



## Capacity limits for face processing

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Received 28 January 2004; revised 12 October 2004; accepted 22 November 2004

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### Abstract

We present three experiments in which subjects were asked to make speeded sex judgements (Experiment 1) or semantic judgements (Experiments 2 and 3) to face targets and nonface items, while ignoring a solitary flanking distractor face or a nonface stimulus. Distractors could be either congruent (same response category) or incongruent (different response category) with the target. Distractor congruency effects were consistently observed in all combinations of target–distractor stimulus pairs, except when a distractor face flanked a target face. The failure to find congruency effects in this condition was explored further in a fourth experiment, in which four task-irrelevant flankers were simultaneously presented. Once again, no face–face congruency effects were found, even though comparison distractors interfered with face and nonface targets alike. However, four simultaneously presented distractor faces did not interfere with nonface targets either. We suggest that these experiments demonstrate a capacity limit for visual processing in these conditions, such that no more than one face is processed at a time.

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*Keywords:* Face; Capacity limit; Distractor

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### 1. Introduction

A central issue in the study of selective visual attention concerns the extent to which task-irrelevant stimuli are processed. One established technique of measuring such processing is target–distractor interference, in which responses to a task-relevant target stimulus can be affected by a simultaneously presented task-irrelevant distractor. To the extent that distractors are processed, target RTs are slowed by incongruent relative to

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congruent distractors. This *distractor interference* effect is highly robust, at least in situations of low perceptual load (e.g. when only one relevant stimulus is presented; see Lavie, 1995, 2000), and generalizes across various classes of target–distractor stimulus pairs (e.g. letter–letter, Eriksen & Eriksen, 1974; picture–word, Smith & Magee, 1980).

Although a great deal is known about selective attention, rather little is understood about how visual attention and face processing interact. This is remarkable as there is probably no other class of visual stimuli that can match the social and biological importance, and that has been studied as extensively as the human face (e.g. Bruce & Young, 1998; Young, 1998). This is also unfortunate as the role of selective attention may be imperative in understanding how the human brain processes faces. The experiments reported here sought to explore the relation between selective attention and face processing in target–distractor interference paradigms. Specifically, we examined whether responses to a target *face* can be affected by distractor *faces*.

A number of studies indicate that people may be unable to ignore irrelevant distractor faces (Jenkins, Burton, & Ellis, 2002; Lavie, Ro, & Russell, 2003; Young, Ellis, Flude, McWeeney, & Hay, 1986). Consequently, in a face–face interference task, one might expect the normal pattern of interference to occur, with target RTs varying as a function of distractor congruency. However, a few recent studies hint against this reasoning and suggest that face processing may be subject to capacity limits, such that only a single face can be processed at a time (Boutet & Chaudhuri, 2001; Jenkins, Lavie, & Driver, 2003; Palermo & Rhodes, 2002). If that is true, processing a target face may prevent the intrusion of a distractor face, thereby eliminating any congruency effects from that distractor.

To date, several studies have shown that irrelevant face distractors are processed reliably with a concurrently presented nonface target. Young et al. (1986) examined interference effects between simultaneously presented photographs and printed names of famous people. Using a semantic classification task (pop-star/politician), participants were required to classify either the face or the name whilst ignoring the distractor, which could be either congruent (e.g. same occupation) or incongruent (different occupation) with the target. Names reliably interfered with the classification of faces. More importantly, faces also interfered with the classification of name targets. Indeed, faces interfered more with names than names interfered with faces. Recently, Lavie et al. (2003) extended this paradigm to investigate the effect of task-relevant load on irrelevant distractor processing. According to Lavie's perceptual load theory of selective attention (Lavie, 1995, 2000), the processing of visual information proceeds automatically until available capacity is exhausted. Therefore, irrelevant information is excluded from processing when task-relevant, attended-to stimuli demand all available capacity. To provide a test for this theory with meaningful stimuli, Lavie et al. (2003) measured interference from a flanking distractor upon the classification of a central word or a famous name embedded among several letter strings. Perceptual load of the relevant task was manipulated by varying the number of strings in the interference displays. In accord with the load theory, congruency effects from meaningful nonface distractors, such as photographs of fruits and musical instruments, were eliminated by increasing relevant load. Intriguingly though, interference from famous face distractors was entirely unaffected by these load manipulations, leading Lavie et al. (2003) to suggest that face processing may proceed automatically, independent of target processing.

Comparable conclusions can be drawn from a study by Jenkins et al. (2002) in which an irrelevant famous face distractor showed equivalent repetition priming independent of variations in task-relevant load in a letter-string task, even though explicit memory for the faces was markedly affected by this manipulation. There have also been a number of reports of prosopagnosic patients who, despite being explicitly unable to recognise familiar faces, nevertheless show the normal pattern of interference from distractor faces, when asked to make semantic classifications of names (e.g. De Haan, Young, & Newcombe, 1987; Sergent & Signoret, 1992) and these findings have been used extensively to inform theories of covert recognition in prosopagnosia (Young & Burton, 1999). However, although all these results suggest that face processing is very robust across manipulations which should make it difficult, none imply that it is entirely capacity-free. Indeed, Lavie et al. (2003) suggest that face processing may be subject to its own capacity limits.<sup>1</sup>

So far, evidence for face processing limits has been rather indirect, and has accrued from studies that were not originally motivated by this issue. Palermo and Rhodes (2002) asked subjects to remember a centrally presented target face while matching two flanker faces. Memory for the central face was then assessed using a two-alternative recognition test, consisting of either two intact faces, the target and a foil image that differed from the target by one feature (e.g. a pair of eyes), or two exemplars of a particular feature, one of which was extracted from the target. Successfully matching the flanker faces resulted in better memory for intact targets than individual features, but only when the flanker faces were presented inverted, a finding that is consistent with the whole-to-part recognition advantage for faces studied under full attention (e.g. Tanaka & Farah, 1993). Conversely, matching upright flanker faces eliminated this advantage, suggesting a processing limit for upright, intact faces that is independent of resources for inverted face processing.

