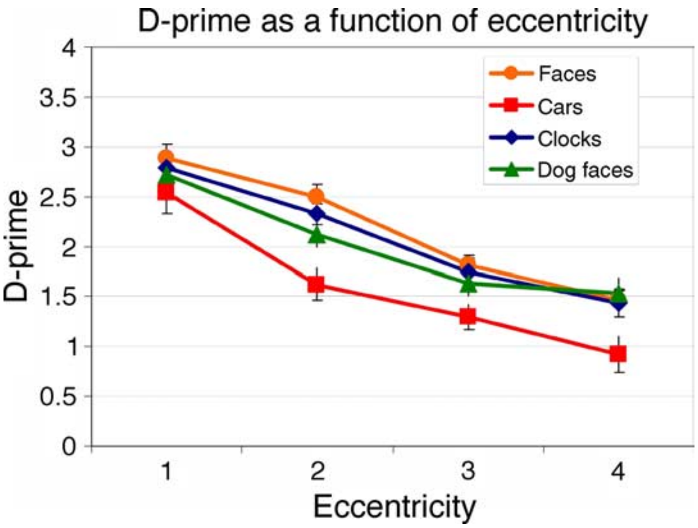

Figure 2. Performance (d′) for Experiment 1. Images were presented as single items at various eccentricities. Performance decreases with increasing eccentricity. Face targets have no advantage over dog face and clock targets. All three of these target categories are easier to detect than car targets. In this and all subsequent figures, the error bars are standard error of the mean.

main effect of category was also significant ($F(3, 69) = 9.4$, $p < 0.01$), indicating some categories were significantly easier to detect than others. Bonferroni adjusted pair-wise comparisons indicated that faces were easier to detect than cars ($p < 0.01$), but not significantly easier to detect than dog faces ($p = 1.0$) or clocks ($p = 1.0$). No significant interaction effect was found, indicating that the decrease in performance with eccentricity does not significantly depend on target category.

To investigate whether the absence of a face advantage held for every ring, we defined contrasts between the four categories presented at every ring. Results are given in Table 2 and indicate that in ring 1, closest to fixation, faces were not significantly easier to detect than any other target category, in ring 2 faces had an advantage over car and dog targets, and in rings 3 and 4 there was a significant face advantage compared to car targets only.

There was no significant advantage for faces in ring 1, closest to the point of fixation. This may have been due to a ceiling effect, but these results are also in accordance with previous findings of no advantage for singly presented faces (Ro et al., 2001; Rousselet et al., 2003). Our results show that cars have a significant disadvantage compared to faces, dog faces and clocks at all peripheral locations, perhaps indicating that cars may not be an adequate control. Clocks and dog faces were detected as easily as faces at greater eccentricities in this uncrowded condition. This may be due to their individual characteristics, such as the relative roundness of both clocks and dog faces, although it is also possible that clocks and dog faces are detected more easily because of their similarity to faces. If the visual system puts extra significance on detecting faces (e.g. Cerf et al., 2008; Fletcher-Watson et al., 2008; Morton & Johnson, 1991; Tomalski et al., 2009), stimuli that share face properties may benefit (Cerf et al., 2008). Nevertheless, there was no additional advantage for the more "face-like" dog face stimuli, suggesting that roundness or another homogeneous within-category characteristic may have been the defining factor for superior detection performance in this experiment.

Our results indicate that under these conditions, single faces have no significant advantage over our control targets at eccentricity nearest the point of fixation. However, this experiment presented single unmasked stimuli at short presentation times. While this precluded eye movements, subjects were able to perform attentional shifts to the appearance of the stimulus. In our second experiment, we forced subjects to spread attention over the entire visual field by presenting stimuli on both sides of a central fixation point.

Experiment 2

In our first experiment, we presented only one stimulus for each trial. Exposure was brief to preclude eye movements, but attention could have been directed to the stimulus (despite its eccentricity). In addition, while presentation was brief, the stimulus was not masked. In the second experiment, we presented stimuli on both sides of a central fixation point, limiting the possibility of attentional shifts to the stimuli, and backward masked the stimuli. Our first goal was to ascertain whether under these conditions, single face targets would have an advantage over control targets, and how this advantage would be influenced by eccentricity. A second goal of this experiment was to investigate a possible advantage for faces under conditions of crowding. Therefore, another condition in this experiment presented the same face targets and controls flanked by non-face and non-control distracters. Stimuli were again backwards masked, and target location uncertainty was identical to the first

	Cars		Dog faces		Clocks	
	$F(1, 23)$	p	$F(1, 23)$	p	$F(1, 23)$	p
Ring 1	1.95	0.215	0.6	0.25	0.2	0.47
Ring 2	18.7	**0.001**	4.9	0.04	2.2	0.15
Ring 3	14.4	**0.001**	1.5	0.24	0.3	0.60
Ring 4	8.9	**0.003**	0.04	0.84	0.01	0.93

Table 2. Detection performance contrasts between face and other target categories for each ring in the single image condition. Significant values are in bold, critical alpha with Bonferroni correction = 0.004.

condition, as subjects knew in advance which position in the flanked displays could hold the target. A face advantage over other objects which is caused by a perceptual advantage, such as selective sparing from the lower retinal acuity of the periphery should be present in both the single and the array experiments. If there is an additional face advantage due to an ability to detect faces under crowded conditions, then this should be evident from a greater relative face advantage in the flanked than in the single condition.

