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Dual-Target Cost in Visual Search for Multiple Unfamiliar Faces

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Abstract

The efficiency of visual search for one (single-target) and either of two (dual-target) unfamiliar faces was explored to understand the manifestations of capacity and guidance limitations in face search. The visual similarity of distractor faces to target faces was manipulated using morphing (Experiments 1 and 2) and multidimensional scaling (Experiment 3). A dual-target cost was found in all experiments, evidenced by slower and less accurate search in dual- than single-target conditions. The dual-target cost was unequal across the targets, with performance being maintained on one target and reduced on the other, which we label "preferred" and "non-preferred" respectively. We calculated the capacity for each target face and show reduced capacity for representing the non-preferred target face. However, results show that the capacity for the non-preferred target can be increased when the dual-target condition is conducted after participants complete the single-target conditions. Analyses of eye movements revealed evidence for weak guidance of fixations in single-target search, and when searching for the preferred target in dual-target search. Overall, the experiments show dual-target search for faces is capacity- and guidance-limited, leading to superior search for one face over the other in dual-target search. However, learning faces individually may improve capacity with the second face.

Keywords: Visual Search, Faces, Dual-Target Cost, Guidance, Capacity, Eye Movements

Public Significance Statement

Many surveillance tasks involve searching simultaneously for more than one unfamiliar face. This study demonstrates that searching for two unfamiliar faces is extremely difficult. In fact, attempting to search simultaneously for more than one unfamiliar face leads to the prioritization of one face, and the relative shedding of the other target face. Our findings can be applied to help improve the search for faces for security practitioners engaged in real-world surveillance tasks.

Dual-Target Cost in Visual Search for Multiple Unfamiliar Faces

Visual search has been studied extensively. The majority of models of visual search have been based on data from relatively simple variants of search tasks: for example, requiring participants to search for a single, simple target amongst a set of simple distractors (e.g., coloured shapes: Treisman & Gelade, 1980). Recent research, inspired by real-world search tasks such as airport baggage screening, has found that search performance declines when participants are faced with searching for multiple targets at once (e.g., Menneer, Barrett, Phillips, Donnelly & Cave, 2007). This cost emerges when searching for two targets, either of which can appear (disjunctive dual-target search). The attentional limitations demonstrated in this dual-target cost are providing useful new clues as to how search targets are stored in visual working memory and how those representations contribute to guidance of attention towards search targets (Menneer, Cave, Kaplan, Stroud, & Donnelly, in prep.).

Here, we subject unfamiliar faces to this dual-target search paradigm in order to determine whether or not a dual-target cost for faces exists and how it manifests itself, and thereby contribute understanding of the limitations in representing faces. Visual search for specific faces requires comparing targets stored in memory to perceptual representations of faces in a search array. Unfamiliar faces are complex, multi-feature objects that share a high degree of similarity to one another. As a consequence, the representation of target faces must be detailed in order to achieve successful search. Such precision and complexity places demands on working memory, potentially resulting in fragility and limits of representation that have not previously been observed within the context of visual search tasks.

Indeed, to prelude our results, we find that searching for two unfamiliar faces is very difficult, with one target face being poorly represented while performance is maintained for the other target face. Poor representation is evidenced in accuracy, recognition of the target, and guidance of attention.

While improved search for faces with robust representations has been found (own face compared to unfamiliar faces, Tong & Nakayama, 1999), most studies using visual search paradigms for faces have focused on face "pop-out" in search such as detecting emotional faces (see Frischen, Eastwood, &,Smilek, (2008) for a review). Therefore, predictions about face search for unfamiliar faces and for multiple faces amongst distractor faces must come from experiments using stimuli other than faces.

In the visual search for objects and features, searching for more than one target often leads to an effect labelled the dual-target cost (e.g., Menneer et al., 2007). The dual-target cost is found for simple as well as more complex stimuli and persists even after practice (Menneer, Cave, & Donnelly, 2009). In some circumstances, such as when searching for colour targets, overall speed decreases and accuracy falls when searching for two targets compared with single-target search, but both targets can be found with accuracy levels above chance. Indeed, much of the previous research on searching for multiple targets suggests that separate mental representations of all targets can be maintained successfully (Barrett & Zobay, 2014; Beck, Hollingworth, & Luck, 2012; Grubert & Eimer, 2015, 2016; Irons, Folk, & Remington, 2012; Stroud, Menneer, Cave, & Donnelly, 2012; Wolfe, 2012).

However, there is evidence that both targets are not equally and successfully represented in dual-target search. Search for dissimilar and unfamiliar shape targets results in one target being shed; *i.e.,* participants give up searching for a non-preferred target (Menneer et al., 2007). Menneer et al. (2007) reasoned that target shedding is a consequence of a profound limitation in our visual working memory capacity for complex visual objects (Alvarez & Cavanagh, 2004). Faces are complex objects and evidence suggests that visual search slopes are shallower for colour than for faces, indicating that the extra information load for faces limits working memory capacity (Eng, Chen & Jiang, 2005). If target shedding increases when working memory capacity is inadequate, the likelihood of target shedding should be high in face search.

Given differences in previous findings about the representation of multiple targets, and previous work suggesting limitations for representing complex objects, we here examine dual-target search for faces. The main issues we explore are the extent to which it is possible to simultaneously search for more than one unfamiliar face target, and whether both target representations are maintained equally or whether there are limitations in the number of faces that can be represented. These experiments have the potential to enhance our understanding of visual cognition in two different ways. First, the results will test the generality of the limitations that lead to the dual-target cost, which could reveal general aspects of storage of search targets and their effects on attentional selection. Second, they will indicate how the encoding and use of face stimuli is similar to and how it differs from that of other visual stimuli.

Beyond visual search, three lines of evidence show limitations in processing unfamiliar faces. First, when participants are shown two overlaid and transparent faces, participants experience perceptual rivalry (Boutet & Chaudhuri, 2001; see also Donnelly, Hadwin, Cave, & Stevenage, 2003) when faces are close to upright. The finding has been interpreted as showing we can only experience one face as a facial Gestalt at a time. Second, the difference between matching whole and part faces from target to probe faces (the whole-part effect; Davidoff & Donnelly, 1990; Tanaka & Farah, 1993), commonly used as a marker of holistic face processing, is removed if participants must simultaneously match two flanker faces at the same time (Palermo & Rhodes, 2002). The finding has been interpreted as showing that only one stimulus at a time can receive face-specific processing. Third, in contrast to distractor congruency effects found with name distractors, the presence of distractor faces of a different gender to target faces does not increase the response time of gender classifications of target faces (Experiment 1, Bindemann, Burton, & Jenkins, 2005: see also Neumann, Schweinberger, Wiese, & Burton, 2007). The finding has been interpreted as showing a face-specific capacity limit that prevents interference from neighbouring faces. All told, there seems to be rather consistent evidence of a limitation in the processing of figure-ground, representation, and semantic information in relation to unfamiliar faces, which all suggests that processing operates for one face at a time. If the resources for representing target faces in visual search are limited, then faces might be treated like complex unfamiliar shape targets in dual-target search, with a shedding of one target.

There is already evidence of a cost in representing multiple faces: when unfamiliar face targets are to be identified amongst unfamiliar distractor faces in a line-up procedure, response speed is slowed and accuracy is worse when identifying one of two targets relative to identifying only one (Megreya & Burton, 2006; Bindemann, Sanford, Gillatt, Avetisyan, & Megreya, 2012; Megreya & Bindemann, 2012). Also, evidence from ERP has shown that when two faces must be remembered in an identity-matching task, performance is impaired relative to a single face (Towler, Kelly, & Eimer, 2015).

Here we examine this cost of representing two unfamiliar faces in the context of visual search. We aim to understand the nature of the cost by measuring the cost for each target individually and by using eye movement measures to understand how the representations of target faces are utilised, in terms of both guidance towards targets and the recognition of a target once located. In addition, we interpret our results in the context of previously reported limitations for processing multiple faces, by considering the capacity for representing faces. Based on our previous studies of visual search for shapes, we predict that participants will manage disjunctive dual-target search for unfamiliar faces by representing and searching for one target (what we call a preferred face) at the expense of the other target (the non-preferred face). Preferred faces will be searched for effectively, but search for non-preferred faces will be much less effective, as it was for complex objects (Menneer et al., 2007; Menneer, Stroud, Cave, Li, Godwin, Liversedge, & Donnelly, 2012). We further predict that shedding of the non-preferred target will occur despite the fact that participants are able to search for and recognize both targets accurately when searching for each independently.

Shedding need not imply a complete inability to search for the non-preferred face given that sensitivity to the face may increase with repeated exposures, and because search ability depends on the similarity between the targets and distractors. Therefore, some ability to search for the non-preferred face may be found with practice or if both preferred and non-preferred dual-targets differ markedly from distractors. While we predict that dual-target face search will lead to worse detection of non-preferred targets than preferred targets, the detection of the non-preferred target may remain above chance.

The dual-target cost in visual search is often associated with reduced attentional guidance to targets compared with single-target search. Guidance to targets is reflected in eye movement fixations to targets and distractors during search. In guided search, the probability of fixations to distractors that are similar to targets is greater than to those dissimilar to targets (Stroud, Menneer, Cave, Donnelly, & Rayner, 2011). In the present experiments, we manipulate the similarity of distractors to targets so that we can measure whether or not fixations to distractor faces increase as distractor faces become more similar to targets. In other words, does guidance occur for faces, and if so, does reduced guidance contribute to the dual-target cost as found for coloured and x-ray image targets (Stroud et al., 2012; Menneer et al., 2012)?

The evidence of limitations in the processing of faces listed above makes it very unlikely that guidance to targets might be achieved from representations of whole faces. Rather, in order to guide attention to faces, it seems more likely that simple features, not whole-face representations, will be used, with attention being guided to the items with target-like features (Wolfe, Cave & Franzel, 1989). While guidance to faces seems unlikely, we predict that any evidence of guidance will be stronger for preferred than non-preferred face targets.

In summary, we examine visual search for one compared to two unfamiliar faces. We hypothesise that in dual-target face search (1) accuracy will be lower than in single-target face search, (2) limitations in representing multiple unfamiliar faces in working memory will lead to shedding, whereby participants maintain accurate search for a preferred face target but perform poorly with the non-preferred target, (3) weak representation of the non-preferred target will also be evidenced by difficulty in recognizing that target once fixated, and (4) there may be some evidence of guidance to preferred face targets but not non-preferred face targets. The results will provide new evidence about the similarities and differences between the representation and processing of faces compared with other visual objects, and will also give a broader picture of the interactions between working memory and attention that produce the dual-target cost.

Experiment 1

In Experiment 1, participants searched for the same two targets throughout the experiment[1] and the visual similarity of distractors to target faces was manipulated using morphing. Morphing between faces allows for control of similarity based on image pixels rather than similarity in a psychological face space. There were two groups of distractors, with each group providing a range of similarity values to one of the targets. We predicted that search performance would not differ between the two face targets across the two single-target

[1] It could be rightly argued that experiencing the same faces throughout the experiment causes the faces to become less unfamiliar. However, we conducted a pilot experiment that showed participants performed at chance when target faces differed from trial to trial, which persuaded us to keep targets constant throughout.

searches. In contrast, participants would be faster and more accurate with a preferred target in dual-target search (Menneer et al., 2007).

If attention is guided to faces, then it will be reflected in the rates of fixations to distractors. When a target is present, unguided serial and self-terminating search would, on average, lead to 50% of distractors being fixated before the target is located. If search is instead guided, the probability of fixations to distractors in guided search would be lower than 50% when a target is present. In addition, in guided search, the probability of fixating distractors that are similar to targets will be greater than for those that are dissimilar to targets.

Method

Participants

Sixteen participants were recruited via an opportunity sample in return for course credit or payment. Age ranged from 19-29 years (M = 22.56, SD = 3.86) and four participants were male. All participants had normal colour vision and normal or corrected to normal visual acuity. Full ethical approval was granted from the University of Southampton prior to commencing the experiment.

Stimuli

Faces used in this experiment were from the Glasgow Unfamiliar Face Database (GUFD, Burton, White & McNeill, 2010). We used two photos (one from set C1 and one from set C2 within the database) of each of eight individuals: four male and four female faces. Only closed-mouth neutral faces with eyes looking forwards were used. Faces were chosen based on similar hair colour (brown) and absence of glasses, beards and hair covering the face. Male and female faces formed two separate stimulus sets. The eight face identities from the GUFD were 004, 005, 053, 064 for the female set and 007, 008, 010, 024 for the male set. Photographs from C1 were shown to participants to define the target faces.

Photographs (and morphs) used in the search displays were taken from set C2. Therefore participants could not use an image matching process to perform search.

Morph faces were created for use in the experiment using a morphing program written in Matlab (Adams, Gray, Garner, & Graf, 2010). First, all faces from set C2 that were to be used in the search displays were morphed to contain 5% of a carrier face of the same gender (face 299 for females and face 271 for males). All eight C1 faces to be used as the preview target images were also morphed with 5% of the corresponding carrier face identity from the C1 set. This first stage of morphing was conducted to ensure that target faces could not be identified simply via an absence of morphing.