Using a different technique, Boutet and Chaudhuri (2001) observed perceptual rivalry of two upright overlapping faces, one rotated 45° clockwise and the other 45° counterclockwise, whereby only one of the faces could be retrieved at a subsequent recognition test. Two inverted faces, on the other hand, were perceived as an ambiguous combination of both, again suggesting a limit to the number of upright faces that can be processed. Finally, Jenkins et al. (2003) examined *dilution* of congruency effects in a famous name categorization task. They found that interference from a famous distractor face could be diluted by the presence of another (response-neutral) face, but not by phase-shifted faces,<sup>2</sup> inverted faces, or meaningful nonface objects. In other words, processing of

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<sup>1</sup> It is worth noting here that there is already considerable research contrasting face and nonface processing. This research suggests that faces are processed in a different, holistic manner to inverted faces and objects, in which individual features and the configuration of these features are not separable sources of information (see e.g. Tanaka & Farah, 1993; Tanaka & Sengco, 1997). Other evidence also suggests that faces are processed in a specialized brain region (e.g. Haxby, Hoffman, & Gobbini, 2000; Kanwisher, McDermott, & Chun, 1997). This brain region appears to be devoted to holistic processes primarily recruited by faces, but might also respond to some other homogeneous objects classes for which one has particular visual expertise (see e.g. Gauthier et al., 2003). However, although we turn to this topic briefly in the general discussion, note that the purpose of this paper is not to address the issues of face-specificity and expertise.

<sup>2</sup> These were phase-shifted or greatly scrambled versions of the face stimuli that were no longer recognizable as a face but provided matching low-level visual energies.

the distractor face seemed to be reduced by competition from an additional face, but not by general competition from different classes of stimuli.

The results of these studies, then, can be interpreted as initial evidence for capacity limits in (upright) face processing. However, some aspects of these data might also contradict this interpretation. Thus, recognition accuracy of the target faces still averaged between 70 and 80% in Palermo and Rhodes' (2002) study, even during the matching of two upright faces. This indicates that, on the majority of trials, the flanker faces *and* the target face in a display were processed. Yet, since these stimuli were displayed for a substantial duration ( $\geq 1.5$  s), and participants were required to match the peripheral flanker faces before encoding the central target, it is also possible that these faces were processed sequentially. Similarly, Boutet and Chaudhuri's (2001) findings with upright overlapping faces might reflect the recruitment of inhibitory mechanisms to suppress the representation of one of the two face targets to enable the accurate perception of the other, instead of the initial failure to process both. But, in the former case, this might again reflect serial rather than parallel face processing due to relatively long exposure times of 1 s. Note also that overlapping faces represent a hypothetical situation that the human face processing system is not confronted with outside the laboratory. This makes it difficult to specify exact capacity limits from these studies. Finally, although Jenkins et al. (2003) observed dilution of face distractor interference with a name target by the addition of another face distractor, name–face interference was not completely eliminated, suggesting that both distractors may have been subject to some processing. However, Jenkins et al. (2003) only measured *task-irrelevant* face processing in a name–face interference paradigm. Without taking resources attributed to task-relevant processing into account, this also makes it difficult to make a direct inference about capacity limits.

Thus, there is substantial evidence that task-irrelevant faces are processed even under difficult conditions, provided that only a single face is presented at a time, but there is also some mixed evidence to suggest that face processing may be capacity limited when more than a single face is presented. The main aim of the present study was to investigate whether such limits might apply in a target–distractor interference paradigm. If limits on face processing do apply, it is possible that responses to a target *face* might not be influenced by a distractor *face* after all, as the resources needed to process the distractor would already be engaged in processing the target. Given the remarkable generality of distractor interference effects, this strikes us as a somewhat counterintuitive prediction. Here we provide a direct test for this prediction over a series of four experiments.

## 2. Experiment 1

In this experiment, target–distractor interference was assessed with unfamiliar faces in a sex classification task. Sex judgements to faces can be performed quickly, reliably and without difficulty. Moreover, faces usually contain some salient external cues, such as hairstyle, that can be used to make sex decisions. Consequently, one might expect sex judgements to give rise to face–face interference. In order to examine this question, a variation of Young et al.'s (1986) task was used. Subjects were asked to classify stimuli presented at fixation as being male or female. These target stimuli were either photographs

of unfamiliar faces or printed four-letter forenames, and they were flanked by distractor images of faces or names. Processing of the distractor was assessed via its congruency effects on target RTs (i.e. same sex vs. different sex). Therefore, congruency effects were measured under four conditions. These conditions involved combining a face target and a face distractor (in the FACE–face condition), combining a face target and a name distractor (the FACE–name condition), combining a name target and a face distractor (the NAME–face condition), and combining two names (the NAME–name condition). If face processing is subject to capacity limits, processing a target face should prevent intrusion of a distractor face, eliminating congruency effects in that situation. Other target–distractor combinations should yield standard congruency effects.

### 2.1. Subjects

Thirty students from the University of Glasgow participated in the experiment in return for a small payment. All had normal or corrected to normal vision.

### 2.2. Design and stimuli

An Apple Macintosh computer was used to present stimuli and record responses, using PsyScope 1.2.5. Photographs of four unfamiliar female and four unfamiliar male models served as face stimuli. These images were cropped to remove extraneous background, but the outlines of all faces including differences in hairstyle were preserved. In addition, four four-letter printed female forenames (Anne, Kate, Lisa, and Mary) and four male forenames (Hugh, John, Paul, and Tony), shown in 36-point Times font, served as name stimuli. All face images were greyscale on a black background and measured 3.6 cm × 4.5 cm (subtending 3.4 × 4.3° of visual angle at a viewing distance of 60 cm). The names were printed white on black and measured between 2.4 cm (the shortest name) and 3.1 cm (the longest name) in width (2.3–3.0° of visual angle). These 16 images were used to construct stimulus displays containing a central target image (face or name), flanked by a distractor image (face or name) that could be congruent or incongruent with the target image. The nearest target–distractor contours were 1.25 cm apart (1.2° of visual angle; see Fig. 1). Distractors were equally likely to appear on the left or right of the target (this manipulation produced no reliable effects or interactions and is therefore not reported further below).

Pairing each of the 16 target stimuli with each class of distractor (face or name) under each level of congruency (same or different sex) resulted in a total of 64 displays. For displays in which target and distractor were the same type and sex (e.g. two male faces, or two male names), different images were used (see Fig. 1).

