

The effects of social and symbolic cues on visual search: Cue shape trumps biological relevance*

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Arrow signs are often used in crowded environments such as airports to direct observers' attention to objects and areas of interest. Research with social and symbolic cues presented in isolation at fixation has suggested that social cues (such as eye gaze and pointing hands) are more effective in directing observers' attention than symbolic cues. The present work examines whether in visual search, social cues would therefore be more effective than arrows, by asking participants to locate target objects in crowded displays that were cued by eye-gaze, pointing hands or arrow cues. Results show an advantage for arrow cues, but only for arrow cues that stand out from the surroundings. The results confirm earlier suggestions that in extrafoveal vision cue shape trumps biological relevance. Eye movements suggest that these cueing effects rely predominantly on extrafoveal perception of the cues.

Keywords: Social attention, eye movements, visual search, extrafoveal vision

Highlights:

- Past research suggests that cue shape determines the strength of extrafoveal cues
- The present work shows that such shape effects extend to visual search
- Cues that stand out from the surround enhance search more strongly
- In day-to-day viewing cue shape therefore precedes biological relevance

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Studies of social attention have suggested that gaze cues have strong effects on an observer's attention and eye movements (Bayliss & Tipper, 2006; Driver et al., 1999; Friesen & Kingston, 1998; Friesen & Kingstone, 2003; Friesen, Moore, & Kingstone, 2005; Frischen, Bayliss, & Tipper, 2007; Friesen, Ristic, & Kingstone, 2004). In these studies, participants are presented with an image of a person with an averted gaze, followed by a peripherally presented target. For example, a photograph is shown at fixation with a person looking left or right, which participants are told to ignore. After a delay a target is shown left or right of fixation. Participants are asked to respond to the target, either by indicating its location (by pressing a response key or by making an eye movement), or by identifying the target (e.g., discriminate between the letters 'T' and 'F'). In such paradigms, congruent cues (eye gaze in the direction of the target) lead to faster response times and fewer response errors than incongruent cues (directed in the opposite direction). These congruency effects of gaze cues are found for unpredictable cues (valid on 50% of the trials) and counterpredictive cues (valid on less than 50% cue of the trials; Driver et al., 1999), which has led to the suggestion that gaze cues lead to exogenous cueing of attention. The suggestion was reinforced by findings of inhibition of return (faster responses for incongruent cues) for cue-target intervals beyond 2400ms (Frischen et al., 2007; Frischen & Tipper, 2004). Later studies, however, have argued against the special status of gaze cues, showing similar effects of unpredictable (Tipples, 2002) and counterpredictive (Tipples, 2008) arrow cues.

Strong effects of gaze cues have also been found in visual search situations. In natural scenes, changes were detected more easily when they were in the cone of view of a centrally presented actor (Langton, O'donnell, Riby, & Ballantyne, 2006). Centrally presented gaze cues were also effective at reducing search times in a four item visual search task (Kuhn, Pagano, Maani, & Bunce, 2015; Kuhn & Tipples, 2011). Eye movements recorded in these tasks were more often in the direction of the (unpredictive) gaze cue than to one of the other locations (Kuhn et al., 2015; Kuhn & Tipples, 2011). Such strong effects of cues given by other people in the scene agree with findings showing that people in a scene strongly attract the observer's gaze (Birmingham, Bischof, & Kingstone, 2008, 2009a, 2009b).

Search tasks applying gaze cues have often placed the gaze cue at fixation. In day-to-day viewing, however, cues are often embedded in the scene, and may only be seen from extrafoveal vision until an eye movement to the cue is made. Gaze cues away from fixation do not appear to have the same strong cueing effects as gaze cues at fixation (either on response selection, or on responses to a cued object). For example, when participants were instructed to respond to a gaze cue at fixation, incongruent distractor hands placed away from fixation interfered with responses to the gaze cues, but extrafoveal gaze cues did not influence responses to centrally presented gaze or hand cues (Burton,

Bindemann, Langton, Schweinberger, & Jenkins, 2009). In contrast to averted eye-gaze cues, rotated heads did produce interference effects when presented in extrafoveal vision (Burton et al., 2009; Langton & Bruce, 2000). The effects of extrafoveal gaze cues varied across studies. While two studies found limited effects of eye-gaze cues in extrafoveal vision (Burton et al., 2009; Hermens, Bindemann, & Burton, in press), one study with cartoon-like averted gaze cues did find interference from these cues (Nummenmaa & Hietanen, 2009a). Eye movements towards the cues, initially presented away from fixation, do not seem to influence these effects. When eye movements were allowed (Hermens et al., in press; Langton & Bruce, 2000), eye-gaze cues still weakly influenced participants' responses, while pointing hands and arrows strongly affected response selection. These results led to the conclusion that having a distinct outline may be more important for a strong cue than biological relevance (Hermens et al., in press).

The possible difference between gaze cues presented at fixation and those away from fixation raises the question how gaze cues influence visual search when the cue is embedded in a scene rather than presented at fixation. In most common situations where cues are placed to direct observers to a potential target (e.g., the departures hall at an airport or a check-out at a supermarket), the cue is not immediately perceived at fixation. It is therefore of interest to determine whether gaze cues are still effective when not (initially) viewed at fixation. The studies by Burton et al. (2009), Hermens et al. (in press), and Langton and Bruce (2000) all required participants to perform a task on the cue, and it is therefore unclear whether participants engage with cues in a similar manner if they are not part of the task instruction. How people search for objects embedded in visual scenes has been studied extensively in a paradigm known as visual search (Wolfe & Horowitz, 2008). In a typical visual search experiment, participants are presented with a search target (identified separately on each trial, or provided as a general instruction at the beginning of a block of trials), followed by a search array. Search efficiency is measured by comparing response times and error rates across different conditions (e.g., varying the number or type of distractors). Most visual search experiments use simple stimuli, such as colored lines or simple shapes, but recent experiments have started to look into search for more complex objects (e.g., Henderson, Brockmole, Castelhana, & Mack, 2007; Klein & MacInnes, 1999; Torralba, Oliva, Castelhana, & Henderson, 2006) and in real-life situations (Foulsham, Chapman, Nasiopoulos, & Kingstone, 2014). While visual search can be performed without moving the eyes, people show a natural tendency to move their eye during search. Studies have suggested that forced fixation has little influence on visual search, and found that eye movement parameters often show very similar patterns of results as response times measures (Klein & Farrell, 1989; Zelinsky & Sheinberg, 1997).

While eye movement patterns have been studied for stimuli containing social and symbolic cues, many of these studies relied on participants freely viewing the images (Birmingham et al., 2008, 2009a, 2009b; Castelhamo, Wieth, & Henderson, 2007) or asked participants to locate the people in the scene (Ehinger, Hidalgo-Sotelo, Torralba, & Oliva, 2009; Fletcher-Watson, Findlay, Leekam, & Benson, 2008), and therefore it is unclear what effects cues have when participants perform a visual search for a particular object (other than the cue). The work by Fletcher-Watson et al. (2008) has suggested that participants, when either freely viewing a pair of images or when making a gender decision about the person in one of the two images, tend to look at the image with the person, first fixating the person and later the object being looked at by the person. This suggests that gaze cues strongly direct an observer's eye-gaze, but it is unclear whether such effects of gaze cues are also found when an observer is actively looking for a particular object in the scene.

To examine the influence of social and symbolic gaze cues embedded in search arrays, the present work examined how such cues influence eye movements and target detection in visual search. Different eye-gaze, pointing hands, and arrow cues were compared. The stimuli were presented in circular arrangements of line-drawings of objects (Figure 1a, inspired by Findlay, 1997; Findlay, Brown, & Gilchrist, 2001). By using rings of line-drawings of objects rather than photographs of cluttered scenes, the distance between initial fixation and the location of the search target could be systematically varied.

