Congruency between viewers' movements and the region of the display being sampled speeds up search through an aperture

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Declaration of Conflicting Interests

None.

Data Availability

The data and analysis scripts for these experiments are available at https://osf.io/nxdyh/. The eye-tracking images themselves are not available due to privacy issues.

Abstract

Searching for a target amongst distractors is faster when moving an aperture over the search display than when moving the search display beneath an aperture. Is this because when moving the aperture each item is sampled at a different position, while when moving the search display all items are sampled at the same position? When moving the aperture, it might therefore be easier to keep track of where one has already searched. Experiment 1 showed that, when the extent of the search display is visible to provide an additional reference frame, participants still found targets faster when moving the aperture. Experiment 2 showed that, even when the aperture and search display constantly moved around the screen together so that remembering where on the screen one had already searched is less useful, participants still found targets faster when moving the aperture. Experiment 3 showed that inverting the mapping between movements of the mouse and the item they were toggled to reversed the outcome: for the inverted mapping search was faster when moving the search display than when moving the aperture. We conclude that the congruency between the user’s movements and the spatial region of the search display that they are sampling from is critical for speeding up search.

Keywords: egocentric, allocentric, reference frame, spatial compatibility, visual search

Introduction

In everyday visual search tasks, it is advantageous to remember where we have already looked so that we do not look there again (Kristjánsson, 2000; Redden, MacInnes, and Klein, 2021; Takeda and Yagi, 2000, Vo and Wolfe, 2015; Wang and Klein, 2010): a phenomenon often referred to as inhibition of return. How do people remember where they have already searched? When looking for their gloves, people will probably remember having looked on the shelf or the floor near the door, or in their coat pocket. This corresponds to remembering the position of items relative to other items (in an allocentric reference frame) rather than relative to themselves (in an egocentric reference frame). In tasks such as memory-guided reaching and grasping, people remember locations relative to where they are looking (Medendorp et al., 2003, Thompson and Henriques, 2011), but remembering positions for memory-guided reaching (Henriques et al., 1998; Medendorp and Crawford, 2002; Ambrosini et al., 2012) and grasping (Selen and Medendorp, 2011) might be different because a single target item is presented. In a visual search scenario, multiple item positions need to be remembered to avoid revisiting the same location unnecessarily. Using gaze-centred coordinates in this scenario means that the item positions will quickly become unreliable because they must be updated with each eye and head movement (Smeets et al., 2006). An advantage of relying on an allocentric reference frame is that items' relative positions do not change when the observer changes position. Having such information has been reported to be advantageous in memory-guided reaching (Krigolson and Heath, 2004; Krigolson et al., 2006; Obhi and Goodale, 2005). A potential disadvantage in complex scenes is that it requires people to remember the scene in considerable detail for it to be effective.

To investigate how people remember where they have already searched, we scrutinize the finding that searching for an item by moving an aperture through which only a small part of a display is visible (which we will refer to as aperture search) is faster when moving the aperture over the search display than when moving the search display beneath the aperture (Bury et al., 1982; Fujii & Morita, 2020). Fujii and Morita (2020) asked participants to search for a target amongst distractors using a touch panel. At any time, they only saw the items beneath the aperture. In some trials their finger movements were linked to the aperture. In other trials they were linked to the search display. The available visual information was limited in the same manner in both cases, so it is not obvious why the search times would differ.

One possible explanation for search times being shorter when moving the aperture is that moving an aperture mimics the way people move their eyes in daily life, although nowadays people also frequently sample information through apertures, such as when using a mobile phone (Fujii & Morita, 2020). Another possible explanation, the one that we set out to investigate in this paper, is related to the spatial reference frame used. Participants have the same allocentric spatial information available to them in both scenarios, such that there is no reason to expect any difference based on remembering which positions in the search display they have already visited and what items they saw there. However, when moving the aperture, people also have egocentric information available to them, because each position in the search display is sampled at a different egocentric position (unless they move with respect to the screen). Thus, they might complement their judgements of which parts of the search display they have already examined with judgements of where they have already looked, possibly based on their direction of gaze and the position of their hand when doing so. When moving the search display beneath the aperture, all items are sampled at the same egocentric position and the same position on the screen, such that allocentric information within the search display must be used to guide the search. It is possible that being able to use additional egocentric information when moving the aperture is responsible for search being faster when doing so. In particular, determining where the aperture is directed within the search display is probably more difficult to judge when moving the display beneath the aperture than when moving the aperture over the display, which is likely to make search less efficient.

