Running head: Face specific capacity limits

Perceptual Load Effects on Processing Distractor Faces Indicate Face-Specific Capacity Limits

Volker Thoma

School of Psychology, University of East London, UK

Nilli Lavie

Institute of Cognitive Neuroscience, University College London, UK

Address correspondence to:

Volker Thoma

School of Psychology, University of East London,

Water Lane, London, E15 4LZ, UK.

e-mail: v.thoma@uel.ac.uk

fax: +44 (0)20 8223 4937

Abstract

The claim that face perception is mediated by a specialized ‘face module’ that proceeds automatically, independently of attention (e.g., Kanwisher, 2000) can be reconciled with load theory claims that visual perception has limited capacity (e.g., Lavie, 1995) by hypothesizing that face perception has face-specific capacity limits. We tested this hypothesis by comparing the effects of face and non-face perceptual load on distractor face processing. Participants searched a central array of either faces or letter-strings for a pop star versus politician’s face or name and made speeded classification responses. Perceptual load was varied through the relevant search set size. Response competition effects from a category-congruent or incongruent peripheral distractor face were eliminated with more than two faces in the face-search task but were unaffected by perceptual load in the name search task. These results support the hypothesis that face perception has face-specific capacity limits and resolve apparent discrepancies in previous research.

Key words: attention, perceptual load, face recognition, modularity, processing capacity

Perceptual Load Effects on Processing Distractor Faces Indicate Face-Specific Capacity Limits

The ability to recognize faces is an important visual system function of high sociobiological value. Indeed, this ability is often claimed to be mediated by a specialized 'face module' (Fodor, 1983; 2000; Kanwisher, 2000) that operates in an automatic and mandatory fashion, processing any face input, independently of attention or voluntary will. In the present study we use the load theory framework (Lavie, 1995, 2005) to address this claim. Load theory proposes that visual perceptual processing has limited capacity but proceeds in a mandatory, involuntary fashion on all input within its capacity. The effect of level of load on perceptual processing plays therefore a critical role: in tasks of low perceptual load, people perceive additional task-irrelevant input even if this causes distraction, due to the mandatory nature of perceptual processing. In contrast, in tasks of high perceptual load, perceptual capacity is consumed by processing task-relevant information and thus any irrelevant distractors are simply not perceived.

Previous research suggested that face distractors may be an exception, in that in some cases face distractors had been perceived even in tasks involving high levels of perceptual load, that were sufficient to eliminate processing of non-face distractors (e.g. Lavie, Ro, & Russell, 2003). While these demonstrations may imply that face perception is fully automatic in the sense that it is both mandatory and independent of attentional capacity, in line with the face module claims, previous studies have only varied the level of perceptual load in tasks involving non-face objects or words. It therefore remains possible that face processing does have capacity limits, but that these are specific to processing faces. In other words, face processing may be modular and encapsulated (Fodor, 1983) so that it is unaffected by the presence of other non-face objects, but has its own face-specific capacity limits. In the present study we set out to test this claim. The literature we review below provides provisional support for this rationale.

Perceptual load research

Load theory received much support in studies showing that increases in perceptual load (e.g. tasks with a greater number of items, or with a more demanding perceptual discrimination) cause reduced processing of any task-irrelevant items (see Lavie, 2005, 2010). These effects of perceptual load have been shown across the range of perceptual processing from low level visual processing such as detecting stimulus presence (Carmel, Saker, Rees, & Lavie, 2007; Cartwright-Finch & Lavie, 2007; Macdonald & Lavie, 2008; Schwartz et al., 2005; Simons & Chabris, 1999), or motion (Rees, Frith, & Lavie, 1997) to higher levels, involving letter discrimination (Lavie, 1995; Lavie & Cox, 1997; Lavie & Fox, 2000) and recognition of meaningful distractor images of objects (Forster & Lavie, 2008; Jenkins, Lavie, & Driver, 2005; Lavie, Lin, Zokaei, & Thoma, 2009; Pinsk, Doniger, & Kastner, 2004) and places (Yi, Woodman, Widders, Marois, & Chun, 2004).

All of these tasks showed reduced distractor processing with higher perceptual load, in support of load theory. In the case of distractor faces however, Lavie et al. (2003) reported an exception. Using Young and colleagues' (Young, Ellis, Flude, McWeeny, & Hay, 1986) face-name response competition task, modified to vary perceptual load, Lavie et al. asked their participants to search a central column of letter strings for a famous name and indicate whether it was a politician's or a pop star's name. They were also asked to ignore a distractor face presented in the periphery, which could be congruent (a pop star's face for a pop star name), incongruent (a pop star's face for a politician's name) or neutral (an anonymous face) in regard to the target. Perceptual load in the name search task was manipulated through the search set size. The results revealed that the distractor faces produced response-competition effects on response times (RT) irrespective of the level of perceptual load in the task. Moreover, these results were unique to distractor faces, because when perceptual load was manipulated in a similar name search task, but now concerning musical instruments, distractor images of the musical instruments only produced response competition effects in the low load search task but not in the high load conditions.

These results suggest that faces are special stimuli for attention and provide support for the proposal that face perception may be subserved by an automatic face processing module. A few subsequent studies provided further support for this claim. Reddy, Wilken & Koch (2004) showed that performance of a face gender discrimination task did not decline when it was combined with a demanding letter discrimination task (finding a target letter in a display with 5 non-target letters) under dual task, compared to single task conditions. Neumann and Schweinberger (2008) found that in a letter search task the level of perceptual load (varied through embedding the target in a string of identical letters in low load or different letters in high load) did not modulate electrophysiological (EEG) correlates of repetition suppression for distractor faces upon which the letters were superimposed. Using the same paradigm, but including also repetitions for houses and hands, Neumann, Mohamed, and Schweinberger (2011) replicated Neumann and Schweinberger's (2008) earlier finding that the N250r EEG marker of repetition suppression was found for faces irrespective of the level of load in the letter search and also reported that repeated houses or hands did not lead to any EEG marker of repetition suppression under either low or high perceptual load in the search task. Other studies that report measures of distractor processing also indicate that recognition of distractor faces may remain unaffected by the level of perceptual load during distractor presentation, at least as far as implicit measures of familiarity are used. For instance, familiarity judgment latencies are facilitated by the prior presentation of famous distractor faces during a letter search task, and this effect holds irrespective of the level of perceptual load in the search (Jenkins, Burton, & Ellis, 2002).