Furthermore, by relying on sets of line drawings rather than natural images, objects could be placed at any place in the scene, which would not have been possible without digital manipulation in images of natural scenes. Before the presentation of the search array (which always consisted of two rings of objects), the target object was shown (Figure 1a). On valid cue trials, a cue was placed in the other ring adjacent to the target and pointing at the target.

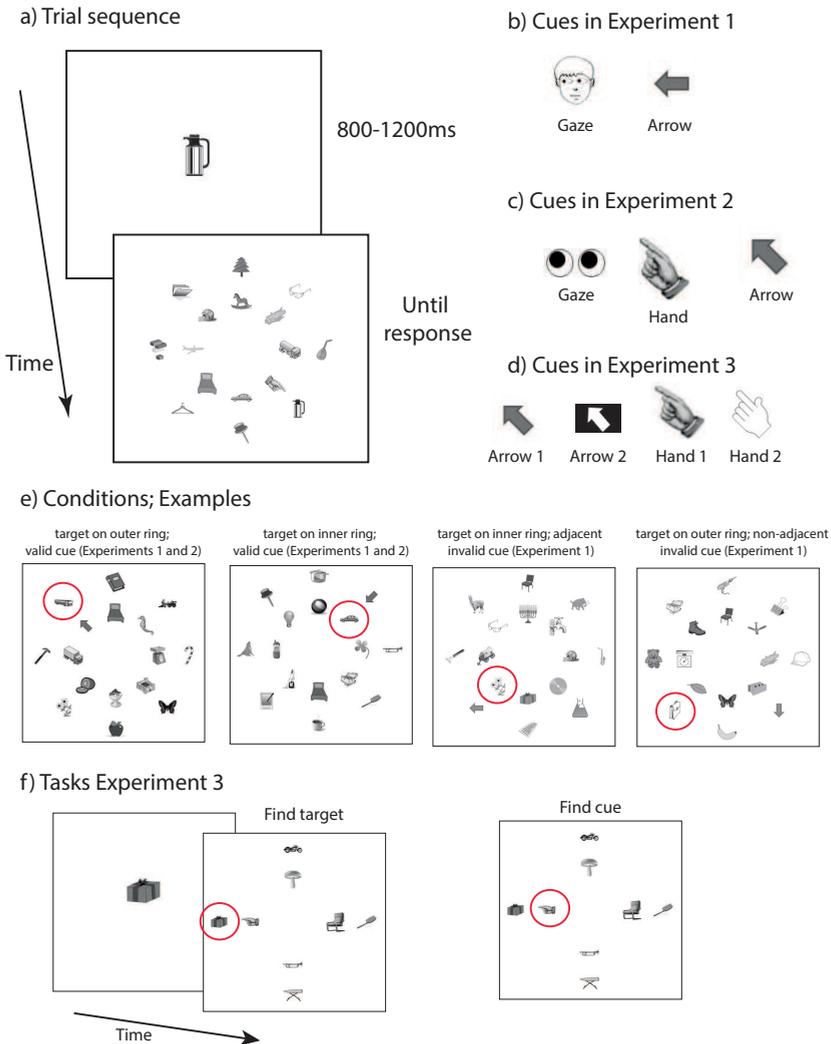


Figure 1. a) Trial sequence. A drift correction target (consisting of a black circular disk with a white center, presented in the middle of the screen, not shown) was followed by the search target for a random interval between 800ms and 1200ms and the search array. In Experiment 1, participants performed a go-nogo task, in which they only responded when the target was present, and otherwise waited for the trial to time-out (after 3500ms). In Experiments 2 and 3, participants indicated (by using the numpad keys of the keyboard) the location of the target, irrespective of the ring in which it occurred. The image shows an example of a valid hand cue. For valid gaze and arrow cue trials, the hand was replaced by gaze and arrow stimuli directed at the search target. b) Cues used in Experiment 1, consisting of an eye-gaze cue and an arrow cue. c) Cues in Experiment 2, consisting of a pair of gazing eyes, a pointing hand and an arrow cue. d) Cues in Experiment 3, consisting of two types of arrows and two types of hands. e) Examples of the various stimulus conditions. The search target is illustrated by a circle around the object

(circle not actually present in the experiment). The images show examples of (1) a target in the inner ring, (2) a target in the outer ring, both validly cued, (3) an invalid adjacent cue, and (4) an invalid non-adjacent cue. f) Illustration of the two tasks in Experiment 3, which examined whether cues that stand out lead to stronger cueing of the search target. The first task was the same as in Experiments 1 and 2 and involved finding a predefined search target. The second task involved locating the cue itself (cue absent trials removed).

In Experiment 1, a gaze cue (from a previous study, shown to induce cueing when presented at fixation by Quadflieg, Mason, & Macrae, 2004) was compared to an arrow cue. Valid cues were compared with invalid adjacent (cue next to the target), invalid non-adjacent (cue elsewhere in the rings), and no cue conditions. A go-nogo task was applied in which participants were asked to press a key as quickly as possible when they saw the search target, but to withhold their response when the target was absent (catch trials). This paradigm avoided possible confusions between the response key location and the location of the search target location on the screen (as in the Simon effect, e.g., Simon, Sly, & Vilapakkam, 1981). Because the effects of the cues in Experiment 1 were found to be relatively weak, the cue validity was increased in Experiment 2 (to 100%) and the sample size increased. In this second experiment, the gaze cue was made more salient (line-drawings of the eyes only), and compared to another social cue (a pointing hand), shown previously to induce interference effects when presented away from fixation (Burton et al., 2009). Participants were now asked to indicate the location of the search target, rather than its presence. Again, arrow cues were found to facilitate response times, with weaker effects of pointing hands and gazing eyes. To determine the influence of cue shape in these effects, Experiment 3 varied cue shape within cue identity by comparing two hand cues of different shapes and two arrow cues with different backgrounds. Experiment 3 also included a condition in which participants were asked to search for the cue (rather than the target object) to examine whether cueing effects are linked to how easily the cue can be found, and the sample size was increased further.

Experiment 1

Experiment 1 compared the influence of valid, adjacent and non-adjacent invalid gaze and arrow cues on visual search for a target to a visual search without such cues.

Method

Participants. Fifteen students (eleven female) from Royal Holloway University of London (UK) and the University of Leuven (Belgium) took part in the experiment in return for payment (seven participants) or course credit (eight participants). All provided written consent for the study that was approved by the local ethics committees.

Apparatus. The experiment was completed in two locations (Royal Holloway University of London (UK) and the University of Leuven (Belgium)) with virtually identical setups. In both settings, participants were tested in a quiet experimental room without outside windows. Stimuli were presented on a 21 inch CRT monitor placed at 57cm from the observer

(distance controlled by a chin rest). Stimuli were presented by a standard PC running the experiment created in the Experiment Builder software (SR Research Osgood, ON, Canada) under the Windows XP operating system. Eye movements were recorded using an EyeLink II system (SR Research Osgood, ON, Canada), controlled by a second PC, in pupil-only mode at 500Hz. Drift correction was used on every trial to compensate for drift possibly occurring in this mode. Responses were collected from a standard PS2 keyboard.

Stimuli. Stimuli consisted of a semi-random selection of 196 clipart images taken from the internet, sourced using Google Image Search. Images were line-drawings of objects, vehicles, animals, food items, plants and buildings (examples in Figure 1a). In selecting the objects, duplicates of the same category of objects were generally avoided. Images were converted to grayscale and resized to a maximum width and height of 65 pixels (2.5 degrees of visual angle at the 57cm distance used). Gaze cues were modified versions of the cue used by Quadflieg et al. (2004), by creating eight versions with gaze directions in all eight cardinal direction (up, up-right, right, down-right, down, down-left, left, up-left; examples shown in Figure 1b for leftward cues). By using the cue from a previous study, it was clear from past evidence that the cue was effective when presented at fixation in a cueing task. For the symbolic cue, a simple arrow shape was created in Microsoft Powerpoint (illustrated in Figure 1b), pointing in one of the eight main directions. The trial sequence is illustrated in Figure 1a. Each trial started with the EyeLink's drift correction target (a small black disc with a small white center, 0.3 deg in diameter). This drift correction target was followed by a preview of the (randomly selected) search target (for 800 to 1200ms) and the search display of sixteen objects, arranged in two rings with diameters of 5.5 and 9.5 degrees (inspired by the work by Findlay, 1997; Findlay et al., 2001).

