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Attention shifts and memory averaging

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When observers are asked to localize the final position of a moving stimulus, judgements may be influenced by additional elements that are presented in the visual scene. Typically, judgements are biased toward a salient non-target element. It has been assumed that the non-target element acts as a landmark and attracts the remembered final target position. The present study investigated the effects of briefly flashed non-target elements on localization performance. Similar to landmark attraction, localization was biased toward these elements. However, an influence was only noted if the distractor was presented at the time of target disappearance or briefly thereafter. It is suggested that memory traces of distracting elements are only averaged with the final target position if they are highly activated at the time the target vanishes.

A phenomenon that has received much interest in experimental psychology is the mislocalization of the final position of a moving target (see Hubbard, 1995b, for an overview). In early studies by Freyd and colleagues (e.g., Freyd & Finke, 1984; Freyd & Johnson, 1987) subjects were asked to indicate whether the final orientation of a rectangle in a sequence of still frames that implied its rotation was the same as the orientation of a probe stimulus presented after target offset (see Figure 1A). Compared to probe stimuli rotated opposite to the direction of motion, observers were more likely to accept probes rotated further in the direction of motion as having the same orientation. The forward displacement of the judged final position has been attributed to representational momentum (e.g., Freyd & Finke, 1984). Freyd and colleagues (e.g., Freyd, 1987) suggested that observers continuously extrapolate the position of the moving target while it is visible and are unable to stop the extrapolation process at target offset, which results in a forward shift (but see Kerzel, 2000; Kerzel, Jordan, & Müsseler, 2001, for an alternative view). The "same–different" method used by Freyd and colleagues was restricted to the evaluation of displacements occurring in the direction of motion.

In more recent experiments on representational momentum, observers were presented with a target moving on a linear trajectory either to the left or to the right, starting from the edge of the computer screen (see Figure 1B). At a random point along its trajectory, the target disappeared, and observers were asked to position a cursor on the remembered final position of

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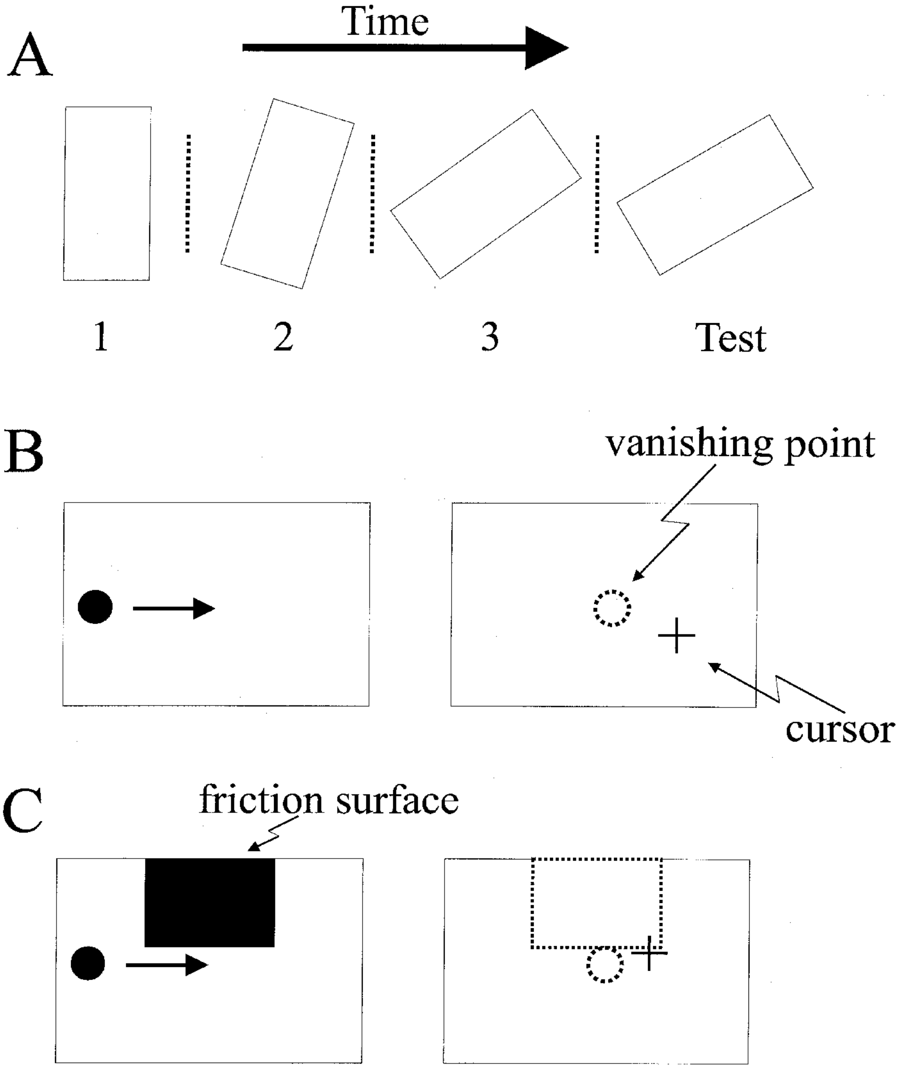

Figure 1. Schematic drawings showing paradigms used to study memory for the final position of a moving target. *Panel A*: To imply the rotation of a rectangle, a rectangle is presented successively at three different orientations (1–3). The centre of the rectangle remains at the same position on the screen (unlike in the graph). Each presentation (~250 ms) is followed by a blank interval (~250 ms) such that no impression of smooth motion is elicited. The observer is asked to indicate whether the rotation of the last presentation of the target stimulus (3) is the same as that of a test stimulus. Typically, observers show a tendency to judge a test rectangle that is rotated slightly further in the direction of rotation to be at the same orientation as the target ("representational momentum"; e.g., Freyd & Finke, 1984). *Panel B*: A target (indicated by filled circle) moves smoothly on a linear trajectory and vanishes at a random point along its trajectory. The observer is asked to position a cursor ("+", sign) on the target's final position (dotted circle). Typically, the judged position is displaced in the direction of motion and downward (e.g., Hubbard & Bharucha, 1988). *Panel C*: When a large stationary object is displayed, and the target appears to slide along the surface, the forward bias is decreased ("representational friction"), and the remembered location is shifted towards the surface ("memory averaging"; see Hubbard, 1995a, 1998).

the target. This cursor-positioning procedure allowed for the evaluation of displacement along the axis of motion and along the axis orthogonal to the direction of motion. Typically, it has been found that judgements deviate from the actual vanishing point (VP) in the direction of motion and downwards (e.g., Hubbard & Bharucha, 1988).