To find out whether search is faster when moving the aperture than when moving the search display is because people have access to egocentric information about the items' positions, we investigated the effect of both improving allocentric information by showing the extent of the search display (Experiment 1) and making egocentric information (and positions on the screen) less informative by constantly moving the aperture and search display around the screen together (Experiment 2). Showing the extent of the search display provides a *landmark* for participants to encode the items of the display relative to, even if the aperture is not moving. Therefore, any advantage that arises from having a better idea of where the aperture is directed in the display, should also be present when moving the display if its extent is clearly visible. Additional landmarks are beneficial when using an allocentric reference frame (Krigolson and Heath, 2004; Obhi & Goodale, 2005), with stable landmarks such as the edges of the search display that we introduce being particularly helpful because they allow observers to reliably compute spatial relations between objects (Byrne and Crawford, 2010).

Constantly moving the aperture and search display together across the screen (Experiment 2) reduces the reliability of judging positions with respect to oneself, and other landmarks outside the search display. This is the case even if one were to constantly adjust all the remembered egocentric positions in accordance with the artificially introduced movements. Over time, the reliability of localising previously visited egocentric positions will decline (Smeets et al., 2006; Prime et al., 2007), and therefore reduce the reliability of egocentric information (Byrne and Crawford, 2010). Constantly moving the aperture and search display together might therefore reduce the advantage of searching by moving the aperture because in both cases one will have to primarily rely on allocentric information from within the search display. When the extent of the moving search display is shown, judging positions with respect to the display itself should be the most reliable, so we expect the difference between the moving aperture and moving search display to disappear.

Search was faster when moving the aperture over the search display, even when the extent of the search display was visible (Experiment 1) and the search display constantly moved around the screen (Experiment 2). Experiment 3 therefore tested whether the difference in search time was due to the dynamics of the mouse-movements being different when using the two different control methods. This was tested by inverting the mapping between the mouse movements and the item they were toggled to. This manipulation can be conceptualised as influencing stimulus-response compatibility (see Proctor & Vu, 2006, for a review), namely the congruency between the user's movement and movement of a visual stimulus (aperture or search display). We found that search was faster when participants moved the mouse leftward to sample from the left side of the search display, irrespective of what item the mouse was toggled to.

General Methods

Participants

Twenty-four young adult participants took part in each experiment (approximate age range 18 – 30 years). Participants either volunteered to take part, took part for course credit, or were reimbursed 10 euros per hour. All participants provided written informed consent. The experiments were approved by the local ethics committee and conducted in accordance with the Declaration of Helsinki.

Stimulus and Procedure

The experiment was conducted in a normally illuminated room. The stimuli were presented at 240 Hz on an ASUS TUF VG279QM 27 inch (90 x 34 cm) monitor with a resolution of 1920 x 1080 pixels. Participants were free to sit as they liked and used a standard USB optical mouse to complete an aperture search task in which the part of the search display that was visible depended on the position of the mouse. They were instructed to search for a dark grey ring (inner and outer diameters of 1.2 and 2 cm, respectively; the target) amongst similar rings with a gap at a random position along the ring (5% of the ring was missing; distractors) as quickly as possible. The boundary of the search display was 42.5 x 14.5 cm. The target was somewhere on the search display among 9 distractors (see Figure 1). Each of the ten items were positioned at random on each trial, ensuring that their edges were at least 1 cm from the boundaries of the display and from each other. The bright search display with grey items was only visible through a 5.1 cm diameter aperture, so that only a small part of the display was visible at any moment. Moving the aperture beyond the display or the display beyond the aperture allowed people to see the edge of the display as a part that had the same shade of grey as the area outside the aperture. The centre of the aperture could not move further than the edge of the display to ensure that participants could not get 'lost' outside the display. In two blocks of trials, the computer mouse was linked to the aperture such that when the mouse moved, the aperture moved over the static search display (Figure 1, left panels). In another two blocks of trials, the computer mouse was linked to the search display such that when the mouse moved, the search display moved under the static aperture (Figure 1, right panels). Participants were instructed to click the left mouse button when they had found a target item, ending the trial. Each trial started with both the aperture and the search display centred on the screen. In some cases, the boundaries of the search display were always visible as a brighter rectangle (Figure 1, upper panels) that moved with the search display if necessary (Figure 1, upper right panel).