Design. Participants performed a total of 192 trials each. The objects presented in each of these trials were randomly selected from the set of 196 images. On the majority of the trials (83.3%), one of the objects in the array was the search target (presented before the rings of objects), while a smaller portion of trials (16.7%) were target-absent trials the search target, where the initially presented search target was not in the search array. The target-absent trials served as catch trials to ensure that participants were trying to locate the target and not simply pressing the response key on every trial. On target-present trials, the position of the target in the array was varied systematically.

The target present trials were divided into four categories to test the effects of cue validity and cue position. On *valid cue* trials (16.7% of the overall number of trials), the cue was presented next to the target (in the other ring, replacing the object that was originally in that location; see Figure 1d for examples of the conditions), pointing in the direction of the target. *Invalid, adjacent cue* trials (16.7% of the trials) had a cue next to the target, but the cue pointed in any other (randomly chosen) direction than the target. This condition tested whether the presence of the cue, rather than its orientation could be used to find the search target. *Invalid, non-adjacent cue* trials (16.7%) had the cue somewhere else in the ring, not pointing at the target. Finally, 33% of the trials were no-cue trials and had a target but no cue. Cues were equally often gaze and arrow cues. The order of the 192 trials was randomized for each participant.

Procedure. To allow for breaks, the set of 192 trials was divided in four blocks of 48 trials each. This break also allowed for a (re)calibration of the eye tracker, if required. Each trial consisted of a drift correction (until the experimenter pressed the space-bar of a separate keyboard, to confirm central fixation), the search target (presented for a random duration between 800 and 1200ms) and the search array (until the participant pressed the space-bar positioned in front of them or until time-out at 3500ms). On trials without a target (the catch trials), participants were asked to withhold their response. In Experiment 1, participants were not informed about the presence of the cues, and no feedback was provided. The experiment took approximately 30 minutes to complete.

Data analysis. Eye position was recorded in both eyes, but because pupil detection was generally better for the left eye, the eye movement analysis focused on the recordings from this eye. The raw eye movement coordinates were parsed into fixations and saccades using the EyeLink's parser with the default velocity (30 deg/sec) and acceleration (9,500 deg/sec²) thresholds. Fixations were then assigned to regions of interest surrounding the objects in the array consisting of circles with a diameter of 50 pixels (1.9 degrees) around each object. Incorrect responses were rare: Participants gave a response on catch trials in 1.46% of the trials and failed to respond to a present target on 1.67% of the trials. These incorrect responses were removed from the data analysis. Before computing mean responses, excessively slow or fast responses (defined as responses times more than 3 standard deviations away from the mean for each participant) were removed, leading to the removal of an average of 2.1% of the trials. Statistical analyses were performed using IBM SPSS Statistics version 21. Sidak corrections were used to correct for multiple comparisons, being slightly less conservative than Bonferroni corrections.

Results

Figure 2 provides an overview of the results of Experiment 1. Gaze cues did not influence detection times of the search target (compared across the different gaze cueing conditions and the no-cue condition; $F(3,42) = 1.97, p = 0.13, \eta_p^2 = 0.12$), with effect sizes of paired comparisons between the valid and no-cue condition of $d = 0.26$, the invalid adjacent cue and no-cue condition of $d = 0.47$, and between the invalid and no-cue condition of $d = 0.25$). In contrast, valid arrow cues led to faster detection of the search target, compared to invalid arrow cues and the no-cue condition ($F(1,14) = 7.25, p = 0.017, \eta_p^2 = 0.34$). Paired comparisons revealed marginally significantly faster detection in the presence of valid arrow cues, compared to the no-cue condition ($t(14) = 2.69, p = 0.0175, d = 0.70$; just short of statistical significance with a Sidak corrected critical alpha level of 0.017). No such differences with the no-cue condition were found for invalid adjacent arrow cues ($t(14) = 0.70, p = 0.50, d = 0.18$) and non-adjacent arrow cues ($t(14) = 0.15, p = 0.88, d = 0.040$).

Analysis of the eye movements showed that participants fixated the target on most trials (Figure 2b) and that target fixation was independent of the cueing condition ($F(3,42) = 0.38, p = 0.73, \eta_p^2 = 0.026$). The cue was much less often fixated (Figure 2c), and cue fixation depended on whether cue was next to the target (contrast comparing adjacent valid and invalid cues to non-adjacent cues; gaze: $F(1,14) = 19.8, p = 0.001, \eta_p^2 = 0.59$; arrow: $F(1,14) = 11.7, p = 0.004, \eta_p^2 = 0.45$). Valid and invalid adjacent cues, however, were equally often fixated (for gaze cues: $F(1,14) = 1.36, p = 0.26, \eta_p^2 = 0.089$; for arrow cues: $F(1,14) = 2.15, p = 0.16, \eta_p^2 = 0.13$). Because the cues were not very often fixated, an analysis of response times with and without fixation on the cue, which could have informed whether cues exert their effects predominantly from extrafoveal vision, was not possible.

Fixations on the cue did not often lead to subsequent fixations on the target (around 10% to 25% of trials, see Figure 2d). There was a non-significant

trend towards stronger cue following from valid arrow cues (comparison of valid and invalid adjacent cues: $F(1,14) = 1.63, p = 0.22, \eta_p^2 = 0.10$; comparison between valid adjacent and invalid non-adjacent cues: $F(1,14) = 2.79, p = 0.12, \eta_p^2 = 0.17$). No such trend was observed for gaze cues (comparison of valid and invalid adjacent cues: $F(1,14) < 0.01, p = 0.98, \eta_p^2 < 0.01$; comparison of valid adjacent and invalid non-adjacent cues: $F(1,14) = 2.93, p = 0.35, \eta_p^2 = 0.062$).

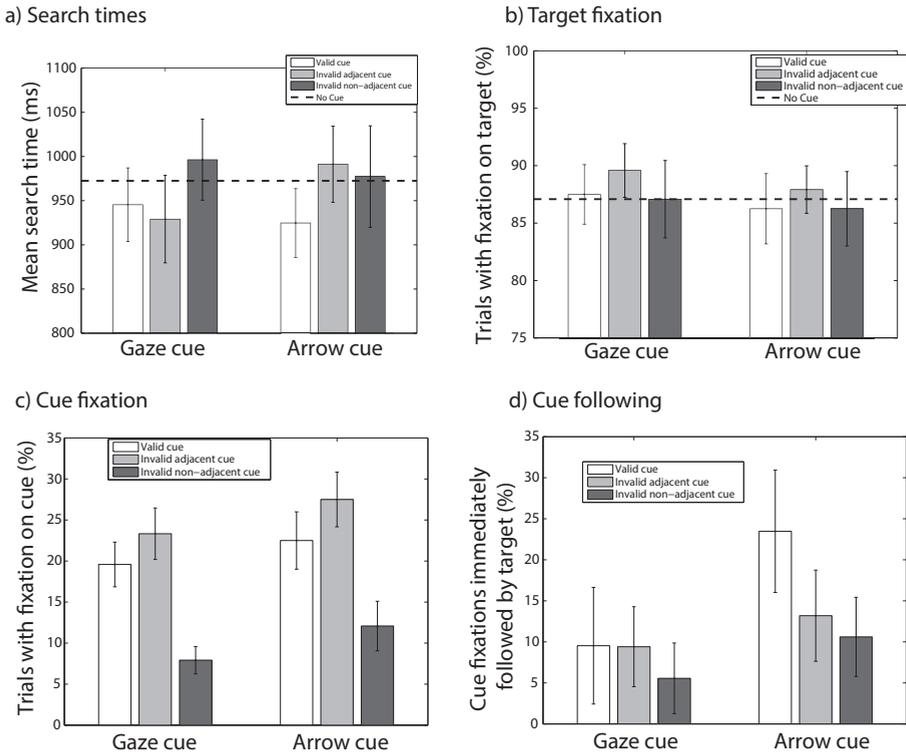


Figure 2. Results of Experiment 1. a) Search target detection times for the different cueing conditions. b) Percentage of trials in which the target was fixated. c) Percentage of trials in which the cue was fixated. d) Cue following, in which the first fixation on the cue was immediately followed by a fixation on the target. In all data plots, the error bars show the standard error of the mean across participants.

