Journal of Experimental Psychology:
Learning, Memory, and Cognition
2009, Vol. 35, No. 3, 666–677

0278-7393/09/$12.00 DOI: 10.1037/a0014870

Effects of Spatial Cueing on Representational Momentum

Timothy L. Hubbard, Anuradha Mohan Kumar, and Charlotte L. Carp
Texas Christian University

Effects of a spatial cue on representational momentum were examined. If a cue was present during or after target motion and indicated the location at which the target would vanish or had vanished, forward displacement of that target decreased. The decrease in forward displacement was larger when cues were present after target motion than when cues were present during target motion. If a cue was present during target motion, high-relevant cues (that indicated the final location of the target) led to larger decreases in forward displacement than did low-relevant cues (that indicated only the horizontal coordinate of the final location of the target). If a cue was present after target motion, there was a trend for low-relevant cues to lead to larger decreases in forward displacement than did high-relevant cues. Possible explanations involving displacement of the cue or landmark attraction are considered. Implications for the relationship of attention and representational momentum, and for whether representational momentum reflects an automatic process, are discussed.

Keywords: representational momentum, attention, spatial cognition, spatial memory, displacement

Memory for the final location of a moving target is often displaced in the direction of anticipated target motion, and this has been called *representational momentum* (Freyd & Finke, 1984; for review, see Hubbard, 2005). This displacement is influenced by a variety of variables related to the (a) target (e.g., direction of target motion; Hubbard, 1990), (b) display (e.g., retention interval; Freyd & Johnson, 1987), (c) context (e.g., direction of target motion relative to a landmark; Hubbard & Ruppel, 1999), and (d) observer (e.g., activation of action plans; Jordan & Knoblich, 2004). The latter category, variables related to the observer, has received relatively little empirical investigation. One of the observer variables that seems to influence representational momentum involves the allocation of attention: Whether increasing or decreasing the attention potentially allocated to a target can influence the representational momentum of that target is a question of empirical and theoretical interest. Experiments examining the effect of attention on representational momentum have used a divided attention task (e.g., Hayes & Freyd, 2002) or presentation of a distractor (e.g., Kerzel, 2003a), but surprisingly, a more direct test in which the spatial location of a target is cued has not been reported. Accordingly, the experiments reported here examined the effects of such spatial cueing on representational momentum.

In one of the first studies of the relationship of attention and representational momentum, Hayes and Freyd (2002) simultaneously presented a dot that moved leftward or rightward and a square that grew or shrank in size. The probability that a subsequent probe would be for either the final location of the dot or for the final size of the square was varied as a way to manipulate the amount of attention allocated to each stimulus; presumably, the stimulus less likely to be probed would be less attended. For the dot, forward displacement and variability of responses increased with decreases in attention. For the square, there was a trend toward accepting smaller probes with decreases in attention, and this might have reflected a bias toward a smaller size (cf. Hubbard, 1996) that became stronger with decreases in attention.[1] In another experiment, Hayes and Freyd had participants view a horizontally translating dot, and some participants also completed a simultaneous counting task, in which they counted aloud by ones, twos, or threes to the beat of a metronome. The dual-task (dot plus counting) condition resulted in larger forward displacement and larger variability than did the single-task (dot alone) condition. Hayes and Freyd suggested representational momentum was an automatic process and that attention was required to halt the forward displacement. More broadly, they suggested that attention was required to initiate any type of change in a dynamic event.

Kerzel (2003a) presented implied upward or downward motion of a square target, and on some trials, a large distractor was presented during the retention interval between when the target vanished and when the probe appeared. The distractor could be to the left or right (along the axis orthogonal to target motion) of the final location of the target, or it could be in front of or behind (along the axis of target motion) the final location of the target. When no distractor was present, memory was displaced forward, whereas when a distractor was present, memory was displaced backward (i.e., presentation of the distractor reversed the pattern of

Timothy L. Hubbard, Anuradha Mohan Kumar, and Charlotte L. Carp, Department of Psychology, Texas Christian University.

Portions of these data were reported at the European Conference on Visual Perception, Arezzo, Italy, August 2007, and at the Vision Sciences Society, Naples, Florida, May 2008.

