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The onset-repulsion effect and motion-induced mislocalization of a stationary object

Timothy L Hubbard, Jon R Courtney
Department of Psychology, Texas Christian University, Fort Worth, TX 76129, USA;
e-mail: t.hubbard@tcu.edu
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Abstract. The influence of a moving target on memory for the location of a briefly presented stationary object aligned with the initial location of that moving target was examined. Memory for the location of the stationary object was displaced backward (ie in the direction opposite to target motion), and memory for the initial location of the moving target was also displaced backward (consistent with an onset-repulsion effect); displacement of the stationary object did not differ from displacement of the moving target. Displacement in memory for the initial location of a moving target was not influenced by whether or not a stationary object aligned with that initial location was also presented. The results demonstrate that motion-induced mislocalization can occur in a direction other than the direction of motion, and are consistent with the hypothesis that dynamics of a moving target can influence memory for a nearby stationary object.

1 Introduction

An observer's judgment regarding the position of a moving target is often biased. When memory for the location of the initial (onset) portion of a target's trajectory has been measured, memory is often displaced backward (in the direction opposite to target motion) or forward (in the direction of target motion), and these displacements have been referred to as the 'onset-repulsion effect' (eg Thornton 2002) and the 'Fröhlich effect' (eg Müsseler and Aschersleben 1988), respectively. When memory for the location of the final (offset) position of a target's trajectory has been measured, memory is often displaced in the direction of anticipated target motion, and this has been referred to as 'representational momentum' (eg Freyd and Finke 1984; for review, Hubbard 2005). Although numerous studies have shown that displacement in memory for the initial (eg Hubbard and Motes 2005; Müsseler et al 2002) or final (eg Gray and Thornton 2001; Hubbard 1993; Hubbard and Ruppel 1999) location of a moving target is influenced by the presence of a nearby stationary object, fewer studies have considered the complementary question of whether displacement in memory for the location of a stationary object can be influenced by the presence of a nearby moving target.

In one study of the effects of a moving target on the perceived location of a nearby stationary object, Munger and Owens (2004) presented a flashed object that was aligned with the orientation of a rotating target or located slightly beyond or behind the orientation of the rotating target. If the target continued to rotate after the flashed object vanished, then observers were more likely to judge that a flashed object located beyond the orientation of the rotating target was aligned with the target. Munger and Owens suggested this pattern was consistent with a flash-lag effect (a mislocalization in which a briefly presented stationary object aligned with a moving target is judged to lag behind that moving target; for reviews see Krekelberg and Lappe 2001; Nijhawan 2002): if perception of the flashed object was delayed relative to the perception of the rotating target, then the flashed object would need to be presented slightly beyond the orientation of the rotating target in order for the flashed object and the target to appear aligned. If the rotating target vanished when the flashed object vanished, observers were less likely to judge a flashed object located beyond the rotating target was aligned with the target, and this is consistent with the lack of a flash-lag effect when the target and flashed object vanish simultaneously (eg as in Brenner and Smeets 2000; Eagleman and Sejnowski 2000; Whitney et al 2000).

Whitney and Cavanagh (2000) presented pairs of stationary lines located on opposite sides of a rotating radial grid pattern. The stationary lines were mislocalized in the direction of rotation of the grid, and this mislocalization occurred even when the lines did not appear to move and were physically separated from the rotating grid. Whitney and Cavanagh suggested this provided evidence of a more generalized position-coding mechanism that analyzes both moving stimuli and stationary stimuli, and that localization of a stationary stimulus depends on motion-processing mechanisms that are active even at some distance from the stimulus. Durant and Johnston (2004) presented stationary lines located on opposite sides of a rotating bar or along an arc on either side of two columns of vertically moving gratings. The stationary lines were mislocalized in the direction of the moving stimulus, and this displacement increased with increases in the velocity of the moving target, was not influenced by background flicker, and was stronger when the flashes were closer to the moving target. Durant and Johnston suggested the mislocalizations in perceived alignment reflect feedback to primary visual cortex from motion-selective cells in extrastriate areas that have receptive fields overlapping the retinal location of the stationary object.