Discussion

Experiment 1 showed that valid arrow cues lead to a faster detection of search targets compared to invalid arrow cues and the no-cue condition. Such facilitation of detection times was not found for valid gaze cues. Eye movements

showed that targets were looked at in the majority of trials (around 87%). Cues, in contrast, were looked at only in a minority of trials (around 10% to 25%). This suggests that the (weak) effects of the valid arrow cue were the consequence of extrafoveal viewing of the cue. Such an interpretation is consistent with earlier findings suggesting that arrows (and pointing hands) are more effective when presented (initially) in extrafoveal vision (Burton et al., 2009; Hermens et al., in press; Langton & Bruce, 2000), although such an advantage of arrows over eye-gaze cues has not been universally found (see, Nummenmaa & Hietanen, 2009a). The reduced cueing from gaze cues in extrafoveal vision, compared to foveal vision (e.g., Driver et al., 1999) may be due to crowding of the pupils in the face or eye-balls of the eye-gaze cue in extrafoveal vision (Martelli, Majaj, & Pelli, 2005).

While the effect size of the effect of valid arrow cues was relatively large ($\eta_p^2 = 0.34$, for the overall effect, $d = 0.70$ for the comparison between the valid cues and the no-cue condition), cueing effects just reached statistical significance. Experiment 2 therefore applied a larger sample size. In addition, the number of trials with a valid cue was increased and participants were made aware of the presence of the cues, to examine whether top-down influences increase cueing effects. Experiment 2 also increased the size of the gaze cue (by presenting a pair of eyes only, rather than eyes embedded in a face, with the overall size of the cue being the same), and added a pointing hand cue, previously shown to be effective in extrafoveal vision (Burton et al., 2009; Hermens et al., in press; Langton & Bruce, 2000).

Experiment 2

Experiment 2 investigated whether knowledge of the cue always being valid affected its influence on visual search, and compared two social cues (eye-gaze, pointing hands) and one symbolic cue (arrow cue) with a condition without any cues.

Methods

Participants. Twenty-one first and second year students from the University of Aberdeen (UK) (four male, aged between 17 and 25 years) took part in Experiment 2 in return for course credit. All had normal or corrected-to-normal vision and all provided written consent for the study approved by the local ethics committee.

Apparatus. Stimuli were presented on a 19 inch Dell flat screen, positioned at 60cm from the observer (distance controlled by a chin rest). A standard PC with software created in Experiment Builder (SR Research, ON, Canada) was used to present the stimuli. Eye movements were recorded using an EyeLink 1000 desk-mount system with a camera positioned just under the screen. Eye movements, sampled at 1000Hz, were recorded from the right eye from most participants, except for two, in whom the left eye led to better tracking and was recorded instead. A standard USB keyboard was used to collect the responses.

Stimuli. The same 196 internet clipart images from Experiment 1 were used. In addition to the arrow cue from Experiment 1, an eye-gaze cue (created using Powerpoint) and a pointing hand cue (adopted from openclipart.org) were used (Figure 1c). The gaze cue was constructed from two horizontally aligned circles (serving as the eye balls) and two filled discs (serving as the pupils), with the eyes looking in one of eight possible directions (up, up-right, right, down-right, down, down-left, left, up-left). As before, the search array contained sixteen objects, arranged in two rings with diameters of 5.5 and 9.5 degrees. Objects were presented on a screen resolution of 1024 by 768 pixels (corresponding to a surface of 37.5cm by 30cm). The inner ring of objects had a diameters of 300 pixels (10.46 degrees), whereas the outer ring was 500 pixels (17.35 degrees) wide. Objects were a maximum width or height of 65 pixels (2.27 degrees of visual angle).

Design. Participants each conducted 200 trials (8 practice and 192 experimental trials). Four different cueing conditions were used: Valid arrow cues, valid eye gaze cues, valid hand pointing cues, and a no cue condition. In the conditions with a cue, the cue was always pointing at the target (100% valid cues). Each of the cue conditions was presented 50 times (twice in the practice block and 48 times in the remaining trials). Within the experimental trials, for each cue condition, the target was presented three times in each of the 16 possible positions in the rings (leading to the 48 trials per cue condition). As before, on each trial, sixteen objects were randomly selected from the set of 192 objects, and one of these sixteen objects was randomly selected as the search target. On trials with a cue, the object next to the target in the other ring was replaced by the cue that was pointing at the target. The order of the trials was randomized for each participant.

Procedure. After providing written consent and receiving instructions, participants took place in the chin rest looking at the screen. They were asked to place their preferred hand on the key-pad section of a standard keyboard connected to the stimulus presentation PC. Before the start of the experiment, the eye tracker was calibrated using the standard nine-point calibration procedure, which was repeated until the recorded eye gaze positions were aligned with the three by three grid on which the calibration targets were presented. They were then presented with the stimulus sequence illustrated in Figure 1a. A drift correction target was shown until the experimenter pressed the space-bar to confirm fixation. The target was then presented for 700ms, followed by a blank for 400ms and the search array until key-press or a time-out of six seconds.

Participants were asked to locate the target and press the corresponding key on the numerical pad of the computer keyboard to indicate its location. For example, if the target object was in the top left location, participants were asked to press the top left key of the numerical pad ('7'). This was irrespective of whether the target was in the inner or the outer ring. The mode of responding was changed with respect to Experiment 1 into a task that required the localization of the target. In contrast to Experiment 1, participants were now informed about the presence of the cues and were told that cues were always valid and could therefore be used at their advantage. Also in contrast to Experiment 1, feedback was now presented (for 500ms) in the form of a word 'Correct!' (in green) or 'Incorrect' (in red) for correct and incorrect responses, respectively.

Data analysis. Data analysis was similar to Experiment 1. Incorrect responses were removed as well as excessively slow and fast responses (more than 3 standard deviations from the mean) before computing mean response times for each participant. Circular regions around the objects were used for assigning fixations to the different regions of interest. Statistical analyses were conducted using IBM SPSS 21.