The authors thank David Sessi and Katrina Will for assistance in data collection and thank J. Scott Jordan and Iring Koch for helpful comments.

Correspondence concerning this article should be addressed to Timothy L. Hubbard, Department of Psychology, Texas Christian University, Fort Worth, TX 76129. E-mail: TimothyLeeHubbard@gmail.com

[1] Hubbard (1995, 1996) suggested that displacement toward a smaller size for targets moving in depth was an example of boundary extension. It is interesting that Courtney and Hubbard (2004) found that boundary extension also increases under conditions of divided attention.

displacement). Kerzel suggested that this finding contradicted the view that attention was necessary for stopping extrapolation of implied target motion (i.e., for stopping representational momentum), and he suggested that visual attention was involved in generating and maintaining forward displacement, rather than involved in stopping forward displacement. Kerzel then further suggested that backward displacement when the distractor was present reflected a memory averaging process in which the final location of the target reflected an average of the target's final location and its previous locations.

The conclusions of Hayes and Freyd (2002) and of Kerzel (2003a) regarding the relationship of attention and representational momentum appear at odds; Hayes and Freyd suggested that attention is necessary to stop representational momentum, whereas Kerzel suggested that attention is necessary to generate or maintain representational momentum. Furthermore, Hayes and Freyd suggested that representational momentum is an automatic process; but given that a lack of attention to initiate a process is a typical criterion for an automatic process (e.g., see Posner & Snyder, 1974, 1975), Kerzel's view is consistent with the idea that representational momentum is not an automatic process. However, there are significant methodological differences between the experiments of Hayes and Freyd and the experiments of Kerzel, and these methodological differences, rather than effects of attention per se, might have contributed to the differences in their data and conclusions. For example, in Hayes and Freyd's experiments the manipulation of attention occurred during presentation of the target and was relatively long in duration, whereas in Kerzel's experiment, the manipulation of attention occurred after the target vanished and was relatively short in duration. In an attempt to consider whether differences in the timing and duration of the attentional manipulation can account for the different results of Hayes and Freyd and of Kerzel, we consider the timing of spatial cueing relative to when the target vanishes and the duration of the spatial cue in the experiments reported here.

Allocation of attention might influence representational momentum, even when that allocation is not intentionally manipulated. Hubbard and Motes (2002) had participants indicate the initial location at which a target appeared or the final location at which a target vanished. Although a possible role of attention was not addressed in the analyses or discussion, Kerzel (2004) pointed out that the displacement pattern exhibited by Hubbard and Motes's participants was consistent with an effect of attention. Specifically, forward displacement seemed to decrease slightly when participants did not know until after the target vanished whether they would have to report initial location or final location (and so they had to keep both locations in memory) relative to when participants knew before the target appeared whether they would have to report initial location or final location (and so they only had to keep one location in memory). Kerzel suggested that forward displacement decreased when attentional load was higher (i.e., when less attention was allocated to a specific location). To test this, he had participants report (a) either initial location or final location of a single target (i.e., attend to one point), (b) both initial location and final location of a single target (i.e., attend to an entire trajectory), or (c) either initial location or final location of one of two targets (i.e., attend to two trajectories). Representational momentum was not influenced by attentional load per se, but attentional load did interact with whether smooth or implied target motion was presented. Kerzel concluded attentional load could modulate but not eliminate representational momentum.

In previous studies that examined effects of attentional allocation on displacement, the allocation of attention was manipulated by influencing processing load; processing load was increased by presenting a concurrent task, presenting a distractor stimulus, or having participants remember more locations from a target trajectory or more trajectories. When a concurrent task or distractor stimulus was presented, that stimulus was typically irrelevant to the task of target localization. However, Müsseler, Stork, and Kerzel (2002) reported that whether a concurrent nontarget stimulus was relevant to target localization influenced displacement of that target. Müsseler et al. (2002) flashed a dot when a target vanished. When the dot was relevant to the task (i.e., when participants were instructed to indicate the location of the target when the dot flashed), memory was displaced slightly backward, whereas when the dot was irrelevant to the task (i.e., when participants were instructed to ignore the dot and to indicate where the target vanished), memory was displaced forward. The slightly backward displacement when the dot was relevant suggests that a nontarget stimulus relevant to the localization task could decrease (or even eliminate) representational momentum. Thus, it could be predicted that a nontarget stimulus more relevant to target localization (e.g., that cued the final location of a target) would decrease forward displacement more than would a nontarget stimulus less relevant to target localization.