In Munger and Owens (2004), Whitney and Cavanagh (2000), and Durant and Johnston (2004), observers judged the alignment of a moving target and a stationary object or the alignment of two stationary objects separated by a moving target. These studies all involved judgments of perceived alignment (ie relative location), and did not directly address effects of a moving target on memory for the absolute location of a stationary object. Hubbard (2008) presented a stationary object spatially and temporally aligned with the end of motion of a horizontally moving target. After the stationary object and moving target vanished, a probe appeared, and observers judged whether the probe was at the same location as the location of the previously presented stationary object. Memory for the stationary object was displaced in the direction of target motion. The magnitude of this displacement increased with increases in target velocity, decreased with increases in the distance of the stationary object (along the axis orthogonal to target motion) from the moving target, and was larger after a retention interval of 250 ms than after retention intervals of 50 or 450 ms. Hubbard suggested this pattern of displacement supported the hypothesis that representational momentum of the moving target influenced the representation of the location of the stationary object.

Mislocalization of perceived alignment in Munger and Owens (2004), Whitney and Cavanagh (2000), and Durant and Johnston (2004), as well as displacement in remembered location in Hubbard (2008), are all examples of motion-induced mislocalization of a stationary stimulus. In motion-induced mislocalization, motion of a moving stimulus influences the judged location of a nearby stationary stimulus. Although there are potentially many different mechanisms for motion-induced mislocalization, the focus here will be on whether an onset-repulsion effect can produce motion-induced mislocalization. If a dynamic such as representational momentum contributes to motion-induced mislocalization (cf Hubbard 2008), then it could be predicted that other dynamics such as an onset-repulsion effect might similarly contribute to motion-induced mislocalization. Indeed, finding such similarities in the effects of representational momentum and onset repulsion on nontarget stimuli could offer important constraints on a more general theory of the dynamic properties of mental representation. In the studies presented here, a moving target similar to those previously found to result in an onset-repulsion effect was shown, and we examined whether such a moving target influenced the remembered location of a nearby stationary object.

2 Experiment 1

In experiment 1, observers viewed a leftward or rightward moving target on each trial, and a stationary object aligned with the initial location of the moving target was presented during the initial portion of target motion. After the moving target vanished, a stationary probe was presented. The probe was presented at the same vertical coordinates as the previously presented stationary object, and was either slightly behind (relative to the direction of target motion) the horizontal coordinates of the stationary object, aligned with the horizontal coordinates of the stationary object, or slightly beyond the horizontal coordinates of the stationary object. Observers judged whether the probe was at the same location as the stationary object or at a different location, and pressed a designated key on a computer keyboard to indicate their response. The moving target and stationary object were presented on an otherwise blank background similar to that previously shown to lead to an onset-repulsion effect in memory for the initial location of a target (eg Actis-Grosso and Stucchi 2003; Hubbard and Motes 2002; Thornton 2002). Therefore, if the representation of the stationary object is influenced by the displacement of the moving target, then memory for the location of a stationary object aligned with the initial location of the target should be displaced in the direction opposite to target motion.

2.1 *Method*

2.1.1 *Participants.* The participants were sixteen undergraduate observers from Texas Christian University who participated for partial course credit and were naive to the hypotheses.

2.1.2 *Apparatus.* The stimuli were displayed upon, and the data collected by, an Apple iMac desktop computer equipped with a 15 inch color monitor.

2.1.3 *Stimuli.* The moving target and stationary object were square shapes 20 pixels (approximately 0.83 deg of visual angle) in width and 20 pixels in height. The moving target was a filled black square, and the stationary object was a black outline square with a white interior; all stimuli were presented against a white background. Although Thornton (2002) suggested that pursuit eye movements did not cause the onset-repulsion effect, in order to minimize any potential contributions of smooth-pursuit eye movements to any potential displacement, implied target motion was used. On each trial, there were five successive presentations of the target that implied either consistent rightward motion of the target or consistent leftward motion of the target, and, consistent with the previous representational momentum literature, these are referred to as 'inducing stimuli'. As shown in figure 1, each inducing stimulus was presented for 250 ms, and there was a 250 ms interstimulus interval (ISI) between successive inducing stimuli. For rightward motion, the first inducing stimulus appeared approximately midway between the left side and the center of the display, and the horizontal coordinates of each successive inducing stimulus were located 40 pixels (approximately 1.66 deg of visual angle) to the right of the previous inducing stimulus. For leftward motion, the first inducing stimulus appeared approximately midway between the right side and the center of the display, and the horizontal coordinates of each successive inducing stimulus were located 40 pixels to the left of the previous inducing stimulus. The vertical coordinates of the inducing stimuli were approximately centered along the vertical axis.