A stimulus set was created from four identities of the same gender, as illustrated in Figure 1. Morphs between two adjacent identities in the set were created at 20% increments for each of the four adjacent pairings. This morphing process created a pool of 16 distractors (non-targets), comprising four distractors from each "arm" of the set. Distractors were defined by distance from the target in similarity space, providing a measure of how similar each distractor was to the target face(s). There were four steps of increasing dissimilarity from targets. Participants were only exposed to one stimulus set (either male or female), with targets selected from diagonally opposite positions in the stimulus space. The set of 16 distractor faces in a stimulus set was seen by all participants shown this stimulus set, but the target pairs varied across participants.

All faces were presented in colour and in an oval annulus to remove the majority of the hair and to ensure outline was not used as a matching cue. All stimuli were presented against a white background and text instructions were presented in black.

Figure 2 illustrates the trial procedure. Target preview faces appeared at a size of 1.90 by 3.20 cm in the centre of the screen at a visual angle of 1.55° by 2.62°. When two target previews were shown for dual-target search, the targets were presented at the same size as in single-target search, but next to each other with a overall width of 7.00 cm creating a visual angle of 5.71°.

In the search displays, each face was placed in one of eight locations equally spaced in a circle with a radius of 11.50 cm. Trial faces appeared at the same size as target preview faces. The overall ring of trial faces extended a size of 15.50 cm by 18 cm on the screen creating a visual angle of 12.49° by 14.42°.

On target-present trials, seven distractors were present, and on target-absent trials, eight distractors were present. The combination of distractors presented on a trial within a session (either search for target A, search for target B or dual-target search: henceforth referred to as search type) were randomly generated for each search type and participant with the following constraints: All distractor faces were different within a trial and each distractor was shown an equal number of times across a search-type session. Note that distractors were not constrained to the same level of target-similarity on each trial in order to allow guidance to some distractors (target-similar) over others (target-dissimilar) to emerge if possible.

Apparatus

Stimuli were presented on a ViewSonic Graphics Series G225f CRT monitor with screen size 40.60 cm x 30.80 cm in a darkened room. Participants were seated at a distance of 70 cm giving a visual angle of 30.11° by 23.75° for the screen. Screen resolution was 1024 x 768 with a refresh rate of 100 Hz. Participants responded by clicking buttons on a ResponsePixx button-box. An SR Research Limited Eye-Link 1000 eye tracker operating at 1000 Hz and a nine-point calibration with maximum mean-average visual angle error of 0.5° was used to record monocular eye movements. A chinrest with headrest was used to stabilise participant head position.

Design and Procedure

A 2 (search type) x 2 (trial type) x 4 (step) repeated measures design was used. Participants completed three search-type sessions: single-target search for target A, single-target search for target B and dual-target disjunctive search for A and B. However, search for single targets were combined for analysis to give two conditions: single-target and dual-target search. Trial type was either target-present or target-absent. Targets appeared on 50% of trials and only one target appeared in the display on target-present trials. The step factor indicated how similar distractors were to target faces. Steps 1-4 indicated 20% decreases in morph contribution of the target face. Step 1 was most similar (80% target face) and step 4 least similar to the target (20% target face). Each participant completed 256 trials for single-target search for A, 256 trials for single-target search for B, and 256 trials for dual-target search. For the dual-target present trials, each target was present an equal proportion of times: 64 trials for each target. Target preference (preferred versus non-preferred) was determined post-hoc, so details are provided in the Results section.

Participants completed three separate sessions (one for each search type) with the opportunity to take breaks within sessions. All three sessions were completed within two weeks. Each search-type session began with eye tracker calibration during which participants looked at dots on the screen without moving their head. Once calibration was achieved, participants completed 10 practice trials. For the experimental trials, participants were shown a fixation dot in the centre of the screen used to check for drift followed by a preview of the target face(s) was shown for 1000 ms. Participants had to fixate the preview (bounded by a gaze contingent window) to trigger the presentation of the search display. Participants were instructed to search the display by freely moving their eyes but not their head. Participants responded by indicating a target face was “present” by pressing the left button or “absent” by pressing the right button on the response controller. They were told that in the dual-target condition, only one of the two targets could be present in the search display and this would be a "present" trial. The search display was shown until participants made a response, which ended the trial and began the next. Participants were given auditory feedback for their responses, with a beep for an incorrect button press on a trial. Instructions were given at the beginning of each search-type session. Participants were given breaks at least every 64 trials and re-calibration took place after every break. Target sets and order of search type were counterbalanced across participants.

Results

Repeated measures ANOVAs were used to analyse the accuracy, response time (RT) and eye movement measures, and a Greenhouse-Geisser correction was applied for any violations of sphericity. All *t*-tests had their *p*-values Bonferroni corrected prior to being reported and we report generalised eta-squared as a measure of effect size for ANOVAs (Bakeman, 2005).

Behavioural Measures

Proportion correct. Proportion correct results are presented in Figure 3. Data were collapsed across the two single-target searches to allow a comparison of single- compared to dual-target trials. The data were analysed using repeated measures ANOVAs with search type (single- and dual-target) and trial type (target-present and target-absent) as the factors.

The main effects of search type and trial type were significant ($F(1,15) = 11.88$, $p = .004$, $\eta^2_G = .202$; $F(1,15) = 12.83$, $p = .003$, $\eta^2_G = .121$). Response accuracy was higher in single- ($M = 0.78$, $SE = 0.02$) than dual-target search ($M = 0.68$, $SE = 0.03$), as was expected, and on target-present ($M = 0.77$, $SE = 0.02$) than target-absent ($M = 0.70$, $SE = 0.03$) trials. There was no interaction of search type and trial type ($F(1,15) = 2.99$, $p = .104$, $\eta^2_G = .007$).

Performance was compared across preferred and non-preferred targets on target-present trials[2]. A preferred target and non-preferred target were determined for each participant by examining accuracy to individual target faces in the dual-target condition. The target with the higher accuracy was categorised as "preferred" and the target with the lower accuracy was categorised as "non-preferred" for each participant[3]. The factors for this analysis were search type (single- and dual-target) and target preference (preferred and non-preferred). The critical interaction of interest is between search type and target preference, and it was significant ($F(1,15) = 6.63$, $p = .021$, $\eta^2_G = .052$). Breaking this interaction down, there was no significant difference in accuracy for the preferred target between the single- ($M = 0.85$, $SE = 0.02$) and dual-target ($M = 0.80$, $SE = 0.04$, $p = .300$) conditions, but accuracy was significantly reduced for the non-preferred target in dual-target ($M = 0.63$, $SE = 0.05$) compared to single-target ($M = 0.79$, $SE = 0.03$, $p = .004$) search. This is important because it confirms that participants establish a preferred target in dual-target search. A one-sample *t*-test showed accuracy for the non-preferred target in the dual-target condition was above chance ($t(15) = 2.76$, $p = .015$). This demonstrates that participants had not entirely abandoned search for the non-preferred target.

Mean correct RT. Response time (RT) data were analyzed as were the accuracy data. All RT data were log transformed prior to analysis to normalise the distribution, but raw means are reported here for descriptive statistics. Mean correct RT results are presented in Figure 4. The main effects of search type and trial type were significant ($F(1,15) = 22.29$, $p < .001$, $\eta^2_G = .091$; $F(1,15) = 39.88$, $p < .001$, $\eta^2_G = .103$ respectively). Participants were faster in single- ($M = 4436.36$, $SE = 270.53$) than dual-target search ($M = 5339.71$, $SE = 384.64$) and

[2] Performance on target-absent trials cannot be assigned to one target or the other in dual-target search.

[3] There were eight targets and four target pairs. Each target pair was shown to four participants. In these pairings, two targets were never preferred, one target was preferred once, two targets preferred twice, one target was preferred three times and two targets were preferred four times.

on target-present (M = 4629.08, SE = 314.63) than target-absent (M = 5405.94, SE = 344.49) trials. The interaction between search type and trial type ($F(1,15) = 5.28$, p = .036, η^2_G = .002) was significant. The difference between single- (M = 4244.39, SE = 281.89) and dual-target (5013.77, SE = 371.30) conditions was significant for target-present trials (p = .049), whereas the difference between single- (M = 4820.30, SE = 270.21) and dual- (M = 5991.58, SE = 442.29) target conditions did not reach significance for target-absent trials (p = .055).

With respect to preferred and non-preferred targets, the critical interaction between search type and target preference did not reach significance for the RT data ($F(1,15) = 1.30$, p = .271, η^2_G= .004).

In summary, the accuracy data show a shedding for the non-preferred target in dual-target search, relative to the preferred target. This preference was not reflected in the RT data.

Eye Movement Measures

Fixations shorter than 60 ms or longer than 1200 ms were removed, which led to 2.29% of the data being excluded. Data were removed from incorrect trials and any fixations that coincided with a response. Fixations more than 2° from the centre of the nearest interest area were also removed. The final data set consisted of 95,944 fixations.

In this, and all subsequent sections reporting eye movement data, we report (1) Probability of fixations to targets, (2) Probability of fixations to distractors on target-present trials, (3) Probability of fixations to distractors on target-absent trials, and (4) The time taken to respond to a target once it was fixated. The first three measures provide measures of search guidance towards targets and target-similar distractors. The fourth measure represents the time to recognize a target and therefore reflects the relative quality of the target representation.

Probability of fixation data for target-present and target-absent trials are presented in Figure 5. Verification times are presented in Table 1. Global eye movement measures are presented in Supplemental Materials 1.

Probability of fixations to targets. The probability of fixation to targets was calculated as the proportion of trials on which the target was fixated at least once out of the total number of trials in which the target was shown. Fixations to targets were analyzed in a 2 (search type: single or dual) x 2 (target preference: preferred or non-preferred) repeated measures ANOVA. The main effects of search type and target preference were significant ($F(1,15) = 9.94, p = .007, \eta^2_G = .090$; $F(1,15) = 7.24, p = .017, \eta^2_G = .062$, respectively). Targets were more likely to be fixated in single- ($M = 0.91, SE = 0.02$) than dual-target ($M = 0.84, SE = 0.03$) search and when preferred ($M = 0.91, SE = 0.02$) than non-preferred ($M = 0.85, SE = 0.03$). The interaction of search type and target preference was not significant ($F(1,15) = 3.64, p = .076, \eta^2_G = .015$).

Probability of fixations to distractors on target-present trials. The probability of fixations to distractors on present trials was calculated as the proportion of trials in which a specific distractor was fixated at least once out of the total number of target-present trials on which that distractor appeared. Fixations made to distractors when finding preferred and non-preferred targets (i.e. correct target-present trials) in single- and dual-target conditions were examined to explore guidance using a 2 (search type: single or dual) x 2 (target preference: preferred or non-preferred) x 4 (step: 1-4) repeated measures ANOVA. As noted earlier, guidance should result in the distractor fixation rates below 50% on target-present trials and/or rate decreasing with dissimilarity from target (i.e., an effect of step).

The main effects of search type and step were significant ($F(1,15) = 13.03, p = .003, \eta^2_G = 0.231$; $F(2.02,30.37) = 14.45, p = .001, \eta^2_G = .013$ respectively). The probability of fixating distractors was higher in the dual-target ($M = 0.63, SE = 0.03$) than single-target condition (M = 0.54, SE = 0.04). Probability of fixation to distractors decreased with step from target (M = 0.61, SE = 0.03; M = 0.59, SE = 0.03; M = 0.57, SE = 0.04; M = 0.57, SE = 0.03 for steps 1-4 respectively).

There was a significant interaction of search type and target preference, ($F(1,15)$ = 5.13, p = .039, η_G^2 = .016). The probability of fixating distractors when non-preferred targets were presented in dual-target search (M = 0.67, SE = 0.04) was higher than in all other conditions (M = 0.54, SE = 0.04; M = 0.55, SE = 0.03; M = 0.59, SE = 0.04 for single-target preferred, single-target non-preferred and dual-target preferred). The three-way interaction of search type, target preference and step was marginally significant ($F(2.34, 35.15)$ = 3.27, p = .051, η_G^2 = .004). The interaction of target preference and step was significant in the dual-target ($F(2.13, 32.00)$ = 3.46, p = .041, η_G^2 = .010) but not single-target condition ($F(2.47, 37.12)$ = 0.51, p = .641, η_G^2 = .010). In dual-target search there was an increased probability of fixation on non-preferred target trials (M = 0.64, SE = 0.03) relative to preferred target trials (M = 0.58, SE = 0.04, p = .018) at step 1, but no significant differences at steps 2-4 (ps > .073). All other interactions were non-significant (Fs < 3.40, ps > .085, η_G^2< .017).

Probability of fixations to distractors on target-absent trials. The probability of fixations to distractors on target-absent trials was calculated as the proportion of target-absent trials in which a type of distractor was fixated at least once out of the total number of target-absent trials on which it appeared.