### 2.3. Procedure

Subjects viewed the displays at a distance of 60 cm, which was kept constant by means of a chin-rest. Each trial began with a fixation cross for 750 ms, followed by the target–distractor display for 200 ms, and ended with a blank interval until a response was made. Subjects were instructed to classify the target image as Male or Female, as quickly and as

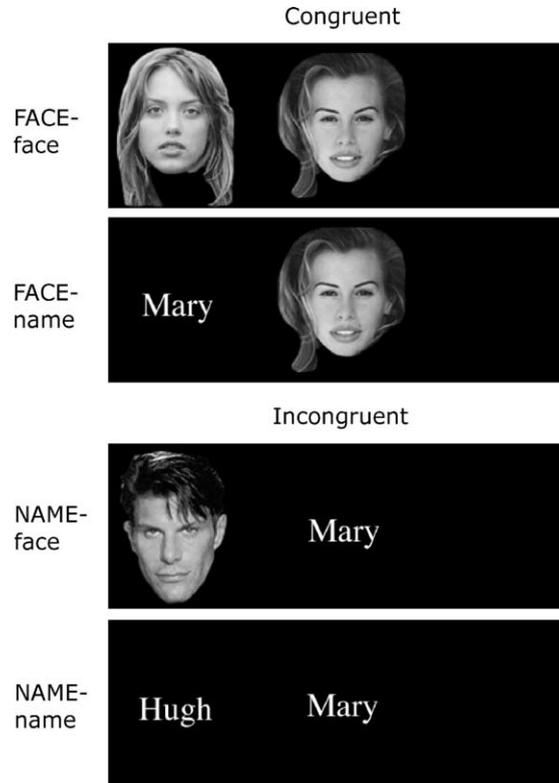


Fig. 1. Example displays from Experiment 1.

accurately as possible, while ignoring distractors. Feedback for errors was given immediately by a short warning tone. Button-press response latencies were measured from stimulus onset. Subjects completed one practice block of 32 trials and 6 experimental blocks of 64 randomly ordered trials, and could take short breaks between blocks.

#### 2.4. Results

Fig. 2 shows the means of the median correct RTs for all conditions. A 2 (face vs. name target)  $\times$  2 (face vs. name distractor)  $\times$  2 (congruent vs. incongruent) analysis of variance showed a significant main effect of Congruency,  $F(1,29)=23.31$ ,  $P < .01$ , with slower responses to incongruent displays, and a main effect of Target type,  $F(1,29)=32.51$ ,  $P < .01$ , with faster responses to face targets than to name targets, but no main effect of Distractor Type,  $F(1,29) < 1$ . The effect of Target type was modified by an interaction with Distractor type,  $F(1,29)=6.02$ ,  $P < .05$ , an interaction with Congruency,  $F(1,29)=7.73$ ,  $P < .01$ , and a three-way interaction between all factors,  $F(1,29)=5.48$ ,  $P < .05$ . As Fig. 2 suggests, analysis of simple main effects revealed significant congruency effects in the FACE–name condition,  $F(1,29)=4.52$ ,  $P < .05$ , the NAME–face condition,  $F(1,29)=16.06$ ,

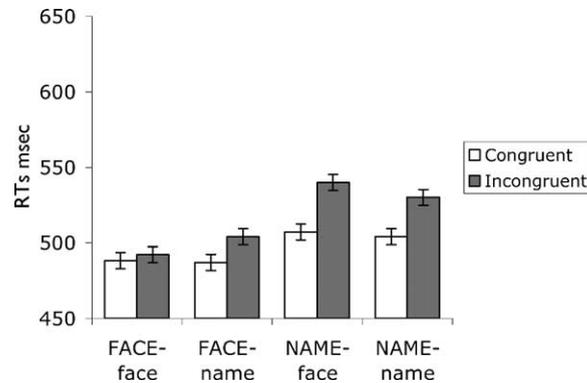


Fig. 2. Means of median RTs (in ms) for classifying target images as male or female in Experiment 1. Vertical bars represent the standard error of the means and are based on within-participant variability (see Loftus & Masson, 1994).

$P < .01$ , and the NAME–name condition,  $F(1,29) = 9.62$ ,  $P < .01$ . In contrast, there was no effect in the FACE–face condition,  $F(1,29) < 1$ .

Error rates were analysed as the RT data. Incongruent displays resulted in a slight increase in errors in the NAME–face (incongruent 8%, congruent 4%), and NAME–name conditions (6 vs. 5%), but no corresponding increase in the FACE–face (3 vs. 3%), or FACE–name conditions (4 vs. 4%). ANOVA showed a significant main effect of Congruency,  $F(1,29) = 9.91$ ,  $P < .01$ , a main effect of Target type,  $F(1,29) = 23.03$ ,  $P < .01$ , and an interaction of Target type with Distractor type  $F(1,29) = 6.67$ ,  $P < .05$ . In addition, a significant congruency effect was found in the NAME–face condition,  $F(1,29) = 32.56$ ,  $P < .01$ . No other comparisons were significant.

## 2.5. Discussion

These results show an intriguing pattern as distractor congruency effects were observed in all combinations of stimuli, except when a target face was flanked by a distractor face. Therefore, faces can, in general, act as distractors: in fact the largest congruency effect was in the condition in which a target name is flanked by a distractor face (see Fig. 2). Similarly, target faces can be subject to congruency effects, as exerted here by name distractors. Moreover, the observed distractor extinction does not seem to be a generalised within-category phenomenon, as distractor names exerted normal congruency effects on target names.

We interpret this data as evidence for a processing limit for faces in these conditions, such that processing a face target prevents simultaneous access to facial sex information from a flanking distractor. However, the absence of face–face interference in a sex classification task is nonetheless surprising, as the face stimuli preserved salient external sex-cues such as hairstyle. On the basis of such cues, irrelevant faces could have been classified even without processing actual face-information. Thus, these data suggest that the processing of an attended-to face target prevents the processing of all sex-related information from an additional irrelevant face, including even salient external features.

### 3. Experiment 2

Experiment 1 provides initial evidence for face processing limits in a target–distractor interference paradigm. Experiment 2 was designed to replicate the pattern of results of Experiment 1, and to extend these findings to a semantic classification task. Unlike the sex decisions of Experiment 1, the retrieval of semantic information requires access to a person’s identity, thus providing a test for another category of facial information (e.g. Bruce & Young, 1986; Burton, Bruce, & Hancock, 1999; Burton, Bruce, & Johnston, 1990). Moreover, previous studies examining NAME–face interference have typically used semantic decisions, such as occupational judgements, to assess task-irrelevant face processing (Jenkins et al., 2003; Lavie et al., 2003; Young et al., 1986). In fact, Lavie et al. (2003) showed, using this type judgement, that face distractors affect name classification even under conditions that do not normally allow for distractor interference. Thus, if the absence of face–face interference that was observed in Experiment 1 persists with a semantic task, then this would provide further evidence for face processing limits in this type of paradigm.