All these previous studies used a non-face task to load attention. Thus it remains possible that face perception is modular, in the sense that it is insensitive to the level of load involved in the perception of non-face objects. Nevertheless such a face module may have its own face-specific capacity limits restricted to the demand on face processing. A few studies provide preliminary evidence in support of this claim. However, as none of these studies have manipulated the level of perceptual load in the face processing task, it is impossible to draw any clear conclusions about perceptual capacity from their results (i.e. it is not clear that face processing capacity was challenged without a manipulation that increases the demand on processing capacity). Bindemann, Burton, and Jenkins (2005) found that famous distractor faces (pop stars or politicians, of US or UK nationality) only produced response competition effects on responses to target names (of either UK or US politicians) or national flags (of either UK or US) but produced no response competition effects on responses to famous target faces. Using the same stimuli, Bindemann, Burton, and Jenkins (2007) replicated the same pattern of results with a measure of identity-based repetition priming effects. Famous distractor faces only produced identity-based priming effects when presented with a target flag but not a target face. Although these findings certainly point to a form of face-specific interference it is not clear that this interference reflects a particularly restricted face perception capacity, allowing only one face to be perceived at a time, or a specific effect of the task used. For instance, the contrast between flags and faces may be due to differences in the relative salience or ease of extraction of nationality information for this different type of stimuli (flags and faces): both factors play an important role in the effects of response competition and priming. Indeed, the interpretation of these results in terms of face-specific perceptual capacity limits is somewhat unlikely given far higher estimates for perceptual capacity for non-face objects (e.g., Lavie & Cox, 1997; Pylyshyn, 1994; Treisman, Kahneman, & Burkell, 1983).

Palermo and Rhodes (2002) demonstrated that the advantage in detection of a face part (e.g., the mouth) when it is presented within a face (indicating holistic face processing) can be found when people pay full attention to the target face, while ignoring two flanker faces, but such advantage is eliminated when the participants have to pay attention to the two flanking faces as well. Moreover, paying attention to scrambled or inverted flanker faces did not affect target face processing, suggesting that the modulation was specific to upright faces. The effect of reduced target face processing when people have to pay attention to two other faces is in line with our suggestion of face-specific capacity limits, but once again since the level of load was not manipulated a firm conclusion regarding processing capacity is not warranted. We therefore set out to test the hypothesis that face perception has face-specific capacity limits by manipulating the level of perceptual load for either face (Experiment 1) or non-face (Experiment 2) target stimuli and testing the effects on the processing face distractors.

Experiment 1

In Experiment 1 we used a search plus classification task similar to that used in Lavie et al's (2003) study but replaced the names of famous people (used in their study as targets in a search task containing nonsense strings) with faces. Participants were asked to search for a famous face presented in one of three display positions (at the central fixation point, above or below it) and classify it into a pop star's or a politician's face, while ignoring a famous distractor face presented in the periphery (Figure 1). The level of perceptual load in this face search task was varied through the relevant search set size. The famous face target was either presented alone (relevant set size 'one') or among one (relevant set size 'two') or two (relevant set size 'three') additional anonymous non-target face (Note 1). Interference effects from the distractor face were assessed as a function of face-search load. If distractor face processing depends on face-specific capacity limits it should be modulated by the increase in the number of faces in the search task.

Method

Participants. Sixteen paid UCL students (six male, mean age 29 years) participated. All reported normal or corrected-to-normal vision. Before the experiment participants were asked to name photographs of the famous faces used in the experiment. Only one person (out of seventeen asked) could not name all politicians and pop stars and was therefore excluded from the experiment.

Stimuli and Procedure. Participants sat at approximately 60 cm away from a 15" CRT monitor. E-prime (version 1.1) was used to run the experiment. The face set was the same as that used in Lavie et al. (2003) which has age-matched (circa 40 to 55 years of perceived age) images of politicans and pop stars. Participants were required to search for a famous face among one, two, or three faces, presented with the face center at fixation, or at 3 cm (2.86 degrees of visual angle) above or below fixation, and indicate by a speeded key press whether it was of a politician or a pop star. An irrelevant distractor face was also presented with its center at 4 cm (3.82 degrees) to the left or right of fixation. The distractor face could either be the same image as the target (congruent condition) or of a person from the opposite category (incongruent condition, Figure 1). The same image was used in the congruent condition (rather than a different image from the same category or the same person) to avoid an ambivalent condition, which can cause a conflict in its own right, as has been demonstrated in previous behavioural studies (e.g., Santee & Egeth, 1982). As the same procedure was used in Lavie et al.'s (2003) study, this also allowed us to compare our results with those of Lavie et al. (2003). Six faces were used for each category. A set of twelve anonymous male faces was used as non-targets. The face images were greyscale with a standardized vertical size of 3 cm (2.86 degrees of visual angle) for targets and nontargets and 3.4 cm (3.24 degrees) for distractors. Target identity and positions were counterbalanced with respect to distractor identity and position. Each participant ran through a practice block of 72 trials followed by 10 experimental blocks of 72 trials each. Within each block, all conditions were randomly intermixed. Displays remained visible until the participant responded or 3 seconds elapsed. The average stimulus luminance of the faces was 65 cd/m^2.

Figure 1 about here

Results

Incorrect responses (and those with RT shorter than 200 ms, 1% of all trials) were excluded from the RT analyses. Figure 2 presents the mean correct RTs as a function of the experimental conditions. A within-subject ANOVA with the factors of set size and congruency revealed a main effect of set size, $F(2, 30) = 241.79$, $p < .001$, $MSE = 1969.23$, $eta^2 = 0.94$. RT was significantly increased by each increase in the search set size ($p < .001$ in all comparisons) with an average search slope of 122 ms. This finding confirms that search load was manipulated effectively with the increase in the face search set size. There was also a main effect of congruency, $F(1,15) = 13.83$, $p < .01$, $MSE = 500$, $eta^2 = 0.48$. However, the congruency effect was qualified by an interaction with set size, F(2, 30) = 5.80, $p < .01$, $MSE = 574$, $eta^2 = 0.28$, reflecting significant distractor congruency effects at set size one, $F(1,15) = 20.93$, $p < .001$, and set size two, $F(1,15) = 9.44$, $p < .01$ (with no difference between these effects, $F < 1$) but no distractor congruency effects at set size three, $F < 1$.

Table 1 about here

Mean error rates were around 3% for all conditions except for that of a congruent distractor in set size 2 (M= 3.6%) and their ANOVA revealed no main effect of congruency ($F < 1$) or load ($F < 1$), and no significant interaction between these factors, $F(1, 30) = 1.72$, $MSE = .001$, $p = .19$, $eta^2 = .10$. Thus, the results provide preliminary support for our hypothesis that face processing is subject to face-specific capacity limits.