The stationary object appeared when the initial inducing stimulus appeared, and vanished when the initial inducing stimulus vanished (and so the stationary object was displayed for 250 ms); by having the stationary object appear when an inducing stimulus appeared and vanish when that inducing stimulus vanished, the possibility that the stationary object could be misperceived as a subsequent inducing stimulus should be diminished. When the stationary object was presented above the inducing stimuli,

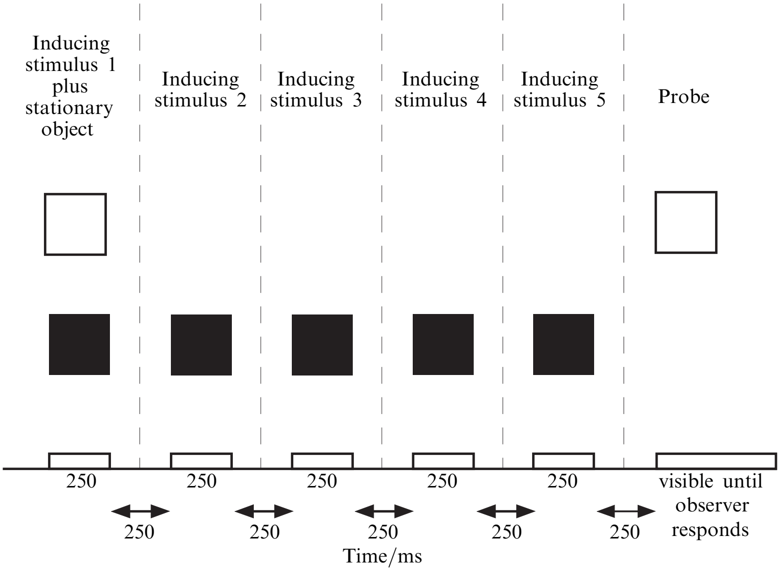

Figure 1. The structure of a trial in experiment 1. There were five inducing stimuli; each inducing stimulus was presented for 250 ms, and there was a 250 ms interstimulus interval between successive inducing stimuli. The stationary object was presented at the same time as the first inducing stimulus. The probe was presented after a retention interval of 250 ms, and remained visible until the observer responded. The horizontal dimension reflects when each stimulus was presented, and does not reflect the spatial arrangement of the stimuli.

the bottom of the stationary object was 20 pixels above the top of the initial inducing stimulus; when the stationary object was presented below the inducing stimuli, the top of the stationary object was 20 pixels below the bottom of the initial inducing stimulus. In order to minimize potential contribution of other motor movements to any potential displacement, observers judged whether a subsequently presented probe was at the same location as the previously presented stationary object. The probe was a black outline square with a white interior and was of the same size as the stationary object. The probe was presented at the same vertical coordinates as the stationary object, and was at one of seven horizontal positions relative to the previous location of the stationary object: −9, −6, −3, 0, +3, +6, or +9 pixels. Positions denoted by a minus sign indicated the probe was backward (ie shifted in the direction opposite to motion of the moving target) from the previous location of the stationary object by the indicated number of pixels; positions denoted by a plus sign indicated the probe was forward (ie shifted in the direction of motion of the moving target) from the previous location of the stationary object by the indicated number of pixels; the zero position was the same as the previous location of the stationary object. Each participant received 112 trials [7 probes (−9, −6, −3, 0, +3, +6, +9 pixels) × 2 directions (leftward, rightward) × 2 heights (above, below) × 4 replications] in a different random order.

2.1.4 *Procedure.* Observers were first given a practice session consisting of 10 practice trials that were randomly drawn from the experimental trials. Observers initiated each trial by pressing a designated computer key. The inducing stimuli were presented, and the stationary object was visible during the presentation of the initial inducing stimulus. Eye movements were not controlled or monitored. The retention interval between the disappearance of the final inducing stimulus and the appearance of the probe was 250 ms. After the probe appeared, observers pressed a key marked S or a key marked D to indicate if the location of the probe was the same as, or different from, the previous location of the stationary object, respectively. Observers then initiated the next trial.