#### 3.1. Subjects

Thirty students from the University of Glasgow participated in the experiment in return for a small payment. All had normal or corrected to normal vision by self-report.

#### 3.2. Stimuli and procedure

The procedure was identical to that of Experiment 1, except that the decision to be made was whether the targets (faces or names) were pop-stars or politicians. The surnames and faces of four male pop-stars (Kurt Cobain, Eminem, Michael Jackson, and Elvis Presley) and four male politicians (George Bush, Bill Clinton, Colin Powell, and Donald Rumsfeld) served as stimuli. All images were presented in greyscale at a size of 3.6 cm × 4.5 cm (subtending 3.4 × 4.3° of visual angle). The face images were cropped to remove extraneous background, but hairstyle and face outline remained intact. The surnames were shown in 18-point Arial font, measuring between 1.7 and 2.9 cm in width (1.6–2.8° of visual angle). As in Experiment 1, these images were used to construct stimulus displays containing a central target face or target name, flanked by a face or a name distractor. Distractors were presented at least 1.25 cm (1.2° of visual angle) from the nearest target contours and were equally likely to appear left or right of the target (see Fig. 3).

Combining each of the 16 stimuli with each class of distractor under two levels of congruency (same or different occupation) resulted in 64 displays. For displays in which the target and distractor were the same type and occupation (e.g. the faces of two pop-stars), different images were used.

#### 3.3. Results

Fig. 4 shows the means of the median correct RTs for all conditions. As before a 2 (face vs. name target) × 2 (face vs. name distractor) × 2 (congruent vs. incongruent) ANOVA

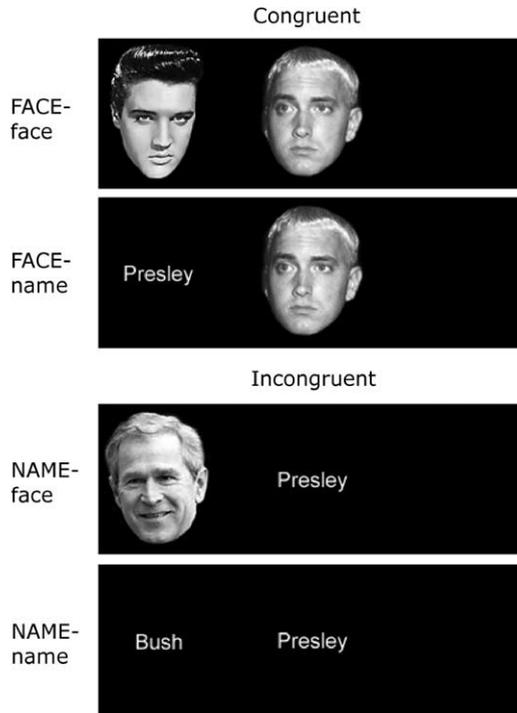


Fig. 3. Example displays from Experiment 2.

showed a main effect of Congruency,  $F(1,29)=42.36, P<.01$ , with slower responses to incongruent vs. congruent targets, and a main effect of Target type,  $F(1,29)=26.02, P<.01$ , with faster responses to face targets. In addition, a main effect of Distractor type was found,  $F(1,29)=4.89, P>.05$ , reflecting slower responses to displays containing face distractors than displays with name distractors. These main effects were modified by

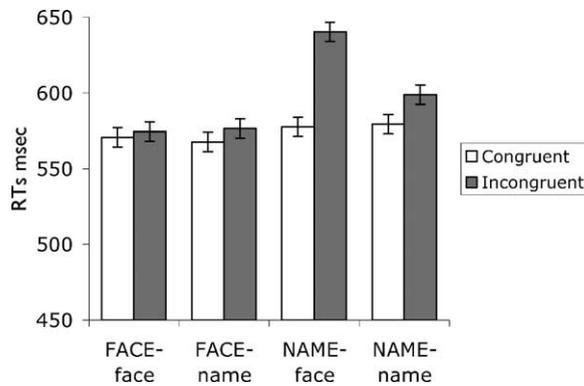


Fig. 4. Means of median RTs (in ms) for classifying target images as pop-stars or politicians in Experiment 2. Vertical bars represent the standard error of the means.

two-way interactions between each of the factors (Target type  $\times$  Distractor type,  $F(1,29) = 13.96$ ,  $P < .01$ ; Target type  $\times$  Congruency,  $F(1,29) = 33.47$ ,  $P < .01$ ; and Distractor type  $\times$  Congruency,  $F(1,29) = 8.09$ ,  $P < .01$ ), and a three-way interaction between all factors,  $F(1,29) = 17.53$ ,  $P < .01$ . As can be seen from Fig. 4, simple main effects analysis revealed significant congruency effects in the NAME–face condition,  $F(1,29) = 74.32$ ,  $P < .01$ , and the NAME–name condition,  $F(1,29) = 7.19$ ,  $P < .05$ . However, there were no congruency effects in the FACE–face,  $F(1,29) < 1$ , or the FACE–name condition,  $F(1,29) = 1.47$ .

An analogous analysis of the error rates was carried out. Incongruent displays resulted in an increase in errors in the FACE–name (incongruent 5%, congruent 3%), the NAME–face (13 vs. 6%), and the NAME–name condition (7 vs. 6%). However, no corresponding increase was observed in the FACE–face condition (4 vs. 4%). ANOVA revealed main effects of Congruency,  $F(1,29) = 33.39$ ,  $P < .01$ , Target type,  $F(1,29) = 28.01$ ,  $P < .01$ , and Distractor type,  $F(1,29) = 7.01$ ,  $P < .05$ . As for the RTs, there were also interactions between each of the factors [Target type  $\times$  Distractor type,  $F(1,29) = 20.41$ ,  $P < .01$ ; Target type  $\times$  Congruency,  $F(1,29) = 15.27$ ,  $P < .01$ ; and Distractor type  $\times$  Congruency,  $F(1,29) = 6.22$ ,  $P < .05$ ], and a three-way interaction between all factors,  $F(1,29) = 22.28$ ,  $P < .01$ . Significant congruency effects were found in the FACE–name,  $F(1,29) = 4.45$ ,  $P < .05$ , and NAME–face conditions,  $F(1,29) = 67.22$ ,  $P < .01$ . No other comparisons were significant ( $F < 1$ ).