Figure 2 about here

Experiment 2

Our hypothesis suggests that capacity for face perception is only limited to faces. The contrast between Experiment 1's demonstration of load modulation and Lavie et al.'s (2003) findings of no such load effect with a central letter search task is in support of this claim. But an experiment directly comparing load effects between face and non-face stimuli within the same task is required to establish this more firmly. This was the purpose of Experiment 2. In Experiment 2 we compared distractor face interference on search RT between a search task for faces (as before) and a search task for names (as in Lavie et al., 2003). Perceptual load was manipulated again through the search set size. To simplify the design we now used just two levels of perceptual load (either low load or high load, as established in the previous experiment). The faces search task involved one face in the low load condition and three faces in the high load condition (as before). Pilot testing was conducted to find conditions under which performance RT and accuracy show that the name-search task was at least as difficult as in the comparable load conditions of the face-search task. This was important in order to ensure that results showing a greater distractor effect in the name search are not due to this task involving lower level of load. As a result of this pilot the name-search task involved three letter strings (a target name and two meaningless letter strings) in the low load condition and six letter strings (a target name and five non-target meaningless letter strings, as in Lavie et al., 2003) in the high load conditions.

Method

Participants. 58 paid students from University College London and the University of East London (19 male, mean age 29 years) participated for pay or course credit. All the participants reported normal or corrected-to-normal vision and were randomly assigned to one of two groups A or B (n = 29 each). One participant in group B had a load effect that was 2.5 standard deviations below the mean load effect (218 ms) and also uniquely responded more slowly in a low load than in a high load condition but with higher error rates in the latter, suggesting a possible speed-accuracy tradeoff. This participant was therefore excluded from the analyses. Before the experiment participants were asked to name photographs of the famous faces used in the experiment. All participants could name the faces correctly.

Stimuli and Procedure. The face stimuli were the same as in Experiment 1 except that the face set now comprised of four faces in each category (see Appendix). Participants were randomly assigned to the group with faces as targets and non-targets (group A) or with letter strings (a target name and meaningless letter strings as non-targets) (group B). Note that following on Lavie et al's. (2003) method, meaningless letter strings were used in the name search task instead of other common names, so that the effects of set size increase perceptual load rather than load on higher-level semantic processing. There were only two levels of load for both groups. For group A, a relevant set size of one face was used in the low load condition and a relevant set size of three faces was used in the high load condition. For group B a relevant set size of three letter strings was used in the in low load condition and a relevant set size of six letter strings was used was used in the high load condition. Pilot testing showed that these set sizes produced a similar load effect on latencies as found in Experiment 1. The trial procedure in both groups was similar to Experiment 1, except that for group B the target and non-target faces were replaced with letter strings: targets consisted of the names of the famous individuals (one name was selected in random on each trial from the set of four famous names for each category) and the non-target stimuli were meaningless or 'nonsense' letter strings but with first name and surname structure kept, e.g. 'Rydre Tsueer'. Participants were instructed to find the real name of a famous person among the two (low load) or five (high load) nonsense letter strings and to indicate per key press whether it was a politician or pop star.

As in Experiment 1 the relevant search display was presented in a vertical column placed in the center of the display. The face stimuli were of the same dimensions and positions as those used in Experiment 1. The letters were shown in Arial 12 (bold), and the horizontal expanse of the letter strings was between 3.5 (3.34 degrees) and 4.9 cm (4.68 degrees). The vertical expanse from the top edge to the bottom edge for the set of target plus non-target strings was 3 cm (2.86 degrees) in the low load displays (the same as that used in the low load displays in group A) and 6 cm (5.73 degrees) in the high load condition (the same as the vertical distance between the upper and lower face center points in high load displays of group A).

The position of target and non-target stimuli was counterbalanced within a block. In both groups participants started with a practice block followed by four experimental blocks of 96 trials each. Displays remained visible until the participant responded or 2 seconds elapsed. As in Experiment 1, participants heard a beep sound when they made an error or took too long. There was a short break between blocks.

Figure 3 about here

Results

Incorrect responses (and those with RT shorter than 200 ms, 2% of all trials) were excluded from all RT analyses. Figure 3 presents the mean correct RTs as a function of the experimental conditions. Mixed model ANOVAs were performed on RTs and error rates with the within factors of load (high vs. low) and congruency (congruent vs. incongruent) and the between factor of group (name search vs. face search). The RT ANOVA revealed main effects for congruency, $F(1, 55) = 69.62$, $p < .001$, $MSE = 989$, $eta^2 = 0.56$, load, $F(1, 55) = 1834$, $p < .001$; $MSE = 1544$; $eta^2 = 0.97$, and group, $F(1, 55) = 38.82$, $p < .001$; $MSE = 10769$; $eta^2 = 0.41$. Response times were higher for incongruent compared to congruent conditions, increased from low load to high load, and were slower for the group performing name search than the group performing face search.

There was a significant interaction between congruency and group, $F(1, 55) = 10.93$, $p < .01$; $MSE = 989$; $eta^2 = .16$. Congruency effects were smaller in the face search group than in the name search group. This is explained by the significant 3-way interaction, $F(1, 55) = 4.08$, $p < .05$; $MSE = 993$; $eta^2 = .069$. Whereas load reduced the congruency effects in the face search group, $F(1, 28) = 6.63$, $p < .05$, $MSE = 746$; $eta^2 = .19$, as in Experiment 1, load had no effect on congruency in the name search group, $F(1, 27) = 0.23$, $p = .57$ (see Figure 3). Indeed the congruency effects did not significantly differ between the face ($M = 31$ ms; $SD = 5.67$) and name ($M = 44$ ms; $SD = 7.79$) search groups in the low load conditions, $t(1, 55) = 1.07$, $p = .29$.

There were no other significant interactions (all *F*s < 1.23). Notice in particular that the load effect on RT was equivalent between the face-search group (*M* = 223 ms) and the name-search group (*M* = 218 ms, *F* < 1 for the interaction of group and load).

Table 2 about here

The ANOVA on error rates also showed main effects for congruency, $F(1, 55) = 8.50$, $p = .005$, $MSE = .001$, $eta^2 = 0.13$, and load, $F(1, 55) = 28.99$, $p < .001$, $MSE = .029$, $eta^2 = 0.34$: error rates were higher for incongruent compared to congruent conditions, and increased from low load to high load (see Table 2) in line with the RT effects. There was no main effect for group, $F(1, 55) = 3.01$, $p = .088$, $MSE = .003$, $eta^2 = .05$, but a trend of higher error rates in the name-search group was consistent with the RT results. There was a significant interaction between load and group, $F(1, 55) = 17.85$, $p < .001$, $MSE = .001$, $eta^2 = .05$, indicating that error rates increased more from low load to high load conditions in the name-search group compared to the face-search group. There was no interaction between load and congruency, $F(1, 55) = 2.78$, $p = .101$, nor any other interaction (all *F*'s < 1.11).