The experiments reported here examined the effects of spatial cueing on representational momentum. A nontarget stimulus, referred to as a *cue*, was present during target motion (similar to the concurrent divided attention task in Hayes & Freyd, 2002) or during the retention interval after the target vanished (similar to the subsequent distractor in Kerzel, 2003a), and the duration of the cue was varied. Each experiment provides unique information regarding the effects of spatial cueing on representational momentum, and comparison across experiments allows examination of the hypothesis that differences between the findings of Hayes and Freyd (2002) and the findings of Kerzel (2003a) resulted from the presentation time relative to target motion or from the duration of the attentional manipulations in those studies. The attentional manipulations in Hayes and Freyd and in Kerzel involved tasks or stimuli irrelevant to the target, and so in some of the experiments reported here, relevance of the cue to the target varied. Cues presented at the same display coordinates as the final location of a horizontally moving target were considered high-relevant cues, and cues presented above or below the display coordinates of the final location of a horizontally moving target were considered low-relevant cues. Presumably, more attention should have been allocated to the location corresponding to the final location of the target when (a) a cue was present than when a cue was absent, and (b) a high-relevant cue was present than when a low-relevant cue was present.

Experiment 1

In Experiment 1, participants viewed rightward or leftward implied motion. A cue was present during the entire duration of target motion and was either a high-relevant cue (i.e., presented at the location where the target would vanish) or a low-relevant cue (i.e., presented above or below the location where the target would vanish). A high-relevant cue should presumably enable more attention to be allocated to the final location of the target. If the hypothesis that attention decreases representational momentum is correct (cf. Hayes & Freyd, 2002), then forward displacement of the target should be decreased when a cue is present, and the decrease should be larger when a high-relevant cue is present than when a low-relevant cue is present. If the hypothesis that attention maintains or generates representational momentum is correct (cf. Kerzel, 2003a), then forward displacement of the target should be increased when a cue is present, and the increase should be larger when a high-relevant cue is present than when a low-relevant cue is present. Participants received two blocks of trials: In the high-relevant block, half the trials included a high-relevant cue, and half the trials were control trials that did not include a cue; and in the low-relevant block, half the trials included a low-relevant cue, and half the trials were control trials that did not include a cue.

Method

Participants. The participants were 30 undergraduates from Texas Christian University who were recruited via posted announcements, participated for partial course credit, and were naive to the hypotheses.

Apparatus. The stimuli were displayed upon and the data collected by an Apple iMac desktop computer equipped with a 15-in. color monitor.

Stimuli. The moving target and probe were black square shapes 20 pixels (approximately 0.83° of visual angle) in width and in height and were presented against a white background. On each trial, and as shown in Figure 1, there were five successive presentations of the target that implied consistent rightward motion of the target or consistent leftward motion of the target, and these are referred to as *inducing stimuli*. Each inducing stimulus was presented for 250 ms, and there was a 250-ms interval 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° 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 of the display.

The probe on each trial was presented at the same vertical coordinates as the moving target on that trial and was located at one of nine horizontal positions relative to the final location of that moving target: −12, −9, −6, −3, 0, +3, +6, +9, or +12 pixels. Probe positions denoted by a minus sign indicate that the probe was backward (i.e., shifted in the direction opposite to target motion) from the final location of the moving target by the indicated number of pixels, and probe positions denoted by a plus sign indicate that the probe was forward (i.e., shifted in the direction of target motion) from the final location of the moving target by the indicated number of pixels; the zero probe position was the same as the final location of the moving target.