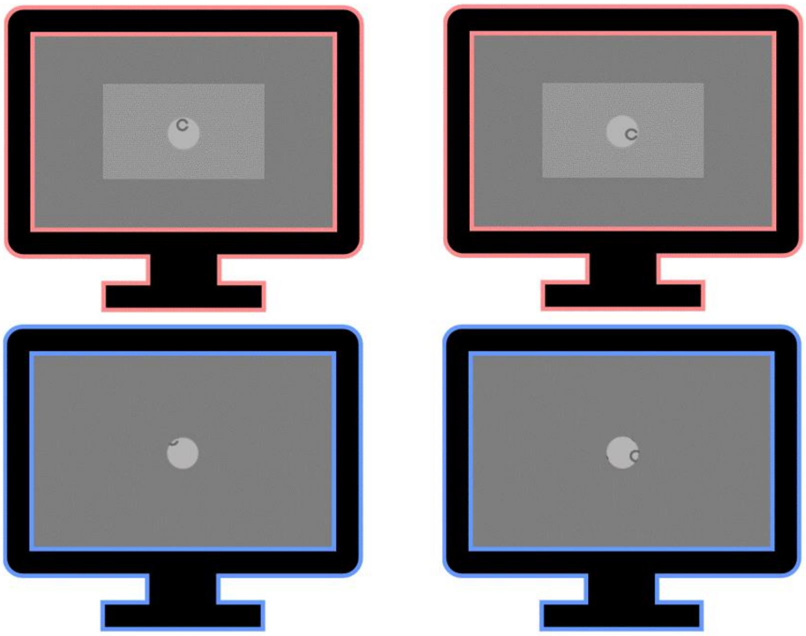

Figure 1. Short animations of the two control methods (columns) and visual displays (rows) in Experiment 1 (animation can also be accessed at https://osf.io/nxdyh/?view_only=f73d1974df9d4e9c94b79ac68cf45256). Mouse movements either move the aperture across the static search display (left panels) or move the search display to reveal different parts through the static aperture (right panels). The edges of the search display were either visible (top panels; red) or not (bottom panels; blue).

Design

All three experiments used a within-subject design with two independent variables, resulting in four experimental conditions per experiment. In Experiments 1 and 2 the independent variables were the control method (move aperture, move search display) and visibility of the extent of the search display (visible extent, uniform surround). In Experiment 3, the extent of the search display was always visible, and the independent variables were the control method and mapping (standard, inverse). In all experiments, each participant completed four blocks of 100 trials, one for each of the experimental conditions. The order in which participants completed the four blocks was fully counterbalanced across participants (24 participants were needed to include all possible orders). The experiment was completed in a single session that took approximately 1 hour including the explanation and reading and signing the informed consent form.

Data Analysis

We calculated the median time to find the target for each participant in each condition and then conducted a 2 x 2 repeated measures ANOVA to evaluate whether performance was influenced by the two independent variables of each study. We also report the number of errors participants made (i.e., trials where participants clicked the mouse when the target was not within the aperture) but did not remove trials with errors from the analysis. In Experiment 3, we also analysed the participants' mouse movements. Moreover, we recorded the eye movements of 15 of the participants with a Pupil invisible eye tracker (Pupil Labs, GmbH). We calculated the median velocity of the cursor, and the fraction of time the participants' gaze was within the aperture. The data and analysis scripts for these experiments are available at https://osf.io/nxdyh/?view_only=f73d1974df9d4e9c94b79ac68cf45256. The eye-tracking images themselves are not available due to privacy issues.