Results

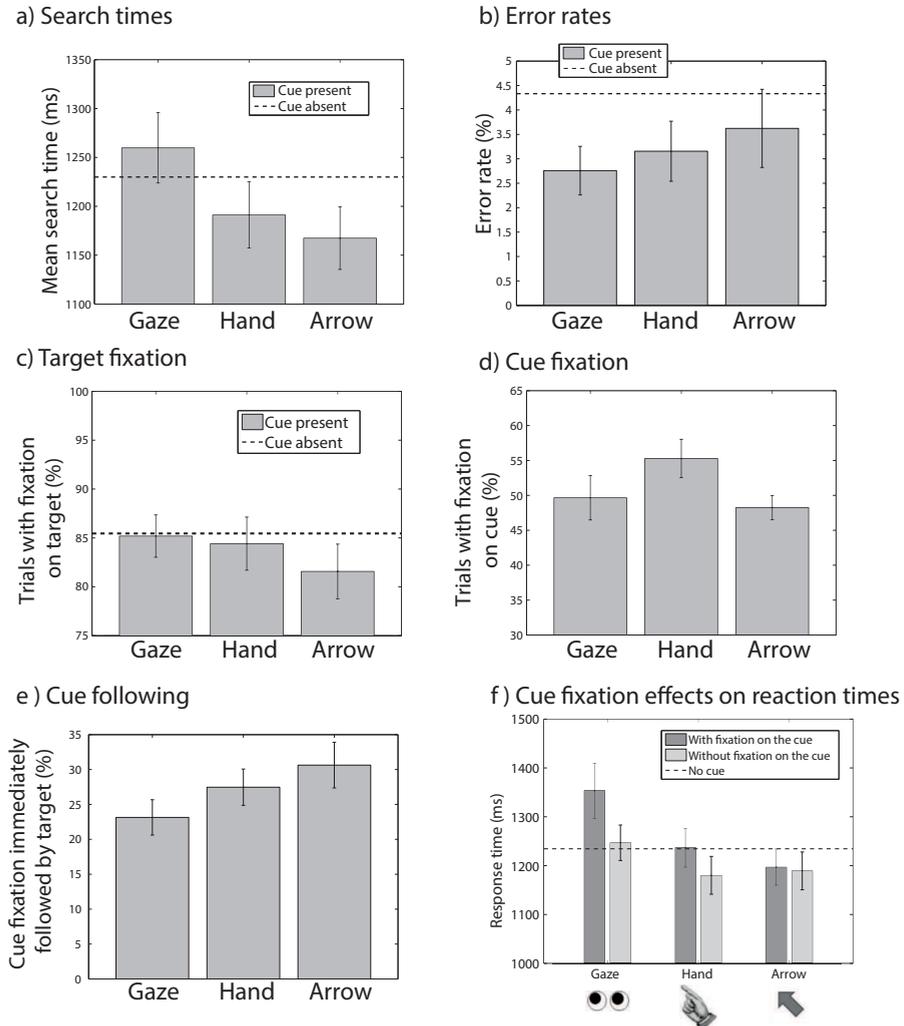


Figure 3. Results of Experiment 2. a) Search target localization times. b) Error rates in reporting the location of the target. c) Percentage of the trials with at least one fixation on the target. d) Percentage of the trials with a fixation on the cue. e) Percentage of trials with the first fixation on the cue immediately followed by a fixation on the target. In all data plots, the error bars show the standard error of the mean across participants.

Figure 3 plots the results of Experiment 2. Response times significantly depended on the cueing condition ($F(3,60) = 7.47, p < 0.001, \eta_p^2 = 0.27$). Sidak corrected paired comparisons between the different cues and the no-cue condition, showed significantly faster target localization in the presence of arrow

cues ($t(20) = 2.73, p = 0.013, d = 0.60$; Sidak corrected threshold = 0.017). In contrast, no such facilitation of target localization was found for gaze ($t(20) = 1.53, p = 0.14, d = 0.33$) or pointing hand ($t(20) = 2.02, p = 0.057, d = 0.44$) cues. Error rates were low (Figure 3b) and did not differ significantly across conditions ($F(3,60) = 1.69, p = 0.18, \eta_p^2 = 0.078$).

Fixations on the target were similar to Experiment 1, with percentages around 85% of the trials with at least one fixation on the target (Figure 3c). Differences in target fixations between cueing conditions did not reach significance ($F(3,60) = 2.74, p = 0.051, \eta_p^2 = 0.12$), also reflected in none of the comparisons between the cue-present and cue-absent condition reaching significance after Sidak correction ($p = 0.81, p = 0.54, \text{ and } p = 0.033$, for the eyes, hand, and arrow cues; Sidak corrected threshold at 0.017). Experiment 2 saw more fixations on the cue than Experiment 1 (Figure 3d), possibly due to the cue always being valid and next to the target. Cue fixations differed across cue conditions ($F(1.57,31.3) = 6.19, p = 0.009, \eta_p^2 = 0.24$), and Sidak corrected comparisons showed that this was due to hands being fixated more often than the eyes ($t(20) = 3.41, p = 0.003, d = 0.75$) and the arrows ($t(20) = 3.52, p = 0.002, d = 0.77$; Sidak corrected threshold = 0.017), without a difference between the eyes and the arrows ($t(20) = 0.54, p = 0.60, d = 0.11$). Cue following, with a fixation on the cue immediately followed by a fixation on the target, was more frequent in Experiment 2 than in Experiment 1, suggesting an effect of the validity of the cue. Cue following did not differ significantly across the cues ($F(2,40) = 2.89, p = 0.067, \eta_p^2 = 0.13$), although the difference between the gaze and arrow cue was close to significance under Sidak correction ($t(20) = 2.43, p = 0.025, d = 0.53$; Sidak corrected threshold = 0.017), with stronger cue following for arrow cues. Figure 3f examines the effects of fixating the cue on search times to the target. Paired samples t-tests showed that fixations on the cue led to longer search times for gaze cues ($t(20) = 2.48, p = 0.022, d = 0.54$), but not for hands ($t(20) = 1.40, p = 0.18, d = 0.31$) or arrows ($t(20) = 0.23, p = 0.82, d = 0.049$).

Discussion

Experiment 2 replicated the stronger effects of arrow cues ($d = 0.60$; medium effect size) than gaze cues ($d = 0.33$, small effect size) on localization of the search target. Arrow cues showed a trend towards more frequent cue following (with a saccade from the cue to the target) than gaze cues. In contrast to earlier studies (Burton et al., 2009; Hermens et al., in press), suggesting that extrafoveally presented hand cues exert strong cueing effects on the observer, Experiment 2 did not reveal a significant effect of the hand cues on target localization (although the effect approached statistical significance, the associated effect size of $d = 0.44$ must be considered as small by Cohen's criteria).

Comparison of the observed effect sizes of search times in Experiments 1 and 2 suggests that the increased validity of the cues did not lead to faster

detection of the target (gaze cue to no cue comparison: $d = 0.26$ in Experiment 1, and $d = 0.33$ in Experiment 2; arrow cue to no cue comparison: $d = 0.70$ in Experiment 1 and $d = 0.60$ in Experiment 2). The change from eyes within a face (Experiment 1) to eyes in isolation (Experiment 2) appears to have increased the effectiveness of the cue (given that the arrow cue became slightly less effective in Experiment 2, where a localization task was used rather than the detection task of Experiment 1), but not to a large extent. Cue fixations were more frequent in Experiment 2, and led to slightly more direct fixations on the target (cue following), which suggests that increasing the validity of the cue led to more cue fixations, but not to more effective cues. This interpretation of the data was further supported by the finding that fixating the cue either led to longer (eye gaze cues) or similar (hands and arrows) search times. The increase in search times after fixation of the gaze cues is in line with findings in children, where eye gaze cues impaired the disengagement of attention from central fixation (Gregory, Hermens, Facey, & Hodgson, 2016).

Experiments 1 and 2 compared biologically relevant and symbolic cues, suggesting that the symbolic arrow cues may be more effective than the biologically relevant gaze and pointing hand cues. However, it is unclear whether the differences between the various cues can be explained from the distinctiveness of the shape of the cue, as suggested by Hermens et al. (in press). Experiment 3 therefore compares the influences of cues that have the same identity (both hands, or both arrows), but with different outlines (for the arrows: an arrow outline versus a rectangular outline, for the hands: a more pointed outline versus a more rounded outline) and textures (for the arrows: a dark arrow on a white background versus a bright arrow on a dark background, for the hands: a highly textured hand against a simple outline of a hand). By varying the overall appearance of the cues, but keeping their identity (arrow or hand), the role of cue appearance versus the role of the cues identity could be compared. Verbal feedback from the participants in Experiments 1 and 2 also suggested that some cues may be more effective, because they stand out more clearly from their surrounding. This hypothesis was tested in Experiment 3 by measuring response times to localize the cue, in addition to localizing the target, and correlating these search times. Finally, from Experiments 1 and 2, it is unclear whether cues may be more effective when they are embedded in a less cluttered environment.