In contrast, usage of the cursor adjustment procedure revealed that displacements occurred in directions other than the direction of motion. For instance, memory for the final position of a moving target was displaced downward, which shows that in addition to representational momentum, mental analogues of gravity distort the memory for the final position of a moving target (e.g., Hubbard & Bharucha, 1988). Further environmentally invariant and non-invariant factors that produce distortions of visual memory were identified, such as friction, mass, weight, context, and expectation about the future path (see Hubbard, 1995b).

Additionally, a mechanism that is not obviously related to physical laws or expectations was found to produce distortions of the judged final position. When observers were asked to localize the final position of a target moving in a visual scene consisting of more than one element, localization was biased toward salient elements in the scene. Hubbard (1995a, 1998) observed a tendency to localize the target's final position toward a large surface close to the target (see Figure 1C). For instance, when a large stationary object was presented below a horizontally moving target, the downward bias increased. In contrast, a surface above the moving target reduced the downward bias (Hubbard, 1995a). This effect was attributed to memory averaging of target and surface position (Hubbard, 1995a, 1998). Further, Hubbard and Ruppel (1999) found that forward displacement was larger when the target moved toward a large stationary stimulus than when it moved away from it. Hubbard and Ruppel's interpretation was that landmark attraction biased memory for the final target position toward the stationary element and thereby increased or decreased the effect of representational momentum.

The term landmark (e.g., Sadalla, Burroughs, & Staplin, 1980) most commonly denotes salient information in a memory task that is used as a reference point. Reference points are assumed to be better known than other places and may therefore serve as the basis for the spatial localization of other points. For instance, a student may use the cafeteria as a reference point for giving directions to the psychology building. Various distortions of spatial memory have been observed with respect to such reference points (e.g., Bryant & Subbiah, 1994; McNamara & Diwadkar, 1997; Sadalla et al., 1980; Tversky, 1981; Tversky & Schiano, 1989). For instance, estimates of distances between landmarks and non-landmarks were often asymmetric. Estimates of the distance from a non-landmark to a landmark were less than estimates of distances from a landmark to a non-landmark (McNamara & Diwadkar, 1997; Sadalla et al., 1980). For instance, if a student was asked to estimate the distance from the psychology building to the cafeteria, estimates are expected to be lower than if he was asked to estimate the distance from the cafeteria to the psychology building. The landmark apparently "attracts" memory of non-landmarks.

In experiments on memory for spatial maps, stimuli were typically viewed for relatively long periods of time (in the order of minutes). Participants were given a new stimulus to memorize during a study phase (e.g., Tversky & Schiano, 1989), or the stimuli were already known to the participants (map of the campus, country, etc.; e.g., McNamara & Diwadkar, 1997; Sadalla et al., 1980; Tversky, 1981). Moreover, the displays were static. The dynamic displays used by Hubbard (1995a, 1998; Hubbard & Ruppel, 1999), differed in a number of ways from the displays used in research on spatial maps. Viewing times were rather brief (in the order of seconds), and because the target was moving, there was uncertainty about the to-be-remembered location even while the target was visible. Most importantly, landmarks in the studies of Hubbard were learned at the same time as the target itself, whereas landmarks in the previous studies were well known because of training or prior experience.

Therefore, it may be that the role of landmarks in the organization of spatial knowledge differed for static and dynamic displays. With concurrent viewing of target and landmark, it is unclear whether the landmark was used to organize spatial knowledge about the stimuli. As no prior training took place, and observers did not know the landmark stimuli beforehand, it is a matter of debate whether the landmark stimuli were actually used as reference points. Alternatively, one may suggest that the attraction of the remembered target position toward the static object was due to memory averaging of target and static object. According to this view, the role of the static object is not that of a landmark in the sense of a reference point, but rather that of an irrelevant element that influences target localization due to a tendency to average its position with that of the target. To denote the different role assigned to the secondary element, the term distractor is used to refer to the irrelevant object in the scene. As no strict operational definition of "landmark" has been given in previous papers, this nomenclature may help to avoid confusion about the presumed role of the non-target element.

However, if it was the case that distracting elements are averaged with the target, one may wonder why it is that we do not average the position of a target on the computer monitor and that of random elements in the visual field, such as an empty coffee mug next to the monitor. In other words, if the memory representation of the position of a moving target is averaged with memory representations of distracting elements, additional assumptions are needed that specify the particular conditions in which memory averaging occurs. Otherwise, memory averaging would also be predicted for the target and the empty coffee mug.

In the present paper, the hypothesis is put forth that memory averaging depends on the time-varying activation of the distracting element and the resulting strength of its memory trace. If the activation of an element is high when the target disappears, then its memory trace is strong, and memory averaging occurs. If, on the other hand, the activation of the element is low at the time of target disappearance, the memory trace is weak, and no memory averaging occurs. This assumption rules out arbitrary averaging between target and stray elements in the visual field because the stray elements have a low level of activation. It is suggested that—among other factors—the activation of an object results from the attentional resources that are devoted to the object. For instance, in the studies of Hubbard (1995a, 1998; Hubbard & Ruppel, 1999) a large stationary element (about 5°–14°) was presented in addition to the moving target (about 1°—2°). Because the object was large compared to the target and close to the centre of the screen, it may be assumed that it attracted observers' visual attention and gaze occasionally. Therefore, the resulting memory trace was strong, and memory averaging occurred. However, as the target remained on the screen for long periods of time (in the order of seconds), the target's level of activation remained constant such that no direct test of the activational account was possible. However, evidence in favour of the activation account comes from a study in which the context surrounding the target was manipulated. Hubbard (1993) observed that the influence of a surrounding context on memory for the final orientation of a rotating stimulus was stronger if the context was presented after target offset than if the target was visible while the target was rotating. As the activation of the distractor is expected to be highest while it is visible, this finding is consistent with the assumption that memory averaging depends on the distractor's level of activation.