Methods

Participants

A total of 18 subjects, of which eight were males, ranging in ages from 20 to 31, (average: 24) participated in Experiment 2. None of these subjects had participated in Experiment 1. Subjects were recruited from among the student body of the Hebrew University—5 subjects participated as part of the requirements for undergraduate studies, the remaining subjects were paid for participation and performance. All subjects provided prior written consent to participate in the experiment and had normal or corrected-to-normal vision.

Stimuli

Stimuli were created from the same collections of 42 photographs each of clock faces, dog faces, cars and faces, and 165 distracter photographs comprised of a wide variety of other objects. The photographs were cropped, gray-scaled, contrast-enhanced and equalized for Fourier amplitude as in Experiment 1.

In the single condition of this experiment, every trial consisted of a simultaneous display of two stimuli at equidistant horizontal positions on either side of a central fixation point. One half of the trials were target present trials, in which one of the two stimuli was the target. In target absent trials, both stimuli were distracters. The flanked condition of this experiment presented the exact same targets under the same conditions, but this time they were surrounded by 8 distracters (Figure 3). As a result, any possible target always appeared at the central location of the square of 9 photographs, and subjects were informed of this fact beforehand. Each individual photograph in this experiment measured 3.6° by 3.6°.

Eccentricities of the different positions were about 2.5 degrees more eccentric than in Experiments 1 or 3; they were 6.5°, 12.5° and 18.5°, for positions 1, 2 and 3 respectively.

Procedure

The experiment contained 8 different types of blocks (four targets: faces, dog faces, clocks and cars, at two

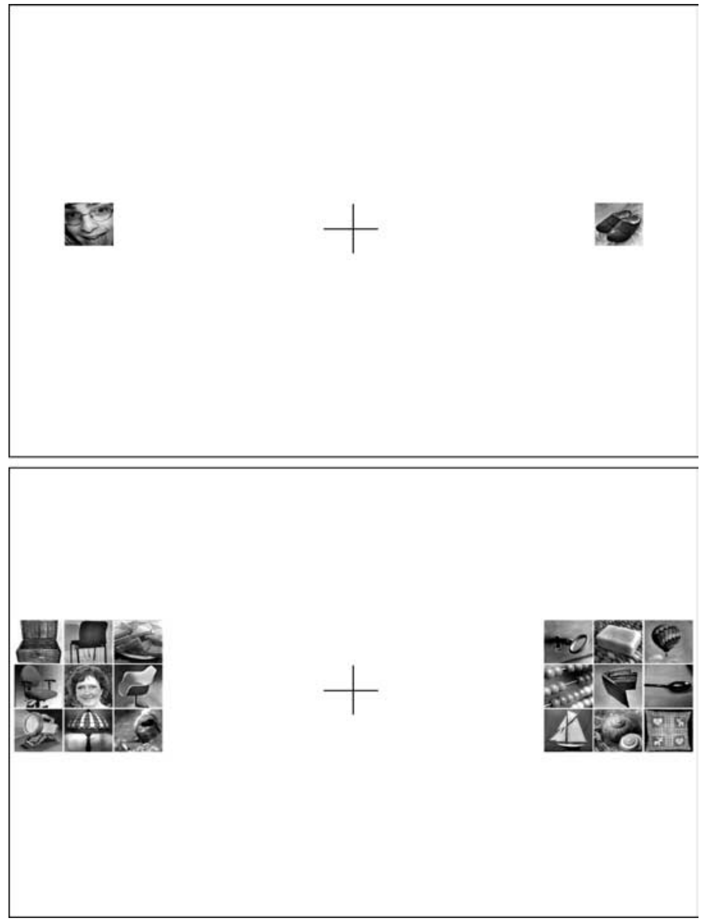

Figure 3. Example stimulus for the single and flanked conditions at the greatest eccentricity position in Experiment 2. Target is the face, left. When targets were present, they could appear at the left or right, but always in the central position within the flankers. The single condition (top) presented the same targets at the same positions, but without flankers.

conditions: single and flanked), and consisted of two halves; each half of the experiment contained all 8 possible blocks, so that the total experiment consisted of 16 blocks. Each block contained 60 trials. The order of blocks was pseudorandomized over subjects and over the first and second half of the experiment. Stimuli of the first block for every combination were different from the stimuli of the second block presenting the same combination.