Target-absent trials in dual-target search cannot be assigned to one target or the other as they were for target-present trials. Therefore, in order to compare the probability of fixation data in dual-target search with those in single-target search, single-target probabilities for the two different targets need to be combined. Specifically, we need to determine the probability that each distractor type would be fixated at least once if subjects conducted two separate single-target searches. Fixations to a given distractor can occur in single-target search for target A as well as in single-target search for target B. Comparing the dual-target fixation probability against the mean of the two single-target probabilities would not be very informative; we would expect more distractors to be fixated in the dual-target condition because with two targets there will be more distractors that are similar to a target. On the other hand, simply summing the probabilities across the two single-target searches would overestimate the combined probability; in fact, it could lead to values greater than 1. Instead, the probability of fixation in the single-target condition was calculated as the probability of fixation from the target A session plus the probability of fixation from the target B session and these data then had the probability of fixation in both A and B sessions subtracted from them (i.e., OR probability for non-mutually exclusive events, as used in Menneer et al., 2012):

$$P(A \cup B) = P(A) + P(B) - P(A \cap B)$$

Fixations were compared using a 2 (search type: single or dual) x 4 (step: 1-4) repeated measures ANOVA. The main effect of search type was significant ($F(1,15) = 4.94$, $p = .042$, $\eta^2_G = .233$). Probability of fixation was higher in the single- ($M = 0.98$, $SE = 0.01$) than the dual-target ($M = 0.93$, $SE = 0.03$) condition. Thus, the distractor faces are fixated less often in dual-target search than they would be in two separate single-target searches. The main effect of step and interaction of search type and step were not significant ($F(1,15) = 0.95$, $p = .345$, $\eta^2_G = .004$; $F(1,15) = 4.44$, $p = .052$, $\eta^2_G = .004$ respectively).

Verification Time. Verification time (in milliseconds; see Table 1) is the time from first fixating a target to responding. All verification times were log-transformed prior to analysis to normalise the distribution, but raw means are reported here for descriptive statistics. Verification times were analyzed using a 2 (search type: single or dual) x 2 (target preference: preferred or non-preferred) repeated measures ANOVA. The main effect of search type was significant ($F(1,15) = 15.46$, $p = .001$, $\eta^2_G = .085$). Verification times were longer in the dual- (M = 2236.60, SE = 238.11) than the single-target (M = 1609.13, SE = 190.18) condition. The main effect of target preference and interaction of search type and target preference were not significant ($F(1,15) = 4.32$, $p = .055$, $\eta^2_G = .029$; $F(1,15) = 2.46$, $p = .137$, $\eta^2_G = .011$ respectively).

Discussion

Experiment 1 shows that the search for two unfamiliar faces is difficult. In fact, when searching for two face targets, participants used a strategy that diminished performance with a non-preferred target but not with a preferred target relative to single-target baselines. These results are in line with shedding found in search for objects (Menneer et al., 2007) and consistent with our prediction.

In relation to guidance to face targets, we anticipated guidance, if present at all, would be very weak and restricted to single-target search and preferred targets in the dual-target condition. Across all conditions, fixation rates to distractors were at or exceeded 50%. Nevertheless, on target-present trials, fixations to distractors increased with their similarity to targets, consistent with distractors similar to targets attracting attention. On the target-absent trials, the fixation rates to distractors show that search was close to exhaustive. The conclusion we reach is that guidance, if present, is very limited. This evidence of guidance (an effect of step) was equally apparent for preferred and non-preferred targets.

Fixation of >50% distractors implies that search continued after the target was fixated, because, without guidance, on average, the target should be fixated after half of the distractors have been fixated. An alternative explanation is that >50% of distractors are fixated because search is being driven by the other target, leading to fixation of distractors similar to both targets. However, this explanation would only apply in the dual-target search condition, whereas slightly more than 50% distractors were also fixated in single-target. Verification times were long in all conditions (>1.5 seconds), indicating that search continued after the target was fixated. We also calculated the number of distractors visited after the first fixation on the target. More distractors were visited after first fixating a target in dual-target than single-target search, and after first fixating the non-preferred than preferred target. In fact, statistical analysis of these data revealed the interaction between task and preference was significant (see Supplemental Materials 2).

This continued search and the effect of target-similarity appear in conflict, providing evidence against and for guidance respectively. However, together these patterns suggest that the guidance was potentially disruptive to target identification, with target-similar distractors drawing attention away from the fixated target.

The simplest explanation of reduced accuracy with non-preferred faces is that it reflects a reduced quality of face representation to verify and reject items as targets. Such an explanation is consistent with the eye movement data, in which the probability of fixating distractors when the non-preferred target was present on dual-target trials was higher than in the other conditions. In addition, while verification times were long in all conditions, they were numerically longer for non-preferred targets in the dual-target condition, although this interaction was not statistically significant. The reduced quality of the representation for the non-preferred target seems likely to be a result of working memory limitations for representing faces. However it may instead reflect the cost of switching target templates during search from the default (preferred) template to the non-preferred template. Perhaps this switch cannot be performed without interference between the two templates, thereby reducing the quality of the representation. In practice both accounts produce the same predictions and we shall not consider this issue further.

Despite the reduced accuracy of responses to the non-preferred target in dual-target search, the non-preferred target must have been weakly represented in dual-target search. If this had not been the case, non-preferred targets would have been missed entirely and fixations to distractors when non-preferred targets were presented in dual-target search would have resembled those on target-absent trials.

Experiment 2

In Experiment 2, we repeated Experiment 1 but changed the way targets were defined with respect to each other and to distractors. In Experiment 2 some distractors shared features with both targets while other distractors shared features with neither target. In addition to confirming the findings of Experiment 1, we sought stronger evidence of guidance through increased fixations to distractors similar to both targets relative to those similar to neither target.

Method

All experimental details were the same as for Experiment 1, except for those outlined here.

Participants

Sixteen participants took part in Experiment 2. Age ranged from 19-24 years (M = 20.44, SD = 1.50) and four participants were male.

Stimuli

Target pairs were created from adjacent targets, defined as those sitting on the same "arm" in the sets used for Experiment 1. Therefore, there were four pairings per set, with eight in total across the male and female sets: F1 and F2, F2 and F3, F3 and F4, F4 and F1, M1 and M2, M2 and M3, M3 and M4, or M4 and M1. Thus, distractors in the trial could be morphs of both the targets, morphs with one of the targets or morphs with neither target (see Figure 6).

Design

In order to test for an effect of similarity of distractors to two, one or no targets, a factor of "arm" was included in the design, and step was not included in the analysis. The design was a 2 (search type) x 2 (trial type) x 3 (arm) x 4 (step) repeated measures design. The arm factor of "both", "one" or "none" described whether distractors were morphs of both target faces, morphs with one target face or morphs with none of the targets. Distractors were morphed in 20% steps from the original faces, but the factor step does not apply in the analysis as step describes the similarity of the morph from the single target only on the "one" arms. However, step was not meaningful on the "none" arm as there was no morph similarity to targets, and step could be measured from either target on the "both" arm.

Results

The results were analyzed in the same way as in Experiment 1.

Behavioural Measures

Proportion correct. Proportion correct results are presented in Figure 3. The main effect of search type ($F(1,15) = 7.42$, $p = .012$, $\eta^2_G = .037$) was significant. Participants were more accurate in single- ($M = 0.72$, $SE = 0.03$) than dual-target search ($M = 0.65$, $SE = 0.03$). Neither the main effect of trial type ($F(1,15) = 0.07$, $p = .800$, $\eta^2_G = .002$) nor the interaction of search type and trial type ($F(1,15) = 0.15$, $p = .706$, $\eta^2_G = .001$) reached significance.

With respect to preferred and non-preferred targets[4], the critical interaction of search type and target preference was significant ($F(1,15) = 7.99$, $p = .013$, $\eta^2_G = .036$). Accuracy was lower to non-preferred targets in dual-target search ($M = 0.54$, $SE = 0.05$) than to the preferred-target in dual-target search ($M = 0.76$, $SE = 0.05$, $p = .005$) and both single-target searches ($M = 0.68$, $SE = 0.05$; $M = 0.78$, $SE = 0.05$ for non-preferred and preferred respectively). No other contrasts were significant.

A one sample *t*-test did not find any significant difference between accuracy for the non-preferred target in the dual-target condition and chance performance at 0.50 ($t(15)$ =

[4] There were eight targets and eight target pairs. Each target was shown to four participants. One target was never preferred, two targets were preferred once, two targets preferred twice, two targets preferred three times and one target was preferred four times.

0.82, p = .423). This demonstrated that participants were unable to search effectively for both the preferred and the non-preferred target simultaneously.

Mean correct RT. Mean correct RT results are presented in Figure 4. The main effects of search type and trial type were significant (F(1,15) = 7.06, p = .018, η^2_G = .074; F(1,15) = 56.16, p < .001, η^2_G = .185 respectively). Participants were faster in single- (M = 4496.70, SE = 242.19) than dual-target search (M = 4940.29, SE = 220.86) and on target-present (M = 4467.11, SE = 199.78) than target-absent (M = 5221.25, SE = 231.93) trials. The interaction between search type and trial type (F(1,15) = 10.59, p = .005, η^2_G = .011) was significant. There was a difference between single- (M = 4820.30, SE = 270.21) and dual-target (M = 5581.46, SE = 442.29) conditions on target-absent trials (p = .045), whereas there was no difference between the single-target (M = 4244.39, SE = 281.89) and dual-target (M = 5013.77, SE = 371.30) conditions on target-present trials (p = .240).

With respect to target preference, the critical interaction between search type and target preference did not reach significance (F(1,15) = 0.11, p = .748, η^2_G < .001). The target preference revealed by the accuracy data was not reflected in the RT data.

Eye Movement Measures

The eye movement data were analyzed as in Experiment 1. Of the original data, 2.06% was removed giving a final data set consisting of 89,430 fixations. The main issue of interest was in relation to fixations made on present trials to distractors on “both”, “single” and “none” arms. Fixations were analyzed as in Experiment 1 except the step factor was replaced with arm (three levels: “both” versus “one” versus “none”) to examine the effect of target similarity on eye movements. Probability of fixation results for target-present and target-absent trials are presented in Figure 7. Verification times are presented in Table 1. Global eye movement measures are presented in Supplemental Materials 1.

Probability of fixations to targets. With respect to fixations to targets, the main effects of search type and target preference were not significant ($F(1,15) = 3.21$, $p = .093$, $\eta^2_G = .014$; $F(1,15) = 0.90$, $p = .357$, $\eta^2_G = .011$). The interaction of search type and target preference was significant ($F(1,15) = 5.33$, $p = .036$, $\eta^2_G = .025$). The non-preferred target in dual-target search was fixated less often in than the preferred target in dual-target search and either target in single-target search, but the differences were not significant after Bonferroni correction.

Probability of fixations to distractors on target-present trials. The main effects of target preference and arm were significant ($F(1,15) = 7.63$, $p = .015$, $\eta^2_G = .076$; $F(1.58,23.69) = 24.45$, $p < 0.001$, $\eta^2_G = 0.040$ respectively). The probability of fixating distractors was higher when the non-preferred target was present ($M = 0.65$, $SE = 0.03$) compared with the preferred target ($M = 0.57$, $SE = 0.03$). The probability of fixating distractors was lower to faces from the "none" than "both" and "one" arms ($M = 0.57$, $SE = 0.03$ versus $M = 0.65$, $SE = 0.03$, $p < .001$ versus $M = 0.61$, $SE = 0.03$, $p = .029$ respectively). There was a trend for a difference in fixations to "one" and "both" arms ($p = .088$). No other main effects and interactions reached significance (Fs < 3.68, $p > .074$, $\eta^2_G < .070$).

Probability of fixations on target-absent trials. The main effects of search type and arm were significant ($F(1,15) = 25.62$, $p < .001$, $\eta^2_G = .414$; $F(1,15) = 8.43$, $p = .011$, $\eta^2_G = .217$). Probability of fixation was higher in the single- ($M = 0.98$, $SE = 0.01$) than dual-target ($M = 0.95$, $SE = 0.01$) condition. As in the target-absent trials of Experiment 1, distractors were less likely to be fixated in dual-target search than they would be in two separate single-target searches. Probabilities of fixation were higher to distractors from the "both" arm ($M = 0.98$, $SE = 0.01$) than the "none" arm ($M = 0.96$, $SE = 0.01$, $p < .001$). There were no differences for fixations to distractors on the "one" arm ($M = 0.97$, $SE = 0.01$, ps $> .137$)

relative to those on the "both" and "none" arms. The interaction of search type and arm did not reach significance ($F(1,15) = 2.87$, $p = .111$, $\eta^2_G < .018$).

Verification Time. The main effect of target preference was significant ($F(1,15) = 8.84$, $p = .009$, $\eta^2_G = .109$). Verification times were longer in search for non-preferred ($M = 2185.65$, $SE = 194.22$) than preferred targets ($M = 1590.05$, $SE = 154.20$). The main effect of search type and interaction of search type and target preference were not significant ($F(1,15) = 2.69$, $p = .122$, $\eta^2_G = .021$; $F(1,15) = 0.59$, $p = .452$, $\eta^2_G = .004$ respectively). See Table 1.