In the present paper, assumptions about the proposed boundary conditions for memory averaging are tested more directly. If memory averaging depended on the strength of the memory trace of the distractor, then manipulation of the distractor's activation at target offset should influence the degree to which memory averaging occurs. To this end, the standard paradigm used to study memory displacement of the final position was modified in several ways. As in the studies of Hubbard, observers were shown the smooth motion of a target on a linear trajectory that disappeared at a random point along its trajectory. Then, subjects were asked to indicate where the target vanished by clicking on it with a mouse cursor. In contrast to previous studies, however, the distracting element was only briefly presented in the retinal periphery. Abrupt onsets in the retinal periphery are known to elicit involuntary shifts of attention to the stimulated region (e.g., Miller, 1989; Posner, 1980). Thus, when a distractor is presented, it is expected to have a high level of activation due to the involuntary shift of attention. However, the activation is expected to fade rapidly after offset of the distractor, as attention will return to the target in the absence of a second element. Thus the memory trace of a distractor that is briefly flashed some time before the target vanishes is expected to be relatively weak and is not expected to yield strong memory averaging. In contrast, the memory trace of a target that is attended (i.e., flashed) at the time the target vanishes is expected to be relatively strong and should therefore produce memory averaging. Thus, a dynamic perceptual process is expected to contribute to memory averaging.

This approach is consistent with recent findings indicating that the forward displacement of the final target position of a moving target ("representational momentum") is highly dependent on perceptual processes. For instance, it has been shown that forward displacement with smooth target motion is absent when the observer does not follow the target with the eyes (Kerzel, 2000; Kerzel et al., 2001). Therefore, it appears justified to ask whether perceptual processes other than eye movements, such as dynamic attending, contribute to memory distortions.

EXPERIMENT 1

In Experiment 1, the distractor was briefly flashed with the last presentation of a horizontally moving target. If there was some truth to the idea that the activation of distracting elements in the scene produces memory traces of a strength sufficient to induce memory averaging, one would expect a shift in the remembered final position of the moving target toward the second element. As a distracting stimulus, a disc similar in size to the target was briefly flashed above or below the vertical centre of the screen at an eccentricity of 5°. Thus it was ensured that observers did not confound the target and distractor position, and that they did not have enough time to initiate or complete an eye movement toward the distractor (e.g., Rayner, Slowiaczek, Clifton, & Bertera, 1983).

On the other hand, the brief exposure duration and the peripheral presentation made it rather unlikely that the position of the distractor would be better remembered than that of the target, and that it would subsequently provide a useful reference point ("landmark") to recollect the target's final position. Rather, it was a new element that was learned at the same time as the target. If the attentional activation resulting from the abrupt onset was sufficient to induce memory averaging, a trend toward the distractor should be observed. The asymmetry that is induced by an additional element above or below the target is along the axis orthogonal to the direction of motion (which was horizontal). Thus, effects of the distractor on localization of the final target position are expected primarily along the vertical axis.

The stimuli used in the present experiments are similar to those used in experiments on the flash lag effect (FLE). In the FLE, the position of a moving object is displaced with respect to a briefly presented stationary stimulus (e.g., Khurana, Watanabe, & Nijhawan, 2000; Nijhawan, 1994). When the moving and the stationary object are spatially aligned, the stationary, flashed object is perceived to lag behind the moving object. In contrast to experiments on the FLE, however, observers in the present experiments are instructed to pursue the target with their eyes. Thus, there is only very little retinal motion as long as the moving stimulus is accurately tracked. With smooth pursuit of the moving target, the FLE is known to be absent (Nijhawan, 2001). That is, moving target and flashed distractor are perceived to be spatially aligned. Therefore, one may assume that the flashed stimuli in the present experiment are actually perceived exactly above and below the moving object, and not behind the moving object.

Method

Participants

A total of 14 students at the Ludwig -Maximilians University of Munich were paid for their participation. All reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Apparatus and stimuli

The stimuli were created using a Matrox Millenium graphics card controlled by a personal computer. The display had a resolution of 1280(11) × 1024(V) pixels on a 21″ (diagonal) screen. One pixel measured 0.034°. The refresh rate was 96 Hz.

The target was a black disc with a diameter of 0.83° on a white background. The target entered from one edge of the screen and moved at 12°/s toward the opposite side. The target's trajectory was at the vertical centre of the screen. The target disappeared randomly at one of five possible VPs that were 2.5° apart and centred around the midpoint of the display window. VPs to the left of the screen centre received a negative sign (–5°, –2.5°), and those to the right received a positive sign (+2.5° +5°). The target position was updated on each screen refresh, yielding the impression of smooth motion. A black disc equal in size to the target was used as a distractor. It was presented 5° above or below the VP of the target. The distractor was presented in the same refresh cycle as the last target presentation. Presenting the distractor for only one refresh cycle resulted in a presentation time of 10.4 ms.

Monitoring of eye movement

The horizontal position of the left eye was monitored with a head-mounted, infrared, light-reflecting eyetracker (Skalar Medical B. V., IRIS Model 6500). The analog signal was bandpass, demodulated, and low-pass filtered (DC 100 Hz, 3 dB). The experimenter controlled the eye position on a LCD display and rejected trials in which the observer did not pursue the target. If an eye movement error occurred, the experimenter pressed a key, and feedback about the error was given. The trial was repeated in the remainder of the block. In none of the experiments reported here did the error rate exceed 1% of the trials.

Procedure

Participants sat in a dimly lit room 50 cm from the screen. Head movements were restricted by a chin rest, and viewing was binocular. Observers were instructed to follow the target with their eyes. They received 15 practice trials drawn randomly from the experimental trials. Each trial was initiated by pressing a button. After 750 ms, the target appeared and moved along its trajectory. Then, 500 ms after the target had disappeared, a cross-hair cursor appeared randomly at one of four equally probable locations at the horizontal centre of the screen. These locations were 1.5° or 3° above or below the trajectory of the target (the vertical centre). The cursor location was varied to avoid usage of the cursor position as a reference point. This was done when the axis of primary interest was vertical—that is, when the distractors were presented above or below the target. Participants were instructed to position the cursor as exactly as possible on the position where they thought the target had vanished and to confirm the position by a click of the left mouse button. No feedback was provided.

Each condition resulting from the factorial combination of distractor type (up, down, no distractor), direction of motion (left, right), VP (– 5°, – 2.5°, 0°, 2.5°, 5°) was repeated eight times for a total of 240 trials.

Results

The deviations of the adjusted cursor position from the actual VP were determined. The deviation along the horizontal direction of motion is referred to as *M-displacement,* and the deviation along the orthogonal, vertical axis as *O-displacement*. M-displacement in the direction of motion received a positive sign, and M-displacement in the opposite direction a negative sign. O-displacement received a negative sign when the cursor was positioned lower than the actual VP and a positive sign when the position was higher. Preliminary analysis showed that the initial cursor position did not affect M- or O-displacement in any of the Experiments reported here, such that cursor position is not included in the analysis.