Thus Experiment 2 results showed that a manipulation of perceptual load that appeared to be similarly effective in both the name and face search tasks (or perhaps to some extent somewhat stronger for the names search as revealed by the greater effect of load on errors) had no effect on distractor face processing. Only high load in the face search task eliminated distractor face processing.

Experiment 3

The results of Experiment 2 lend support to our prediction that faces are a special class of stimuli with face-specific capacity limits. The selectivity of perceptual load effects to a manipulation of load within face processing only is exactly as predicted on the basis of our a-priori hypothesis (see also Lavie et al., 2003). However, the results of Experiments 1-2 in themselves remain open to an alternative interpretation which attributes the contrasting results pattern to a difference in efficiency of the perceptual load manipulation for the face search compared to the name search. Indeed, although the load manipulation led to a greater increase in the error rates for the name search than the face search, while the effect of load on RT was equivalent between the two tasks, the name search task did have longer RT overall and hence a smaller proportional increase in the RT (20%) compared to the face search task (24%) with higher load. Thus, one could question whether the load manipulation was somewhat less effective for the name search than for the face search (Note 2). This interpretation is somewhat unlikely given a previous demonstration that a similar manipulation of perceptual load in name search was effective in reducing the processing of non-face distractor objects (Lavie et al., 2003). Nevertheless, to further test our face-specific capacity hypothesis we sought to examine whether our manipulation of load in the name search task can be effective in reducing the processing of distractor names rather than faces. The task in Experiment 3 was thus very similar to that used for group B (name search with different set size) in Experiment 2 except that the distractor faces were now replaced with distractor names of politicians or pop stars.

Method

Participants. Sixteen students (six male, mean age 25 years) from the University of East London took part in exchange for course credit.

Stimuli and Procedure. Experiment 3 was run exactly as Experiment 2 for group B, with the following changes: whereas the target and non-target strings were shown in exactly the same conditions (also in 4 blocks with one training block), the distractor stimuli now consisted of names rather than face stimuli. The distractor names were either the same (congruent condition) as the target name or the name of a famous person from the opposite category. The distractor name was shown with the first name centred above the surname of the politician or pop star (0.8cm; 0.07 degrees) and the center 4 cm (3.82 degrees) to the left or right of fixation. Whereas the target and non-target strings were shown in ARIAL 10 font, the font for the distractor was GEORGIA 18 (bold) to allow better legibility in the periphery. The same person identities were used as in Experiment 2, with the exception that “John Major” was replaced with “Gordon Brown” (since the former could not be usually remembered as an active politician by most of our participants).

Results and Discussion

Incorrect responses (and those with RT shorter than 200 ms, 1.5% of all trials) were excluded from the RT analysis. Table 3 presents the mean correct RTs and error rates for the different experimental conditions. A within-subject ANOVA of the RT with the factors of load and congruency revealed no main effect of RT for congruency, $F(1, 15) < 1$, MSE = 2249; eta^2 = .06, but a significant main effect of load, $F(1, 15) = 546.99$, $p < .001$; MSE = 2311; eta^2 = 0.99, and a significant interaction of load and congruency, $F(1, 15) = 5.38$, $p < .05$; MSE = 7197; eta^2 = .26. As can be seen in Table 3 this interaction reflected the reduction in the distractor congruency effect which was found the low load condition, $F(1,15) = 5.08$, $p < .05$, but not in the high load condition, $F(1,15) < 1$. Error rates did not vary between the conditions (M= 6.2% in each condition, see Table 3).

Table 3 about here

These results demonstrate that our manipulation of perceptual load in the name search task is effective in reducing the processing of name distractors.

The contrast in the effects of perceptual load in the name search on distractor name versus distractor face processing was further confirmed in the three-way interaction, $F(1, 42) = 4.97$, $p = .031$; $MSE = 1280$, $eta^2 = .11$, between load congruency and Experiment that was found in a mixed-model ANOVA of the RT in Experiment 3 and in group B in Experiment 2. The contrast between the reduced distractor name processing in Experiment 3 and the lack of effect on face-specific effect of load observed in Experiments 1 and 2 is further supportive of our hypothesis that faces have face-specific capacity limits.

Experiment 4

Another potential alternative account for the current pattern of results is in terms of a modified variation of the original dilution account (Kahneman & Chajczyk, 1983) in which the added items in the higher set size may reduce distractor interference in the response competition paradigm due to some form of visual interference, e.g. crosstalk among visual features (Benoni & Tsal, 2010, 2012; Tsal & Benoni, 2010; Wilson, Muroi, & MacLeod, 2011) instead of a draw on perceptual capacity as we propose here (as well as in the original concept of dilution, Kahneman & Chajczyck, 1983, and its later application to distractor faces, Jenkins, Lavie & Driver, 2003). Although there are now demonstrations that dilution effects are indeed explained by a draw on perceptual capacity as proposed in load theory (e.g., capacity spills over to the closer items to the target, or those grouped with it, in cases where it is not allocated to the distractor, see Lavie & Torralbo, 2010; Yeh & Lin, 2013), it seemed worthwhile to address it here (see Note 2). Thus in Experiment 4, in addition to the low and high load conditions, we also included a new ‘low-load/dilution’ condition, in which the displays contained one intact face target presented among scrambled nontarget faces. This condition was of low load because it allowed for a target pop out, however it involved dilution because the display set size was the same as in the high load condition, and also contained the same amount of visual features, (see method for more detail) as those in the high load condition. If the effects of load are due to a form of visual interference for example visual feature crosstalk, as per the dilution account, then this condition should also reduce distractor interference. If the effects are due to a draw specifically on face processing capacity as we hypothesized then they should only be found in the high load condition.

Method

Participants. Ten UCL students (four male, mean age 24 years) participated. All reported normal or corrected-to-normal vision.

Stimuli and Procedure. The stimuli and procedure were similar to those of Experiment 1 except for the following changes. In the condition of low load/dilution two scrambled faces replaced the intact nontarget faces. The faces presented as target or nontarget were cropped so that the top of the face had a standardized rectangular shape, and each face subtended a standard size of 2.5 cm (2.39 degrees) vertically and 1.9 cm (1.81 degrees) horizontally.