The cue was a red plus sign, and the horizontal and vertical arms of the plus sign were each 20 pixels long and 4 pixels thick (the width and height of the cue was the same as the width and height of the inducing stimuli and probe). In high-relevant trials, the cue was presented at the location at which the target on that trial would vanish. In low-relevant trials, the cue was horizontally aligned with, and 120 pixels (approximately 4.98°) above or below, the location at which the target on that trial would vanish (such a location was analogous to the location of distractors to the left or right of vertically moving targets in Kerzel, 2003a).[2]

In each block, each participant received 216 trials (2 cues [present, absent] × 9 probes [−12, −9, −6, −3, 0, +3, +6, +9, +12] × 2 directions [leftward, rightward] × 6 replications) in a different random order.

Procedure. Cue type was blocked, with high-relevant cues in one block and low-relevant cues in a second block. There was a 3- to 7-day separation between the first and second blocks for each participant, and the order of cue types across blocks was counterbalanced across participants. In each block, participants were first given a practice session consisting of 10 practice trials that were randomly drawn from the experimental trials in that block. In the high-relevant block, participants were instructed that if a cue were present, the cue would indicate the location at which the target would vanish. In the low-relevant block, participants were instructed that if a cue were present, the cue would be above or below the path of target motion. For both blocks, on trials in which a cue was present, the cue appeared when the initial inducing stimulus appeared and vanished when the final inducing stimulus vanished (when the final inducing stimulus appeared in high-relevant trials the cue was superimposed on that stimulus and was clearly visible). For all trials, the retention interval between the disappearance of the final inducing stimulus and the subsequent appearance of the probe was 250 ms. After the probe appeared, participants pressed a key marked *S* or a key marked *D* (the *M* and *C* keys, respectively, of a standard keyboard) with the right or left index finger, respectively, to indicate whether the location of the probe was the same as or different from the final location of the moving target. Participants then initiated the next trial.

Results

The probabilities of a *same* response for each probe position are shown in Figure 2. Consistent with previous studies in the representational momentum literature (e.g., Freyd & Jones, 1994; Hubbard, 1993; Munger, Solberg, Horrocks, & Preston, 1999), estimates of the direction and magnitude of displacement in remembered location were determined by calculating the arithmetic weighted mean (i.e., the sum of the products of the proportion of *same* responses and the distance of the probe from the final location of the moving target, in pixels, divided by the sum of the

[2] Kerzel (2003a) referred to his distractors as "irrelevant." However, the distractors in his study were directly to the left or right of, or directly above or below, the final location of a vertically moving target; thus, the location of each distractor provided information about either the *x* coordinate or the *y* coordinate of the final location of the target. Because partial information regarding the final location of the target was given by the location of the distractor, such distractors were not actually irrelevant to the task of target localization. Given this, the current experiments refer to cues equivalent to the "irrelevant" distractors in Kerzel as *low relevant* and to cues that possess even more information about the final location of the target as *high relevant*.