M-displacement. A three-way analysis of variance (ANOVA, Distractor Type × Direction of Motion × VP) showed an effect of VP, $F(4, 52) = 4.01$, $p < .0065$. M-displacement decreased from the leftmost (1.43°) to the rightmost (1.17°) VP. The interaction between VP and direction of motion was significant, $F(4, 52) = 3.37$, $p < .015$, showing that M-displacement decreased for rightward motion from the leftmost to the rightmost VP (1.6° vs. 1.1°), whereas this was not the case for leftward motion (1.3° vs. 1.2°). Overall, M-displacement was different from zero (1.3°), $t(13) = 7.07$, $p < .0001$.

O-displacement. Means are plotted in Figure 2. A three-way ANOVA revealed a significant effect of distractor type, $F(2, 26) = 5.87$, $p < .0079$. Planned contrasts ($p < .05$) confirmed that negative O-displacement without distractor (– 0.21°) was more pronounced than that with a distractor appearing above (– 0.16°) and less pronounced than with a distractor appearing below (– 0.32°). The interaction between distractor type, direction of motion, and VP reached significance, $F(8, 104) = 2.88$, $p < .0062$. Overall, O-displacement was significantly different from zero (– 0.23°), $t(13) = 4.66$, $p < .0004$.

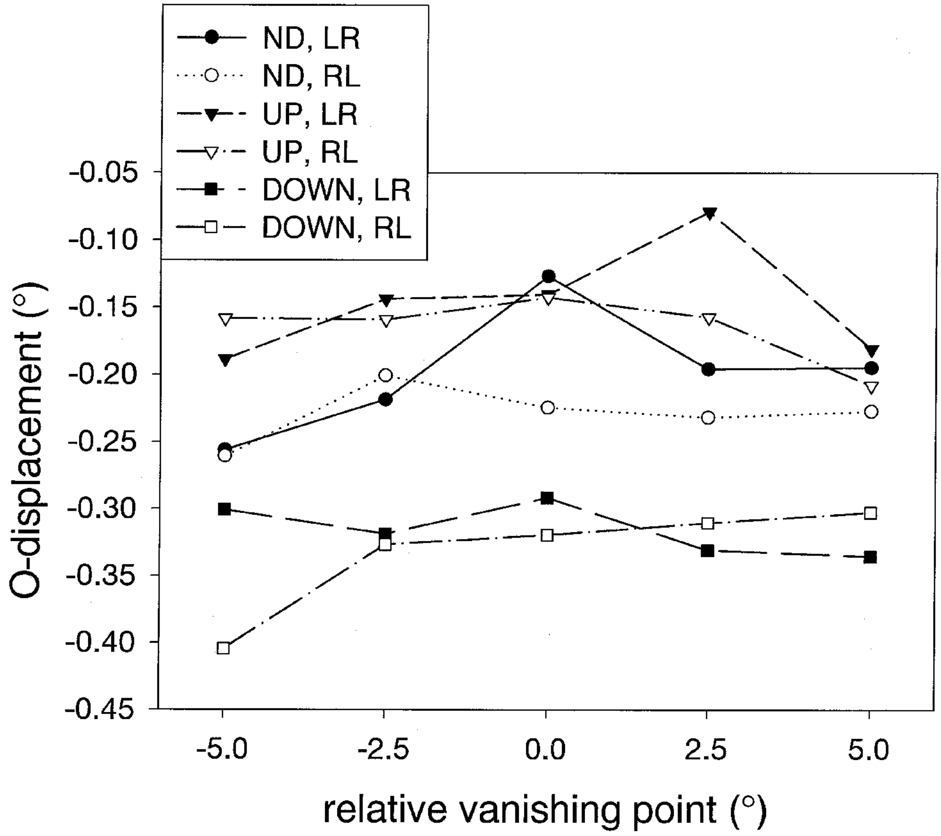

Figure 2. Mean O-displacement as a function of vanishing point relative to the screen centre, direction of motion (LR = left-to-right, RL = right-to-left), and distractor type (ND = no distractor, UP = distractor above, DOWN = distractor below) in Experiment 1.

Discussion

The position of the distractor had an influence on memory for the last seen position of a moving target. Compared to a neutral condition in which no distractor was presented, the judged final location was shifted upward with a distractor appearing above the target and downward with a distractor appearing below. Also, previously reported distortions of the final position were replicated (e.g., Hubbard & Bharucha, 1988). The target was displaced in the direction of motion and downward (e.g., Hubbard, 1995a; Kerzel et al., 2001). The fact that the presentation times only allowed for an attention shift to the distractor position but not for extended learning of the distractor position lends support to the assumption that the dynamic activation of positions in space leads to memory traces that are strong enough to be averaged with the target's final position. Further, the effects of VP and direction of motion suggest that localization performance was not uniform across the target's trajectory. As observers were instructed to follow the target with their eyes, these interactions may reflect effects of expectation on pursuit eye movements. In the present experiment, and in some of the following experiments, the pattern of M-displacement suggests that M-displacement was strongest at the beginning of the movement. With rightward motion, more M-displacement was observed with VPs on the left, whereas the opposite was true with leftward motion. Possibly, pursuit eye movements were fastest at the beginning of the pursuit and slowed down towards the end (see Kowler, 1989; Mitrani & Dimitrov, 1978). Further, known asymmetries in representational momentum as a function of direction of motion may have affected localization (Halpern & Kelly, 1993). However, the exact nature of these interactions warrants further research, in particular more accurate monitoring of eye movements, which is beyond the scope of the present paper.

EXPERIMENT 2

Experiment 2 was designed to explore further the time-varying dynamics of attentional activation of spatial positions. To this end, the time interval between presentation of the probe and disappearance of the target was varied. The distractor was presented some time before or after the last presentation of the target. If a high degree of activation as a function of dynamic attending was responsible for the subsequent memory averaging, no memory shift to the distractor location was expected with distractor presentation prior to target disappearance. As described earlier, attention may return to the target position if the distractor is presented some time before target offset. Thus the activation of the distractor position is expected to be low when the target disappears, such that a weak memory trace results. Therefore, no memory averaging is expected prior to distractor presentation. In contrast, the memory trace of a distractor appearing after target offset is expected to be strong and to result in memory averaging.

Method

Participants

A total of 9 students at the Ludwig-Maximilians University of Munich were paid for their participation. All reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Apparatus, stimuli, and procedure

Apparatus, stimuli, monitoring of eye movements, and procedure were as those in Experiment 1. The distractor was flashed for 10.4 ms above or below the target and five refresh cycles before or after the last target presentation, resulting in stimulus-onset asynchronies (SOAs) of –52ms or +52ms, respectively. A total of 40 distinct trials resulting from the factorial combination of distractor location (up, down), SOA (+52 ms, –52 ms), direction of motion (left, right), and VP (–5°, –2.5°, 0°, 2.5°, 5°) were repeated eight times for a total of 320 trials.