Discussion

In Experiment 2 we replicated Experiment 1, but used distractors that were related to both, one or neither of the targets. The accuracy data showed a shedding of the non-preferred target in dual-target search. As in Experiment 1, non-preferred targets were weakly represented in dual-target search. The weakness of the target representation for non-preferred targets in dual-target search is reflected in the overall fixation rates to distractors, which were at or in excess of 50% on target-present trials. Some target matches must be failing after a target is fixated. As in Experiment 1 we looked to verification times for additional evidence of the weak representation of non-preferred targets in dual-target search. The verification times were longer for non-preferred targets, but this was so across both single- and dual-target searches. Again verification times were long in all conditions with the interaction between target preference and search type numerically present but not statistically significant. As in Experiment 1, distractors were visited after the first fixation to the target. More distractors are visited after fixating non-preferred than preferred targets and in dual-target than single-target search. Unlike in Experiment 1, the interaction between task and preference did not reach significance (see Supplemental Materials 2).

In Experiment 2 we sought evidence of guidance by comparing fixations to distractors that were similar to "both", "one" or "none" of the targets. The significant effect of "arm" on fixation rates shows that fixations are more likely to items similar to targets than dissimilar to them. The effect of target-distractor similarity is significant in target-present and target-absent conditions, indicative of search guidance. In Experiment 2, the evidence of guidance to targets exists but, given fixation of >50% of distractors, this guidance must be rather weak. As in Experiment 1, this guidance may interfere with target identification, also reflected in the long verification times, due to distractors signalling target similarity when the target has already been fixated.

Experiments 1 and 2 provide a consistent set of data with respect to searching for two unfamiliar faces. Searching for two unfamiliar faces is hard, with the costs of dual-target search being managed through the shedding of one face. The experiments are, however, limited in one specific respect. The morphing of the target faces together with the 5% morph with a base face across all stimuli means that the faces share visual characteristics with each other, and therefore similarity across the stimulus set is relatively high compared with what might occur for separate, un-morphed, faces. The search task is therefore likely to be difficult, and indeed was difficult even in single-target search. Might the shedding of the non-preferred face target actually be a function of overall task difficulty? In other words, shedding could be an artifact of task difficulty.

In Experiment 3 we tested this hypothesis by running a comparable task to Experiments 1 and 2 but using multi-dimensional scaling to establish targets and distractors.

Experiment 3

In Experiment 3 similarity was manipulated using multidimensional scaling to allow more variability between face identities than in Experiments 1 and 2. We used the spatial arrangement method (SpAM, Hout, Goldinger & Ferguson, 2013; Hout, Godwin, Fitzsimmons, Robbins, Menneer, & Goldinger, 2016) and multidimensional scaling to produce a plot of similarity between faces in the set to create distractors with steps of similarity to the target faces. Distractors were not morphs related to targets but faces of different identities. If shedding is still found in Experiment 3 it will confirm shedding occurs as a consequence of dual-target search per se, and not as a by-product of searching for two faces amongst very similar distractors.

Method

All experimental details were the same as for Experiment 1, except for those outlined here.

Participants

Twenty-four participants took part in Experiment 3. Age ranged from 18-25 years (M = 20.88, SD = 1.36) and nine participants were male.

Stimuli

To define the stimulus set, a different set of participants completed an online task of organising faces on a screen by their similarity so that multidimensional scaling (MDS) could be used to create plots of the similarity of the sets of faces (SpAM, Hout et al., 2013). The goal was to create a similarity space for the faces positioned in an approximate circle. This would allow definition of pairs of face targets across the circle, with a range of faces falling between them in terms of similarity.

The face similarity space was created based on contributions from 50 participants (38 female, 12 male, M =19.88 years, SD = 1.51 years) after excluding participants whose mean time taken to complete the task was more than 2 SD from the mean. They were asked to place faces that looked more visually similar closer together by using the mouse to drag the faces to new positions on the screen[5]. Each participant completed two trials: one with 20 female faces to organise, and one with 20 male faces to organise.

[5] By using MDS, stimulus similarity space is determined by perceived similarity rather than based on image properties such as pixel characteristics (Hout et al., 2016).

The task was completed online, hosted through the University of Southampton iSurvey website. The Flash program recorded the x and y coordinates of each face placement and the distance from each face to each other face. The distances for each possible face pairing were averaged across the participants, submitted to ASCAL multidimensional scaling (MDS) analysis. This analysis uses the distances between objects as a measure of dissimilarity; the larger the number, the more dissimilar the faces. Presented in Supplemental Materials 4 are the two-dimensional MDS spaces for female and male faces, with the 12 faces selected in each set (Supplemental Materials 4, Supplemental Figure 4).

From these MDS plots we selected twelve faces based on the following criteria: (1) Create a circle of faces selected overall; (2) Select faces that are closest to the centre of the MDS space as long as the selection maximises differences between the faces; (3) Where the difference between pairs of faces would be small, alternative faces may be selected; (4) Ensure opposite faces in the circle have a large distance and are, therefore, dissimilar to each other. Face pairs were chosen from opposite sides of the space (Figure 8). These pairs form target A and target B in Experiment 3. For each set (male and female), there were six possible target pairs. Unlike in Experiments 1 and 2, all faces in the set were used as targets and distractors across participants, although, as in Experiments 1 and 2, each participant had the same target pair throughout.

All target preview faces appeared at a size of 2.20 cm by 3.10 cm in the centre of the screen at a visual angle of 1.55° by 2.62°. When two target previews were shown for dual-target search, the targets were presented at the same size as in single-target search, but next to each other with a overall width of 7.40 cm creating a visual angle of 5.71°.

Apparatus

As in the previous two experiments, stimuli were presented on a ViewSonic Graphics Series G225f CRT monitor with screen size 39.50 cm x 29.00 cm in a darkened room.

Participants were seated at a distance of 70 cm giving a visual angle of 31.51° by 23.41° for the screen. Screen resolution was 1024 x 768 with a refresh rate of 100 Hz. Participants responded by clicking buttons on a ResponsePixx button-box. An SR Research Limited Eye-Link 1000 plus eye tracker operating at 1000 Hz and a nine-point calibration to no more than 0.5° of visual angle error was used to record eye movements monocularly. A chinrest with headrest was used to stabilise the participant's head.

Design and Procedure

The design was a 2 (search type) x 2 (trial type) x 5 (step) repeated measures design. See Figure 8 for labelling of distractors in the design. As in Experiment 1, steps 1-5 indicate decreases in similarity to the target face based on the MDS output. Step 1 was most similar and step 5 least similar to the target. The step was coded post hoc in relation to each participant's preferred target in dual-target search (step 1 closest to the preferred target). These same step labels were also used for single-target analysis. Each participant completed 260 trials for single-target search for target A, 260 trials for single-target search for target B, and 260 trials for dual-target search and order of the search type sessions were counterbalanced across participants.

Results

The data were analyzed in the same way as in Experiments 1 and 2.

Behavioural Measures

The data from two participants were removed due to errors in the eye movement reports from one of their sessions. From the remaining participants, 74 trials (out of 17160) were removed due to technical issues. The highest number lost was 17 trials from one session of 260 experimental trials (participant 22 session b). Behavioural measures were calculated based on the remaining 17086 trials.

Proportion correct. Proportion correct results are presented in Figure 3. The main effects of search type and trial type were significant ($F(1,21) = 6.43, p = .019, \eta^2_G = .089$; $F(1,21) = 10.62, p = .004, \eta^2_G = .074$). Participants were more accurate in single- ($M = 0.97$, $SE = 0.01$) than dual-target search ($M = 0.89$, $SE = 0.03$), and on target-absent ($M = 0.97$, $SE = 0.01$) than target-present ($M = 0.91$, $SE = 0.02$) trials. There was also an interaction of search type and trial type ($F(1,21) = 5.69, p = .027, \eta^2_G = .024$). The difference in accuracy between single-target ($M = 0.96$, $SE = 0.01$) and dual-target ($M = 0.86$, $SE = 0.04$, $p = 0.011$) trials was larger the present trials, than the difference in single-target ($M = 0.99$, $SE < 0.01$) compared to dual-target ($M = 0.96$, $SE = 0.01$, $p = .020$) absent trials.

With respect to preference[6], the critical interaction of search type and target preference was significant ($F(1,21) = 9.44, p = .006, \eta^2_G = .045$). There was no significant difference in accuracy between preferred ($M = 0.98$, $SE < 0.01$) and non-preferred ($M = 0.95$, $SE = 0.01$, $p = .091$) targets in the single-target condition, but accuracy was lower to the non-preferred target ($M = 0.78$, $SE = 0.07$) compared to the preferred target ($M = 0.95$, $SE = 0.02$, $p = 0.024$) on dual-target trials. A one-sample *t*-test showed accuracy for the non-preferred target in the dual-target condition was significantly above chance ($t(15) = 3.92, p < .001$).

Mean correct RT. Mean correct RT results are presented in Figure 4. The main effects of search type and trial type were significant ($F(1,21) = 12.43, p = .002, \eta^2_G = .157$; $F(1,21) = 265.50, p < .001, \eta^2_G = .542$ respectively). Participants were faster in single- ($M = 2997.59$, $SE = 72.91$) than dual-target search ($M = 3467.23$, $SE = 144.53$) and on target-present ($M = 2871.60$, $SE = 93.70$) than target-absent ($M = 3954.02$, $SE = 111.76$) trials. The interaction between search type and trial type ($F(1,21) = 1.84, p = .189, \eta^2_G = .003$) was not significant.

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[6] Each target pairing was only shown twice and so we do not report data in relation to target preference for each target.

With respect to preference, the critical interaction between search type and target preference was not significant, $F(1,21) = 1.08$, $p = .310$, $\eta^2_G = .004$.

Eye Movement Measures

Eye movement data were treated as in Experiment 1 and 2. Of the data, 4.13% was removed giving a final data set consisting of 132,910 fixations. The data were analyzed as in Experiment 1 but with five levels on the step factor. Probability of fixation results for target-present and target-absent trials are presented in Figure 9. Verification times are presented in Table 1. Global eye movement measures are presented in Supplemental Materials 1.

Probability of fixations to targets. No main effects or interactions reached significance (Fs < 3.89, ps $> .062$, $\eta^2_G < .053$).

Probability of fixations to distractors on target-present trials. The main effects of search type and target preference were significant ($F(1,21) = 16.96$, $p < .001$, $\eta^2_G = .218$; $F(1,21) = 15.68$, $p < .001$, $\eta^2_G = .193$ respectively). Probability of fixation was higher in the dual- ($M = 0.48$, $SE = 0.03$) than single-target ($M = 0.38$, $SE = 0.02$) condition and to the non-preferred ($M = 0.47$, $SE = 0.03$) compared to preferred ($M = 0.38$, $SE = 0.03$) target. No other main effects or interactions were significant (Fs < 3.17, ps $> .090$, $\eta^2_G < .003$).

Probability of fixations on target-absent trials. The main effect of search type was significant ($F(1,21) = 9.19$, $p = .006$, $\eta^2_G = .256$). Probability of fixation was higher in the single- ($M = 0.98$, $SE = 0.01$) than dual-target ($M = 0.95$, $SE = 0.02$) condition. The main effect of step and interaction of search type and step were not significant ($F(1,21) = 2.08$, $p = .164$, $\eta^2_G = .018$; $F(1,21) < 0.01$, $p = .99$, $\eta^2_G < .001$ respectively).

Verification Time. Verification times (see Table 1) were analyzed using a 2 (search type: single or dual) x 2 (target preference: preferred or non-preferred) repeated measures ANOVA. Two participants were removed from the analysis as they did not have values for all four conditions. The main effect of target preference was significant ($F(1,19) = 13.43$, $p =$

.001, η^2_G = .058). Verification times were longer in search for non-preferred (*M* = 829.98, *SE* = 88.59) than preferred targets (*M* = 660.55, *SE* = 34.95). The main effect of search type and interaction of search type and target preference were not significant ($F(1,19) = 4.23$, p = .054, η^2_G = .086; $F(1,19) = 0.49$, p = .491, η^2_G = .005).

Discussion

In Experiment 3, similarity was manipulated using multidimensional scaling to ensure variability between targets and distractors. Using MDS rather than morphing to create distractors increased accuracy in Experiment 3 relative to Experiments 1 and 2. Comparing accuracy statistically across the three experiments revealed main effects of target preference and experiment ($F(2,30) = 35.29$, $p < .001$, η^2_G = .409; $F(2,30) = 6.43$, p = .003, η^2_G = .201), but there was no significant interaction of the two ($F(2,30) = 0.35$, p = .707, η^2_G = 0.014). Accuracy was higher for the preferred (*M* = 0.84, *SE* = 0.02) than non-preferred (*M* = 0.65, *SE* = 0.04) targets and in Experiment 3 (*M* = 0.86, *SE* = 0.04) than Experiment 1 (*M* = 0.72, *SE* = 0.05, p = .047) and Experiment 2 (*M* = 0.66, *SE* = 0.05, p = .004) but there was no difference in accuracy between Experiments 1 and 2 (p = 1.00). Despite this increased accuracy for Experiment 3, there was a dual-target cost with the non-preferred target in the dual-target condition being found 18% less often than the preferred targets, or when the same target was sought by itself. We conclude that shedding occurs in dual-target search for faces, and that this is an effect not limited to when face discrimination is difficult.