Fixation, seating and response procedure were as reported for Experiment 1. Stimuli were displayed on the screen for 40 msec, followed immediately by an identical mask consisting of random noise.

Results and discussion

In Experiment 2, subjects detected face, dog face, clock face and car target photographs located at varying

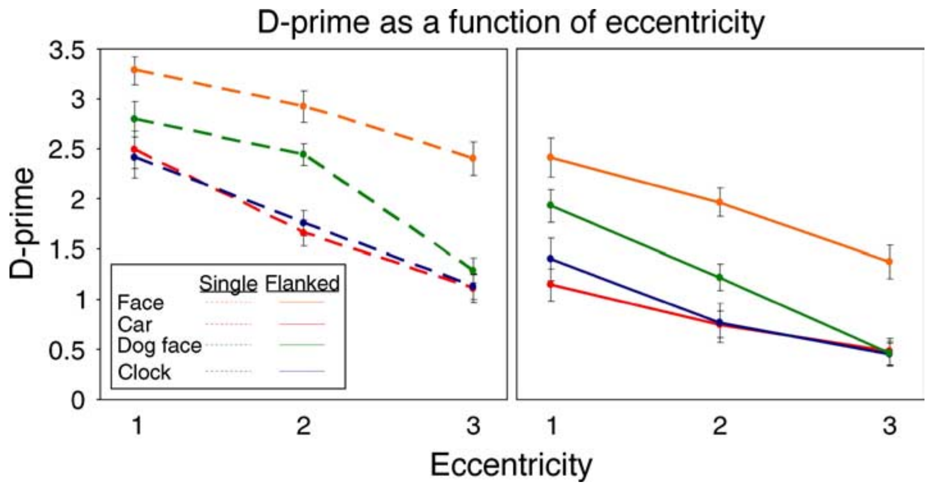

Figure 4. Performance (d′) for Experiment 2. Targets were presented either single or flanked at various eccentricities. Performance decreases with increasing eccentricity. Face targets have an advantage over all other targets, both in the single and flanked conditions.

eccentricities, in a single condition and in a flanked condition, among heterogeneous distracters. Figure 4 shows the d′ values for the different target categories as a function of target eccentricity.

A three way repeated measures ANOVA with main factors of category, eccentricity and presentation condition (single or flanked) with d′ as the dependent variable showed significant main effects for all factors. In accordance with previous findings (Carrasco et al., 1995), detection performance decreased significantly with eccentricity ($F(2, 34) = 69.1$, $p < 0.01$). A significant main effect was found for the category factor ($F(3, 51) = 74.2$, $p < 0.01$), indicating that certain categories were easier to detect than others; Bonferroni adjusted pair-wise comparisons showed that faces were significantly easier to detect than cars, clocks and dog faces at all eccentricities for both the single and flanked presentations (all at $p < 0.01$), except for the comparison of dog vs. face at eccentricity 1 in both flanked and single presentations and dog vs. face on eccentricity 2 in the single presentation. There was a significant main effect for presentation type ($F(1, 17) = 179.7$, $p < 0.01$), indicating that detection performance for the flanked condition was harder than in the single condition. Of the interaction effects, the only significant interaction effect was for category vs. eccentricity, ($F(6, 102) = 3.1$, $p < 0.01$). A comparison of the slopes of average trend lines indicated that in the single condition, average face detection performance deteriorated less than with eccentricity than detection performance for other objects, while in the flanked condition, dog face detection deteriorated most, followed by faces, clocks and cars. The relatively small decrease in performance for the latter two categories may be due to a floor effect.

The second goal of this experiment was to compare the face advantage in the single and flanked conditions. To this end, we defined a normalized Relative Face Advantage (RFA) measure as:

$$\text{RFA} = [d'(F) - d'(OT)]/\text{abs}\{0.5 * [d'(F) + d'(OT)]\}, \quad (1)$$

where d′ (F) is the d′ value of face detection performance, and d′ (OT) is the d′ value of the detection performance for the other targets of dog faces, clock faces or cars. We calculated the face advantage measure for every combination of eccentricity, target category and presentation type separately. Results are shown in Figure 5.