Results

M-displacement. A four-way ANOVA (Distractor Location × SOA × Direction of Motion × VP) showed that M-displacement was smaller with distractors presented above than with distractors presented below (1.3° vs. 1.4°), $F(1, 8) = 6.69$, $p < .0323$. Overall, M-displacement was different from zero (1.4°), $t(8) = 4.11$, $p < .0034$.

O-displacement. Means are presented in Figure 3. A four-way ANOVA on O-displacement showed that negative O-displacement was stronger with a distractor presented below than with a distractor presented above (– 0.31° vs. – 0.2°), $F(1, 8) = 5.98, p < .0402$, and at VPs far from the centre of the screen (– 0.3°, – 0.25°, – 0.23°, – 0.23°, – 0.28°, from the leftmost to the rightmost VP, respectively), $F(4, 32) = 3.01, p < .0323$. Importantly, the interaction of SOA and distractor location reached significance, $F(1, 8) = 24.58, p < .0011$. For distractors preceding target disappearance, no effect of distractor location was observed (– 0.24° vs. – 0.27° for distractor locations above and below, respectively), $t(8) = -0.9, p < .39$. For distractors appearing after target offset, distractors presented above resulted in smaller downward shifts than distractors presented below (– 0.16° vs. – 0.35°), $t(8) = -3.36, p < .01$. Further, the interaction of SOA and direction of motion, $F(1, 8) = 7.21, p < .0277$, showed that with an SOA of – 52 ms, rightward motion produced a stronger downward trend than leftward motion (– 0.27° vs. – 0.24°), whereas there was no difference with an SOA of +52 ms (–0.26° vs. – 0.26°). Also the three-way interaction of distractor position, direction of motion, and VP reached significance, $F(4, 32) = 3.92, p < .0106$. Overall, O-displacement was different from zero, $t(8) = -2.72, p < .0262$.

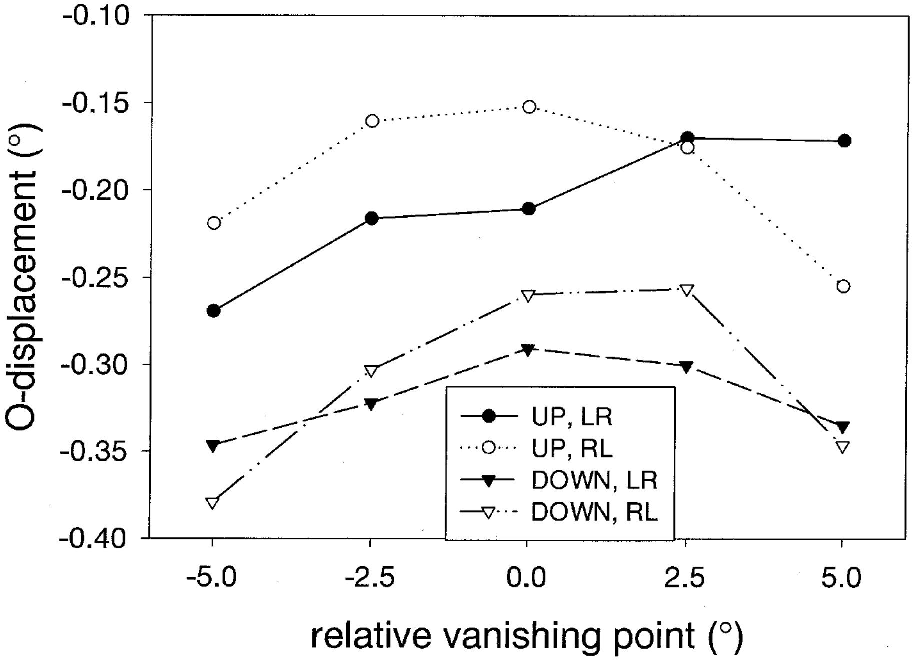

Figure 3. Mean O-displacement as a function of vanishing point relative to the screen centre, direction of motion (LR = left-to-right, RL = right-to-left) and distractor position (UP = distractor above, DOWN = distractor below) in Experiment 2.

Discussion

The main result of the present experiment was that the effect of the distracting stimulus varied as a function of SOA. When the distractor was presented briefly before target offset, no difference in O-displacement was noted. However, with distractor presentation briefly after target offset, a shift towards the distractor occurred. With distractors presented above, the judged final target position was higher than that with distractors presented below. Further, effects of direction of motion and VP on O-displacement emerged. These interactions may reflect differences in the smooth pursuit of the target and require further research. Moreover, M-displacement was affected by distractor location. Forward displacement was less with distractors presented above than with distractors presented below. Thus averaging occurred along more than a single axis, which is consistent with results obtained by Hubbard and Ruppel (1999). The interaction of VP and direction of motion obtained in Experiment 1 failed to reach significance in this experiment. Again, the reason for this may be differences in smooth pursuit behaviour, which is under cognitive or strategic control.

The present results support the view that a redirection of attention towards a peripheral distractor influences localization performance when the shift occurs at or briefly after target offset. When the target was visible for some time after distractor presentation, however, no effect was noted. These results support the view that the activation of a distractor location at target offset influences the strength of the memory trace. Only when the distractor was attended after target offset was the memory trace strong enough to influence localization of the final target position.

In sum, displacement toward a second element along the axis orthogonal to the direction of motion was observed. The direction of this displacement was similar to that observed previously: In Hubbard (1995a, 1998), a large friction surface was presented orthogonal to the direction of motion, and memory averaging toward this surface occurred. Further, Hubbard and Ruppel (1999) observed that landmarks may attract memory of the final position not only orthogonal to the direction of motion but also along the direction of motion. They noted that for targets moving toward a landmark, M-displacement increased, whereas it decreased for targets moving away from a landmark.

EXPERIMENT 3

Experiment 3 was carried out to test whether memory averaging with briefly presented distractors may also be obtained along the direction of motion. To this end, distractors were presented simultaneously above and below the final position of a moving target at three different SOAs with respect to target offset. The distractors could appear some time before the target reached the final position, at the last presentation of the target, or some time after it had vanished (see Figure 4). Because the distractors appeared at the same horizontal position as the final target presentation, and they appeared above and below the vertical offset position, one may consider the distractor to be spatially neutral with respect to the final target position. That is, no asymmetry was introduced by its presence if one considers the static scene.