The increased accuracy in Experiment 3 relative to Experiments 1 and 2 was also reflected in patterns of fixations and verification times. In Experiment 3, on target-present trials, fixation rates for distractors are never far above 50%. In fact, in single-target search and search for preferred targets in dual-target search, distractor fixation rates were reliably less than 50%, which is consistent with some limited degree of guidance to targets in these conditions. Note, however, the evidence for limited guidance being present in Experiment 3 is different to that in Experiments 1 and 2. In Experiment 3 we did not find an effect of target-distractor similarity on fixations. It may be relevant here that the spatial arrangement task for Experiment 3 was done by participants who were able to attend to each face individually. While multidimensional scaling can reveal the perceptual similarity of faces (e.g. Russell, 1980: Russell & Bullock, 1985; Lee, Byatt, & Rhodes, 2000), the similarity decisions in spatial arrangement may not reflect whatever features or properties might be used to guide fixations to the faces preattentively.

On average, participants only visited one distractor following fixating the target for the first time with no differences between the conditions. This is fewer than in Experiments 1 and 2 and suggests participants are not failing to identify the target when they fixate it (Supplemental Materials 2). With respect to verification times, they were much shorter across all conditions compared with Experiments 1 and 2, indicating participants found target identification easier in Experiment 3. That said, the verification times in Experiment 3 parallel those in Experiments 1 and 2 in that the longest verification times of all were found for non-preferred targets in dual-target search.

General Discussion

The goal of the present experiments was to investigate the search for unfamiliar faces. Specifically, we were interested in establishing and characterising the cost of searching for one of two faces relative to a single face. On the basis of previous research on the dual-target cost and on the limitations on representing faces, we predicted that (1) search for two faces would be suffer a dual-target cost in accuracy and (2) lead to the shedding of one face target to preserve search performance on a preferred target. We predicted that weak representation of the non-preferred face would result in (3) difficulty recognizing the target and (4) may result in reduced guidance if guidance to face targets was found at all. We anticipated that guidance to face targets would be weak in all conditions due to likely reliance on simple feature rather than whole-face representations, and that, if present, guidance was more likely in single-target search and with a preferred target in dual-target search. Evidence for guidance was sought in patterns of eye fixations made during search as target-distractor similarity was varied.

From the results of these three experiments we draw four conclusions. First, there is always a cost in searching for more than one unfamiliar face. Second, the cost of searching for more than one unfamiliar face is borne disproportionately across target faces with preferred faces being well represented and non-preferred faces poorly represented. This finding is consistent with evidence for limitations in representing multiple targets (e.g., Menneer et al., 2007) and with capacity limits for complex objects (Alvarez & Cavanagh, 2004), and shows that previous findings of successful representation of multiple targets for simple stimuli (e.g., Beck et al., 2012) and objects from different categories (e.g., Wolfe, 2012) do not generalise to faces. Third, the cost for the non-preferred target arises because the representation of this target is weak, leading to difficulty verifying targets and rejecting distractors, as evidenced by more fixations on distractors and long verification times in dual-target search. In Experiments 1 and 2 the poor target representation also leads to increased visits to distractors following fixations to the target. Fourth, guidance to faces is present but weak. In fact, when search is very difficult (Experiments 1 and 2), guidance may actually interfere with target detection through drawing attention to target-similar distractors due to uncertainty about the target identity. Only when search was easier, in Experiment 3, were distractor fixation rates in single-target and preferred-targets in dual-target search marginally below what would be predicted for an unguided search. In addition there was no evidence of competition from target-similar distractors in Experiment 3, presumably because confidence and certainty about the target identity increases as target-distractor similarity decreases.

Further to search difficulty, there is another explanation why the morphed stimuli may create guidance that interferes with target identification. Salient features can be used to guide search, as outlined in the Introduction. The morphing process creates stimuli that will repeat salient features across multiple faces. When such features exist in the target they will also exist in the target-similar distractors, creating a basis for guidance but also a basis for competition between the target and these distractors. Such competition seems particularly likely to arise when the target is difficult to discriminate from distractors, causing uncertainty about target identity. This point has implications for future studies examining guidance, suggesting that the use of MDS for creating the stimulus space may be preferable to morphing, because it avoids featural information being available across multiple stimuli. In turn, it therefore also avoids interference from distractors with target-similar features drawing attention from the real target. In addition, using separate un-morphed face images creates stimuli that are more ecologically valid. However, when investigating the difficulty of discrimination of targets from distractors, morphing can offer an objective quantification of target-distractor similarity, allowing different levels of difficulty to be tested.

We reasoned that the shedding of non-preferred targets is not absolute and that participants may retain some limited information about non-preferred targets. Given the previous research showing limitations for representing and processing unfamiliar faces in terms of capacity (e.g. Eng et al., 2005; Experiment 1, Bindemann et al., 2005: Neumann et al., 2007; Towler et al., 2015), another way to think about partial shedding is to consider performance in terms of capacity to store preferred and non-preferred targets so that these representations can inform both present and absent responses. A capacity measure can be calculated from the proportion correct values. Dual-target-absent trials cannot be split by preferred and non-preferred targets to calculate the proportions, as the target-absent trials are shared across both conditions. Therefore, in order to estimate these values, a target-present-trial scalar (defined below) was calculated and used to adjust the single-target-absent proportion correct for dual-target-absent. The scalar was calculated from the proportions correct on target-present trials in single- and dual-target search. The proportions for dual-target-absent trials were calculated using the following formulae:

Note. S = single-target trials, D = dual-target trials, Ps = target-present trials, Abs = target-absent trials, Pf = preferred target and NP = non-preferred target.

$$A_{Ps} = \frac{S_{PsPf}}{S_{PsPf} + S_{PsNP}}$$

i.e., The proportion of accuracy on single-target-present trials that is attributable to the preferred target.

$$B_{Ps} = \frac{D_{PsPf}}{D_{PsPf} + D_{PsNP}}$$

i.e., The proportion of accuracy on dual-target-present trials that is attributable to the preferred target.

Target-present-trial scalar:

$$x = \frac{B_{Ps}}{A_{Ps}}$$

i.e., The ratio of accuracies attributable to preferred target for dual-target to single-target.

$$A_{Abs} = \frac{S_{AbsPf}}{S_{AbsPf} + S_{AbsNP}}$$

i.e., The proportion of accuracy on single-target-absent trials that is attributable to preferred-target search.

Dual-target absent ratio:

$$B_{Abs} = x\ (A_{Abs})$$

i.e., The deduced proportion of accuracy attributable to preferred-target search on dual-target-absent trials, using the target-present-trial scalar to adjust the single-target-absent proportion.

Calculating dual-target absent proportions:

$$D_{PfAbs} = 2(\text{Proportion}D_{Abs})(B_{Abs})$$

$$D_{NPAbs} = 2(\text{Proportion}D_{Abs}) - D_{PfAbs}$$

i.e., The accuracy on dual-target-absent trials split by the proportion attributable to preferred-target search, and its subtraction from total accuracy to give the accuracy attributable to non-preferred-target search. The multiplication by 2 is required to give a proportion for each that is out of 1.

The capacity for storing preferred and non-preferred targets in single- and dual-target conditions was determined for participants in each experiment using the following formula:

$$\text{Capacity} = \text{HR} - (\text{HR})(\text{FA})$$

i.e., The accuracy in finding a given target less the proportion of this accuracy that is due to false alarms (rather than being a true hit). Where HR = hit rate and FA = false alarm rate.

All calculated capacity values are displayed in Supplemental Materials 4 (Supplemental Table 2). The overall capacity (summing over preferred and non-preferred faces) for searching for unfamiliar faces in dual-target search was 0.90, 0.87 and 1.67 out of 2 for Experiments 1-3 respectively. In addition, relative to single-target baselines, dual-target search reduced the capacity for preferred targets by 0.01 and by approximately 0.2 for non-preferred targets across all experiments. An important conclusion is that while the overall capacity for targets varied with overall task difficulty, the capacity cost in searching for two faces relative to one face remained constant across all three experiments.

Why one target was preferred over the other was not a motivation for the studies; however, we can explore a few possibilities. In a study in which two faces must be remembered in an identity matching task, Towler et al. (2015) found that the focus of spatial attention at encoding predicts the face successfully maintained in working memory, suggesting focal attention is limited and critical for successful encoding. As our targets were repeated throughout the block and presented as a preview at the start of every trial, encoding was not limited in the same way. We explored whether faces shown to the left (or right) in the dual-target condition lead to preference. Target A was shown on the left and target B on the right in the dual-target condition. The numbers of participants preferring face A (on the left) were 7/16, 7/16 and 13/22 for Experiments 1-3 respectively. We can find no evidence of systematic choice. Participants were not cued to one face as a preferred target, so their asymmetric accuracy was not driven by the design. However, cuing has been used to understand face processing limits (Bindemann et al., 2012). Whether there were some face identities that were more likely to be preferred can only be examined in Experiment 1, in which the same face pairings were repeated four times. Here we can see a preference for female face 3 over female face 1 and to male face 1 over male face 4 on all occasions they appeared. However, when pairings were changed in Experiment 2, the preferred faces changed, and the same preferred faces were not consistently selected; in fact, male face 2 was never preferred on the four occasions it appeared. The preferences appear to be relative to the second face, possibly due to their relative distinctiveness. We deliberately counterbalanced all pairings in Experiments 2 and 3 to prevent effects of pairings emerging in the results (e.g., one face might always be more distinctive than others, meaning it will always be preferred).

If the cost of dual-target search reflects faces being poorly represented, then the cost should reduce as experience with the faces increases. The data we have presented thus far do not allow us to speak to this issue directly, but we did vary the order of single and dual-targets blocks, which allows some preliminary exploration of the issue. To explore how block order influenced performance, the capacity values were analyzed for preferred and non-preferred targets in dual-target search across Experiments 1-3 as a function of block order (i.e. did participants perform the dual-target search first, second or third, Figure 10). Full analysis is presented in Supplemental Materials 5, but the important result is an interaction of target preference and block order ($F(2,45) = 4.77$, $p = .013$, $\eta^2 = .175$): The effect of target preference was significant for dual-target first ($F(1,14) = 10.10$, $p = .007$, $\eta^2 = .419$) and dual-target second ($F(1,15) = 29.98$, $p = .001$, $\eta^2 = .666$) but not for dual-target condition in the third session ($F(1,16) = 2.51$, $p = .133$, $\eta^2 = .136$). Here the capacity for the preferred compared to non-preferred target did not reach significance, though it is still evident numerically ($M = 0.72$, $SE = 0.04$; $M = 0.63$, $SE = 0.06$ for preferred and non-preferred targets respectively). However, previous work has shown that the dual-target cost remains even after extensive practice (Menneer et al., 2009; Menneer et al., 2012). In the current experiments, perhaps the shedding of non-preferred unfamiliar face target is ameliorated, though not removed, by dedicated prior practice with the same faces appearing as single targets before performing the dual-target search. The results suggest that defining the learning conditions (e.g., number and quality of exposures) that allow dual-target face search to be performed accurately is an important goal for future research.

In addition to learning unfamiliar faces to a level of familiarity, future work could also examine the dual-target cost and capacity for representing familiar faces. From studies of face recognition we know that people can recognize familiar faces even in difficult conditions (Hancock, Bruce, & Burton 2000). The speed and accuracy of familiar face search is helped by robust representations in long-term memory that allow recognition across viewpoint, lighting changes and different exemplars (Tong & Nakayama, 1999). It is therefore likely that results for familiar faces would be considerably different from those found here for unfamiliar faces. Indeed, it is possible that multiple highly familiar stimuli may be searched with significantly reduced cost (Shiffrin & Schneider, 1977).

As well as contributing knowledge about face representation and search, the results of this study also have implications for applied tasks. There are many tasks that require identifying the presence of one or more face targets. In security scenarios, such as when monitoring demonstrations, arenas and concourses for multiple known terrorists, criminals or hooligans, these faces may well be relatively unfamiliar to the searcher, and search may be based on few example photographs. Our results suggest that search for multiple unfamiliar target faces should be avoided, but that appropriate training, such as practising search for each face separately, could increase capacity and alleviate the multiple-target cost.

Conclusion

In this series of studies, we have examined dual-target search for faces. We have shown a dual-target cost occurs in the search for two unfamiliar faces. The cost is borne unequally across preferred and non-preferred targets. It results from limitations in representing unfamiliar faces in working memory, which has consequences for guiding search to face targets as well as for recognizing a target once fixated. The dual-target cost can be reduced but not removed by searching for single faces before performing dual-target search.