2.2 *Results*

The probabilities of a 'same' response for each probe position are shown in figure 2. Consistent with previous studies in the displacement literature (eg Hayes and Freyd 2002; Munger et al 1999; Vinson and Reed 2002), estimates of the direction and magnitude of displacement in remembered location were determined by calculating the arithmetic weighted mean (the sum of the products of the proportion of 'same' responses and the distance of the probe from the location of the stationary object, in pixels, divided by the sum of the proportions of 'same' responses) for each observer. The sign of the weighted mean indicated the direction of displacement (ie a minus sign indicated backward displacement in the direction opposite to the motion of the moving target; a plus sign indicated forward displacement in the direction of motion of the moving target), and the absolute value of the weighted mean indicated the magnitude of displacement from the actual location of the stationary object (ie larger absolute values indicated larger magnitudes of displacement). The average weighted mean for each observer ($M = -1.03$) was significantly less than zero ($t_{15} = -5.65$, $p < 0.001$).

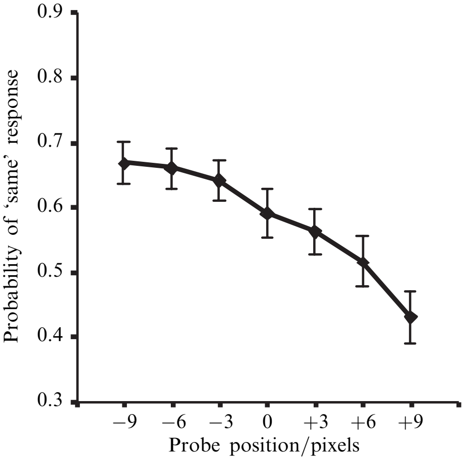

Figure 2. The probability of a 'same' response in judgments of the location of the stationary object as a function of probe position in experiment 1. Error bars reflect the standard error of the mean.

2.3 *Discussion*

An average weighted mean significantly less than zero indicated that memory for the location of a stationary object was displaced backward (ie in the direction opposite to motion of the moving target) from the actual location of that stationary object. This is reflected in the greater probability of a 'same' response for negative probes than for positive probes visible in figure 2; indeed, inspection of figure 2 shows that the left side of the function has not yet begun to descend to zero, and so the magnitude of backward displacement is likely to be even greater than that suggested by the results of experiment 1. Although displacement in memory for the initial location of the moving target was not measured in experiment 1, memory for the initial location of targets similar to those presented in experiment 1 had previously been shown to exhibit backward displacement. Thus, even though displacement of the stationary object is not in the same direction as the motion of the moving target, displacement of the stationary object was presumably in the same direction as displacement of the moving target. The backward displacement is consistent with the hypothesis that motion-induced mislocalization of the stationary object reflected the dynamics of the onset-repulsion effect associated with the representation of target motion, and is also consistent with the broader hypothesis that motion-induced mislocalization of a stationary object can reflect the implied dynamics of a moving target.

An alternative hypothesis for the backward displacement in memory for the stationary object is that the representation of the location of the stationary object was influenced by motion adaptation or a motion aftereffect. Adaptation to motion in a specific direction results in a perceived shift in the location of a stationary object presented after the moving target vanished, and this shift is in the direction of a motion aftereffect (eg De Valois and De Valois 1991; McGraw et al 2002; Nishida and Johnston 1999; Snowden 1998; Whitney and Cavanagh 2003). Although such a displacement in the remembered position of a stationary object is consistent with the backward displacement of the stationary object observed in experiment 1, there are several methodological aspects of experiment 1 that make such an alternative hypothesis unlikely. First, the stationary object was presented at the time of target onset, and so motion adaptation and subsequent motion aftereffects would not have occurred prior to when the stationary object vanished. Second, the duration of the moving target was likely too brief to allow motion adaptation and motion aftereffects to develop. Third, the direction of target motion was randomized across trials for each observer, and so motion adaptation across trials was highly unlikely.