Although the distractors were neutral with respect to the actual vanishing point of the target in the static scene, this does not preclude the possibility that their position introduces a bias during the dynamic viewing of the displays. When the distractors appeared before target

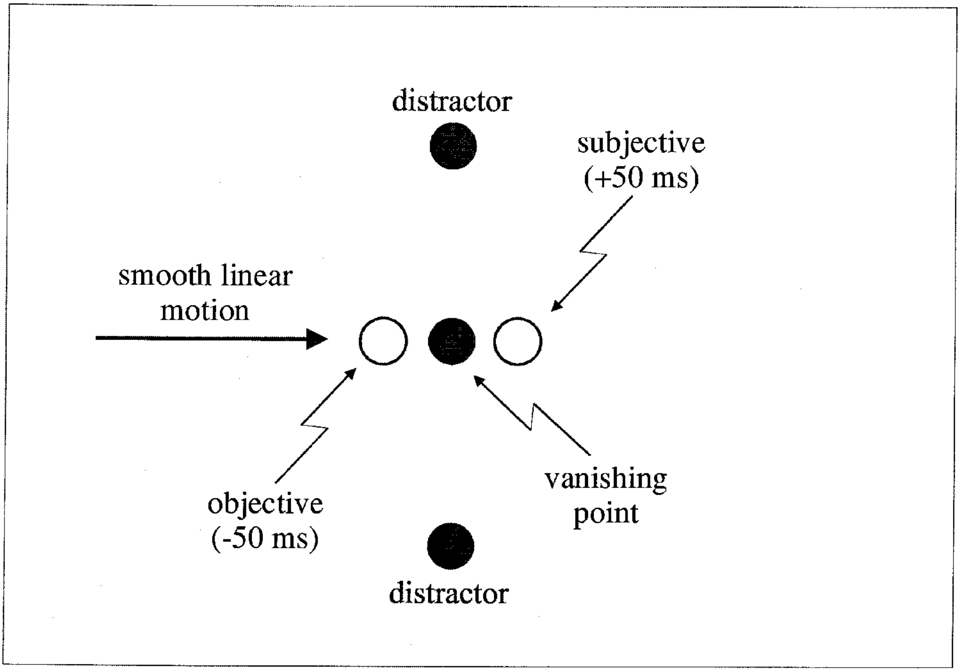

Figure 4. Schematic drawing of the stimuli used in Experiment 3. The arrow indicates the direction of motion. Two distractors were presented with the last presentation of the target, 52 ms before target offset (– 52 ms SOA), or 52 ms after target offset (+52 ms SOA). The distractors appeared 5° above and below the target's final position. With a – 52 ms SOA, the distractors were ahead of the objective target position. With +52 ms SOA, the distractors were behind the subjective target position.

offset, they were ahead of the actual target position. However, attention should have sufficient time to return to the target position with prior distractor presentation, such that memory averaging is not expected with this SOA. More interesting is the situation when the distractors were presented after target offset. Freyd and Johnson (1987) showed that very briefly after target offset, the perceived or remembered position of the target's final position is already shifted into the direction of motion—that is, the subjective VP continuously moves into the direction of motion for some time after target offset. Thus, if the distractors were presented 52 ms after stimulus offset at the horizontal VP, then they will appear to be positioned behind (i.e., opposite to the direction of motion) the subjective VP.

Thus, when the distractors appear after target offset, attention is attracted toward a location opposite to the subjective VP. Again, if attentional activation of a distractor location at target disappearance is sufficient to produce memory averaging, then an effect of the distractor is predicted some time after target offset, but not at target offset or before target offset. Before target offset, attention should have sufficient time to return to the target position; at target offset, the distractor position is neutral with respect to the final target position; only after target offset should an attention shift and a subsequent localization bias opposite to the direction of motion occur.

Method

Participants

A total of 10 students at the Ludwig-Maximilians University of Munich were paid for their participation. All reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Apparatus, stimuli, and procedure

Apparatus, stimuli, monitoring of eye movement, and procedure were as those in Experiment 1 with the following exceptions. Two black discs equal in size to the target were used as distractors. They were presented simultaneously 5° above and below the VP of the target for one refresh cycle (10.4 ms). The distractors were flashed above and below the target five refresh cycles before or after the last target presentation, resulting in SOAs of ±32 ms, or simultaneous with the last presentation (SOA 0 ms). The cursor always appeared at the screen centre.

Design

A total of 30 distinct trials resulting from the factorial combination of SOA (– 52 ms, 0 ms, + 52 ms), directions of motion (left, right), and VP (– 5°, – 2.5°, 0°, 2.5°, 5°) were repeated six times for a total of 180 trials.

Results

M-displacement. Means are presented in Figure 5. A three-way ANOVA (SOA × Direction of Motion × VP) showed that M-displacement varied as a function of SOA, $F(2, 18) = 6.01, p < .01$. Planned contrasts ($p < .05$) showed that M-displacement with simultaneous presentation (1.79°) was not different from M-displacement with distractors appearing before target offset (1.95°), but differed from M-displacement with distractors appearing after target offset (1.63°). The effect of VP was close to significance, $F(4, 36) = 2.56, p < .055$, indicating that more M-displacement was observed close to the centre of the screen (1.71°, 1.82°, 2°, 1.68°, 1.76°, from leftmost to rightmost VP, respectively). Overall, M-displacement was different from zero (1.8°), $t(9) = 6.8, p < .0001$.

O-displacement. A three-way ANOVA revealed an effect of direction of motion, $F(1, 9) = 6.9, p < .0275$. Negative O-displacement was more pronounced with leftward motion than with rightward motion (– 0.29° vs. – 0.24°). Overall, O-displacement was different from zero, $t(9) = -3.69, p < .005$.