For the scrambled faces we used a well-established face scrambling procedure that was based on a 2-D Fast Fourier transformation, which randomizes the phase spectrum, while keeping the amplitude (power spectrum) intact. This results in a random shift of the phase of the component spatial frequencies of each anonymous face image (see McCarthy, Puce, Gore, & Allison, 1997; Jenkins et al., 2003). This transformation changes only the position (i.e. phase) of the spatial frequency components – and hence the configural information – but it does not affect the orientation information of the image, because it retains the distribution of energy (the 2-D amplitude spectrum) across the different face orientations. In addition, the lower part of each of the scrambled faces was slightly cropped around the chin to provide the same outline as the original version of the corresponding intact face.

The conditions of low load (set size one) and high load (set size three with intact nontarget faces) were the same as those used in Experiment 1. The distance between the target and nontargets was kept the same as in Experiment 1 so that the faces above or below fixation were now placed with their center 2.9 cm (2.77 degrees) away from fixation. Distractor faces were presented at the same size and position as in Experiment 1.

Results and Discussion

Incorrect responses (and those with RT shorter than 200 ms, 1.2 % of all trials) were excluded from the RT analysis. Figure 4 presents the mean RTs as a function of the experimental conditions. A within-subject ANOVA of the RT as a function of condition (low load, high load, low load/dilution) and congruency (incongruent, congruent) revealed a significant main effect for condition, $F(2, 18) = 135.21$, $p < .001$, $MSE = 4550$, $eta^2 = 0.94$. Planned contrasts indicated that the mean RT of the high load condition was significantly longer than the mean RT of the low load condition, $F(1, 9) = 175.50$, $p < .001$, and the low load/dilution condition, $F = 159.44$, $p < .001$, while the small increase in RTs (by 30 ms) from the low load to the low load/dilution condition was not significant, $F(1, 9) = 3.34$, $p = .09$. There was also a main effect of congruency, $F(1, 9) = 13.80$, $p < .01$, $MSE = 1206.$, $eta^2 = 0.61$, and more importantly, an interaction of load and congruency, $F(2, 18) = 7.91$, $p < .01$, $MSE = 432$, $eta^2 = 0.47$. As can be seen in Figure 4 this interaction reflected that distractor face congruency effects were significant in the low load, $F(1,9) = 16.25$, $p < .01$, and low load/dilution, $F(1, 9) = 20.67$, $p < .01$, conditions, but not in the high load condition, $F(1, 9) < 1$. Error rates again did not vary (M error rates = 6.9% in each condition).

These results provided further support of our face-specific capacity limits account, while ruling out an alternative account in terms of a form of visual interference, feature crosstalk, or “dilution”. The lack of dilution effects in the present study cannot be explained by reduced visual salience of the scrambled faces, as conceived in computational models of visual salience (e.g. Itti, Koch, & Niebur, 2008). In such models visual salience is registered as a location that stands out on feature maps for colours, intensity and orientation and so forth. All these types of information (as well as overall shape orientation) were retained in the phase-shifted scrambled faces we used, and thus any local salience signal on these feature maps should have been retained as well. Reduced similarity between the scrambled and intact faces cannot explain the lack of dilution effects either, since dilution is known to be found for dissimilar items. For example a row of X’s, brackets, or even “equal” signs have been shown to dilute interference from a distractor word (Kahneman & Chajczyk, 1983; Brown, Roos-Gilbert, & Carr, 1995).

Moreover the very same phase-shifted scrambled faces as those used here, were previously shown to be capable of producing dilution effects (Jenkins et al., 2003). The contrast between this previous demonstration and the lack of any such dilution effect in the present study, might be construed as a failure to replicate dilution. This contrast suggests that the effects of dilution may not be as robust in tasks in which the dilution conditions do not involve a spatial shift of attention to another potential distractor position, as they are in the original studies (in which dilution does involve such shifts of attention). Indeed, in the case of dilution conditions in which the relevant set size is varied (rather than a distractor added in one of the irrelevant distractor positions) a failure to find a dilution effect is already documented. Lavie (1994) did not find effects of dilution, despite the use of a very similar task and design used later on in some of Tsal and Benoni’s (2010) experiments (see Lavie & Torralbo, 2010, for a more detailed discussion of this point).

Figure 4 about here

General Discussion

The present findings demonstrate that the processing of face distractors critically depends on the level of perceptual load specifically involved in face processing. Irrelevant face distractors were perceived under all conditions of load in a name search task, including conditions of high perceptual load (that were previously shown to reduce processing of non-face distractor objects), as well as under conditions of low perceptual load in a face search task (including those involving the so called “dilution” effect, Experiment 4). In contrast, the name search task was shown to be effective in reducing processing of names (Experiment 3), and face distractor processing was reduced with high perceptual load when a face-search task involved three faces.

The striking contrast between the effects of perceptual load in face versus non-face processing was found despite both load manipulations being clearly effective in reducing the search task efficiency (as shown in Experiment 2) and despite the name search task being effective in reducing the processing of distractor names (and in a previous study also shown to be effective in reducing the processing of meaningful distractor objects, Lavie et al., 2003). This dissociation thus strongly suggests that face processing depends only on the level of load involved specifically in face perception, while being immune to perceptual load in other object domains. In this respect distractor faces are an exception to all other types of meaningful distractors (e.g., objects such as household items, fruits, vehicles, and so forth) since their processing had been shown to depend on the level of perceptual load irrespective of the domain in which load was manipulated. For instance, in a series of experiments Lavie et al. (2009) have shown that perceptual load in search task modulated the processing of a wide range of meaningful distractor objects whether the load manipulation involved search for objects or for letters. Many other studies have reported similar effects on distractor processing for manipulations of load in another domain (e.g. letter strings, words, Forster & Lavie, 2008; Lavie et al., 2003; Pinsk et al., 2004; Rees et al., 1997; to name but a few). The conclusion that unlike meaningful non-face distractor objects, distractor faces seem to only have face-specific capacity limits converges with evidence from functional imaging and neuropsychology on the suggestion that faces are processed by a dedicated, perhaps even encapsulated (in the sense that it is immune to effects of non-face load) face module .

This conclusion also provides firm support for our hypothesis that load theory applies to face perception as well, as long as the specialized (perhaps even modular) nature of capacity limits for face perception is taken into account. Our proposal of a face module with face-specific capacity limits can account for the previous demonstrations that face processing is unaffected by the level of load in processing non-face objects (e.g., Fodor, 1983; 2000; Lavie et al., 2003; Neumann & Schweinberger, 2008; Neumann et al., 2011) but can be disrupted by attending to other faces (e.g., Bindemann et al., 2005; 2007; Jenkins et al., 2003; Nagy, Greenlee & Kovacs, 2011; Palermo & Rhodes, 2002) especially when the attention task becomes more demanding (e.g., Jacques & Rossion, 2007; Neumann & Schweinberger, 2009). A module approach stipulates that the face module would just be engaged in the perception of faces, while being unaffected by the processing of non-face objects (‘encapsulated’ processing, see Fodor, 1983).