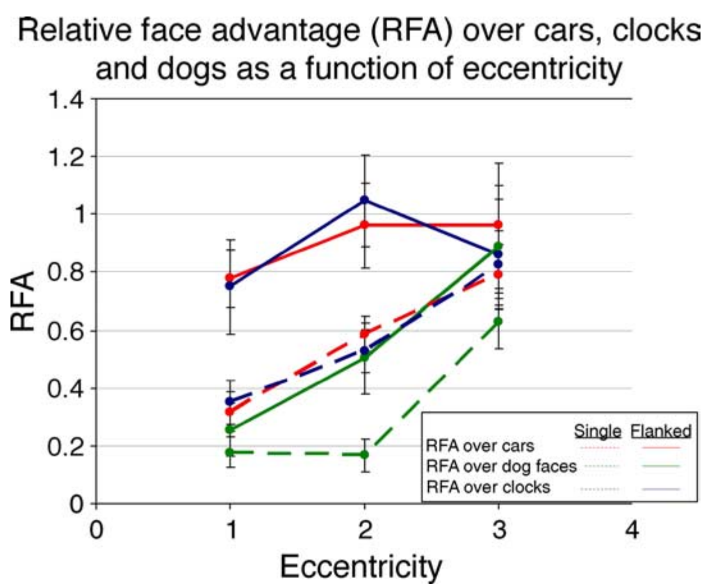

Figure 5. Normalized Relative Face Advantage (RFA) for single and flanked conditions in Experiment 2. The RFA is greater in the flanked than the single condition for all targets and it grows with eccentricity.

A three-way ANOVA analysis on the RFA measure over the factors of category (faces vs. cars, dogs and clocks), eccentricity and presentation type (single or flanked) revealed significant main effects of presentation type ($F(1, 17) = 36.6$, $p < 0.01$), indicating that the RFA is greater in the flanked than in the single condition. The effect of target category was also significant ($F(2, 34) = 8.3$, $p < 0.01$), indicating that the relative advantage of faces over dog targets was smaller than the advantage of faces over cars or clocks. The significant main effect of eccentricity ($F(2, 34) = 4.1$, $p < 0.01$) indicates that the RFA grew with eccentricity.

In this experiment, there was a clear detection advantage for faces in the single, non-flanked condition over all control categories and all eccentricities. This indicates that the lack of face advantage in the results of Experiment 1 may have been due to the possibility of an attentional shift to a lone stimulus, which was not specific to faces; in Experiment 2, subjects were forced to divide attention evenly over both hemifields. In addition, another possible cause for this difference between Experiments 1 and 2 is the presence of a mask, which hampered perceptual processing in the current experiment. The latter suggests that face perception might be completed faster than perception of other stimuli. The second goal of Experiment 2 was to see how much of the face advantage could be attributed to a possible escape from the detrimental effects of crowding. Results clearly show that the relative face advantage is greater in the flanked than in the single condition. It thus seems that face targets have two advantages over control targets. Firstly, they are easier to detect in general, both in central and more peripheral locations. Interestingly, in the single condition dog face targets are detected with the same ease as face targets at the two central eccentricities, suggesting "faceness" as a factor for ease of detection (and not, for example, the roundness of the clock targets). This face detection advantage grows with eccentricity, pointing to the influence of perceptual factors, such as, for example the robustness of face detection to the attenuation of high spatial frequency information (e.g. Halit et al., 2006). Secondly, faces seem better able to overcome the detrimental effects of flankers, as evidenced by the comparison of the RFA for the single and flanked conditions. However, it should be noted that this effect has complex eccentricity dependence, and may saturate at the greatest eccentricity when compared to the case for clocks and cars, though it continues to increase when compared to dog faces. Flanker effects in general are known to increase with eccentricity (e.g. Pelli & Tillman, 2008). However, inspection of Figure 5 shows that the difference of the face advantages between single and flanked conditions does not grow with eccentricity. While it appears to decreases at the greatest eccentricity, this may be due to a floor effect here on the car and clock d-primes. The absence of an interaction effect for d-primes over target category vs. presentation type likewise indicates that over all eccentricities, faces are influenced detrimentally by flankers, in a similar fashion to objects, and do not fully escape crowding effects. Thus, we conclude that there are two face advantage effects with possibly different eccentricity dependencies: a face advantage due to factors favoring face detection under single conditions, which increases with eccentricity, as well as an advantage in overcoming flanker effects, which may not.

Experiment 3

Experiment 2 indicates that single faces have a detection advantage over control targets. In addition, the relative face advantage was greater in the flanked than in the single condition, indicating that faces may have an additional advantage over other objects in crowded conditions, possibly enabling observers to examine more distracters simultaneously in face search than when searching for other objects. In both conditions of Experiment 2 there was an equal, but small, target location uncertainty; the target could appear either at the left or at the right position. In our third experiment, we investigate the face advantage in crowded conditions under greater target location uncertainty. Thus, our third experiment examines a possible face search advantage within a visual search array, when targets could appear anywhere within this array. Exposure time was again limited to preclude the possibility of eye movements. We placed face, car, dog face and clock targets at different eccentric positions from the central point of fixation and measured the face detection advantage.