A second alternative hypothesis to account for the backward displacement in memory for the stationary object is that the moving target provided a larger context that resulted in induced motion of the stationary object. Motion of a larger or enclosing framework often results in perception of motion of a smaller or enclosed stationary object in the opposite direction (eg Brosgole 1968; Heckmann and Howard 1991; Lott and Post 1993; Reinhardt-Rutland 1988, 2003), and so memory for the location of that stationary object might be displaced in the direction of that perceived motion. Although such a displacement in the remembered position of a stationary object is consistent with the backward displacement of the stationary object observed in experiment 1, it is inconsistent with data from previous studies in which memory for a stationary object aligned with the midpoint or final location of the target trajectory was not displaced in the direction opposite to target motion (eg Hubbard 2008). This renders it unlikely that displacement of stationary objects in experiment 1 was due to induced motion, unless induced motion is postulated to occur for a stationary object located near one portion of the target trajectory but not for a stationary object located near a different portion of the target trajectory.

3 Experiment 2

The hypothesis that displacement of the stationary object observed in experiment 1 reflected an onset-repulsion effect is based on the idea that memory for the initial location of the moving target exhibited an onset-repulsion effect. However, displacement of the moving target was not measured, and given that previous studies reporting an onset-repulsion effect have not typically presented a stationary object near the initial location of the target (although see Hubbard and Motes 2005; Müsseler et al 2002), it is unknown to what extent the presence of the stationary object in experiment 1 might have disrupted the onset-repulsion effect. Also, the relationship of displacement of a stationary object aligned with target onset to displacement of the initial position of a moving target has not been examined. Therefore, it is important to examine displacement of the initial location of the moving target when a nearby stationary object is presented, and to compare displacement of the moving target with displacement of the stationary object. Accordingly, in experiment 2, the stationary object and moving target were the same as in experiment 1, but the probe was either for the location of the stationary object or for the initial location of the moving target. Observers were not cued prior to the appearance of the probe on a given trial whether the probe on that trial would be for the location of the stationary object or for the initial location of the moving target. Also, given the high levels of 'same' responses to negative probe positions in experiment 1, we used a larger range of probe distances in experiment 2.

3.1 *Method*

3.1.1 *Participants.* The participants were seventeen undergraduate observers drawn from the same participant pool as in experiment 1; none had participated in the previous experiment.

3.1.2 *Apparatus.* The apparatus was the same as in experiment 1.

3.1.3 *Stimuli.* The inducing stimuli, stationary objects, and probes were the same as in experiment 1, with the following exceptions: the range and number of probe positions was expanded, and probes were also presented for the initial location of the moving target. Probes for the stationary object were black outline squares 20 pixels in width, vertically aligned with the stationary object, and horizontally offset from the previous location of the stationary object by −16, −12, −8, −4, 0, +4, +8, +12, or +16 pixels. Probes for the moving target were filled black squares 20 pixels in width, vertically aligned with the previous location of the initial inducing stimulus, and horizontally offset from the previous location of the initial inducing stimulus by −16, −12, −8, −4, 0, +4, +8, +12, or +16 pixels. Each participant received 288 trials [9 probes (−16, −12, −8, −4, 0, +4, +8, +12, +16 pixels) × 2 directions (leftward, rightward) × 2 heights (above, below) × 2 judgments (stationary object, moving target) × 4 replications] in a different random order.

3.1.4 *Procedure.* The procedure was the same as in experiment 1, with the following exceptions: if the probe was for the stationary object, observers pressed a key marked S or a key marked D to indicate if the location of the probe was the same as or different from the location of the stationary object, respectively; whereas if the probe was for the moving target, observers pressed a key marked S or a key marked D to indicate if the location of the probe was the same as, or different from, the initial location of the moving target, respectively.

3.2 *Results*

The probabilities of a 'same' response for each probe position for stationary objects and for moving targets are shown in figure 3. The weighted mean estimates of displacement for stationary objects were calculated as in experiment 1. The weighted mean estimates of displacement for moving targets were determined by calculating the arithmetic weighted mean (the sum of the products of the proportion of 'same' responses and the distance of the probe from the initial location of the moving target, in pixels,