Experiment 1

Experiment 1 manipulated the allocentric information by either showing the extent of the search display (visible extent, Figure 1, top panels) or not (uniform surround, Figure 1, bottom panels). The visible extent of the search display should improve the allocentric information by both providing information about where the aperture is within the search display, as well as where the search display is relative to the screen. If the absence of egocentric information and the inability to rely on external references such as the edges of the screen to obtain allocentric information when moving the search display beneath an aperture is responsible for the previously observed moving aperture advantage (Fujii & Morita, 2020), showing the extent of the search display might make this difference disappear.

Results

Participants made errors on 3.1% of the trials. Figure 2a shows that when moving the aperture, providing additional allocentric information did not affect the average search time (similar search times for the red and blue bars on the left in Figure 2a). When moving the search display, the average search time was faster when the boundary was visible than when it was invisible (shorter search times for the red than the blue bar on the right in Figure 2a), but neither the effect of providing the visible extent ($F(1,23) = 0.09$, $p = .769$) nor the interaction with control method ($F(1,23) = 2.37$, $p = .138$) was statistically significant. Participants were faster when moving the aperture than when moving the search display ($F(1,23) = 22.29$, $p<.001$). Does the fact that participants were still faster when moving the aperture when the extent of the display was visible (Figure 2a, red bars), so when the difference between the conditions in terms of allocentric information was presumably minimal, imply that having access to egocentric information about the display is critical?