### 3.4. Discussion

This experiment replicates some of the important aspects of Experiment 1 with a semantic decision, which, unlike the sex decision, requires the identification of the face stimuli. As before, the FACE–face condition failed to yield a congruency effect. This was contrasted by a reliable congruency effect in the NAME–face condition, which indicates that irrelevant faces can nonetheless act as distractors when a semantic task is used. This RT pattern is consistent with the idea that face processing is capacity limited under these circumstances. Furthermore, the congruency effect between name targets and name distractors was also replicated, suggesting that famous names, like the four-letter forenames that were used in the previous task, are not subject to analogous capacity limits within this paradigm. However, unlike the sex classification task of Experiment 1, the semantic decision failed to yield a reliable congruency effect when a face target was flanked by a name distractor (a 9 ms trend in this direction did not approach significance). While the RTs failed to show reliable distractor interference in the FACE–name condition, a significant congruency effect in error rates was found. This alone, however, does not support parallel processing of face target and name distractor. Alternatively, it might represent attentional shifts to the distractor locations, which may have enhanced distractor processing to the detriment of accurate target classification.

In line with the present RT pattern, previous studies also obtained less, albeit significant, interference from name distractors during face classification than from face distractors during name classification (Young et al., 1986). Young et al. (1986) suggested that this pattern emerges from the encoding of visual information, whereby faces may be encoded into a form that particularly suits categorization tasks in contrast to names, which may be encoded for naming tasks. Indeed, in naming tasks names do seem to interfere

more with faces than vice versa (Young et al., 1986). An ‘encoding’ explanation could also account for the difference between the FACE–name condition, where faces may have had an encoding advantage, and the NAME–name condition, in which target and distractor were subject to the same processes, in the present experiments. However, according to this explanation, it is still difficult to see why name distractors should interfere with face targets in Experiment 1, as well as in previous studies (Young et al., 1986), but not in Experiment 2.

In contrast to Young et al. (1986), who presented target *and* distractor quite centrally, the distractors always appeared in the periphery in this experiment, clearly separated from the target. Although this arrangement was designed to avoid target–distractor confusion, numerous studies have shown that interference can be significantly reduced by increasing spatial separation between a target and a distractor (e.g. Gatti & Egeth, 1978; Hagenaar & Van der Heijden, 1986; Merikle & Gorewicz, 1979), an effect that is at least partly due to a loss of visual acuity (see e.g. Anstis, 1974; Curcio & Allen, 1990). In the present experiments, any influence of spatial segregation may have been sufficient to eliminate FACE–name interference in Experiment 2 but not in Experiment 1, where the use of a greater font-size may have posed fewer demands on visual acuity. Therefore, an explanation for the absence of FACE–name interference in Experiment 2 could lie in a combination of factors such as the encoding of the different stimulus types, the spatial segregation between target and distractor, and distractor size. Nevertheless, the result of Experiment 2 remains potentially problematic as it raises the possibility that the absence of face–face interference does not reflect face-processing limits in these circumstances, but rather that the famous face targets may not have been subject to any distractor interference at all in the current task. This is explored more thoroughly in the next experiment.

#### 4. Experiment 3

The purpose of Experiment 3 was two-fold. The first aim was again to replicate the interference pattern observed in Experiment 1 with a semantic task, in particular to produce distractor-congruency effects onto famous face targets. The second aim was to examine whether nonface stimuli other than names are subject to interference within this paradigm. To provide an analogue to the semantic task in Experiment 2, images of national flags were used as nonface comparisons and subjects were asked to classify the face and flag targets as being American or British.

##### 4.1. Subjects

Twenty students from the University of Glasgow participated in the experiment in return for a small payment. All had normal or corrected to normal vision by self-report.

##### 4.2. Stimuli and procedure

The procedure was the same as the previous experiments, except that the subjects were instructed to classify the targets as American or British. Three different images each of

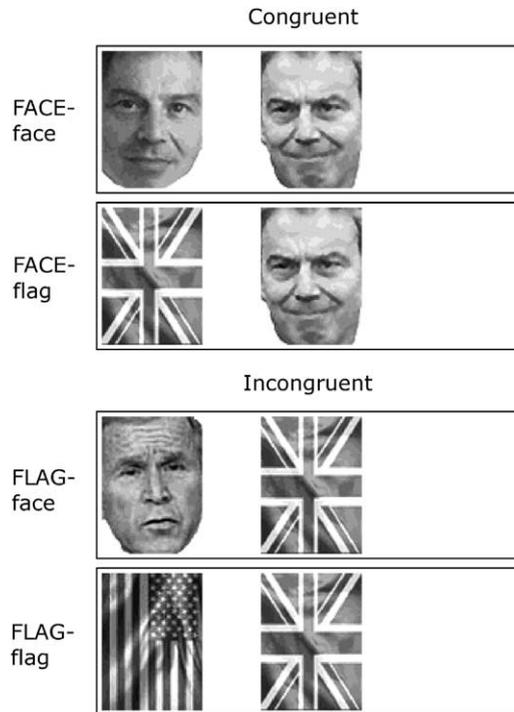


Fig. 5. Example displays from Experiment 3.

Tony Blair (British Prime Minister), George Bush (American President), the Union Jack (British flag), and the Stars and Stripes (American flag) served as stimuli. All images were greyscale at a size of 2.2 cm × 3.0 cm (subtending 2.1 × 2.9° of visual angle). These images were used to construct the stimulus displays as in previous experiments (see Fig. 5). Pairing each of the 12 target stimuli with each class of distractor (face or flag) under each level of congruency (same or different nationality) resulted in 48 displays. All subjects completed one practice block and 8 experimental blocks of 48 randomly ordered trials.