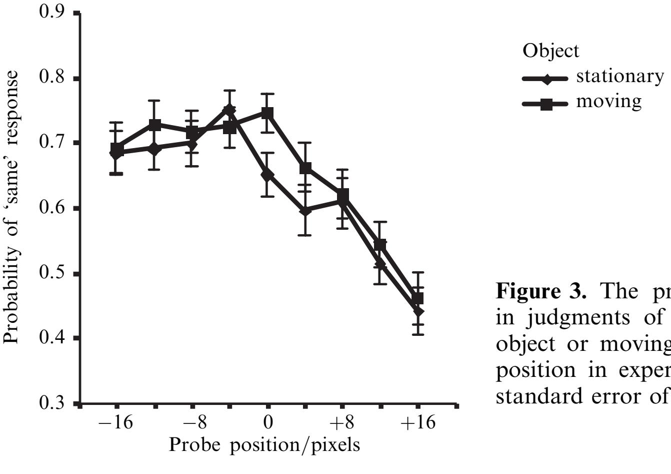

Figure 3. The probability of a 'same' response in judgments of the location of the stationary object or moving target as a function of probe position in experiment 2. Error bars reflect the standard error of the mean.

divided by the sum of the proportions of 'same' responses) for each observer. A paired t-test revealed backward displacement for stationary objects ($M = -1.43$) was not significantly different from backward displacement for moving targets ($M = -1.38$; $t_{16} = -0.04$, $p > 0.84$). The average weighted mean was significantly less than zero for stationary objects ($t_{16} = -2.95, p < 0.01$) and for moving targets ($t_{16} = -3.07, p < 0.01$).

3.3 *Discussion*

Memory for the location of a stationary object was displaced backward from the actual location of that stationary object, and this replicates the displacement pattern observed in experiment 1. Memory for the initial location of the moving target was displaced backward from the actual initial location of the moving target, and this is consistent with an onset-repulsion effect. The results of experiment 2 suggest that an onset-repulsion effect can occur when a stationary object is presented concurrently with the initial appearance of the moving target, and the backward displacement in memory for the initial location of the moving target provides greater confidence in an explanation of displacement of the stationary object that is based on an onset-repulsion effect in memory for the initial location of the moving target. Also, it should be noted that the stationary object was not located along the axis of motion of the target, and so displacement in memory for the initial location of the moving target along the axis of target motion is unlikely to have resulted from memory averaging of the initial location of the target and the location of the stationary object.

The magnitude of backward displacement in memory for the location of stationary objects did not differ from the magnitude of backward displacement in memory for the location of moving targets, and this is consistent with the possibility that an onset-repulsion effect in the representation of the moving target influenced the represented location of the stationary object. The similarity of displacement of the stationary object and displacement of the moving target might initially seem inconsistent with the existence of an onset flash-lag effect (eg as in Eagleman and Sejnowski 2000), as one interpretation of the flash-lag effect is that the stationary (flashed) object is represented as spatially behind the moving target. However, the lack of any significant difference between displacement of the stationary object and displacement of the moving target suggests the perceived misalignment in the flash-lag effect does not reflect differences in spatial processing (eg displacement) per se, and is consistent with previous suggestions that the flash-lag effect reflects differences in temporal processing of the moving target and the flashed object (eg Purushothaman et al 1998; Whitney et al 2000; but see Nijhawan et al 2004).

4 Experiment 3

In experiment 2, the magnitude of backward displacement of the stationary object and the magnitude of backward displacement of the moving target did not differ. It is possible this occurred because the onset-repulsion effect for the moving target influenced memory for both the moving target and the stationary object. Alternatively, it is possible that a larger backward displacement for the moving target was obscured by a flash-lag effect caused by the appearance of the stationary object and that made the moving target appear slightly further forward than it otherwise would have appeared (cf Munger and Owens 2004). One way to examine this possibility is to compare displacement of the initial position of a moving target when a stationary object is presented near the initial position of that target with the displacement of the initial position of an otherwise identical moving target when a stationary object is not presented. Accordingly, in experiment 3, the stationary object and moving target were the same as in experiment 1. The stationary object was presented on half of the trials and was not presented on half of the trials, and probes were always for the initial location of the moving target.

4.1 *Method*

4.1.1 *Participants.* The participants were seventeen undergraduate observers drawn from the same participant pool as in experiment 1; none had participated in the previous experiments.

4.1.2 *Apparatus.* The apparatus was the same as in experiment 1.

4.1.3 *Stimuli.* The stimuli were the same as in experiment 2, with the following exceptions: the stationary object was presented on half of the trials and was not presented on half of the trials, and probes were always for the initial location of the moving target. Each participant received 288 trials [9 probes (-16, -12, -8, -4, 0, $+4$, $+8$, $+12$, $+16$) × 2 directions (leftward, rightward) × 2 heights (above, below) × 2 contexts (stationary object present, stationary object not present) × 4 replications] in a different random order.