Methods

Participants

A total of 24 subjects, of which eight were males, ranging in ages from 20 to 28, (average: 24) participated in Experiment 3. None of these subjects had participated in Experiment 1. Subjects were recruited from among the student body of the Hebrew University—19 subjects participated as part of the requirements for undergraduate studies, and were paid only for correct performance (see Procedure section), the remaining subjects were paid for both participation and performance. All subjects provided prior written consent to participate in the experiment and had normal or corrected-to-normal vision.

Stimuli

Stimuli were created from the same collections of 42 photographs each of clock faces, dog faces, cars and

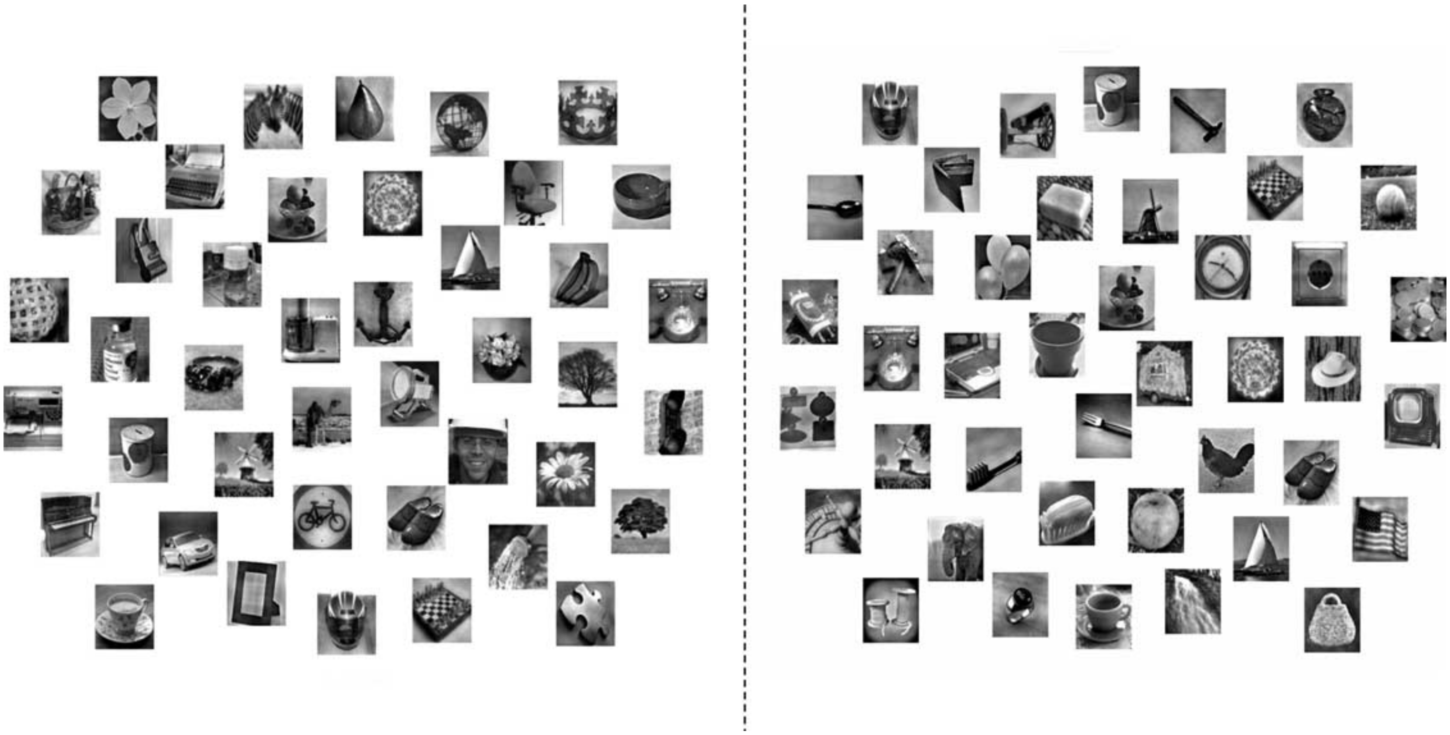

Figure 6. Examples of the stimuli used in Experiment 3. Face, car, dog face and clock targets could appear at each position in the visual search array. Eccentricities of each ring were as in Experiment 1 (see Table 1). Face present stimulus on the left, dog face present stimulus on the right.

faces, and 165 distracter photographs comprised of a wide variety of other objects. The photographs were cropped, gray-scaled, contrast-enhanced and equalized for Fourier amplitude as in Experiment 1.