#### 4.3. Results

As for the previous experiments, the means of the median correct RTs were calculated for all conditions and are shown in Fig. 6. A 2 (face vs. flag target) × 2 (face vs. flag distractor) × 2 (congruent vs. incongruent) ANOVA showed a significant main effect of Congruency,  $F(1,19) = 21.29$ ,  $P < .01$ , with slower RTs to incongruent displays, but no main effects of Target type,  $F(1,19) < 1$ , or Distractor type,  $F(1,19) = 1.09$ . The effect of congruency was modified by an interaction with Target type,  $F(1,19) = 6.94$ ,  $P < .05$ . As Fig. 6 suggests, significant congruency effects were found in the FACE–flag condition,  $F(1,19) = 5.21$ ,  $P < .05$ , the FLAG–face condition,  $F(1,19) = 27.71$ ,  $P < .01$ ,

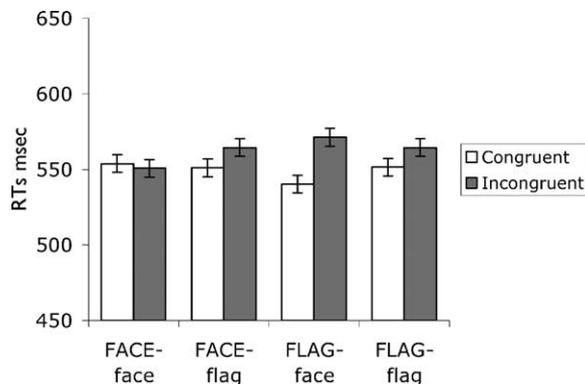


Fig. 6. Means of median RTs (in ms) for classifying target images as British or American in Experiment 3. Vertical bars represent the standard error of the means.

and the FLAG–flag condition  $F(1,19) = 4.82, P < .05$ . In contrast, there was no effect in the FACE–face condition,  $F(1,19) < 1$ .

Error rates mirrored the RT data. Incongruent displays resulted in an increase in errors in the FACE–flag (incongruent 7%, congruent 5%), FLAG–face (8 vs. 5%), and FLAG–flag conditions (7 vs. 4%), but no corresponding increase in the FACE–face condition (4 vs. 5%). ANOVA showed a significant main effect of Congruency,  $F(1,19) = 4.60, P < .05$ , and an interaction between Target type with Distractor type ( $F(1,19) = 6.70, P < .05$ ). No other comparisons were significant.

#### 4.4. Discussion

As in Experiment 2, no evidence of distractor processing was found in the FACE–face condition. Notably, however, in this study face stimuli did interfere with target classification in the FLAG–face condition and were subject to distractor interference as task-relevant targets in the FACE–flag condition. In addition, as in previous experiments our nonface comparison stimuli, in this case, images of flags, displayed reliable within-category interference. These results replicate the pattern that was observed in Experiment 1 and fully extend these findings from a sex decision to a semantic task.

### 5. Experiment 4

To provide a stronger test of the claim that distractor faces do not influence target face processing, we conducted a further study, in which the number of distractors was increased to four (thus increasing four-fold the total amount of congruent or incongruent information in each display). If multiple faces can be processed simultaneously one might expect this to boost any influence of the distractors (see e.g. Eriksen & Hoffman, 1973), leading to measurable congruency effects where none were previously found.

### 5.1. Subjects

Twenty-two students from the University of Glasgow participated in the experiment in return for a small payment. All had normal or corrected to normal vision by self-report.

### 5.2. Stimuli and procedure

These were the same as in Experiment 3, except for the following changes. The former single distractors were replaced by four distractors, positioned around the central target to form a “+” configuration (see Fig. 7). The nearest distractor contours were approximately 1.0 cm ( $1.0^\circ$  of visual angle) horizontally, and 0.9 cm ( $0.9^\circ$  of visual angle) vertically from the target. Twenty celebrities’ faces (10 British, 10 American) and 20 flags (10 British, 10 American) were used as stimuli. In each flanker display, all four distractors were of the same nationality (e.g. four American faces). The faces were drawn from five occupational categories (pop-star, politician, sports-star, comedian, movie-star), so that no occupation occurred more than once in any face display (see Fig. 7). Faces were presented with their external features (i.e. hair, face outline) and the flags were cropped to elliptical shapes in order to produce a closer resemblance between the flag and face outlines (see Fig. 7). Faces and objects measured between 2.1–2.4 cm horizontally and 2.5–3.2 cm vertically ( $2.0\text{--}2.3^\circ \times 2.4\text{--}3.1^\circ$  of visual angle).

Combining each of the 40 targets with congruent and incongruent distractors, under two levels of distractor type, resulted in a total of 160 stimuli. Each subject completed a practice block of 40 trials, followed by eight experimental blocks of 80 trials. Therefore, over the eight experimental blocks each stimulus display was encountered a total of four times. Each condition was equally likely to occur in each block and trial order was randomised separately for all blocks.



Fig. 7. Example displays from Experiment 4.

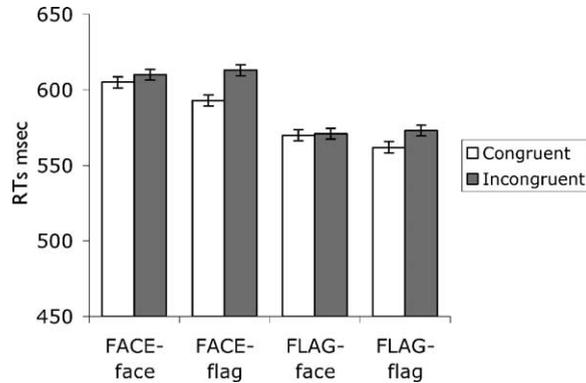


Fig. 8. Means of median RTs (in ms) for classifying target images as British or American in Experiment 4. Vertical bars represent the standard error of the means.

### 5.3. Results and discussion

Fig. 8 shows the means of median correct RTs for all conditions. A 2 (face vs. flag targets)  $\times$  2 (face vs. flag distractors)  $\times$  2 (congruent vs. incongruent) ANOVA revealed a significant main effect of Congruency,  $F(1,21)=26.00$ ,  $P<.01$ , with slower responses to incongruent displays, and a main effect of Target type,  $F(1,21)=56.39$ ,  $P<.01$ , with faster responses to flag targets. These effects were modified by interactions between Target type and Congruency,  $F(1,21)=4.87$ ,  $P<.05$ , and between Distractor type and Congruency,  $F(1,21)=8.77$ ,  $P<.01$ . As Fig. 8 suggests, significant congruency effects were found in the FACE–flag,  $F(1,21)=30.54$ ,  $P<.01$ , and FLAG–flag conditions,  $F(1,21)=9.35$ ,  $P<.01$ , but not in the FLAG–face,  $F(1,21)<1$ , or FACE–face conditions,  $F(1,21)=1.72$ .