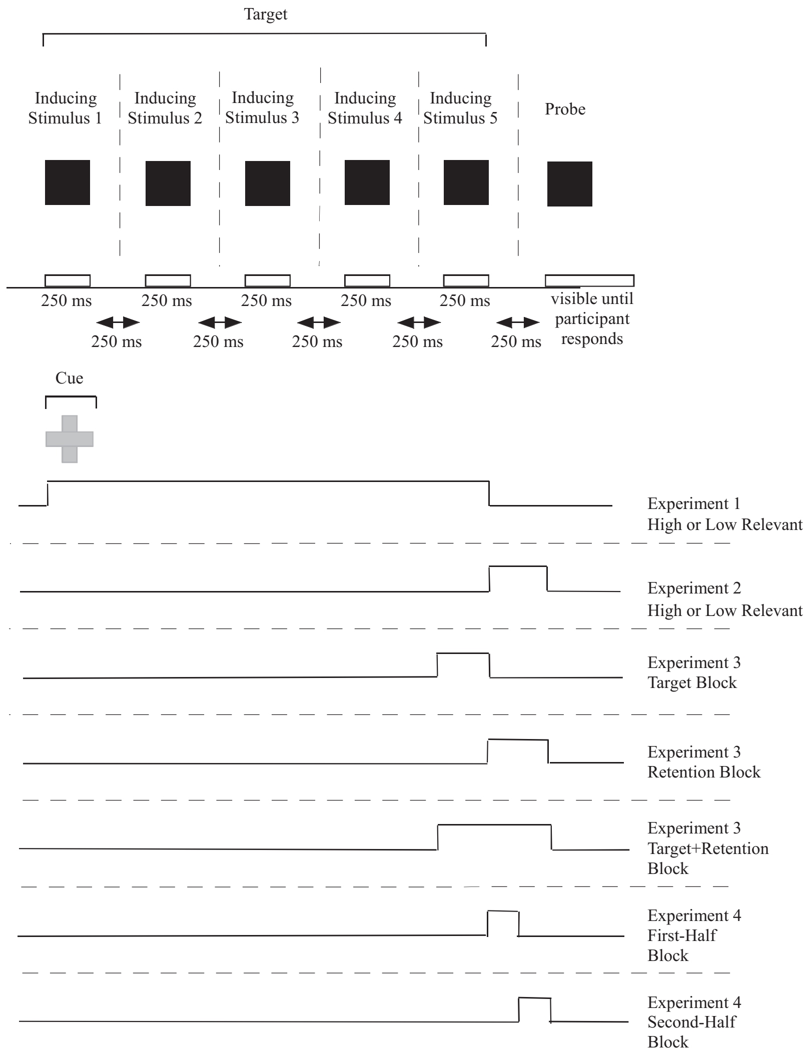

Figure 1. The structure of the experimental trials. The top panel illustrates the target and probe stimuli. In all experiments, there were five inducing stimuli that comprised the target; each inducing stimulus was presented for 250 ms, and there was a 250-ms interstimulus interval between successive inducing stimuli. The probe was presented after a retention interval of 250 ms and remained visible until the participant responded. The bottom panel indicates the cue stimulus. A cue was presented at different times during either target motion or during the retention interval in each of the experiments, and the raised portion of the horizontal line for each experimental condition indicates when the cue was present in that condition.

proportions of *same* responses) for each participant for each condition. The sign of the weighted mean indicates the direction of displacement (i.e., a minus sign indicates backward displacement in the direction opposite to target motion, a plus sign indicates forward displacement in the direction of target motion), and the absolute value of the weighted mean indicates the magnitude of displacement (i.e., larger absolute values indicates larger magnitudes of displacement). A weighted mean significantly larger than zero indicates that representational momentum occurred.

A preliminary analysis of weighted means showed that order was not significant, nor did order interact with any other variables, and so subsequent analyses collapsed across order. Because there were no predicted effects of direction, subsequent analyses collapsed across direction, as well.[3] The weighted means were analyzed in a 2 (Relevance: high, low) $\times$ 2 (Cue: present, absent) repeated-measures analysis of variance (ANOVA). Presentation of a high-relevant cue (M = 1.93, SE = 0.20) resulted in smaller forward displacement than did presentation of a low-relevant cue (M = 2.35, SE = 0.16), $F(1, 28) = 6.30$, $MSE = 1.72$, $p < .02$. When a cue was present (M = 1.19, SE = 0.13) forward displacement was significantly less than when a cue was absent (M = 3.08,

[3] Direction of target motion had been varied across trials primarily to keep the experimental trials from becoming too repetitive and to keep experimental participants more engaged and attentive (i.e., less bored). Analyses in Experiment 1 and in subsequent experiments thus collapsed across direction.