Experiment 3 therefore compared displays with 8 and displays with 16 objects. Because the effect sizes in Experiments 1 and 2 sometimes led to marginally significant effects, the sample size was further increased in Experiment 3.

Experiment 3

Experiment 3 compares two arrow cues and two hand cues with a no-cue condition. Search times for the target and search times for the cues are compared to examine whether cues that can be localized more easily also lead to

stronger cueing. Less crowded displays are compared to more crowded displays to examine the effect of clutter on these cueing effects.

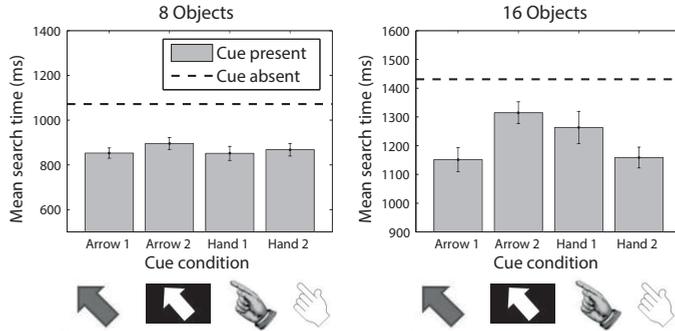
Methods

Twenty-five participants (20 female, 5 male, aged between 18 and 32 years) were recruited from the undergraduate and postgraduate student population at the University of Lincoln (UK). They received course credit for their participation (the majority of the participants), or took part without reimbursement. The experiment consisted of two sections. In the first section, participants were asked to find target objects in arrays of 8 or 16 objects, similar to Experiment 2. In the second section, the target preview was removed, as well as the trials without a cue, and the task of participants was to find the cue. Four types of cues were used: Two arrow cues and two hand cues that differed in their visual properties (see Figure 1). Two of these cues were the same as in Experiment 2 (as a comparison) and two new cues were introduced (a white arrow on a rectangular black shape, and a white outline hand; both of which could stand out more clearly from the surround than the original cues). Cues and target objects were embedded in rings of either 8 objects (in two rings, at the four cardinal directions; see Figure 1f) or 16 objects (as before, again in two rings). Participants all completed the target search task before the cue search task. For each task the order of trials was randomized for each participant. As in Experiment 2, participants responded by indicating the location of the cue or target (irrespective of the ring) by pressing one of eight keys on the numpad section of the keyboard. Participants were encouraged to respond as quickly and accurately as possible. Typically, the experiment took between 25 and 30 minutes to complete.

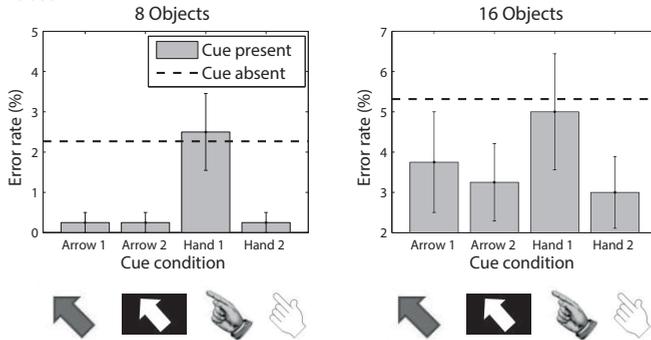
Results

Response times and error rates for the different conditions in Experiment 3 are shown in Figures 4a and 4b. A repeated measures ANOVA showed a significant interaction between the number of objects in the display and the cueing condition ($F(4,96) = 5.54, p < 0.001, \eta_p^2 = 0.19$), indicating that the effects of the cues were different when embedded in 8 or 16 objects. For displays of 8 objects, cueing condition significantly affected response times ($F(2.5, 59) = 27.95, p < 0.001, \eta_p^2 = 0.54$; paired comparison effect sizes with the no-cue condition: arrow 1, $d = 1.36$, arrow 2, $d = 1.11$, hand 1, $d = 1.99$, hand 2, $d = 1.22$). This was due to differences with the no-cue condition, but there was no significant difference in response times between the different types of cues ($F(3,72) = 1.97, p = 0.13, \eta_p^2 = 0.076$). For displays with 16 objects, cueing condition also significantly influenced search times ($F(2.6, 63) = 16.5, p < 0.001, \eta_p^2 = 0.41$). For this condition, the identity of the cue had a significant effect on search times ($F(3,72) = 9.07, p < 0.001, \eta_p^2 = 0.27$), in line with the results from Experiment 2. Paired samples t-tests comparing conditions with a cue with the no-cue condition (paired comparison effect sizes with the no-cue condition: arrow 1, $d = 1.21$, arrow 2, $d = 0.49$, hand 1, $d = 1.10$, hand 2, $d = 1.07$) showed significantly faster search times in the presence of all cues (all p-values smaller than 0.0001), except for the second arrow cue ($t(24) = 2.5, p = 0.022$, not significant after Bonferroni correction). Paired samples t-tests comparing the different cues showed significant differences between the two arrow cues ($t(24) = 5.12, p < 0.0001, d = 1.02$), and between the second arrow and second hand conditions ($t(24) = 5.60, p < 0.0001, d = 1.12$).

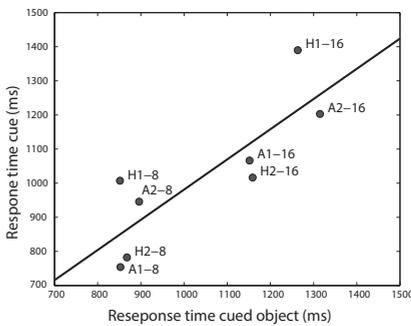
a) Search times



b) Error rates



c) Search time correlations



d) Cue fixation effects on RTs

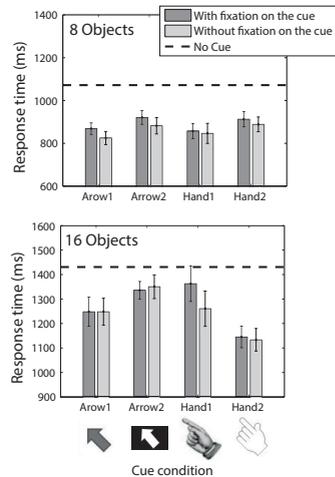


Figure 4. Response times and error rates in Experiment 3. a) Search times for finding the predefined target (left) and for finding the cue (right). b) Error rates in reporting the location of the target (left) or reporting the location of the cue (right). c) Scatterplot comparing response times on the target search task and the cue search task. Each dot in this plot shows the average response time in one of the conditions (H=hand, A=Arrow; the second number indicates the

number of objects in the search array). The solid line shows the best fitting regression line. d) Response times to find the predefined target depending on whether the cue was fixated (top) or not (bottom). Error bars show the standard error of the mean across participants.

Error rates were significantly lower when searching for the target object in arrays of 8 objects, compared to arrays of 16 objects ($F(1,24) = 16.6$, $p < 0.001$, $\eta_p^2 = 0.41$). At the same time, a main effect of cueing condition on error rates was found ($F(2.8, 68) = 3.61$, $p < 0.009$, $\eta_p^2 = 0.13$), in the absence of an interaction between the two factors ($F(2.7, 66) = 0.10$, $p = 0.982$, $\eta_p^2 = 0.004$). Bonferroni corrected pairwise comparisons for displays of 8 objects did not reveal any statistically significant differences between conditions, but the comparison between the first arrow and the first hand cue approached statistical significance ($t(24) = 2.82$, $p = 0.009$, $d = 0.56$). For displays of 16 objects none of the comparisons approached statistical significance (all p -values larger than 0.11).

To examine whether there was a relation between the strength of cueing and the ease of detection of the cue itself, response times to the cues were also collected. Figure 4c plots these response times for the different conditions against each other, showing a strong significant association ($r = 0.84$, $p = 0.0096$), suggesting that cues that are more effective at cueing the target, can also be found more easily. Figure 4d shows that fixations on the cue did not substantially influence response times (none of the paired samples t -tests comparing reaction times between trials with and those without a cue fixation reached statistical significance, all $p > 0.14$).