Discussion

When the distracting stimulus was presented briefly before target offset, no shift of the judged displacement toward the distractor was noted. However, with distractor presentation briefly after target offset, M-displacement was reduced, indicating that a shift from the subjective VP—which was ahead of the objective VP—back to the distractor occurred. These results are fully compatible with the account in terms of dynamic attentional activation. In this view, the allocation of attention to a particular location in space at target offset produces memory averaging. If one were to neglect the dynamics of perceptual processes while viewing the displays,

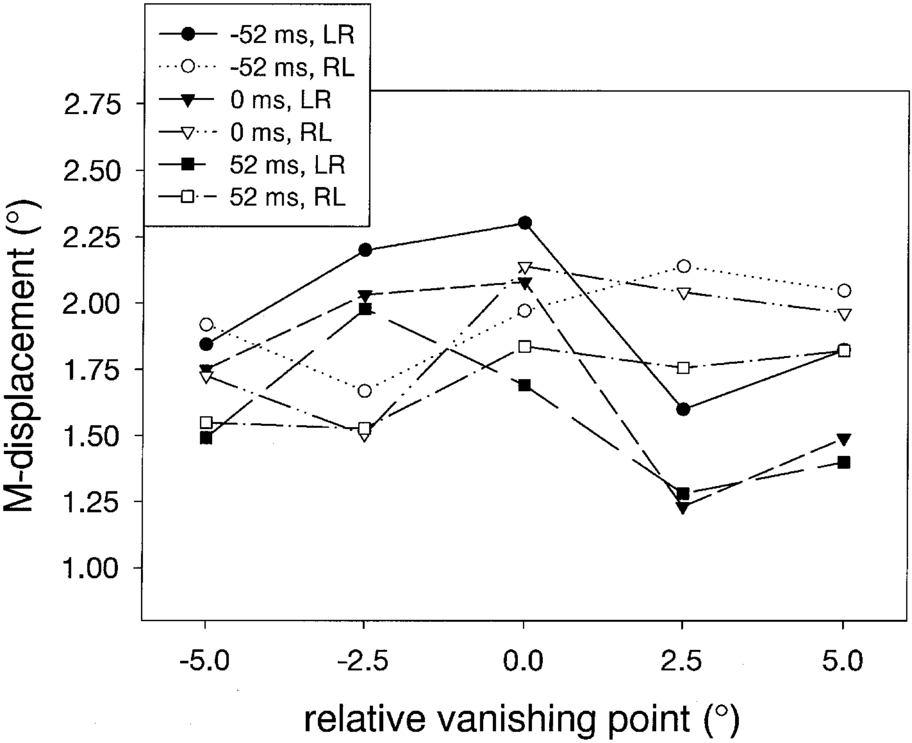

Figure 5. Mean M-displacement as a function of vanishing point relative to the screen centre, direction of motion (LR = left-to-right, RL = right-to-left), and SOA between target offset and distractor presentation in Experiment 3.

one would only expect interactions between two invariable positions: the final subjective target position and the distractor position. Therefore, the same biases should be observed regardless of when the distractor was presented. The results do not conform with this prediction. In contrast, the results support the notion of dynamic coding of position information. Remember that the distractors were spatially neutral with respect to the final horizontal and vertical target position (i.e., they appeared at the last horizontal position, above and below the final target position). A bias along the axis of motion could only be induced relative to the subjective final target position. The subjective final target position with a +52-ms SOA was shifted in the direction of motion, such that the distractors appeared to be behind. Due to a shift of attention toward this location, its activation was high, and subsequent memory averaging resulted.

EXPERIMENT 4

The previous experiments sought to determine whether memory averaging may be produced by briefly presented distractors. In these cases, the judged final position was attracted toward the distractor if the distractor was presented at or slightly after target offset. Presumably, the activation of the distractor at or slightly after target disappearance had to be above a certain threshold for averaging to occur, because distractors presented some time before target offset did not influence localization. One may wonder whether the effects of distracting elements are confined to memory averaging. Possibly, an increase in the number of objects in the scene has adverse effects on memory for the final position. For instance, increasing the number of distractors in the display increases the number of memory traces and therefore increases the memory load. As a consequence, localization performance is expected to deteriorate. The previous experiments do not unambiguously support this assumption. In some experiments, the systematic bias in localization (forward and down; see Hubbard & Bharucha, 1988) increased as a function of distractor position; in others it decreased the bias. In Experiment 1, for instance, a distractor below the trajectory increased the downward bias, whereas a distractor above decreased the bias. In order to test whether memory load may impair localization performance in an unspecific way, the distractor positions in Experiment 4 were chosen such that no specific asymmetry in the stimulus arrangement was introduced: As in Experiment 3, two distractors were presented at an equal distance above and below the final target position. Unlike in Experiment 3, the distractors were presented simultaneously with the last target presentation, avoiding a bias along the axis of motion. To evaluate the effect of memory load, a condition with distractors was compared to a condition without distractors.

Method

Participants

A total of 10 students at the Ludwig-Maximilians University of Munich were paid for their participation. All reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Apparatus, stimuli, and procedure

Apparatus, stimuli, eye movement control, and procedure were as those in Experiment 1, with the following exceptions. Two black discs equal in size to the target were used as distractors. They were presented 5° above and below the VP of the target for one refresh cycle (10.4 ms). The cursor always appeared at the screen centre.

Design

In half of the trials, the distractors were flashed above and below the target simultaneous with the last target presentation (SOA 0 ms). In the other half, no distracting information was presented. A total of 20 distinct trials resulting from the factorial combination of distractor presentation (distractors present, distractors absent), direction of motion (left, right), and VP (– 5°, – 2.5, 0°, 2.5°, 5°) were repeated eight times for a total of 160 trials.

Results

M-displacement. Means are resented in Figure 6. A three-way ANOVA (Distractor Presentation × Direction of Motion × VP) showed that M-displacement was larger with distractors than without distractors (2.03° vs. 1.82°), $F(1, 9) = 10.9, p < .0092$. The interaction of direction of motion and VP reached significance, $F(4, 36) = 12.83, p < .0001$. For rightward target motion, M-displacement decreased from the leftmost to the rightmost VP (2.49° vs. 1.46°). For leftward motion, M-displacement decreased from the rightmost to the leftmost