In Experiment 3, target-present stimuli were composed of a target photograph of a human face, dog face, car or clock face embedded in an array of distracter images. Target absent stimuli contained only distracter images. Each stimulus included 42 images in all, arranged in four concentric circles around the center of fixation (Figure 6). Each individual photograph in this experiment measured 4.4° by 4.4°. Eccentricities of each ring were as in Experiment 1 (see Table 1).

Targets were placed with equal probability in each ring of the visual search array; this placement was pseudo-randomized so that the target appeared an equal number of times in each position of each ring. Targets appeared an equal number of times in all rings except for the fourth ring, which was added only to ensure equal stimulus density for the third ring, and therefore contained only a small number of catch trial targets.

Procedure

Procedure was as in Experiment 1; however stimulus duration for this experiment was 100 msec, and each block included 100 trials.

Results and discussion

In Experiment 3, subjects searched for face, dog face, clock face and car target photographs among heterogeneous distracters at varying eccentricities. Figure 7 shows

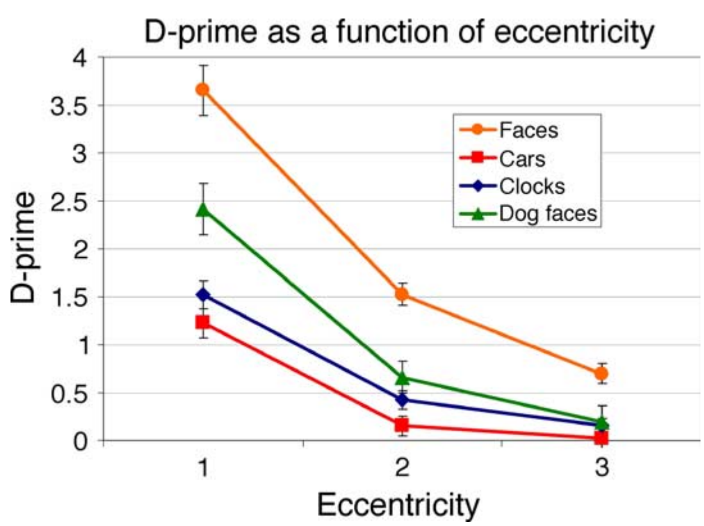

Figure 7. Experiment 3 performance (d′). Targets appeared within a search array. Performance decreased with increasing eccentricity. Face targets have a significant advantage over all three other target categories in this crowded condition.

the d′ values for the different target categories as a function of target eccentricity. Note that the false alarm rate for each eccentricity is taken globally as the experiment could not be blocked by eccentricity.

To analyze the face advantage, we performed a two way ANOVA with main factors of category and eccentricity with d′ as the dependent variable. Violation of sphericity was tested by Mauchly's test and, when necessary, the degrees of freedom were corrected using the Greenhouse–Geisser procedure. There was a significant main effect for both factors. In accordance with previous findings (Carrasco et al., 1995), detection performance decreased significantly with eccentricity ($F(1.5, 33.8) = 168.7$, $p < 0.01$, Greenhouse–Geisser corrected at E = 0.74). Subsequent analyses indicated that this was true for all target categories (face: $F(2, 69) = 75.0$, $p < 0.01$, car: $F(2, 69) = 26.9$, $p < 0.01$, dog: $F(2, 69) = 31.5$, $p < 0.01$, clock: $F(2, 69) = 40.9$, $p < 0.01$),. A significant main effect was found for the category factor ($F(3, 69) = 32.5$, $p < 0.01$), indicating certain categories were easier to detect than others. Bonferroni adjusted pair-wise comparisons showed that faces were significantly easier to detect than cars, clocks and dog faces (all at $p < 0.01$). Dog faces were significantly easier to detect than car targets ($p < 0.05$). There was a significant interaction effect ($F(3.8, 87.8) = 11.0$, $p < 0.01$, Greenhouse–Geisser corrected with E = 0.64), indicating that detection performance for faces deteriorated less rapidly with eccentricity than detection performance for the control targets. Post hoc analyses indicated the interaction was significant for the comparison of faces with cars ($F(2, 138) = 16.5$, $p < 0.01$) and for the comparison of faces with clocks ($F(2, 138) = 14.8$, $p < 0.01$).

We defined contrasts between faces and the other three categories presented at each ring to investigate how the face advantage over each other category changes with eccentricity. Results are shown in Table 3 and indicated that faces were significantly easier to detect than all control target categories at every eccentricity.

Next, we calculated the RFA for all combinations of eccentricity and other target category separately. Results are shown in Figure 8.

A two-way ANOVA analysis on the RFA measure over the factors of category (faces vs. cars, dogs and clocks)

	Cars		Dog faces		Clocks	
	$F(1, 23)$	p	$F(1, 23)$	p	$F(1, 23)$	p
Ring 1	61.8	0.001	14.3	0.002	55.1	0.001
Ring 2	82.9	0.001	43.4	0.001	79.7	0.001
Ring 3	14.4	0.001	12.1	0.003	19.1	0.001

Table 3. Detection performance contrasts between face and other target categories for each ring in the array condition. Critical alpha with Bonferroni correction = 0.004.