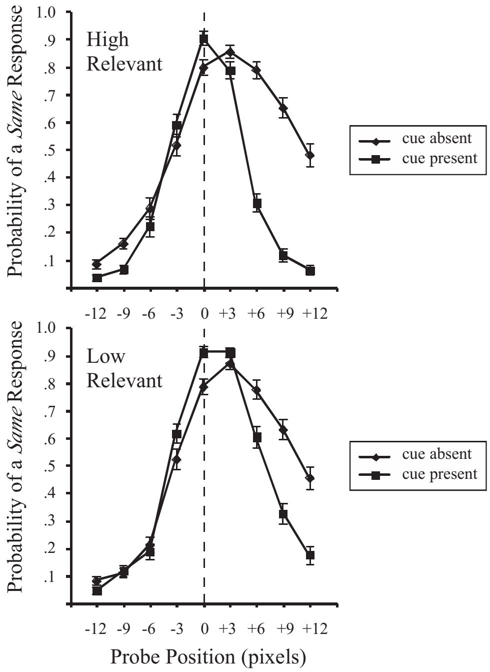

Figure 2. The probability of a *same* response as a function of probe position in Experiment 1. The top panel shows responses in the high-relevant block, and the bottom panel shows responses in the low-relevant block. In each panel, responses when the cue was present are shown by filled squares, and responses when the cue was absent are shown by the filled diamonds. Error bars indicate standard error of the mean.

SE = 0.19), $F(1, 28) = 69.63$, $MSE = 3.07$, $p < .001$. Interpretation of these main effects was tempered by a significant Relevance × Cue interaction, $F(1, 28) = 10.46$, $MSE = 1.79$, $p < .005$. As shown in Figure 2, the decrease in forward displacement resulting from presentation of a cue was larger with high-relevant cues than with low-relevant cues.

In the high-relevant block, the weighted means when the cue was present ($M = 0.70$, $SE = 0.17$), $t(29) = 3.36$, $p < .003$, and when the cue was absent ($M = 3.15$, $SE = 0.30$), $t(29) = 8.85$, $p < .0001$, were significantly larger than zero. In the low-relevant block, the weighted means when the cue was present ($M = 1.69$, $SE = 0.16$), $t(29) = 7.90$, $p < .0001$, and when the cue was absent ($M = 3.02$, $SE = 0.23$), $t(29) = 10.20$, $p < .0001$, were significantly larger than zero.

Discussion

When a cue was present during the entire duration of target motion, forward displacement was decreased, relative to when a cue was absent. Moreover, the decrease in forward displacement was larger when high-relevant cues were present than when low-relevant cues were present. If the cue is hypothesized to increase attention allocated to the cued location, then the decrease in forward displacement when a cue was present is consistent with Hayes and Freyd's (2002) suggestion that increases in attention decrease forward displacement. Furthermore, the larger decrease in forward displacement when a high-relevant cue was present is also consistent with Hayes and Freyd. Alternatively, if the cue is hypothesized to decrease attention allocated to the final location of the target, then the decrease in forward displacement when a cue is present is consistent with Kerzel's (2003a) suggestion that increases in attention increase forward displacement. However, the larger decrease in forward displacement when a high-relevant cue was present is not consistent with Kerzel's (2002) report that a target is localized away from a distractor, as this latter finding predicts that the decrease in forward displacement would be smaller when a high-relevant cue was present. Also, it seems less plausible that a high-relevant cue presented well prior to when the target vanished would actually decrease the amount of attention allocated to the final location of the target. Thus, the results of Experiment 1 seem more consistent with the relationship of attention and representational momentum that was suggested by Hayes and Freyd (2002).

The larger decrease in forward displacement with high-relevant cues is consistent with backward displacement in memory for final location reported by Müsseler et al. (2002) when a relevant flashed dot was presented when the target vanished; in Experiment 1 and in Müsseler et al., forward displacement decreased when a more relevant stimulus was presented near the end of target motion. Such a parallel is interesting given numerous differences in methodology between Experiment 1 and Müsseler et al. (e.g., Experiment 1 involved implied target motion, a relatively long cue duration, and probe judgment; Müsseler et al. involved smooth target motion, a very brief flash, and cursor positioning). Given that different mechanisms might underlie perception of implied motion or smooth motion and that different mechanisms might underlie generation of responses involving probe judgment or cursor positioning (cf. Kerzel, 2003b), similarities in displacement in Experiment 1 and in Müsseler et al. are consistent with the hypothesis that forward displacement reflects a single high-level (i.e., cognitive) mechanism, rather than several different low-level (i.e., perceptual) mechanisms. Also, even though the cue decreased forward displacement, it did not eliminate forward displacement; this highlights the robustness of representational momentum and is consistent with the possibility that at least one component of representational momentum is automatic.