Although it is tempting to attribute all the previous face-specific modulations of face processing to face-specific capacity limits it is important to note that apart from Neumann and Schweinberger (2009) none of the other studies has directly varied the level of load in face processing, and one cannot infer that a limited capacity (face-perception) resource is involved unless the demand on this (face perception) resource is quantitatively varied. It is therefore possible that other factors, or other face-specific interactions can account, at least in part, for the modulations previously reported. For instance, stimulus competition for neural representations (e.g., in face selective areas such as the fusiform face area, or as indicated by ERP amplitude of the N170 component of face processing) is more sensitive to the presence of another face than non-face stimuli (e.g., Jacques & Rossion, 2004, 2007; Nagy, Greenlee, & Kovács, 2011). Other factors such as the relative visual salience of a target and distractor, which are known to determine base-line level of distractor effects may also play a role. It is for example possible that a contribution of factors such as reduced salience and stimulus competition may explain why processing of a distractor face was already reduced by the presence of one target face in Bindemann et al.'s (2005; 2007) studies. As we discuss earlier (in the General Introduction) Bindemann's et al.'s suggestion that face processing has a particularly restricted capacity allowing only one face to be perceived at a time, in a bottle neck fashion, is somewhat unlikely given the higher estimates of perceptual capacity for all other types of non-face objects as well as demonstrations that the capacity for face representations in visual short term memory (as estimated with Cowan's K) is similar to (e.g., Wong, Peterson, & Thompson, 2008) or in some cases better than (Curby & Gauthier, 2007; Scolari, Vogel, & Awh, 2008) other objects of similar level of complexity. It is also inconsistent with the present findings that face distractors are perceived as long as there are less than four faces in the array. However, it is possible that a combination of factors such as reduced salience, increased stimulus competition, and higher load led to modulation of face processing due to the presence of just one more face. This suggestion is consistent with the demonstration that both stimulus competition and increased attentional load (easy left vs. right judgments compared to luminance matching for fairly subtle luminance changes in the more demanding conditions for a fixated task that involved both faces and scrambled faces) independently contributed to reduced amplitude of the N170 related to a lateralized face (Jaques & Rossion, 2006). In further support of this explanation, the task requirement in Bindeman et al.'s studies appeared to be more demanding than in the present task. Cleary recognizing a famous politician as a politician of a particular nationality (as required in Bindemann et al.'s 2005; 2007 studies) is more demanding than the present task requirement to just recognize a famous politician as a politician. Neumann and Schweinberger (2009) have shown that distractor face processing (as indexed by N250 repetition priming effects) continued in the presence of a face target as long as the task demand was low (color judgment) but not when the task demand was high (young vs. old judgments).

Thus the apparent discrepancy between our suggestion that face processing capacity limits are not approached until four faces are presented, and Bindemann's findings of reduced face processing with just one target face can be reconciled by suggesting that their task requirement involved higher load, and that both stimulus competition and the relative salience of the distractor face in their study acted to reduce distractor face processing in the presence of another face more than in the presence of a flag. However, without directly varying the level of load involved in face processing it is impossible to reach a clear cut conclusion with respect to the contribution of capacity limits in the effects found.

In contrast, our manipulation of face-search load and the findings that processing of the distractor face proceeds unaffected by the presence of one or two other faces in the target task (and is only eliminated with three faces in the target task) is strongly suggestive that a face perception is a capacity limited process that can be carried out on a few faces until capacity limits are approached. These findings also rule out alternative account in terms of stimulus competition (as in the biased competition accounts, e.g. Desimone & Duncan, 1995) since stimulus competition effects should already be found for any increase in the number of items (including the low load conditions in Experiment 1) and demonstrate the critical role of loading perceptual capacity instead. Note, however, that our findings do not imply a fixed number of faces as the limit. Rather, as shown in the Neumann and Schweinberger (2009) study, the task demands may lead to a higher or lower load for the same number of faces (see also for example, Carmel, Thorne, Rees, & Lavie, 2011; Cartwright-Finch & Lavie, 2007; and Lavie, 1995, Experiments 2-3; as examples of different levels of load for the same number of non-face objects).

Moreover accounts in terms of differences in relative salience of the distractor versus the target stimuli cannot account for our load effects either. Relative salience was not co-varied with the level of load in our task, and any differences in the base-line level of relative salience should have been pronounced in the low load condition already (see for example Young et al. (1986) demonstration that changing the relative salience in the task context between words and faces can lead to asymmetry in their effects in either direction, i.e. words interfering more than faces or the other way around). However our low load data did not show any asymmetrical trend. Inspection of the magnitude of distractor effects at the low load conditions in the present study demonstrates that the distractor face produced distractor interference of similar magnitude (around 3%-4% congruency effects) to those produced by distractor names and irrespective of whether the target was a name or a face. Thus our task appeared fairly balanced with respect to relative salience of the faces and words. Future research may seek to establish the joint effects of load and salience, with an orthogonal manipulation of both factors. For example faces can be made less salient than words (with respect to providing identity information) by presenting the faces in unusual angles, words salience can be altered by varying the letter styles used and so forth. On the load theory, such research would be expected to demonstrate that the effects of load (demands on capacity) and salience are additive, other views (e.g. Kyllingsbaek, Sy & Giesbrecht, 2011) might implicate interactive effects. Interestingly, extensive training (e.g., as a consequence of a particular expertise) can lead to category-selective processing for the objects of expertise that has similar characteristic to face processing. Future studies may wish to explore the possibility that other stimuli of expertise (for example birds for bird watchers, Gauthier et al., 2000; musical instruments for musicians, e.g., Ro, Friggel, & Lavie, 2009) may also have their own domain-specific capacity limits. Indeed Ro et al. (2009) have shown that musicians were susceptible to interference by distractor images of musical instruments presented in a response competition task (requiring participants to classify names of musical instruments) irrespective of the level of perceptual load in the task, whereas non-musicians were only interfered by the same distractor images under low, but not high, load. An interesting test of the hypothesis that expertise leads to domain-specific capacity limits would be to investigate whether musicians' processing of instruments as distractors will be affected by the level of domain-specific perceptual load (e.g. as varied by the number of musical instruments presented in their relevant task).