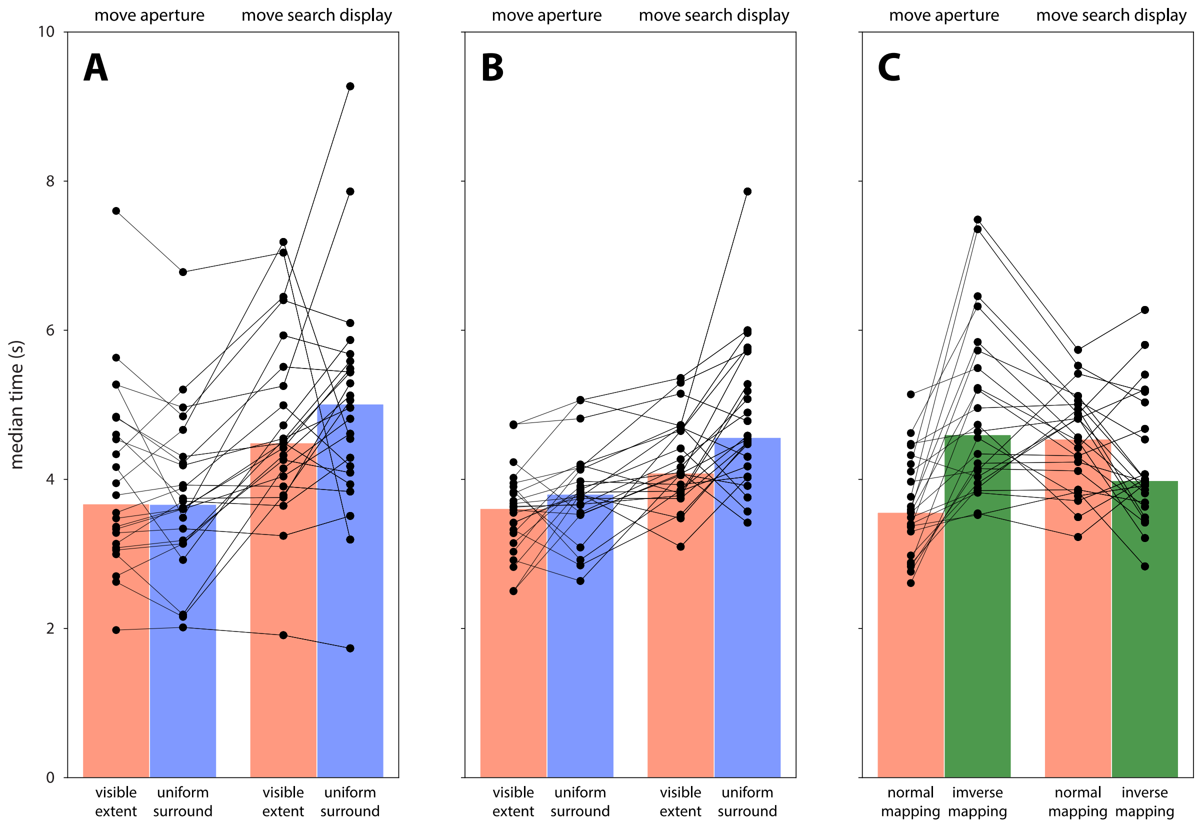

Figure 2. Median time taken to find the targets in Experiments 1 (A), 2 (B) and 3 (C). In each panel, the left two bars show the conditions in which moving the mouse moves the aperture, and the right two bars show the conditions in which moving the mouse moves the search display. The colour of the bars indicates the experimental conditions. Red and green

bars show conditions where the extent of the search display was visible; blue bars show conditions where it was not. Red and blue bars show conditions in which the aperture or search display moved according to the normal mouse mapping. Green bars show conditions in which they moved according to the inverted mapping. Individual participants' data points are displayed in black, with lines connecting the data for each participant.

Experiment 2

To test whether having reliable egocentric information was responsible for participants being faster when moving the aperture than when moving the search display, the egocentric information was disrupted in Experiment 2. To achieve this, we constantly moved the aperture and search display together across the screen. Besides the shifts caused by moving the mouse, the search display and the aperture also followed a slow, smooth two-dimensional path (sinusoidal motion with a cycle duration of 10s horizontally and 11s vertically) across the screen. This meant that the total area of the screen within which targets could appear increased by about 50% compared to when the search display did not move. The additional motion of the display was slow enough not make it difficult to navigate the aperture across the search display, or the search display beneath the aperture, but it meant that the egocentric information was constantly changing and was therefore not as useful for remembering previously visited locations. Our assumption was that this would result in participants being forced to rely more heavily on allocentric information to guide their search in all conditions, including the move aperture condition. Therefore, we would expect longer search times, with more similar search times when moving the aperture and when moving the search display, and that having the visible extent would be beneficial for both control methods.

Results

Participants made errors on 1.4% of the trials. Participants were indeed significantly faster when the extent of the search display was visible than when it was not ($F(1,23) = 15.99$, $p < .001$, shorter search times for the red bars than the blue bars in Figure 2b), with no significant interaction with control method ($F(1,23) = 2.15$, $p = .156$). However, participants were still clearly faster when moving the aperture than when moving the search display ($F(1,23) = 43.84$, $p < .001$). The finding that the search times were not systematically longer in Experiment 2 than in Experiment 1 despite the constant additional motion of the aperture and search display across the screen suggests that the faster search times when moving an aperture over a search display compared with moving a search display beneath an aperture is not entirely due to the ability to use egocentric spatial information. Are participants still faster when moving the aperture because they move the mouse and their eyes differently when using the two different control methods?

Experiment 3

If the ability to rely on egocentric information is not (entirely) responsible for search times being shorter when moving an aperture than when moving the search display, there must be another reason. Since certain mouse-cursor mappings are more intuitive than others (Brenner et al., 2020) and people have prior expectations about how a cursor should move on a screen (Brenner et al., 2022), it is possible that the difference in search times between the two control methods is a consequence of the mapping between the mouse and the item of the display it is toggled to. In the move aperture condition, participants move the mouse left and right to search the left and right sides of the search display, respectively. In the move search display condition, participants move the mouse left to search the right side of the display, and right to search the left hand of the display, because the search display moves with the mouse. The latter might simply be less intuitive.

To test this, we manipulated the mappings between mouse movements and shifts on the screen in half of the trials by swapping the left-right and up-down directions. If the mapping is more intuitive when moving the aperture, we might expect the advantage of moving the aperture to disappear when the mapping is inverted. If guiding the movements themselves is responsible for the advantage of moving the aperture, rather than the advantage being related to remembering where one has already searched, we might also expect to see faster movements for conditions with shorter search times. Another consideration is that it may be easier to identify the items when moving the aperture across a static search display because it is easier to keep one's gaze on items within the aperture.