4.1.4 *Procedure.* The procedure was the same as in experiment 2, with the following exceptions: the probe was always for the moving target, and observers pressed a key marked S or a key marked D to indicate if the location of the probe was the same as or different from the initial location of the moving target, respectively.

4.2 *Results*

The probabilities of a 'same' response for each probe position when a stationary object was present and when a stationary object was not present are shown in figure 4. The weighted mean estimates of displacement in memory for the initial location of the moving target were calculated as in experiment 2. A paired t-test revealed no difference in backward displacement in memory for the initial location of the moving target as a function of whether a stationary object was present ($M = -2.94$) or not present ($M = -2.73$; $t_{16} = -0.97$, $p > 0.34$). The average weighted mean was significantly less than zero when a stationary object was present ($t_{16} = -5.97$, $p < 0.0001$) and when a stationary object was not present ($t_{15} = -4.84$, $p < 0.0002$).

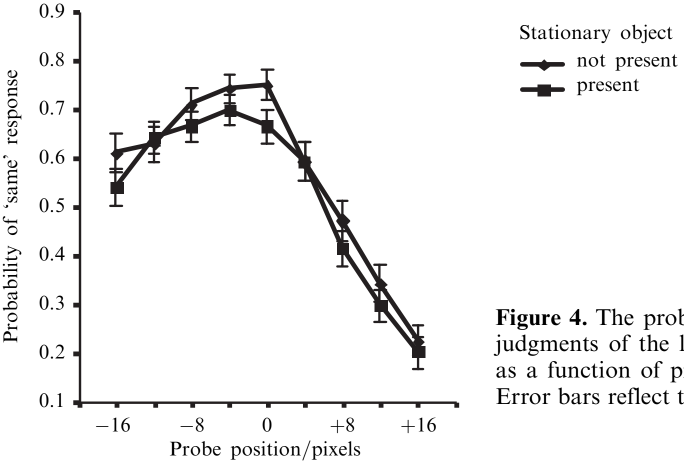

Figure 4. The probability of a 'same' response in judgments of the location of the moving targets as a function of probe position in experiment 3. Error bars reflect the standard error of the mean.

4.3 *Discussion*

Memory for the initial location of a moving target was displaced backward from the actual initial location of that moving target, and this displacement was not influenced by whether a stationary object aligned with target onset was also presented. The hypothesis that the presence of the stationary object caused a flash-lag effect that resulted in the moving target appearing slightly further forward than it otherwise would have appeared can be rejected. Also, distributions of 'same' responses in figure 4 drop off slightly more quickly with increases in positive probe distance from the actual location than do distribution of 'same' responses for probes of the initial location of the moving target in figure 3 from experiment 2. This might be related to the differences in the number of locations observers had to remember (cf Kerzel 2004); in experiment 3, observers had to remember only the initial location of the moving target, whereas in experiment 2, observers had to remember the initial location of the moving target and the location of the stationary object. Indeed, in a comparison of conditions in which the stationary object was presented and observers judged the initial location of the moving target, the magnitude of backward displacement was less for judgments of initial location of moving targets in experiment 2 than for judgments of initial location when stationary objects were present in experiment 3 ($t_{32} = 2.32$, $p < 0.05$).

The lack of an effect of the presence of a stationary object on displacement of the moving target might appear to contradict previous findings that a stationary object could influence representational momentum of the target. However, in those previous studies a stationary object was either presented for a much longer duration (eg Hubbard and Ruppel 1999), located along the axis of motion rather than to the side of the moving target (eg Kerzel 2003), or aligned with target offset rather than with target onset (eg Munger and Owens 2004); more critically, it is not clear that displacement due to an onset-repulsion effect would necessarily exhibit the same properties as displacement due to representational momentum. It is inappropriate to conclude from just the results of experiment 3 that context does not in general influence memory for the initial position of a moving target; indeed, context has been found to influence displacement in memory for initial position when either the relevance (Müsseler et al 2002) or proximity (Hubbard and Motes 2005) of nearby nontarget stimuli is varied. Rather, the results of experiment 3 merely suggest that the results of experiment 2 did not result from the presence of the stationary object influencing backward displacement in memory for the initial position of the moving target.