These results have important implications for applied tasks requiring searching for unfamiliar face targets. Any task requiring searching for multiple unfamiliar faces will be performed poorly, at least with respect to some face targets. Our results suggest that effective prior learning of individual face targets can ameliorate the shedding of target faces.

Determining the learning conditions that enable effective representation and dual-target search for initially unfamiliar faces should be pursued.

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Table 1

Mean Verification Time (ms) for Preferred and Non-Preferred Targets across Single- and Dual-Target Search in Experiments 1-3.

	Single		Dual	
Experiment	Preferred	Non-preferred	Preferred	Non-preferred
Experiment 1	1607.36 (227.44)	1610.90 (186.69)	1760.78 (214.22)	2559.00 (229.36)
Experiment 2	1503.59 (119.48)	2031.33 (248.99)	1676.50 (208.58)	2339.98 (230.86)
Experiment 3	638.50 (72.74)	799.09 (101.46)	905.39 (166.59)	1322.43 (253.32)

Note. Standard error presented in brackets.

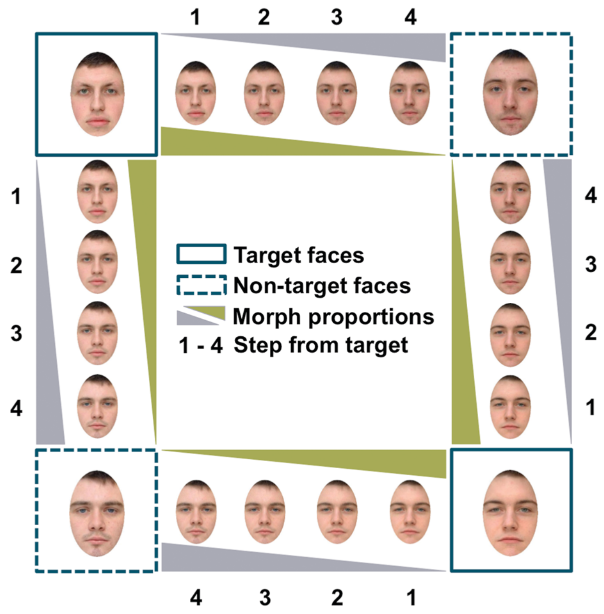


Figure 1. Example of the target and distractor faces contained within the male target set in Experiment 1 and the step labelling applied to distractors.

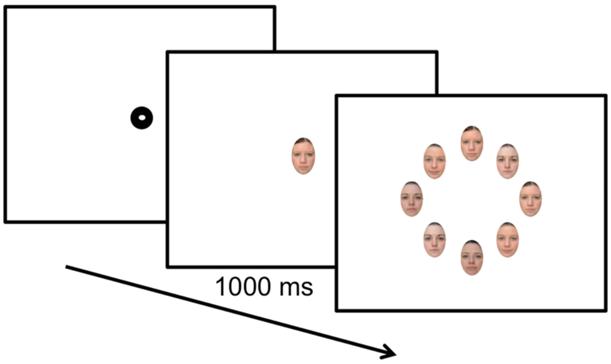


Figure 2. Example of trial procedure with fixation, target preview and search display presented until a response was made.

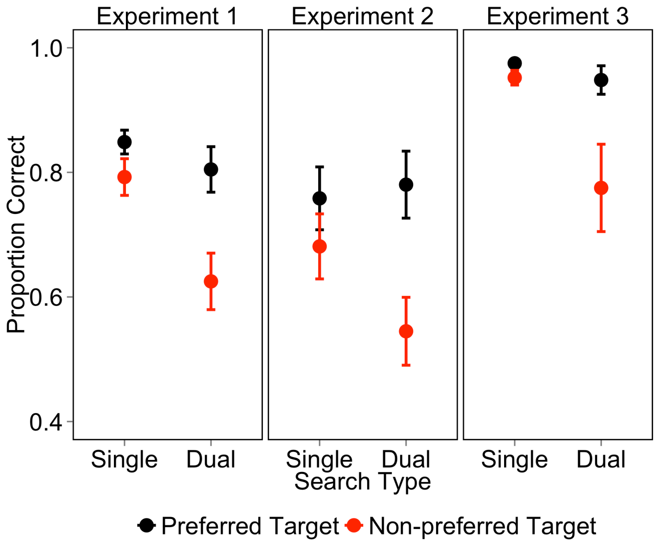


Figure 3. Proportion correct for the preferred and non-preferred target by search type session on target-present trials in Experiments 1, 2 and 3.

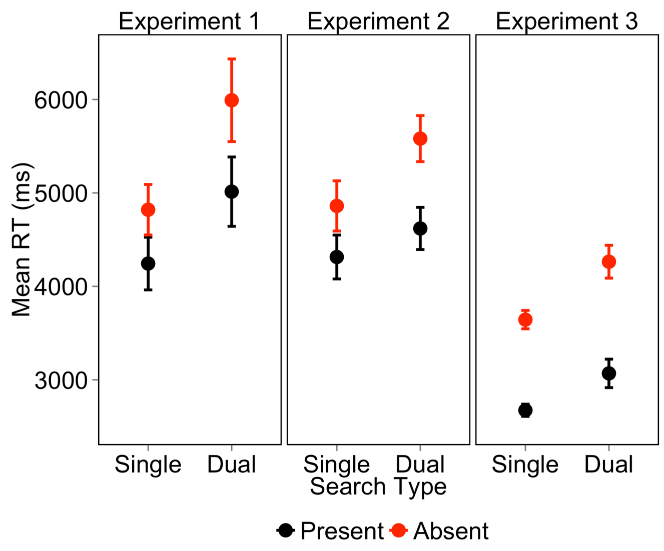


Figure 4. Mean correct RT across target-present and target-absent trials by search type session in Experiments 1, 2 and 3.

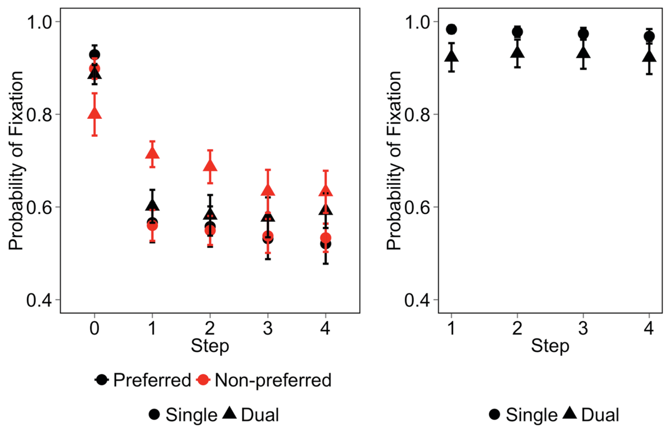


Figure 5. Probability of fixation in target-present trials (left) and target-absent trials (right) for Experiment 1 split by search type and step. In addition, target-present trials are also split by target preference (defined post-hoc) and include probability of fixation to the target (Step 0). Note that data are combined across single-target searches for target-absent trials (see text for details).

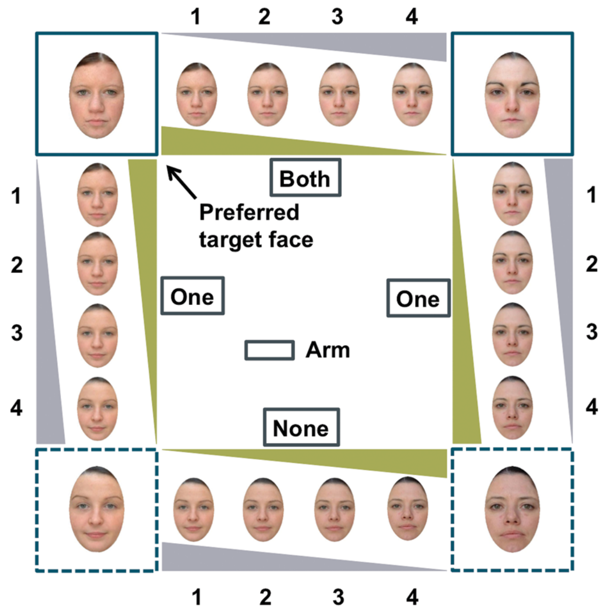


Figure 6. Diagram of the target faces and morph distractors contained within the female target set for Experiment 2. The arm factor refers to whether distractors are similar to both, one or none of the targets.

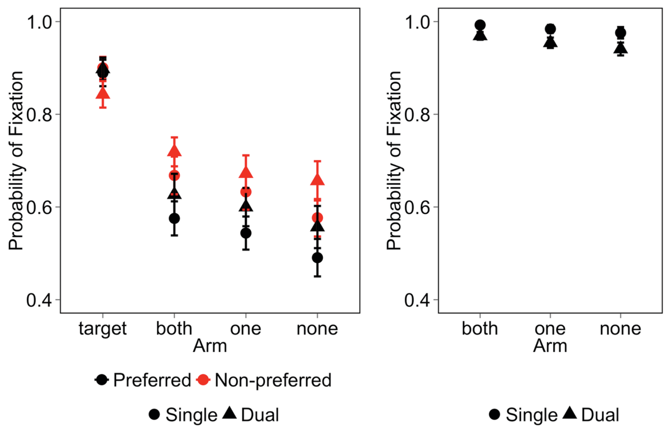


Figure 7. Probability of fixation in target-present trials (left) and target-absent trials (right) for Experiment 2 split by search type and arm. In addition, target-present trials are also split by target preference and include probability of fixation to the target. Note that data are combined across single-target searches for target-absent trials (see text for details).

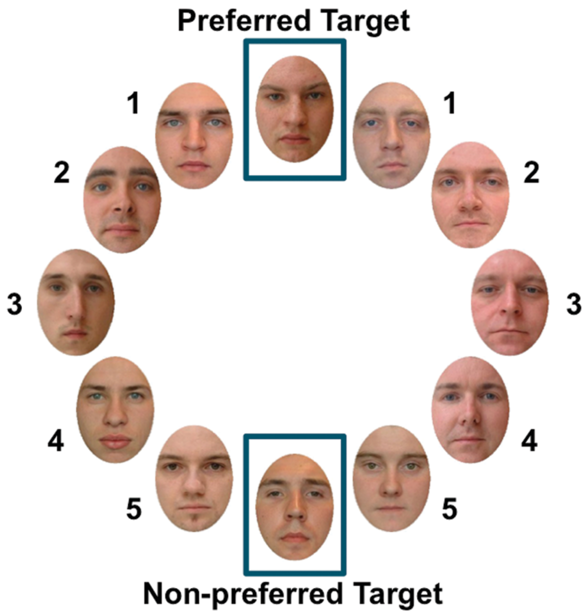


Figure 8. Diagram of the target faces and morph distractors contained within the male target set for Experiment 3 where step is labelled in relation to the preferred target.

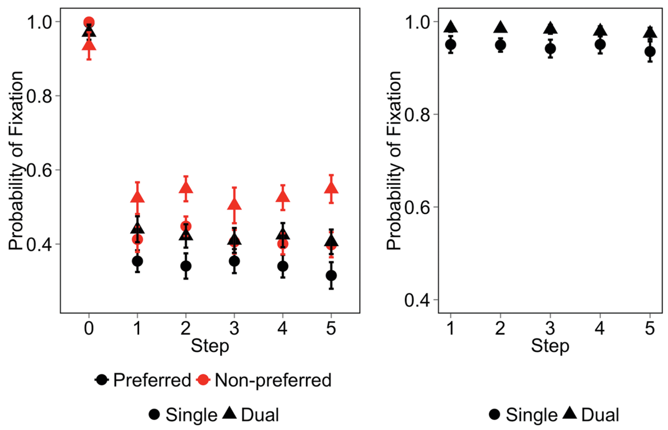


Figure 9. Probability of fixation in target-present trials (left) and target-absent trials (right) for Experiment 3 split by search type and step. In addition, target-present trials are also split by target preference and include probability of fixation to the target. Note that data are combined across single-target searches for target-absent trials (see text for details).

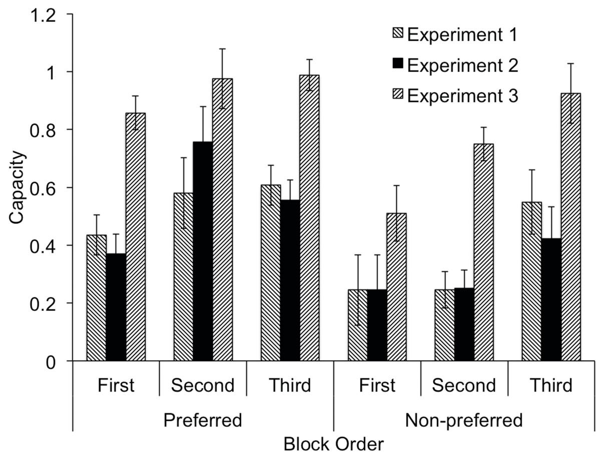


Figure 10. Graph of capacity for preferred and non-preferred target by experiment and whether the dual-target session was performed first, second or third (block order).