Figure 5 provides an overview of the various eye movement measures when participants searched for the object (left column) or for the cue (right column). Averaged across conditions, participants fixated the cue more often when searching for the cue than when searching for the object ($t(24) = 10.9$, $p < 0.001$, $d = 2.19$). Cue fixations were dependent on the cue and the number of objects (interaction: $F(3,72) = 13.6$, $p < 0.001$, $\eta_p^2 = 0.36$, when looking for the object; $F(3,72) = 8.59$, $p < 0.001$, $\eta_p^2 = 0.264$, when looking for the cue). When looking for the object, cue fixations were more frequent in arrays of 8 objects compared to arrays of 16 objects ($F(1,24) = 27.7$, $p < 0.001$, $\eta_p^2 = 0.536$) and depended on the cueing condition ($F(3,72) = 12.8$, $p < 0.001$, $\eta_p^2 = 0.35$), without an interaction between the two factors ($p = 0.43$). Pooled across the two array sizes, more cue fixations were found for the second arrow than for the first arrow ($t(24) = 3.15$, $p = 0.0043$, $d = 0.63$), for the first hand than for the first arrow ($t(24) = 6.91$, $p < 0.001$, $d = 1.38$), and for the first hand, compared to the second hand ($t(24) = 5.83$, $p < 0.001$, $d = 1.17$). When looking for the cue, the opposite pattern emerged, with cue fixations more frequent in arrays of 16 objects than for 8 objects ($F(1,24) = 35.7$, $p < 0.001$, $\eta_p^2 = 0.60$), in the presence of an independent effect of cueing condition ($F(3,72) = 7.90$, $p < 0.001$, $\eta_p^2 = 0.25$). Paired comparisons between cueing conditions, pooled across array size, showed more cue fixations for the second arrow, compared to the first arrow ($t(24) = 3.15$, $p = 0.0043$, $d = 0.63$), more cue fixations for the first hand, compared to the first arrow ($t(24) = 6.90$, $p < 0.001$, $d = 1.38$), and more cue fixations on the first hand, compared to the second hand ($t(24) = 5.82$, $p < 0.001$, $d = 1.17$).

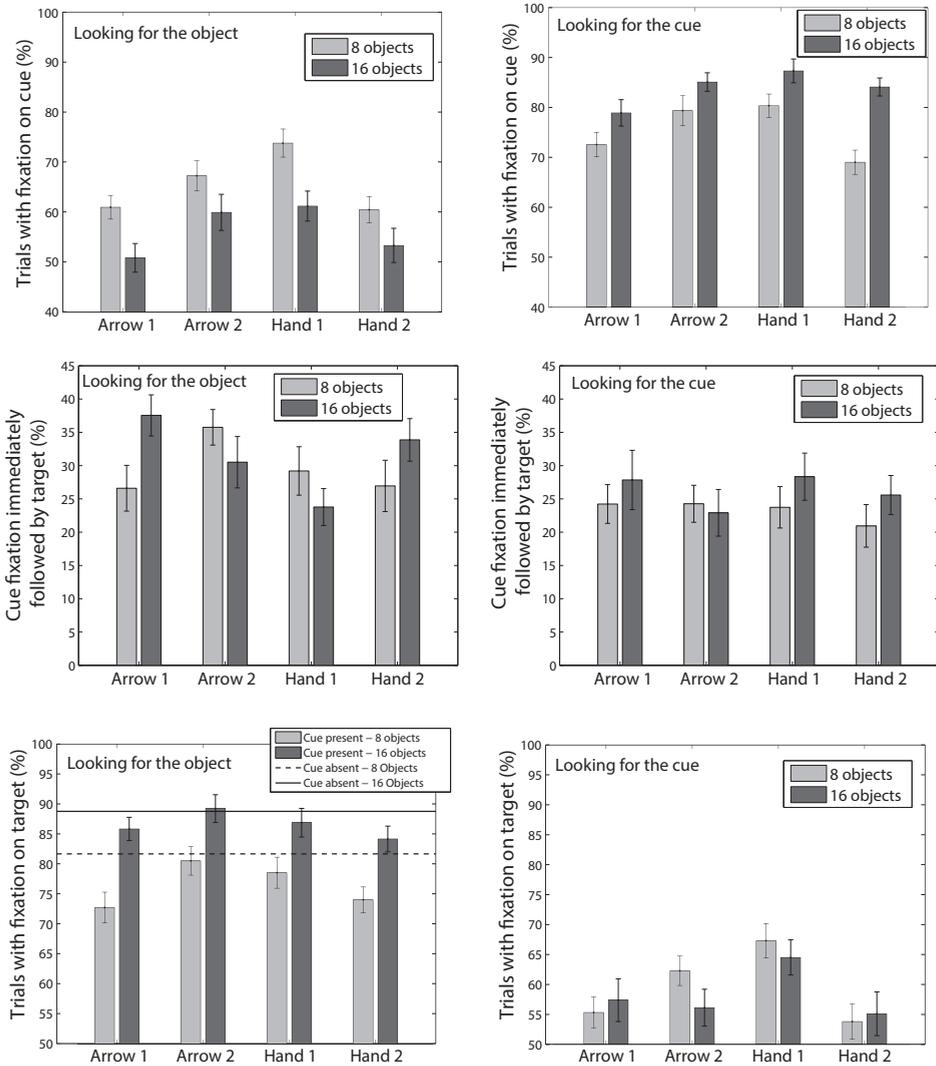


Figure 5. Eye movements characteristics in Experiment 3, when searching for cued objects or cues, showing the percentage of trials with at least one fixation on the cue (top row), the percentage of trials with a fixation on the target immediately after fixating the cue (middle row), and the percentage of trials with a fixation on the target (bottom plot). The left column shows the data when participants searched for the target object, the right column the data for when participants searched for the cue. Error bars in each of the plots show the standard error of the mean across participants.

Cue following, where the first fixation on the cue was immediately followed by a fixation on the target, was more frequent when searching for the target object, than when looking for the cue ($t(24) = 2.43, p = 0.023, d = 0.49$; averaged across the various cueing conditions). When looking for the target, a complex interaction between the number of objects and the cueing condition was found ($F(3,72) = 3.83, p = 0.013, \eta_p^2 = 0.14$). After Bonferroni correction, none of the comparisons between 8 and 16 objects for the search for the object was significant (all p -values larger than 0.042). Bonferroni corrected pairwise comparisons between cues (pooled across number of objects) did not reveal any significant differences either (all p -values larger than 0.025). For the cue search task, none of the effects of number of objects, cueing condition, or interaction was significant (all p -values larger than 0.22).

In contrast to cue fixations, which were only moderately influenced by whether participants looked for the cue or the target, fixations on the target object were much more frequent when looking for the target object than for the cue ($t(24) = 9.65, p < 0.001, d = 1.93$). When looking for the target, the cueing condition ($F(4,96) = 6.42, p < 0.001, \eta_p^2 = 0.21$), and the number of objects ($F(4,96) = 45.0, p < 0.001, \eta_p^2 = 0.65$) influenced the number of fixations on the cued object (in the absence of an interaction, $p = 0.30$). Targets were significantly less often fixated in the presence of the first arrow, compared to no cue ($t(24) = 3.91, p < 0.001, d = 0.78$) and in the presence of the second hand, compared to no cue ($t(24) = 3.18, p = 0.004, d = 0.64$), but no differences with the no-cue condition was found for the other two cues. When looking for the cue, cueing condition ($F(2.4,57) = 7.78, p = 0.025$), but not number of objects ($p = 0.38$) significantly influenced target fixations. Pairwise comparisons showed that the first hand led to significantly more target fixations than the first arrow ($t(24) = 3.50, p = 0.0018, d = 0.70$), and the first hand led to significantly more target fixations than the second arrow ($t(24) = 3.81, p < 0.001, d = 0.76$), and the first hand to significantly more target fixations than the second hand ($t(24) = 3.67, p = 0.0012, d = 0.73$).