5 General discussion

Memory for the location of a stationary object presented near the initial location of a moving target and at the moment of the moving target's appearance was displaced in the direction opposite to motion of that target. The backward displacement in memory for the stationary object observed in experiments 1 and 2 is consistent with an onset-repulsion effect in memory for the moving target observed in experiments 2 and 3. Much as representational momentum of a moving target appeared to influence memory for a stationary target presented near target offset in Hubbard (2008), an onset-repulsion effect appeared to influence memory for a stationary target presented near target onset in experiments 1 and 2. Thus, memory for a stationary object is influenced in similar ways by similar dynamics of a nearby moving target. Such motion-induced mislocalization of a stationary object reflects the implied dynamic of the moving target rather than merely the direction of target motion per se, and to the extent that the onset-repulsion effect (and representational momentum) reflects a high-level process, then consistent with Whitney (2006), it appears that high-level processes can contribute to judgments of position. Also, the presence of a stationary object did not appear to influence displacement of the moving target in experiment 3, suggesting that similarity of the displacements of the stationary object and the moving target did not result from a flash-lag effect.

Why might memory for the location of a stationary target near the initial location of a moving target be displaced in the direction opposite to target motion? If an onset-repulsion effect results from extrapolation of a possible previous trajectory of the target (cf Thornton 2002), then the backward displacement of a stationary object presented at the beginning of target motion might result from spreading activation from the (backward extrapolation of the) representation of the moving target to the representation of the stationary object. Such a spreading activation mechanism is consistent with Hubbard's (2008) suggestion that the forward displacement of a stationary target presented at the end of target motion might result from spreading activation from the (forward extrapolation of the) representation of the moving target to the representation of the stationary object. More generally, the results of the current experiments and of Hubbard (2008) are consistent with the hypothesis that motion-induced mislocalization for a stationary object can result from spreading activation from the representation of a nearby moving target. Along these lines, it might be that the briefer presentation of the stationary object results in a conjunction error in which more strongly established motion signals from the moving target are bound to the stationary object as well as bound to the moving target.

The experiments reported here are also relevant to additional issues in spatial perception and cognition. One such issue involves when memory for initial position exhibits a Fröhlich effect or an onset-repulsion effect (eg see Müsseler and Kerzel 2004). In experiments 2 and 3 we used a probe judgment measure of remembered location, and so the onset-repulsion effect we observed in experiments 2 and 3 is not consistent with Kerzel and Gegenfurtner's (2004) suggestion that a Fröhlich effect occurs when the response measure involves (visual) probe judgments and an onset-repulsion effect occurs when the response measure involves (motoric) pointing. Coupled with Hubbard and Motes's (2002) finding of an onset-repulsion effect with a cursor-positioning response measure and use of smooth target motion, the results of experiments 2 and 3 suggest neither the type of response measure nor the type of target motion uniquely determine whether memory for the initial location of a moving target is displaced forward or backward. Another such issue involves the extent to which eye movements contribute to displacement (eg Hubbard 2005, 2006; Kerzel 2006). Even if observers in experiments 1, 2, or 3 visually tracked the moving target, any contributions of eye movements (and resultant mislocalization toward the fovea; Müsseler et al 1999) would have been in the direction opposite to the actual displacement. Thus, it is doubtful eye-tracking movements contributed to displacement in the current experiments.

Memory for the location of a stationary object briefly presented during the initial portion of a moving target's motion is displaced in the direction opposite to target motion. Such displacement is consistent with previous findings regarding the onset-repulsion effect in memory for the initial location of a moving target, and suggests that memory for the location of a stationary object can be influenced by the presence of a nearby moving target. The backward displacement in memory for the location of a stationary object aligned with the initial location of a moving target is also consistent with previous findings regarding the forward displacement in memory for the location of a stationary object aligned with the final location of a moving target; memory for the location of stationary objects that are aligned with either the initial location or final location of a moving target is displaced in ways consistent with how memory for the initial location or final location of the moving target is displaced. Such a consistency offers an important constraint on theories regarding the dynamic nature of representation, as well as underscoring the importance of context on displacement. Also, the contribution of dynamics such as the onset-repulsion effect (and representational momentum) to motion-induced mislocalization demonstrates that such dynamics are not isolated phenomena, but can contribute to other processes.

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