Finally, we note that while perception of faces may only be subject to face-specific capacity limits, explicit memory recognition for faces does depend on general non-face specific capacity. Jenkins, Lavie and Driver (2005) manipulated perceptual load in a letter search task and found that explicit recognition memory for the distractor faces was substantially reduced under high load. These findings can be reconciled with our suggestion that whereas face perception has face-specific capacity limits (as presently revealed by online measures), recognition memory for faces has general capacity limits. Such a suggestion accords in principle with Fodor's (1983) claims that modules are encapsulated input-processing systems, but their output to central processes - such as memory - can be shared.

In conclusion, our findings provide clear evidence for a face selective processing system ('module') that has its own face-specific limited capacity. Future research may address whether this is a consequence of extensive expertise or whether faces are a unique category for attention and perception.

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Footnotes.

Note 1. Set size three was chosen as a maximum because pilot data showed that this was sufficient to load face perception with a greater set size inducing “data limits” (likely to be due to the reduced acuity in the periphery) as reflected in a substantial increase in the error rates.

Note 2. We thank an anonymous reviewer for suggesting this alternative interpretation.

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Figure Captions.

Figure 1. Example of a display in the incongruent condition with a relevant set size three in Experiment 1. Note: The versions of the faces shown here differ from the images used in the actual experiments due to copyright limitations (see Appendix for lists of famous faces used in this study).

Figure 2: Mean response times for congruent and incongruent conditions as a function of set size in Experiment 1.

Figure 3: Mean response times for congruent and incongruent conditions as a function of set size in Experiment 2.

Figure 4: Mean response times for congruent and incongruent conditions as a function of search condition in Experiment 4.

Appendix:

Experiment 1:

Famous politicians: Tony Blair, Bill Clinton, George W Bush, John F Kennedy, Michael Portillo, John Major

Famous pop stars: David Bowie, Elton John, Elvis Presley, Mick Jagger, Sting, Paul McCartney

Experiment 2:

Famous politicians: Tony Blair, Bill Clinton, George W Bush, John Major

Famous pop stars: Elton John, Elvis Presley, Mick Jagger, Paul McCartney

Figure 1:

Figure 2:

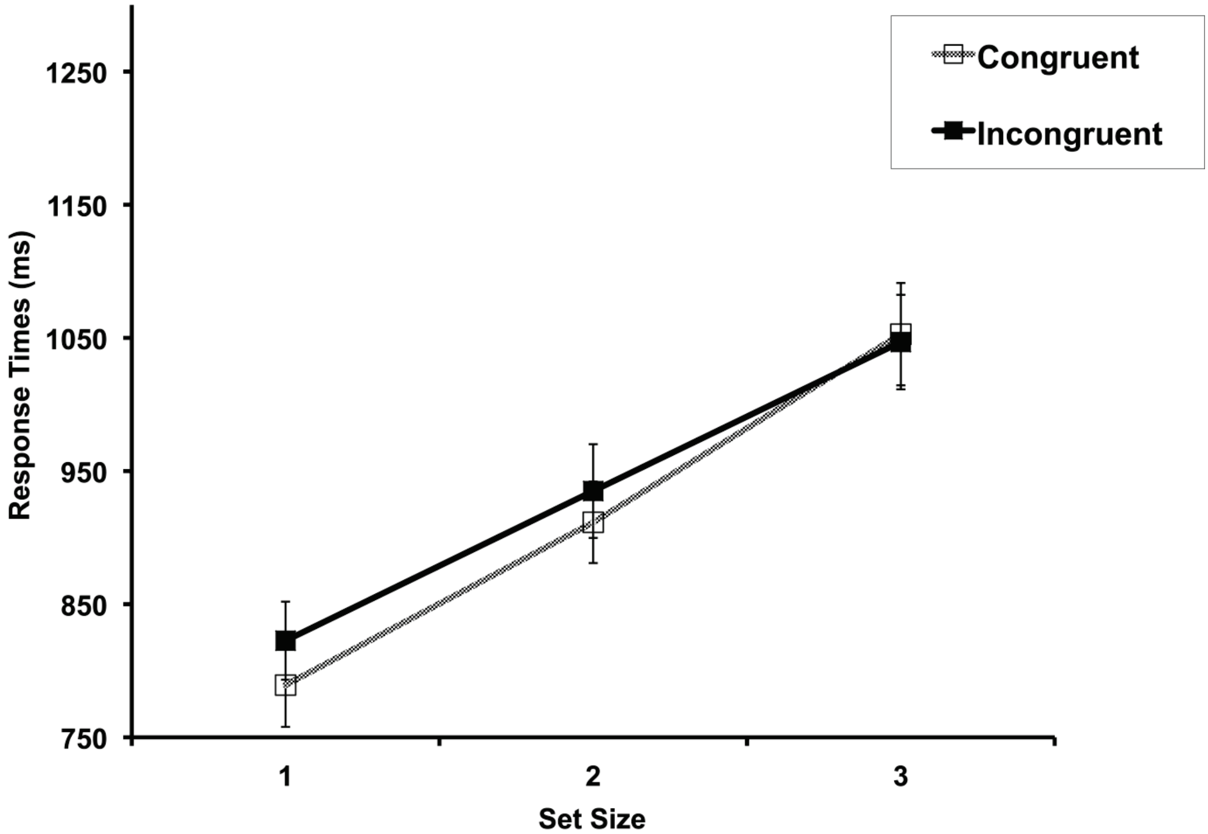

Figure 3:

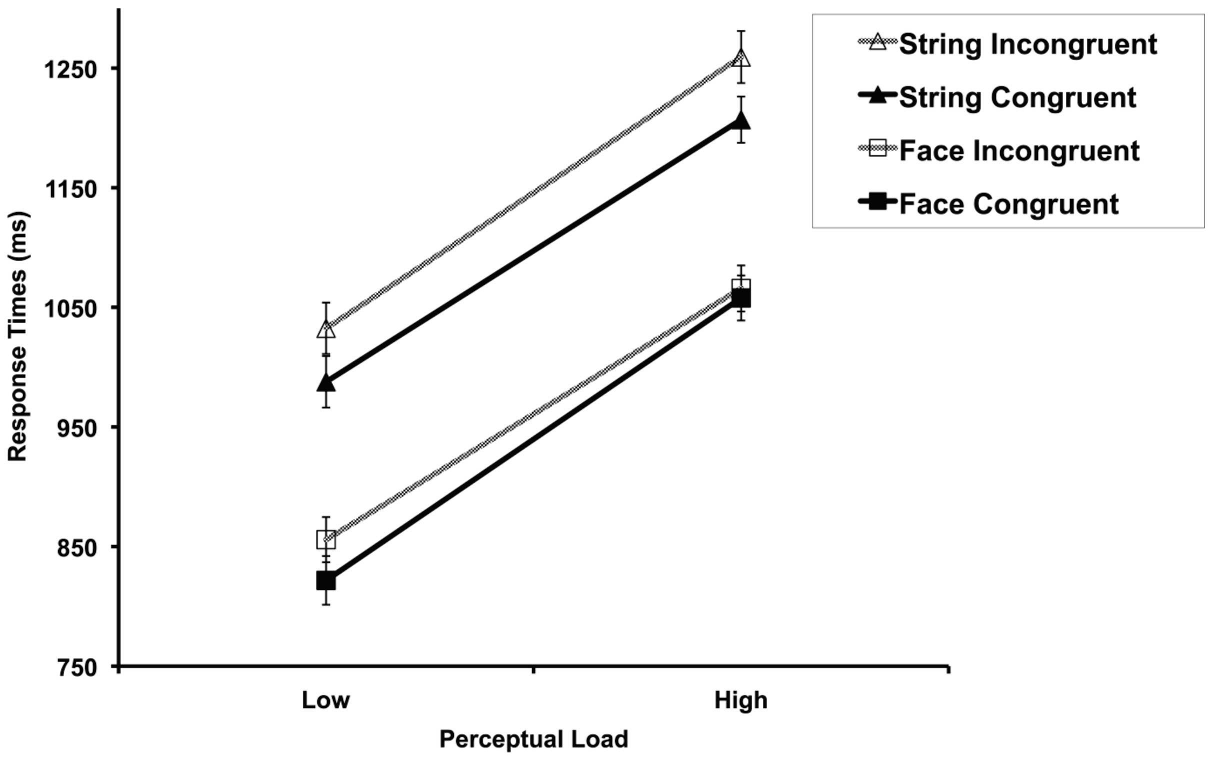

Figure 4:

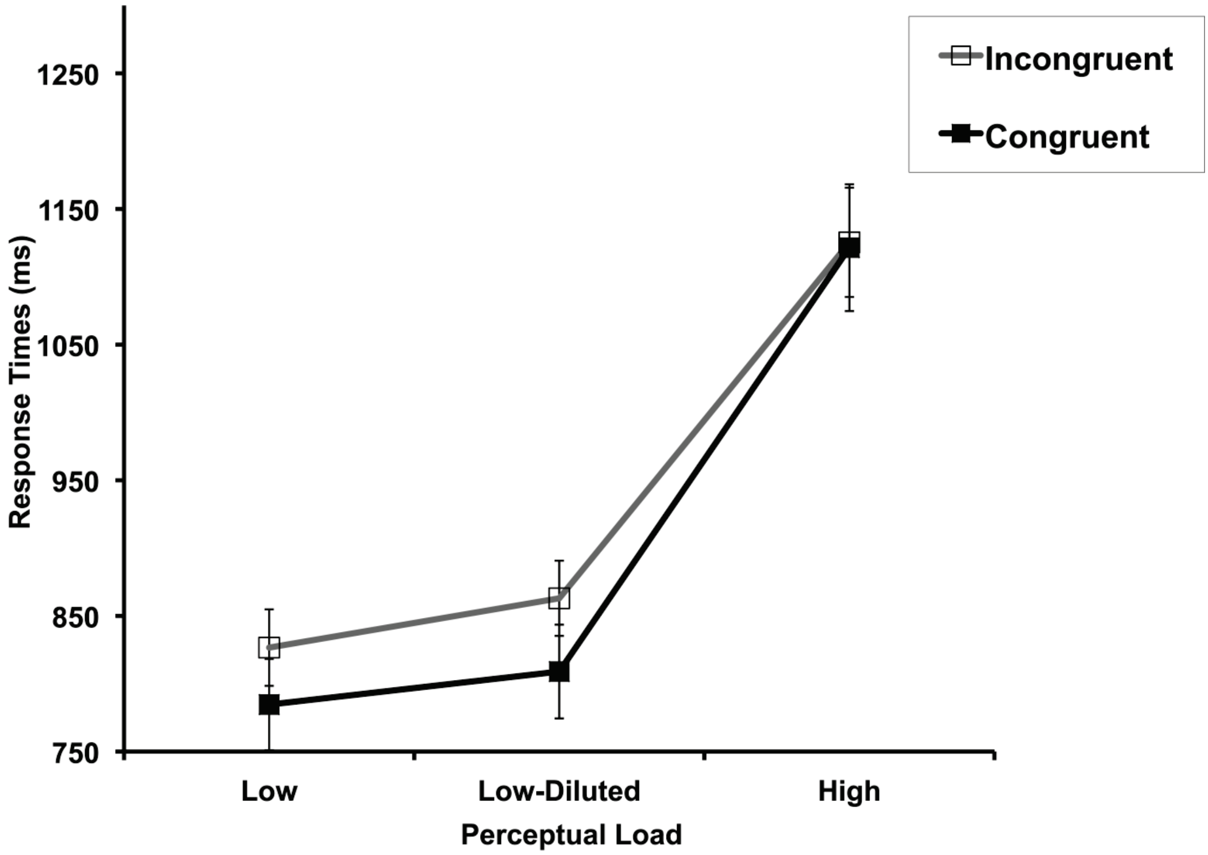

Table 1

Experiment 1: Mean RT (ms), SE and Percentage Errors as a function of distractor condition and face-search set size

	Set Size 1 Congruent	Setsize 1 Incongruent	Set Size 2 Congruent	Set size 2 Incongruent	Set size 3 Congruent	Set size 3 Incongruent
M	789	822	911	934	1052	1047
SE	31	29	30	35	38	35
% error	3.0	3.6	2.7	3.3	2.8	3.4

Table 2

Experiment 2: Mean RT (ms), SE and Percentage Errors as a function of distractor condition and search set size

Name Search	Low Load Congruent	Low Load Incongruent	High Load Congruent	High Load Incongruent
M	987	1032	1206	1259
SE	114	102	113	115
% error	5.8	6.4	10.4	11.4

Face Search	Low Load Congruent	Low Load Incongruent	High Load Congruent	High Load Incongruent
M	822	856	1057	1065
SE	110	103	102	104
% error	5.7	5.6	5.6	6.9

Table 3

Experiment 3: Mean RT(ms), SEs and Percentage Errors as a function of distractor condition and name-search set size

Name Search Group	Low Load Congruent	Low Load Incongruent	High Load Congruent	High Load Incongruent
M	1078	1111	1385	1376
SE	37	33	42	38
% error	5.9	6.1	6.5	6.4