Error rates followed a similar pattern. Incongruent displays showed increased errors in the FACE–flag (incongruent 8%, congruent 5%) and the FLAG–flag conditions (6 vs. 4%), but not in the FACE–face (6 vs. 6%) or the FLAG–face conditions (6 vs. 7%). Main effects of Target type,  $F(1,21)=3.99$ ,  $P=.06$ , and Distractor type,  $F(1,21)=3.78$ ,  $P=.07$ , were not statistically reliable but approached significance. In addition, a Target type  $\times$  Distractor type interaction,  $F(1,21)=7.18$ ,  $P<.05$ , and a Distractor type  $\times$  Congruency interaction,  $F(1,21)=8.32$ ,  $P<.01$ , were found. However, only one congruency effect, in the FACE–flag condition, reached significance,  $F(1,21)=6.57$ ,  $P<.05$ . No other comparisons were significant.

### 5.4. Discussion

Despite a four-fold increase in the amount of potentially distracting information present, distractor faces were still unable to influence responses to target faces. Moreover, we now have the additional finding that *multiple* face distractors fail to produce congruency effects, even onto target *flags* (cf. Experiment 3). In contrast, multiple flag distractors exerted congruency effects upon flag targets and face targets alike. The absence

of interference from face distractors onto nonface targets under conditions in which multiple flag distractors produce reliable congruency effects is perhaps surprising, in particular as the processing of just a single of the four face distractors could have been used to produce the same, reliable face–nonface interference of previous experiments. A possible explanation for this finding is that multiple faces may compete for limited face processing resources (see e.g. Ro, Russell, & Lavie, 2001; Vuilleumier, 2000 for such claims), whereby competition may remain unresolved between several equally task-irrelevant competitors. We return to a fuller discussion of these findings in the general discussion, though before we do so, it is worth considering other potential explanations for these results.

Experiment 4 used a substantially larger number of stimuli than the previous experiments. It is therefore possible that the particular face stimuli chosen were not sufficiently highly associated with the response category (nationality) to produce FLAG–face (and FACE–face) interference. Similarly, although different images were used for the concurrently presented flag distractors, the four flags in a display were always of the same identity (i.e. four Union Jacks) whereas the face distractors represented four different individuals. It seems also likely that flags possess some salient stimulus characteristics for a nationality task that faces cannot match, for example, the simple presence (American flags) or absence (British flags) of stars. Thus, there are a number of factors that could account for the failure to find FLAG–face interference. In fact, target RTs were slightly faster to flags than to faces in this experiment, suggesting that it was generally more difficult to classify faces than the flags. On the other hand, the face images consisted of well-known celebrities and as targets these faces were still classified quickly according to their nationality and with few errors. Moreover, although flags were classified faster as targets than faces in Experiment 4, name distractors also interfered with slow name targets and fast face targets in Experiment 1 (main effect of Target type,  $P < .01$ ; for similar findings see Young et al., 1986). Indeed, the consistency of results across Experiments 1–3 provides at least suggestive evidence that these results might require explanation in terms of face processing limits and competition between multiple distractors.

## 6. General discussion

The present studies were designed to investigate whether responses to a face target can be affected by a concurrently presented distractor face in an interference paradigm. In Experiment 1, participants made a sex decision to faces or forenames, while ignoring a peripheral name or face distractor. Subsequent experiments repeated this design with famous faces and famous names (Experiment 2), and famous faces and images of national flags (Experiment 3) in a semantic classification task. In these experiments, distractor processing was assessed via its congruency effects on target RTs (e.g. same vs. different sex in Experiment 1). Fig. 9 shows a summary of the target–distractor congruency effects of Experiments 1–3. In all three experiments, the FACE–face condition failed to produce a reliable congruency effect. However, this intriguing absence of distractor interference was not because face targets cannot be subject to interference. Indeed, nonface distractors consistently interfered with face classification in Experiments 1 and 3. Similarly,

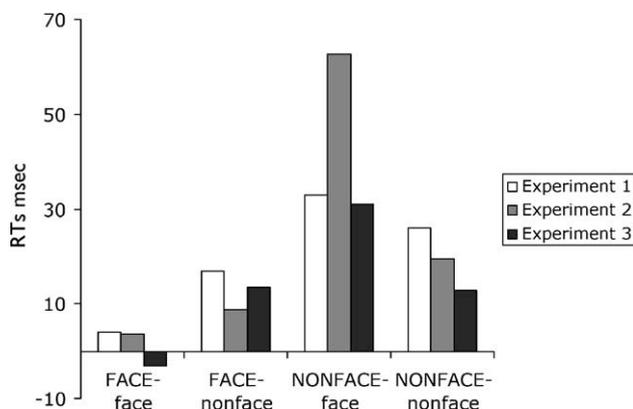


Fig. 9. Summary of the target–distractor congruency effects (incongruent minus congruent RTs, in ms) of Experiments 1–3.

the absence of distractor interference in the FACE–face condition was not because face distractors cannot interfere with target classification, as single face distractors produced significant congruency effects with the nonface targets in all three experiments. Additionally, in contrast to the FACE–face condition all of the nonface comparisons produced reliable within-category interference. In a fourth experiment, the number of distractors was increased to four to boost irrelevant information. As in the previous experiments, no congruency effects were observed between face distractors and face targets (see Fig. 8). In this case, however, the multiple face distractors also failed to interfere with the classification of nonface targets (images of flags).

We interpret these novel distractor extinction effects as evidence that face processing may be subject to capacity limits in these interference tasks, such that only a single face can be processed at a time. A number of previous studies have already suggested capacity limits for face processing (Boutet & Chaudhuri, 2001; Jenkins et al., 2003; Palermo & Rhodes, 2002). However, these studies used very different approaches to the experiments reported here. Boutet and Chaudhuri (2001) used overlapping faces, a hypothetical situation that our face processing system is not confronted with outside the laboratory, while the present studies measured the processing of spatially distinct faces. Palermo and Rhodes (2002) used displays of three faces presented substantially longer ( $\geq 1.5$  s) than the two faces in the present experiments (i.e. 200 ms), and required participants to match two peripheral faces before encoding a central target. Under those conditions, it is likely that the three faces were processed sequentially and, consequently, an exact limit in face processing is again difficult to specify. In contrast, Jenkins et al. (2003) only measured *task-irrelevant* face processing in a NAME–face interference paradigm. Without taking resources attributed to task-relevant processing into account, this also makes it difficult to make a direct inference about capacity limits. Consequently, we believe that the present findings add a substantial new set of data in support of the notion that face processing may be capacity limited.