Supplemental Materials 1

Global Eye Movement Measures

The global eye movement measures of mean fixation duration, number of fixations and total fixation duration are presented for each of the three experiments. The values are mean average values and were analyzed in a 2 (search type: single or dual) x 2 (target preference: preferred or non-preferred) repeated measures ANOVA for each measure.

Experiment 1

Mean fixation duration. There was a main effect of search type ($F(1,15) = 15.22$, $p = .001$, $\eta^2_G = .081$). Participants had shorter mean fixation durations in single- ($M = 260.25$, $SE = 9.09$) than dual-target conditions ($M = 284.12$, $SE = 11.33$). There was no main effect of trial type ($F(1,15) = 1.40$, $p = .254$, $\eta^2_G = .001$) and no interaction of search type and trial type ($F(1,15) = 3.75$, $p = .072$, $\eta^2_G = .002$).

Number of fixations. There was no main effect of search type ($F(1,15) < 0.01$, $p = .959$, $\eta^2_G < .001$). There was a main effect of trial type ($F(1,15) = 40.10$, $p < .001$, $\eta^2_G = .190$). Participants made more fixations on absent ($M = 13.73$, $SE = 0.85$) than present ($M = 10.51$, $SE = 0.77$) trials. There was no interaction of search type and trial type ($F(1,15) = 2.30$, $p = .150$, $\eta^2_G = .003$).

Total fixation duration. There was no main effect of search type ($F(1,15) = 2.06$, $p = .172$, $\eta^2_G = .012$). There was a main effect of trial type ($F(1,15) = 29.77$, $p < .001$, $\eta^2_G = .107$). Total fixation duration was longer on absent ($M = 3476.10$, $SE = 298.30$) than present ($M = 2688.50$, $SE = 277.04$) trials. There was an interaction of search type and trial type ($F(1,15) = 4.98$, $p = .041$, $\eta^2_G = .005$). On present trials there was no effect of search type ($p = .200$), but on absent trials total fixation duration was longer in the dual-target than single-target condition ($p < .001$).

Experiment 2

Mean fixation duration. There was a main effect of search type ($F(1,15) = 8.71$, p = .010, η^2_G = .060). Participants had shorter mean fixation durations in the single- (M = 256.70, SE = 7.89) than dual-target condition (M = 273.72, SE = 8.92). There was a main effect of trial type ($F(1,15) = 9.56$, p = .008, η^2_G = .013). Participants had shorter mean fixation durations on absent (M = 258.01, SE = 7.56) than present trials (M = 267.66, SE = 8.37). There was an interaction of search type and trial type ($F(1,15) = 10.11$, p = .006, η^2_G = .008). There were shorter mean fixation durations to absent than present trials in the single-target condition (p < .001) but no difference in mean fixation durations between absent and present trials in the dual-target condition (p = .230).

Number of fixations. There was no main effect of search type ($F(1,15) = 1.41$, p = 0.254, η^2_G =.012). There was a main effect of trial type ($F(1,15) = 74.11$, p < .001, η^2_G = 0.267). Participants made more fixations on absent (M = 13.51, SE = 0.84) than present (M = 9.97, SE = 0.67) trials. There was no interaction of search type and trial type ($F(1,15) = 3.29$, p = .090, η^2_G =.004).

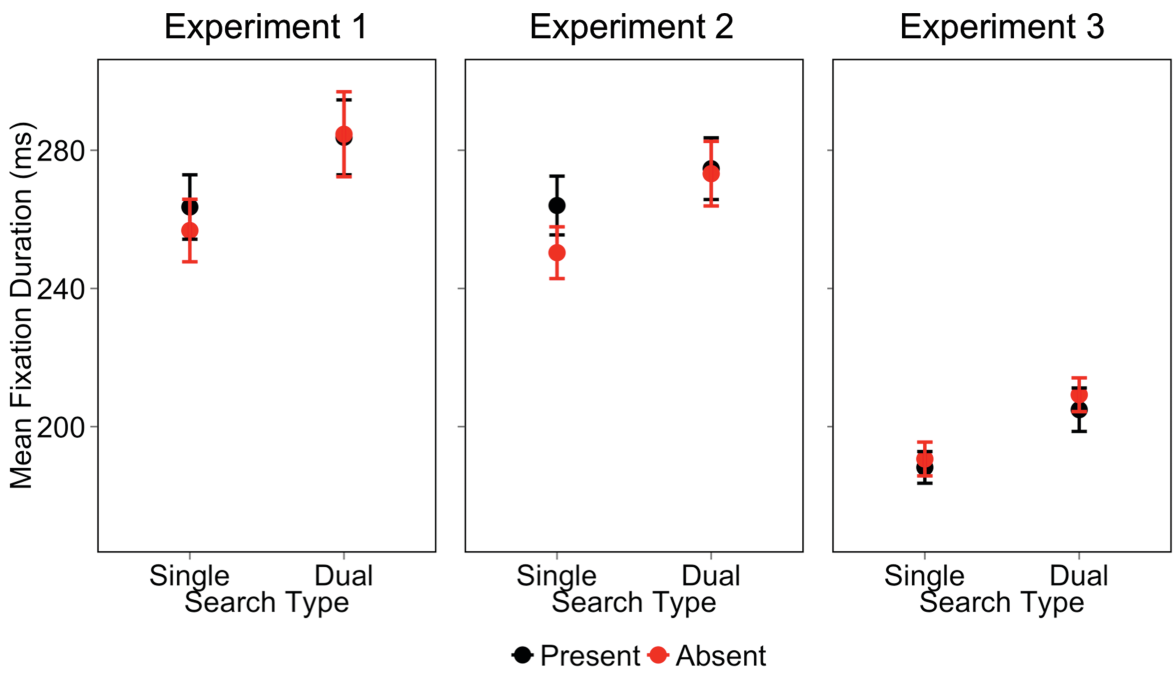
Total fixation duration. There was no main effect of search type ($F(1,15) < 0.01$, p = .951, η^2_G < .001). There was a main effect of trial type ($F(1,15) = 60.30$, p < .001, η^2_G = .188). Total fixation duration was longer on absent (M = 3307.60, SE = 233.88) than present (M = 2502.47, SE = 200.72) trials. There was an interaction of search type and trial type ($F(1,15)$ = 6.41, p = .023, η^2_G = .007). On present trials total fixation duration was longer in the dual-target than single-target condition (p < .001), but on absent trials total fixation duration was shorter in the dual-target than single-target condition but the difference was not significant (p = .077).

Experiment 3

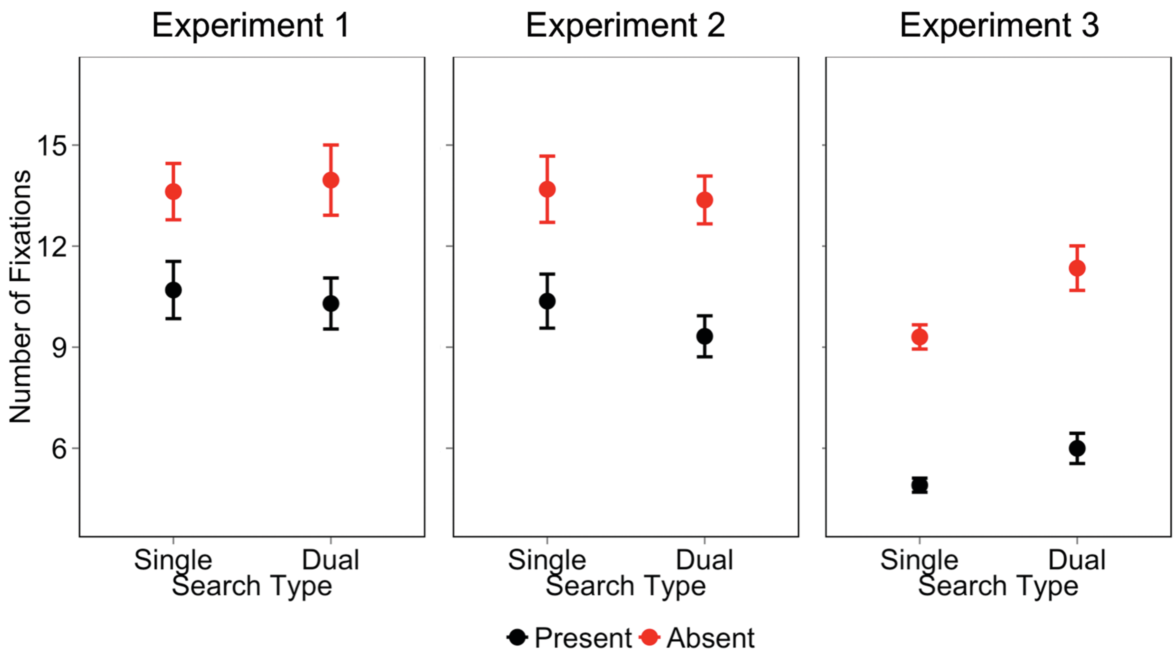
Mean fixation duration. There were main effects of search type and trial type (F(1,21) = 12.32, p = .002, η^2_G = .127; F(1,21) = 31.96, p < .001, η^2_G = .035). Participants had shorter mean fixation durations in the single- (M = 189.44, SE = 4.65) than dual-target condition (M = 207.19, SE = 5.40) and on present (M = 193.66, SE = 4.72) than absent trials (M = 197.68, SE = 4.15). There was no interaction (F(1,21) = 1.40, p = .251, η^2_G = .005).

Number of fixations. There were main effects of search type and trial type (F(1,21) = 10.38, p = .004, η^2_G = .126; F(1,21) = 229.23, p < .001, η^2_G = .58). Participants made more fixations on dual- (M = 8.87, SE = 0.55) than single-target (M = 7.14, SE = 0.27) trials and on absent (M = 10.09, SE = 0.39) than present (M = 5.25, SE = 0.22) trials. There was an interaction of search type and trial type (F(1,21) = 5.71, p = .026, η^2_G = .013). There was a larger increase in fixations between single- and dual-target trials on absent (p < .001) than on present trials (p < .001).

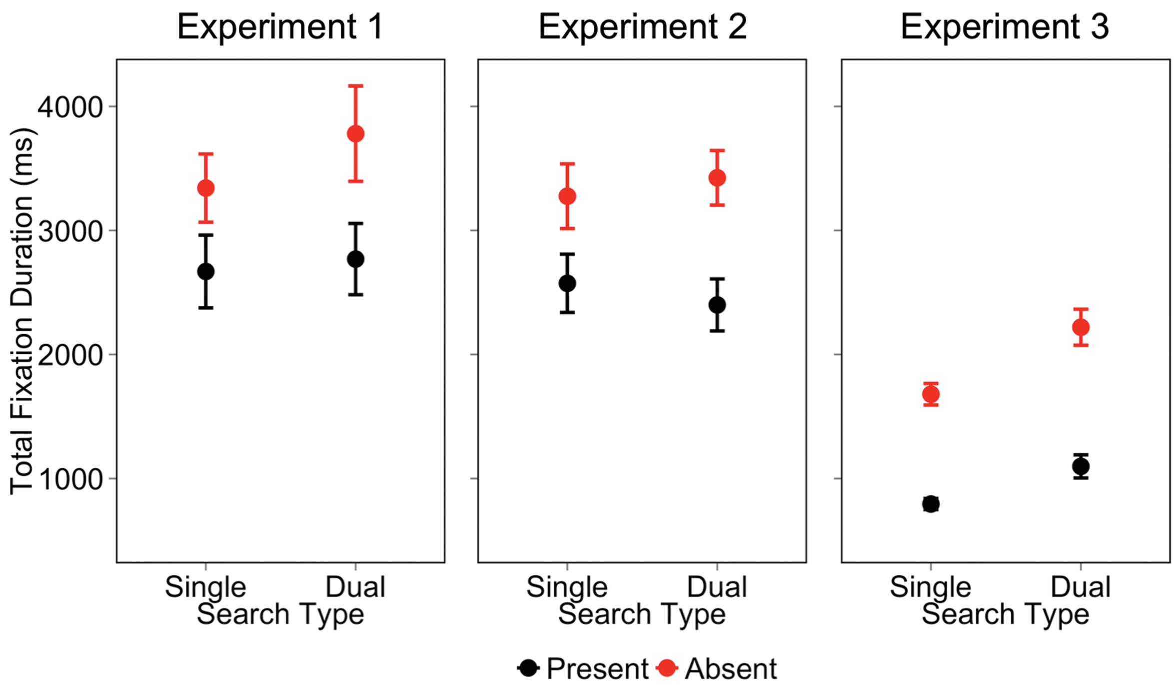
Total fixation duration. There were main effects of search type and trial type (F(1,21) = 13.67, p = .001, η^2_G = .177; F(1,21) = 506.47, p < .001, η^2_G = .688). Total fixation duration was longer on dual- (M = 1700.66, SE = 118.20) than single-target (M = 1244.86, SE = 62.80) trials and on absent (M = 1886.94, SE = 85.38) than present (M = 893.16, SE = 43.67) trials. There was no interaction of search type and trial type (F(1,21) = .05, p = .821, η^2_G < .001).