To determine whether participants kept their gaze within the aperture more of the time when the items within the aperture were static and the aperture was moving, than when the items were moving within a static aperture, we recorded participants' eye-movements at 200 Hz using a Pupil invisible eye tracker (Pupil Labs, GmbH).Gaze data was collected for 15 of the 24 participants. For these 15 participants, all gaze except during blinks (about 6% of the time) were used for the analysis. The actual rate at which gaze was acquired was 199.7 Hz. We interpolated this data and combined it with the position and extent of the aperture as determined by a simple image analysis to determine whether gaze was within the aperture on each image frame of the eye tracker (30 Hz).

Results

Participants made errors on 0.8% of the trials. Rather than an overall difference in search times between when moving the aperture and when moving the search display ($F(1, 23) = 1.19$, $p = .286$) there was an interaction between the control method and the mapping ($F(1,23) = 28.70$, $p < .001$). When moving the aperture, participants were faster when using the normal mapping than the inverse mapping (Figure 2c). When moving the search display, participants were faster when using the inverse mapping than the normal mapping. There was also an overall effect of the mapping: search was faster when using the normal mapping compared with the inverse mapping ($F(1, 23) = 14.87$, $p < .001$).

Figure 3a shows the cursor's median velocity in each of the experimental conditions. We refer to the movement as that of the cursor because it is the movement of either the aperture or the search display, depending on which is moving. The movement was fastest when moving the aperture with the normal mapping, leading to main effects of mapping ($F(1,23) = 6.61$, $p = .020$) and control method ($F(1,23) = 8.64$, $p = .007$) as well as a significant interaction ($F(1,23) = 11.67$, $p = .002$).

Based on the scene images of all sessions of the 15 participants whose eye movements were measured, the viewing distance was 72 ± 13 cm (mean ± standard deviation). At this distance, the diameter of the aperture is 4.3 ± 1.4 deg. The eye tracker's precision of about 1 deg (Ghiani et al., 2023) or less (Ghiani et al., 2024; additional details can be found at: arxiv:2009.00508) should be good enough to get a reasonable estimate of how much of the time participants were looking within the aperture, as long as they did not specifically look very near the inner edge of the aperture a lot of the time. Although precision is high, there are evident, considerable systematic errors. These errors partly originate from parallax due to the placing of the scene camera, and partly from the eye tracking method itself. We can compensate for such systematic errors by assuming that participants were mostly looking at the aperture. We did so by shifting the directions of gaze during each session so that on average gaze was centred on the aperture. Doing so might exaggerate the time spent looking within the aperture, but since systematic errors in eye tracking should be independent of the condition, the comparison between conditions should not be affected, even if our estimate of the time spent looking within the aperture is over- or under-estimated.

Figure 3b shows the fraction of the duration of the experiment during which participants directed their gaze within the aperture for each of the experimental conditions. When moving the search display, participants' gaze was within the aperture for a greater percentage of time than when moving the aperture ($F(1,14) = 40.02$, $p < .001$). There was no overall effect of the mapping ($F(1,14) = 1.15$, $p = .302$) and no significant interaction ($F(1,14) = 10.60$, $p = .453$).