Discussion

Experiment 3 showed that the shape of the cue, rather than its biological relevance determined its influence on search efficiency in crowded (16 objects) displays. In less crowded (8 objects) displays, no differences between cues on search times were found.

Compared to Experiments 1 and 2, the hand and arrow cues led to stronger (larger effect sizes) and more reliable (more often statistically significant) cueing effects (16 objects condition, which was tested across experiments). Differences in statistical significance of the effects may be due to the larger sample size in Experiment 3, but it is unclear why the effect sizes in the 16 objects displays were larger in Experiment 3. Possibly the mixing with the 8 object conditions led to participants to rely more strongly on the cue in the 16 objects condition, but this would need to be investigated further. A comparison with the times to locate

cued objects with the times needed to locate the cue itself, showed that cues that can be located more easily lead to stronger cueing, in agreement with subjective observations from participants. This suggests that for a cue to be effective in a search task, it needs to stand out from the surrounding (which also explains why cues were more effective in less cluttered displays). As in Experiment 2, fixations on the cue did not influence search times, compared to when the cue was not fixated. This finding supports the hypothesis that cueing effects of cues initially presented away from fixation depend on peripheral processing of the cues before they are fixated.

Cues were more often fixated in less cluttered (8 objects) than more cluttered (16 objects) displays, but only when searching for the object. When searching for the cue itself, the opposite pattern was found. Possibly, participants may have made stronger use of the cues in the less cluttered displays, as cues were easier to find. This may also explain why all cues were effective in the less cluttered displays, whereas this was not the case for the more cluttered displays. When searching for the cue itself, participants may have looked at the cue more often in the cluttered condition, because it could not be easily perceived in extrafoveal vision (due to visual crowding).

Cue following, where the first fixation on the cue was immediately followed by a fixation on the target, was relatively weak (around 35% of cue fixations). Cue following was not much more pronounced when looking for the target (35%), compared to looking for the cue itself (25%), suggesting that any tendency to follow the cue was little influenced by the task. Cue following may therefore reflect a fairly automatic tendency to look at what the cue is pointing at, although this tendency is not extremely strong.

Target objects were looked at much less often when looking for the cue itself (around 55% of the trials) than when looking for the target (around 80% of trials). This finding may seem at odds with the finding that cue following was largely independent of the task and that cues were often fixated when looking for the cue. Cue following, however, only accounts for around 20% (80% of 25%) of the fixations on the target when searching for the cue, meaning that most target fixations were unrelated to cue following. This percentage of target fixations due to cue following is similar when searching for the target, meaning that target fixations were largely due to fixations immediately landing on the target, which were more frequent when searching for the target than searching for the cue. Targets were more often fixated in more cluttered displays (16 objects), compared to less cluttered displays (8 objects), in agreement with the interpretation that the search target could be identified more easily from extrafoveal vision in less cluttered displays.

General discussion

Socially relevant cues, such as eye-gaze and pointing hands have been shown to strongly influence an observer's attention when presented in isolation and at fixation (Bayliss & Tipper, 2006; Driver et al., 1999; Friesen & Kingston,

1998; Friesen & Kingstone, 2003; Friesen et al., 2004, 2005; Frischen et al., 2007; Gregory & Hodgson, 2012). The supremacy of social cues over symbolic cues, such as arrows and direction words, however, has been debated (Kuhn & Kingstone, 2009; Tipples, 2002, 2008), and recent studies presenting the various cues away from fixation (Burton et al., 2009; Nummenmaa & Hietanen, 2009a) have suggested that the special role of gaze cues may be limited to presentation at fixation. The present work examined the influence of social and symbolic cues on visual search, where the task of the observers was to find a predefined target object within a grid of distractor objects and the cue. In contrast to previous studies employing gaze cues in similar search paradigms (Kuhn et al., 2015; Kuhn & Tipples, 2011; Langton et al., 2006), the cues were embedded within the search array, rather than presented at fixation. This situation was created to better mimic natural search conditions, where the cue is not always immediately fixated. The results show that, in agreement with previous findings in an interference paradigm (Burton et al., 2009; Hermens et al., in press) that gaze cues are weak cues of direction when presented away from fixation. In contrast, cues with a more distinct shape, such as arrows and pointing hands, did lead to faster localization of the search target. The particular shape of the cue and the extent to which the cue stood out from the surrounding arrow cues determined the strength of cueing, particularly for more cluttered displays. Eye movements suggested that most of the effects of the cues were due to extrafoveal vision of the cues. Cues were not consistently fixated when searching for the search target, fixations on the cue did not often lead to subsequent fixations on the cued object, and fixations on the cues did not lead to faster cue localization. Taken together, the results suggest that arrow cues are more effective than gaze cues in cluttered scenes, although certain pointing hands could provide similarly effective cues.

The use of arrows in visual search was previously examined by Jonides (1980), who presented arrow-heads adjacent to the target's location before the onset of the search array (consisting of a set of eight letters), compared to conditions where the arrow-head appeared elsewhere or where a neutral shape was presented in the center of the screen. The results demonstrated significant benefits of valid arrow cues and costs for invalid arrow cues. The experiments by Jonides (1980), however, differ from the present work in one important aspect: While Jonides (1980) presented the cues before the search array, the presently used cues were presented together with the search array, more closely mimicking day-to-day viewing, where cues do not appear before the rest of the scene. An early appearance is likely to make cues more salient, which may explain the rather large effects of cues in these past experiments.

Other studies examined the influence of social cues on visual search (Kuhn et al., 2015; Kuhn & Tipples, 2011) and change detection (Langton et al., 2006), and found that social cues led to faster localization of the search target or change. These cues, however, were presented at fixation. Previous studies have suggested that cues that are effective at fixation (in particular eye-gaze), may not

be as effective away from fixation (Burton et al., 2009; Hermens et al., in press). The present results agree with these findings, and show that the shape of the cue and how well it stands out from the surroundings, determines how effective the cue is in a cluttered scene.

While the majority of visual search experiments have used simple shapes, such as lines, squares and circles, others have started to use more complex objects and more complex backgrounds (e.g., Wolfe, 1994). The present work used a picture of the search target, presented before the stimulus array. Previous studies have examined whether such pictorial representation of the target is more effective than presenting its category name, either on the subordinate, basic, or superordinate level, and found that pictorial representation led to fastest localization of the target and the largest number of first fixations on the target (Experiment 2 in Maxfield & Zelinsky, 2012). This suggests that to increase the influence of the cues on search efficiency, it may be beneficial to present the target object by its superordinate name (which led to the slowest response times in Maxfield & Zelinsky, 2012). Similarly, cue effectiveness may be increased by reducing the typicality of the target for the category (Maxfield, Stalder, & Zelinsky, 2014).

Differences between cues were particularly strong when embedded in a highly cluttered display (16 objects). All cues tested in less cluttered displays (8 objects) were equally effective. While this may suggest that eye-gaze cues may be effective in less dense displays (these were not tested here), previous work with two competing cues (Burton et al., 2009; Hermens et al., in press) suggests that it is unlikely that gaze-cues are effective in low clutter, except when presented at fixation.

The present results contribute to a growing body of results (Hermens & Walker, 2010; Kuhn & Kingstone, 2009; Nummenmaa & Hietanen, 2009a; Quadflieg et al., 2004; Tipples, 2008) suggesting that the initial results indicating that eye-gaze may be special (Driver et al., 1999; Friesen et al., 2004) may be restricted to certain paradigms and performance measures. Eye-gaze cues may be susceptible to visual crowding (Martelli et al., 2005) and their strong effects could therefore be limited to presentation at fixation and in the absence of visual clutter.

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