Supplemental Figure 1. Graphs showing mean fixation duration (ms) by search type and trial type for Experiments 1, 2 and 3.



Supplemental Figure 2. Graphs showing number of fixations by search type and trial type for Experiments 1, 2 and 3.



Supplemental Figure 3. Graphs showing total fixation duration (ms) by search type and trial type for Experiments 1, 2 and 3.

Supplemental Materials 2

Analysis of the number of distractors visited following the first fixation to the target on correct present trials

On correct trials only, the number of distractors visited following the first fixation to a target were analyzed by preferred and non-preferred targets in dual-target and single-target search across Experiments 1-3.

In Experiment 1 there were main effects of search type ($F(1,15) = 26.39, p < .001, \eta_G^2 = 0.178$) and target preference ($F(1,15) = 8.16, p = .012, \eta_G^2 = 0.046$). More distractors were visited in dual-target ($M = 3.93, SE = 0.19$) than single-target ($M = 3.18, SE = 0.18$) search and following fixations to non-preferred ($M = 3.61, SE = 0.17$) than preferred ($M = 3.34, SE = 0.19$) targets. The interaction of search type and target preference was also significant ($F(1,15) = 6.52, p = .022, \eta_G^2 = 0.032$), with more distractors visited following fixations to non-preferred targets in dual-target search (Supplemental Table 1).

In Experiment 2 there were main effects of search type ($F(1,15) = 6.63$ $p = .021, \eta_G^2 = 0.090$) and target preference ($F(1,15) = 11.28, p = .004, \eta_G^2 = 0.098$). More distractors were visited in dual-target ($M = 4.13, SE = 0.17$) than single-target ($M = 3.53, SE = 0.21$) search and following fixations to non-preferred ($M = 4.01, SE = 0.18$) than preferred ($M = 3.45, SE = 0.17$) targets. The interaction of search type and target preference was not significant ($F(1,15) = 0.64, p = .436, \eta_G^2 = 0.004$), but the numerical trend was that more distractors were visited following fixations to non-preferred targets in dual-target search (Supplemental Table 1).

In Experiment 3 there the main effects of search type, target preference and the interaction of search type and target preference were not significant ($F(1,21) = 0.32, p = .576, \eta_G^2 = 0.006$; $F(1,21) = 2.55, p = .125, \eta_G^2 = 0.028$; $F(1,21) = 2.55, p = .125, \eta_G^2 = 0.028$, Supplemental Table 1).

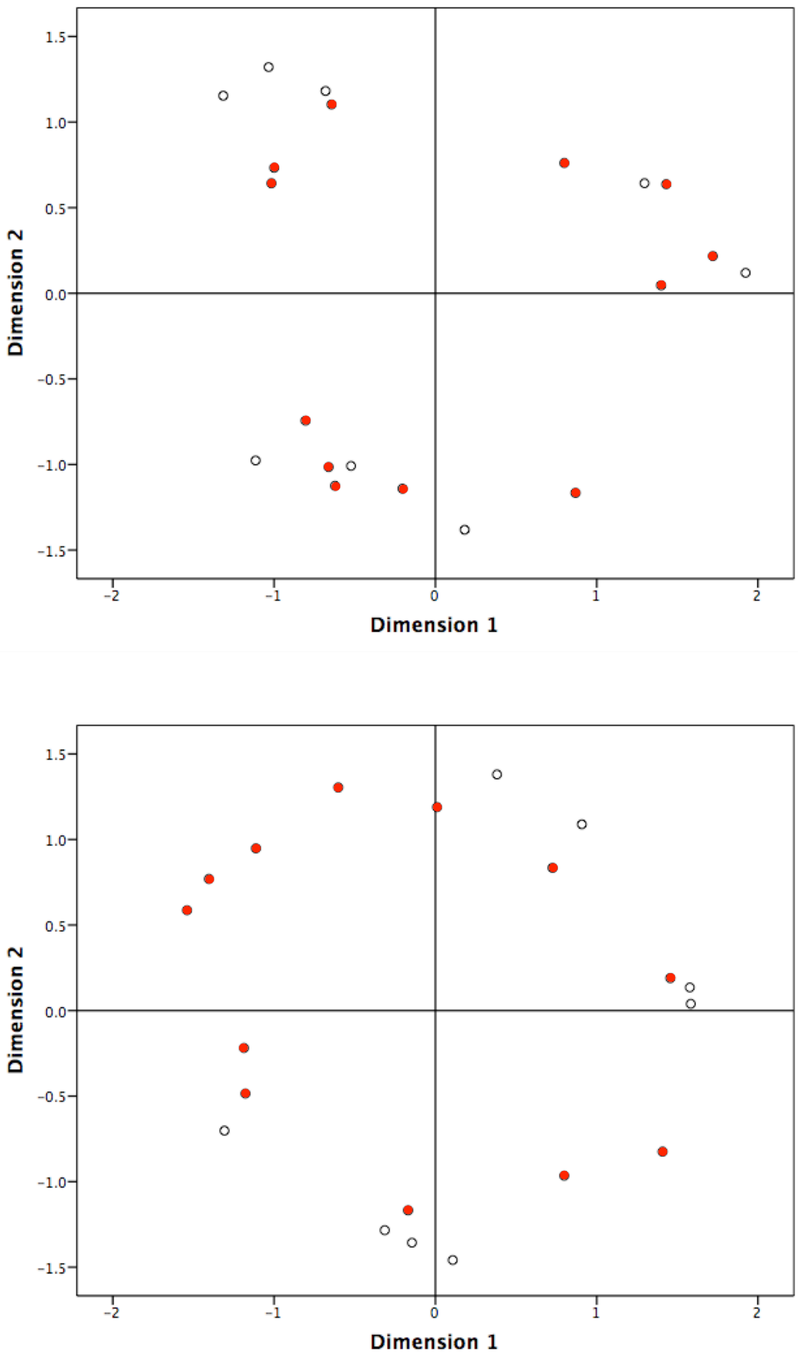
Supplemental Table 1

Mean Number of Distractors Visited Following First Fixation to Targets for Experiments 1-3.

Experiment	Single		Dual	
	Preferred target	Non-preferred target	Preferred target	Non-preferred target
Experiment 1	3.12 (0.21)	3.18 (0.17)	3.56 (0.21)	4.18 (0.21)
Experiment 2	3.27 (0.21)	3.71 (0.24)	3.69 (0.20)	4.35 (0.22)
Experiment 3	1.03 (0.03)	0.93 (0.06)	1.00 (0.00)	1.00 (0.00)

Note. *Standard Error presented in brackets*.

Supplemental Materials 3



Supplemental Figure 4. Multidimensional scaling plots for the female faces (above) and male faces (below) in the spatial arrangement task. The filled circles indicate the faces that were selected for use in the face set for the visual search task in Experiment 3. They were selected to be closest to the centre of the MDS space and maximise (visually) the circular shape of the space.

Supplemental Materials 4

Supplemental Table 2

Table of Capacity Values for Experiments 1-3

	Participant ID	Dual-target		Single-target			
		Preferred	Non-preferred	Preferred	Non-preferred	Preferred Difference	Non-preferred Difference
Experiment 1							
	p01	0.66	0.54	0.84	0.62	0.18	0.08
	p02	0.81	0.46	0.67	0.69	-0.14	0.24
	p03	0.31	0.23	0.79	0.63	0.48	0.41
	p04	0.63	0.31	0.59	0.44	-0.05	0.13
	p05	0.46	0.26	0.44	0.52	-0.02	0.26
	p06	0.58	0.25	0.85	0.31	0.27	0.06
	p07	0.49	0.46	0.42	0.33	-0.07	-0.13
	p08	0.40	0.26	0.36	0.75	-0.04	0.49
	p09	0.53	0.15	0.81	0.67	0.28	0.52
	p10	0.82	0.68	0.87	0.78	0.05	0.10
	p11	0.64	0.10	0.53	0.44	-0.11	0.33
	p12	0.21	0.10	0.73	0.68	0.53	0.57
	p13	0.70	1.00	0.53	0.77	-0.17	-0.23
	p14	0.59	0.15	0.76	0.44	0.17	0.29
	p15	0.54	0.50	0.96	0.89	0.42	0.40
	p16	0.34	0.30	0.53	0.36	0.19	0.06
	Average	0.54	0.36	0.67	0.58	0.12	0.22
	Sum by Search Type	0.90		1.25			
Experiment 2							
	p01	0.31	0.22	0.43	0.29	0.12	0.07
	p02	0.85	0.41	0.94	0.57	0.08	0.16
	p03	0.69	0.26	0.92	0.92	0.23	0.65
	p04	0.58	0.73	0.53	0.53	-0.05	-0.20
	p05	0.89	0.20	0.60	0.44	-0.28	0.23
	p06	0.22	0.25	0.37	0.50	0.16	0.25
	p07	0.32	0.13	0.46	0.19	0.14	0.06
	p08	0.50	0.29	0.64	0.46	0.14	0.18
	p09	0.33	0.07	0.15	0.08	-0.18	0.02
	p10	0.63	0.19	0.57	0.72	-0.06	0.53
	p11	0.88	0.07	0.71	0.63	-0.17	0.56
	p12	0.14	0.47	0.22	0.35	0.08	-0.11
	p13	0.64	1.00	0.67	0.86	0.03	-0.14
	p14	0.67	0.29	0.51	0.69	-0.16	0.41
	p15	0.48	0.18	0.31	0.30	-0.17	0.12
	p16	0.86	0.26	0.63	0.34	-0.23	0.07
	Average	0.56	0.31	0.54	0.49	-0.02	0.18
	Sum by Search Type	0.87		1.03			
Experiment 3							
	p01	0.97	0.97	0.98	0.96	0.01	0.00
	p02	1.00	0.89	0.96	0.98	-0.04	0.09
	p03	0.54	0.09	0.98	0.83	0.44	0.75
	p05	1.00	0.94	0.98	0.99	-0.02	0.06
	p06	0.83	0.02	1.00	0.97	0.17	0.95
	p07	1.00	0.98	0.97	0.98	-0.03	0.00
	p08	1.00	0.84	0.98	1.00	-0.02	0.16
	p09	0.98	0.77	0.98	0.97	0.00	0.19
	p10	0.98	0.82	0.97	0.99	-0.01	0.17
	p11	1.00	1.00	0.99	0.98	-0.01	-0.01
	p13	0.86	0.84	1.00	0.96	0.14	0.12
	p14	0.96	0.96	0.95	0.97	-0.01	0.01
	p15	0.93	0.94	0.95	0.84	0.02	-0.10
	p16	1.00	0.92	1.00	0.97	0.00	0.05
	p17	1.00	0.91	0.94	0.95	-0.06	0.03
	p18	0.89	0.01	0.99	0.86	0.10	0.85
	p19	0.80	0.04	0.89	0.79	0.09	0.75
	p20	1.00	0.98	0.94	0.95	-0.06	-0.03
	p21	0.98	0.39	0.96	0.96	-0.02	0.57
	p22	0.98	0.88	0.98	0.94	0.00	0.06
	p23	1.00	0.84	0.87	0.92	-0.13	0.08
	p24	1.00	0.98	0.98	0.98	-0.02	-0.01
	Average	0.94	0.73	0.97	0.94	0.02	0.21
	Sum by Search Type	1.67		1.91			
Average Across Expeiments						0.04	0.21

Note. Difference calculated as single-target capacity minus dual-target capacity. Sum by search type is the sum of the preferred and non-preferred capacity values within single-target and dual-target search.

Supplemental Materials 5

Analysis of Capacity Values by Preference, Experiment and Block Order

Capacity values (Supplemental Materials 4) were analyzed by preferred and non-preferred targets in dual-target search across Experiments 1-3 as a function of block order. There were main effects of target preference, experiment and block order ($F(1,45) = 37.22$, $p < .001$, $\eta^2 = .453$; $F(2,45) = 31.98$, $p < .001$, $\eta^2 = .587$; $F(2,45) = 7.544$, $p = .001$, $\eta^2 = .251$). There was a greater capacity value for preferred ($M = 0.68$, $SE = 0.02$) than non-preferred ($M = 0.46$, $SE = 0.04$) targets. Capacity was greater in Experiment 3 ($M = 0.83$, $SE = 0.04$) compared to Experiment 1 ($M = 0.44$, $SE = 0.05$, $p < 0.001$) and Experiment 2 ($M = 0.43$, $SE = 0.05$, $p < .001$) but there was no difference between Experiments 1 and 2 ($p = 1$). Capacity was greatest if the dual-target session was performed last ($M = 0.67$, $SE = 0.04$) compared to first ($M = 0.44$, $SE = 0.04$, $p = .001$). However, capacity was no different between last and second ($M = 0.59$, $SE = 0.04$, $p = .059$) and first and second ($p = .531$).

There was an interaction of target preference and block order (detailed in the General Discussion), but all other interactions were not significant (Fs < 1.412, ps $> .245$, $\eta^2 < .112$).