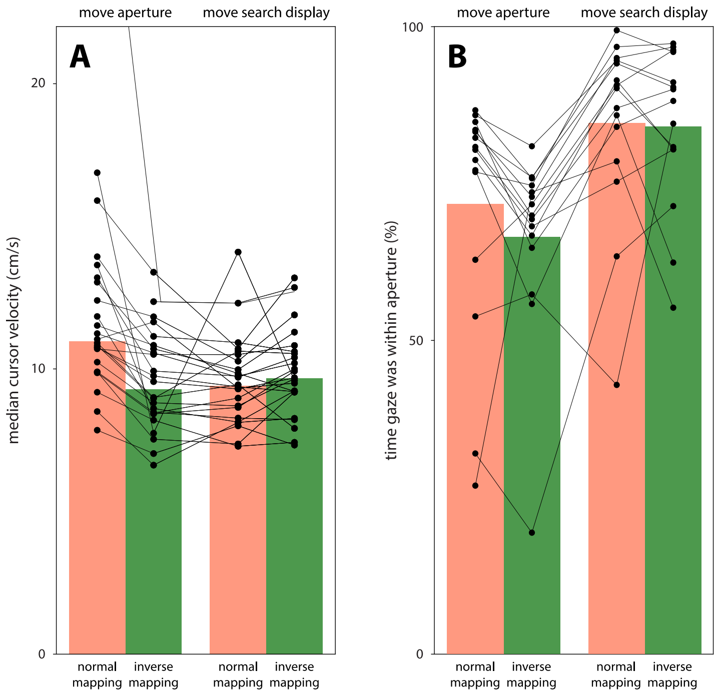

Figure 3. A) Median velocity of the aperture or search display (which we refer to as the cursor velocity). B) Percentage of time gaze was within the aperture. Red bars show conditions where the normal mapping was used; Green bars show conditions where the

inverse mapping was used. Individual participant data points are displayed in black, with lines joining the data for a single participant.

General Discussion

Our goal was to assess whether aperture search is faster when moving an aperture over a search display than when moving a search display beneath an aperture because of the way in which spatial information is represented. We reasoned that allocentric information would be used to guide search when moving the search display because all items are sampled at the same egocentric position whereas a combination of allocentric and egocentric cues could be used when moving the aperture. Experiment 1 tested whether the difference in search times would disappear if allocentric information was improved by showing the extent of the search display since that could be used as a stable landmark (Byrne and Crawford, 2010). The results showed that this was not the case: search times were still clearly faster when moving the aperture than when moving the search display, even when the extent of the search display was visible (Figure 2a). Replacing the identical distractor items with unique letters (Bertera and Rayner, 2000) might help participants build up a more elaborate allocentric representation of the scene, but since that representation could not guide the eye and arm movements in the same way the visible extent can, it is unlikely that such information would make much difference in this study.

To test whether it is the ability to guide search using egocentric cues when moving an aperture that speeds up search times, Experiment 2 sought to impair the reliability of the egocentric information. To achieve this, we slowly moved the aperture and search display together around the screen such that remembering previously visited locations in an egocentric reference frame was no longer reliable (Smeets et al., 2006; Prime et al., 2007). Participants were still clearly faster when moving the aperture compared with the search display (Figure 2b). Seeing the extent of the search display might be more useful when the search display moves around when looking for the target by moving the aperture, but the effect is modest (compare Figures 2a and 2b). Moreover, moving the aperture and search display around generally did not disrupt performance: the overall search times were similar in Experiments 1 and 2. Thus the ability to rely on egocentric information does not appear to be very important.

The difference in search times when moving the aperture and moving the search display persisted when manipulating the reliability of allocentric and egocentric cues. Experiment 3 therefore considered the possibility that the difference is due to the mouse-movements participants used when completing the task using the two different control methods. To gain insight into this, we inverted the mapping between the mouse and the item that it was toggled to. Unsurprisingly, when searching using the aperture, participants were slower for the inverse mapping (Figure 2c). Presumably this is because it was counterintuitive, not corresponding with their prior experience with a computer mouse (Brenner et al., 2020; Brenner et al., 2022). When moving the search display, participants were faster for the inverse mapping. We considered that this advantage may be driven by the inverse mapping being more intuitive for some reason, such that participants were faster at moving the search display around and thus could sample more items in a shorter amount of time. However, the cursor velocity was quite similar for both mappings (Figure 3a). Participants also did not have more trouble keeping their gaze within the aperture for the normal mapping than for the inverse mapping when moving the search display (Figure 3b). This suggests that faster search when using the inverse mapping compared with the normal mapping when moving the search display is not entirely due to implications of the mapping on the speed or accuracy of mouse- and eye-movements. That participants kept their gaze within the aperture for the majority of the time when moving the search display (Figure 3b) is not surprising, because in that case the aperture did not move. But this shows that it is unlikely that controlling gaze is responsible for the observed differences in search times.