In spite of these findings, the exact locus of any bottleneck in face processing remains difficult to specify. The present results indicate only that sex and semantic information, and hence presumably also facial identity, is not extracted from a task-irrelevant face when attention is directed at a face target. However, it remains possible that these distractors may have been subject to *some* processing. Indeed, given that flags and names interfered with face targets in Experiments 1 and 2, it seems likely that the extinguished face distractors also registered at some level. This notion receives further support from Experiment 4, where *multiple* face distractors not only failed to interfere with the classification of our face targets but also the nonface targets, images of flags. The absence of FLAG–face interference in Experiment 4 is particularly striking given the strong nonface–face interference of previous experiments. In fact, in Experiments 1–3, face distractors consistently interfered more with the categorization of names and flags, than with faces. As discussed earlier, this pattern has previously been attributed to the encoding of visual information, whereby faces may be encoded into a form that particularly suits semantic categorization tasks (Young et al., 1986). However, according to this explanation it is difficult to see why faces should interfere more with flags in the nationality task in Experiment 3 than flags interfered with faces. If anything, one might expect flags to be coded into nationality more readily than faces.

In contrast, it is conceivable that a single face distractor produces more interference than a nonface distractor in Experiments 1–3 (onto nonface targets) for the same reason that multiple face distractors fail to interfere with a nonface target in Experiment 4. There have been numerous claims that faces may be particularly good at *capturing* attention (e.g. Ro et al., 2001; Vuilleumier, 2000; but see also Palermo & Rhodes, 2003). If this is so, one might expect solitary face distractors to interfere more strongly with relevant nonface processing by drawing processing resources to the distractor location. On the other hand, if competition for such resources remains unresolved between several simultaneous inputs of equal status, such as the four task-irrelevant face distractors in Experiment 4, then this could extinguish face distractor interference even with a nonface target. Crucially, this would imply that the multiple face distractors were processed as faces at some level, otherwise they would not be in competition with each other.

The extent to which distractor faces are processed could be examined further by assessing face detection in multi-item displays or by measuring repetition priming or negative priming under conditions known to reveal capacity limits. Indeed, evidence from negative priming studies suggests that visual stimuli may still be processed in the absence of any target–distractor interference (e.g. Driver & Tipper, 1989; Mari-Beffa, Estevez, & Danziger, 2000). Thus, it is possible that the distractors of the FACE–face condition were processed to an extent that might be detected using other techniques. In fact, in one study face distractors produced negative priming during a face matching task, which could imply that distractors and targets were processed simultaneously at some level (Khurana, 2000). Alternatively, as stimulus displays were presented for a substantial duration, until a response was made, target and distractor faces may have been processed sequentially. On a related point, note also that the present study only demonstrates absence of interference when subjects are instructed to ignore the distractor. This does not necessarily imply that it would be impossible to process two faces simultaneously if instructed to do so. Given these caveats, it is clear that further research is needed to establish whether the apparent

capacity limits observed in our experiments generalise more broadly to a range of different techniques.

One other aspect of our findings merits discussion. Previous studies suggesting face-processing limits observed different patterns for upright and inverted faces (Boutet & Chaudhuri, 2001; Jenkins et al., 2003; Palermo & Rhodes, 2002), implying a limit specifically for upright face processing. Similarly, others report that the processing of an irrelevant face seems unaffected by variations in task-relevant processing load of nonface stimuli (Jenkins et al., 2002; Lavie et al., 2003), again suggesting a face-processing capacity limit. Our results converge with these suggestions by demonstrating capacity limits in face-processing under conditions that normally allow distractor processing. As in previous studies, a single face distractor was consistently processed alongside a nonface target in Experiments 1–3. Moreover, none of our nonface comparison stimuli (forenames, famous surnames, and images of national flags) displayed analogous processing limits. However, it is worth emphasizing that the present experiments were not designed to examine the issue of face-specificity. In fact, an alternative explanation could seek to avoid the notion of face-specific processing limits altogether, by instead appealing to more general processing limits (e.g. Lavie, 1995, 2000). Thus it is conceivable that the processing of faces, which are a visually complex and homogeneous category of stimuli, is simply more demanding of *general* resources than processing printed names and flags. If so, two faces might exceed general processing capacity, even when two flags or two names, or a face and a flag/name, do not. Note, however, that Jenkins et al. (2003) reported that an intact, irrelevant face produced no more dilution of object word interference than did a phase-shifted face. If faces are simply a disproportionate drain of general resources, it is hard to see why this should be so; one might expect disproportionate dilution in that situation.

To pursue this issue further, it is quite possible that the present processing limits do not apply only to faces, but in fact reflect holistic processing associated with a high level of expertise for a particular class of stimulus. It is widely held that faces are processed as holistic gestalts, in which information about individual features and the spatial relationship of these features are not separable sources of information (see e.g. Tanaka & Farah, 1993; Tanaka & Sengco, 1997). Many researchers argue that face processing is more dependent on holistic information than other stimulus categories (e.g. Carey & Diamond, 1977; Diamond & Carey, 1986; Tanaka & Farah, 1993; Yin, 1969), but at least some types of objects for which we possess a high level of visual expertise appear capable of engaging similar holistic processes (see e.g. Gauthier & Logothetis, 2000; Gauthier & Tarr, 1997). One might thus expect such visual stimuli to be subject to comparable processing limits. Indeed, one recent study suggests that car experts draw on the same processing resources for faces *and* car stimuli when these are presented in a sequential matching paradigm (Gauthier, Curran, Curby, & Collins, 2003). As we have already emphasized, the results in this paper do not address this question at all, and of course it is possible that other classes of stimuli will show similar patterns in an interference task. Nevertheless, we believe that the demonstration of limited capacity processing *for faces* provides a step forward in understanding the nature of visual attention, as well as providing a starting point for future studies of face processing.

## Acknowledgements

This work was supported by an ESRC postgraduate studentship (no. R42200134060) to Markus Bindemann.

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