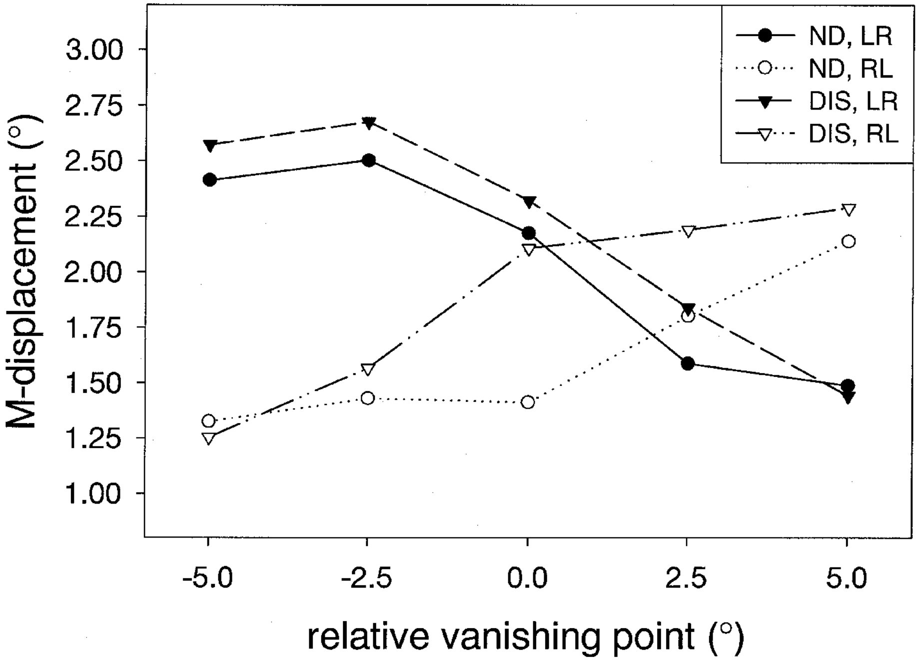

Figure 6. Mean M-displacement as a function of vanishing point relative to the screen centre, direction of motion (LR = left-to-right, RL = right-to-left), and presence of distracting stimuli (ND = no distractors present, DIS = distractors present) in Experiment 4.

VP (2.21° vs. 1.29°). Overall, M-displacement was different from zero (1.9°), $t(9) = 5.84, p < .0002$.

O-displacement. There was a tendency for larger negative O-displacement when a distractor was presented (– 0.14° vs. – 0.2°), $F(1, 9) = 3.78$, $p < .0838$. Overall, O-displacement was different from zero (– 0.17), $t(9) = 3.15, p < .0118$.

Discussion

When two distractors were presented simultaneously with the last target presentation, M-displacement increased. A similar tendency could be observed for negative O-displacement. Thus, presenting distracting information increased an already existing bias to localize the final target position further in the direction of motion than it actually was. This unspecific interference supports the view that increasing the memory load of the observer—that is, increasing the number of active traces in visual short-term memory—makes recollection of the final target position more biased. To some degree, the present results support the distinction between landmark and distractor proposed in the Introduction. Whereas landmarks are supposed to aid recollection of a target position, distractors are usually considered to decrease the level of accuracy. In the present experiment, the accuracy of position judgements decreased, which is more consistent with the notion of a distractor. However, comparison across studies is difficult because the number of landmarks varied. Whereas the studies of Hubbard (1995a, 1998; Hubbard & Ruppel, 1999) used only one stationary landmark, studies on memory for spatial maps typically involved more than one landmark (e.g., McNamara & Diwadkar, 1997; Sadalla et al., 1980; Tversky, 1981).

GENERAL DISCUSSION

In the present series of experiments, evidence was provided for the hypothesis that memory averaging occurs for objects that are briefly presented at target offset or slightly thereafter. It was found that when the distractor was flashed at the time of target offset or briefly thereafter, localization was biased toward the distractor. This effect was found along the axis orthogonal to the direction of motion (Experiments 1 and 2) and along the axis aligned with the direction of motion (Experiment 3). The results support the hypothesis that elements in the display that have a high degree of activation at target offset leave a strong memory trace that is averaged in memory with the final target position. Further, evidence was provided that increasing the memory load by increasing the number of active traces degrades localization performance (Experiment 4). In sum, the present results support the view that memory averaging depends on perceptual processes around the time of target offset.

Typically, elements that influence the localization of a target element have been referred to as landmarks. It was assumed that these elements influence localization because they are particularly well known, and that they are used to recollect the target's position. However, in the present study, this element is referred to as distractor. There are two reasons for this. First, the distracting element was presented only briefly while the target was visible, such that it is questionable whether the position of the distractor was better known than that of the target. Second, the distracting element was presented in the periphery, such that exact localization was made difficult. Thus, it appears unlikely that the object was a useful reference point in the narrow sense of "landmark". Rather, one may assume that the distractor attracted attention and that this shift of attention plays a role in memory averaging.

The present findings are consistent with approaches that stress the importance of attentional processes in the localization of objects in the visual field. For instance, it has been hypothesized that the mislocalization of the first position of a moving target is attributable to attention shifts (Müsseler & Aschersleben, 1998, but see Kirschfield & Kammer, 1999). When observers are asked to determine the first position of a moving target entering a window, judgements deviate from the actual starting position (the edge of the window) in the direction of motion (Fröhlich, 1929). An attentional account assumes that the stimulus entering the window elicits a focus shift toward it. While the shift is occurring, the stimulus continues to move. Because the first reportable representation of the stimulus is not accessible before the focus shift is achieved, the stimulus is perceived at a later position. In this account, the mislocalization is attributable to the temporal characteristics of the focus shift.

In the present study, temporal aspects are important inasmuch as the focus shift has to occur at the time the target vanishes. Presumably, the last shift of attention before target offset may bias later localization judgements. Thus, it is rather the direction of the attention shift that accounts for the mislocalization. In a sense, attention acts to establish a subjective memory map. If attention and target location coincided, such as with distractor presentation at an SOA of –52 ms, no bias was introduced. However, a deviation of target position and attended location at the time of target disappearance introduced a bias. Therefore, one may conclude that attention partially determines the remembered location of a stimulus. When the target is not attended, a shift towards the attended distractor location occurs. This function is quite similar to the assumed function of long-term, well-known landmarks. However, the conditions in which both kinds of effects are observed are vastly different. Whereas attentional distraction is a transient phenomenon occurring with brief exposure duration of the distracting stimulus and high uncertainty about the target location (i.e., when the target is in motion), landmark effects are also observed with long exposure and no uncertainty about target location (i.e., with static stimuli). Thus, the two phenomena should be considered to be complementary.

Besides attention shifts, a number of other perceptual factors have been shown to influence localization. Most prominently, it has been demonstrated that localization of static stimuli is influenced by the point at which focal perception is directed. Stimuli presented in the periphery are localized closer toward the fovea than they actually are (foveal bias; e.g., Mateeff & Gourevich, 1983; Müsseler, Van der Heijden, Mahmud, Deubel, & Ertsey, 1999; O'Regan, 1984; Osaka, 1977). Thus, the current position of focal perception—that is, the foveated position—may influence how stimuli are localized in egocentric space. In the current study, these results are extended to covert attentional shifts. The influence of transient distractors on localization performance shows that the current locus of attention may influence storage of spatial information.

In sum, the present study suggests that the direction of an attention shift may influence memories for the final position of a moving stimulus. When a distractor was briefly presented in the periphery at the time the target vanishes, judgements of the final position were biased toward the location of the distractor. It is suggested that objects with a high level of activation at target offset produce a strong memory trace that is averaged with the to-be-remembered location.

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