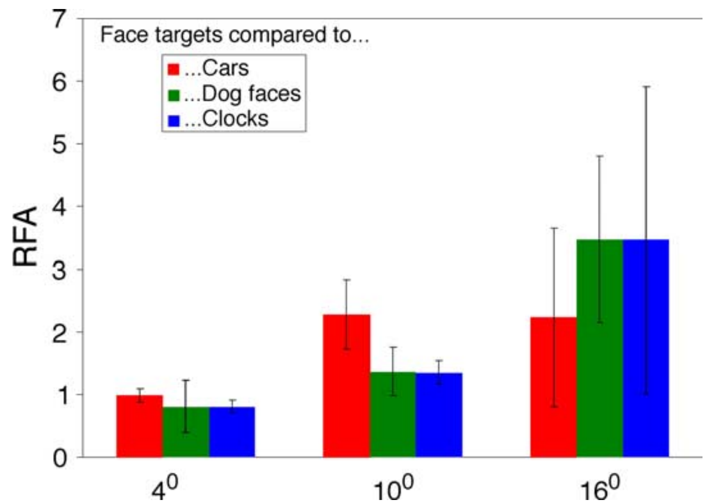

Figure 8. Normalized relative face advantage (RFA) for visual search with target location uncertainty (Experiment 3). The face advantage over all control categories remains, and the RFA again grows with eccentricity.

and eccentricity revealed a significant main effect of eccentricity ($F(1.1, 25.8) = 6.7$, $p < 0.05$, Greenhouse–Geisser corrected with E = 0.56), showing that the face advantage over all other target categories grows significantly with eccentricity. There was no significant main effect for category, and no significant interaction, indicating that the face advantage grows in a similar fashion over all control categories.

In this experiment, there is greater target location uncertainty than in the flanked condition of the previous experiment, where the target could only appear at one of two places; (actually there were 6 a priori locations where the target could appear, but this was narrowed down to two places upon stimulus presentation). In the current experiment, targets could appear at any one of 42 possible places. How does this influence the face advantage? We used 9 multiple independent samples Bonferroni corrected T-tests (3 eccentricities $\times$ 3 control target categories) to compare the relative face advantages calculated from this study with the advantages from the flanked condition in Experiment 2. None of these tests reached significance. This may be taken to indicate that this target location uncertainty does not cause an additional search advantage for face stimuli—however, one should keep in mind that there were small eccentricity differences (about 2.5 degrees) between these two experimental conditions. Further experimentation would be necessary to clarify whether this greater target location uncertainty does or does not cause a greater face detection advantage.

The results of this experiment indicate that under search conditions with target location uncertainty, faces again outperformed control targets. Interestingly, unlike in the single condition of Experiment 2, dog faces are harder to detect than faces at every eccentricity under the conditions of Experiment 3. The relative face advantage once more grows with eccentricity, similar to both the single and flanked conditions of Experiment 2.

General discussion

Previous studies have indicated that faces are fixated preferentially (Fletcher-Watson et al., 2008; Yarbus, 1967), while an RSVP go–no go centrally presented classification task and a similar change blindness task showed no advantage for face detection over control objects (Ro et al., 2001; Rousselet et al., 2003; but see Awh et al., 2004; Landau & Bentin, 2008, for counter evidence). Consideration of this evidence lead us to suggest faces might have a spatial detection advantage, facilitating their detection over other objects precisely when they are not fixated—a peripheral detection advantage. Our results show that such a peripheral detection advantage for faces indeed exists, and that it increases with eccentricity. Specifically, faces do not have an advantage when presented in isolation when there is no spatial uncertainty (except compared to cars). However, when there is a little (Experiment 2) or a lot (Experiment 3) of spatial uncertainty, then faces are identified more successfully in a brief flash than clocks, dog faces, or cars, and this benefit grows with eccentricity. Flanking stimuli (Experiment 2) make the effect more pronounced.

There has been some discussion in the literature on the causes of the face detection advantage over other objects (Cerf et al., 2008; Hershler & Hochstein, 2005, 2006; VanRullen, 2006). One considered alternative was the perceptual low-level salience of faces compared to the surrounding distracters. In as far as salience is defined as the perceptual difference between regions of the visual scene (e.g. Itti & Koch, 2001), this claim now seems increasingly unlikely, as a clear face detection advantage is present even in the total absence of surrounding distracters.