Why then were participants faster when moving the search display in the inverse mapping? In terms of allocentric coding, moving the aperture up and to the right is equivalent to moving the search display down and to the left, so inverting the mapping should influence both control methods in the same manner. In terms of egocentric coding, Experiment 2 shows that people do not rely on items' actual positions, irrespective of the positions of the other items, because otherwise shifting everything around would decrease performance. That comparing the average performance across experiments is a reasonable thing to do is supported by a comparison of the red bars in Figures 2a and 2c. These are the same conditions, but for different participants (those of Experiments 1 and 3), and the performance is very similar. The congruency between the participants' movements and where they search might be relevant for some other reason. For example, when moving the mouse and search display downwards and to the left in the normal mapping, participants are sampling the top right of the search display through the aperture. When moving the mouse downwards and to the left in the inverse mapping, the search display moves up and to the right, so they are sampling the bottom left of the search display through the aperture. We speculate that the congruency between how participants moved and the part of the search display that they visited might make it easier to create an allocentric map of the search display.

Our speculation is related to research showing that spatial compatibilities which govern the relationship between the user and the visual stimulus influence the efficacy of scrolling behaviour, which is similar to moving the search display in our experiment (Corbett & Munneke, 2024). Response-effect compatibility refers to the congruency between the user's movement (response) and the resulting movement of the visual stimulus (effect). Moving the visual content in the same direction as the scrolling movement has been shown to lead to faster performance (Chen & Proctor, 2012; Chen & Proctor, 2013), in line with the default mapping on most current operating systems (e.g., Microsoft Windows and most versions of Mac OS X). Our results show the opposite effect: when moving the search display participants were faster when the visual stimulus moved in the opposite direction to their own movements (i.e., the inverse mapping). Our task was fundamentally different to those used by Chen and colleagues (2012; 2013) in that participants could only view a small region of the search display through the aperture at any time such that they had to engage in a more extensive visual search.

Stimulus-response compatibility refers to the congruency between the visual stimulus to which a response is to be made (stimulus) and the user's movement (response). The static version of this compatibility is often referred to as spatial stimulus-response compatibility: responses are faster and more accurate when the stimulus and response are spatially congruent than when they are not (Fitts & Deininger, 1954; Fitts & Seeger, 1953; see Proctor & Vu, 2006 for a review). Directional stimulus-response compatibility has been used to describe the congruency between the location of the to-be-revealed content and the user's movement (Chen & Proctor, 2013) and has not been studied as extensively.

Müsseler and colleagues (Kunde et al., 2007; Müsseler et al., 2008, 2011) showed that when using a lever to interact with a visual stimulus, the advantage of stimulus-response compatibility (i.e., correspondence between the spatial location of visual content and of the user's hand movement) is contingent upon other spatial compatibilities relating the lever's endpoint and the visual stimulus (Kunde et al., 2007; Müsseler et al., 2011). Our study does not include a physical lever but a virtual connection with a computer mouse. It shows an advantage of stimulus-response compatibility in that participants were faster when they moved leftward to sample from the left side of the search display.

In two experiments, we replicate the finding that participants are faster at aperture search when moving the aperture over a search display than when moving a search display beneath the aperture (Bury et al., 1982; Fujii and Morita, 2020). This finding is consistent across three different input devices: keyboard (Bury et al., 1982), touch panel (Fujii and Morita, 2020) and computer mouse (this study). Neither providing additional allocentric cues by showing the extent of the search display (Experiment 1), nor reducing the reliability of egocentric cues (Experiment 2) eliminated this difference in search times. This suggests that the ability to rely on egocentric information is not (entirely) responsible for faster search when moving the aperture. Experiment 3 showed that inverting the mapping between mouse movements and the item it was toggled to reversed the results: participants were then faster when moving the search display than when moving the aperture. We conclude that it is not what you move (i.e., the aperture or search display) that is critical for the speed of aperture search, but the congruency between your movements and the region of the search display that you are sampling from.

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