What then, causes this face advantage? The comparison of Experiment 1, in which we found no face advantage, and Experiments 2 and 3, in which a clear face advantage was present, points to some possible causes. Firstly, in Experiment 2, subjects were forced to spread attention over the visual field through the simultaneous display of two items, one in each hemifield, whereas in Experiment 1 only one stimulus was present in the visual field. The face advantage under spread attention might point to some attentional benefit for faces (Bindemann et al., 2005; Langton et al., 2008), although in a Posner paradigm face stimuli did not attract attention more than distracter stimuli (Bentin, unpublished data). In any case, an underlying question that needs to be answered is how faces would attract attention. For this to happen, the face stimulus needs to have some pre-attentive initial distinction from other stimuli. The results of Experiment 2 in which the relative face advantage grows with eccentricity, suggests the involvement of perceptual factors that are robust to the attenuation of high frequency information associated with peripheral vision (Goffaux & Rossion, 2006; Halit et al., 2006; Harel & Bentin, 2009). This, however, is not the only face advantage, as evidenced by the better detection of faces and dog faces over cars and clocks at the most central eccentricities tested in Experiment 2. A second difference between Experiments 1 and 2 was the presence of a mask in Experiment 2. As the Fourier spectra of our stimuli were equalized over frequencies, an interaction with our random noise mask that benefited only faces seems unlikely. Nevertheless, a closer investigation of masks that would effectively interfere with face detection may give good indications to the perceptual factors aiding face detection.

Another potential source of the face benefit is related to the relative sparing of face detection from detrimental crowding effects, as evidenced by the greater relative face advantage under flanked than under single conditions. This is an additional advantage; however, note that there was no interaction between target category and presentation type in Experiment 2, and no increase of the RFA with eccentricity in the flanked condition, which could be expected if the face advantage would have reflected a typical crowding effect. It thus seems that the perceptual factor aiding face detection is the main cause for the face advantage, and this advantage becomes even more pronounced in flanked conditions. This is especially true in the comparison of dog face and human face detection: In the single condition, dog face detection is equal to face detection at the two most central eccentricities, but in the flanked condition, face detection is easier than dog face detection at all eccentricities. In addition, the relative face advantage of faces over dogs in the flanked condition grows with eccentricity, suggesting faces benefit from some escape from crowding, but dog faces do not.

Similar to our results, other studies found that faces can escape detrimental flanker effects for tasks such as gender distinction or identification when the flanking objects are not faces, as was the case in our experiment (Loffler, Gordon, Wilkinson, Goren, & Wilson, 2005). However, when the flankers are other faces or face-like stimuli, faces do become subject to crowding effects, suggesting crowding can occur at different loci in the visual system (Farzin, Rivera, & Whitney, 2009; Loffler et al., 2005; Louie, Bressler, & Whitney, 2007).

The general face advantage in peripheral vision may influence the size of the window within which objects can be perceived when searching through an array; the presence of a face may be detected in larger groups and over larger areas than other objects. This advantage of larger search windows diminishes with time as the overlap with already-examined items increases, leading to an approximately exponential fit, with the exponent indicating the number of items perceived simultaneously (Hershler & Hochstein, 2009).

Why would faces withstand flanker effects better than other objects? In a generally accepted view of the visual hierarchy, object recognition is a two-step process; the independent detection of simple features, and the combination of these features into recognizable objects (e.g. Pelli & Tillman, 2008; Treisman & Gelade, 1980). This binding can be understood to occur through fixed-size hard-wired integration fields (Pelli, 2008) or through an interaction with attention (Intriligator & Cavanagh, 2001; Põder, 2006; Treisman & Gelade, 1980). Faces may be able to escape crowding influences through the use of a specialized face processing channel. This means that when this representation becomes activated, there is no need to resolve a binding conflict. Instead, the observed object is immediately classified as being a face.

Computational evidence indicates that human scan paths are better predicted by adding a face detection algorithm to a low-level salience detector, than by the salience detector alone, concurring with the hypothesis of an especially efficient face detection mechanism (Cerf et al., 2008). Specialized face mechanisms could come about in much the same way as other feature detectors are created; by the natural interaction with the visual world. Note, however, that these early mechanisms would not necessarily have to be "low level" mechanisms (Hochstein & Ahissar, 2002). The special status faces enjoy within our natural environment makes for a particularly strong imperative on the visual system to construct dedicated, efficient and robust face detection mechanisms. In addition, certain unique face features may make the creation of specialized face detectors especially easy, although some congenital preference for face-like stimuli is also indicated (Morton & Johnson, 1991). Our present results indicate such a specialized face detection mechanism may make better use of low-frequency information than overall object detection does.

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Commercial relationships: none.
Corresponding author: Orit Hershler.
Email: oritaron@gmail.com.
Address: Edmond J. Safra Campus and Mount Scopus Campus, Hebrew University, Jerusalem, Israel.

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