An alternative hypothesis for the existence of forward displacement of the target when a cue was present is that memory for the cue was also displaced in the direction of target motion. Hubbard (2008) found that memory for the location of a stationary object presented near the final location of target motion was displaced in the direction of target motion. He suggested that this occurred because spreading activation from representational momentum of the target influenced the representation of the stationary object, thus displacing the representation of the stationary object. In Experiment 1, the cue was analogous to the stationary object in Hubbard (2008), and so the cue might have been similarly displaced in the direction of target motion. If the representation of the location of the cue was displaced forward and memory for the location of target was based on the representation of the location of the cue, then memory for the target would also have been displaced forward. The influence of representational momentum of a moving target on a nearby stationary object decreases with increases in the distance of that stationary object from the final location of the target (Hubbard, 2008), so a low-relevant cue would not be displaced as far in the direction of target motion as would a high-relevant cue. If displacement of the target is based upon displacement of the cue, then a low-relevant cue would result in less forward displacement than would a high-relevant cue, but this pattern is opposite to that found in Experiment 1.

An alternative hypothesis for the decrease in forward displacement when a cue was present is that the cue functioned as a landmark. More specifically, it is possible that the decrease in displacement was not due to any increased attention from cueing per se, but was instead due to a combination of landmark attraction (i.e., a bias in the direction of a landmark; see Bryant & Subbiah, 1994) and representational momentum. Hubbard and Ruppel (1999) found that forward displacement of a moving target increased if the target moved toward a landmark and decreased if a target moved away from a landmark. They accounted for this by suggesting that representational momentum combined with landmark attraction such that when representational momentum and landmark attraction operated in the same direction (i.e., target motion was toward the landmark), they summed and forward displacement was relatively large, whereas when representational momentum and landmark attraction operated in opposite directions (i.e., target motion was away from the landmark), they partially canceled and forward displacement was relatively small. If the cue functioned as a landmark, then forward displacement of the target might have decreased when a cue was present, because landmark attraction from the cue partially canceled representational momentum of the target. However, to the extent that a landmark influences the allocation of attention, it is difficult to separate effects of landmark attraction from effects of attention in Experiment 1.

Experiment 2

In Experiment 1, presentation of a cue during target motion led to a decrease in forward displacement of the target. If a cue results in a greater allocation of attention to the final location of the target, and this greater allocation of attention results in a decrease in forward displacement, then presentation of a cue during the retention interval should result in a larger decrease in forward displacement than would presentation of a cue during target motion. This would occur because effects of a cue present during the retention interval would be stronger (i.e., would not have decayed as much prior to the appearance of the probe) than effects of a cue present during target motion. Alternatively, if a cue functions as a landmark, then presentation of a cue during the retention interval should result in a smaller decrease or no change in forward displacement of the target relative to presentation of a cue during target motion. This would occur because the strength of landmark attraction increases or stays the same with increases in retention interval after a landmark vanishes (e.g., see Postma, Huntjens, Meuwissen, & Laeng, 2006; Werner & Diedrichsen, 2002), so effects of a cue present during the retention interval would be weaker than or the same as effects of a cue present during target motion. Accordingly, in Experiment 2, the cue was present during the retention interval. Participants received two blocks of trials. In the high-relevant block, the cue was present at the final location of the target, and in the low-relevant block, the cue was present above or below the final location of the target. As in Experiment 1, half the trials within each block were control trials in which a cue was not presented.

Method

Participants. The participants were 30 undergraduates from the same participant pool used in Experiment 1, and none had participated in the earlier experiment.

Apparatus. The apparatus was the same as in Experiment 1.

Stimuli. The inducing stimuli, probes, and cues were the same as in Experiment 1. In each block, each participant received 216 trials (2 cues [present, absent] $\times$ 9 probes [-12, -9, -6, -3, 0, $+3$, $+6$, $+9$, $+12$] $\times$ 2 directions [leftward, rightward] $\times$ 6 replications) in a different random order.

Procedure. The procedure was the same as in Experiment 1, with the following exception: For trials in which a cue was present, the cue appeared when the final inducing stimulus vanished and vanished when the probe appeared.

Results

A preliminary analysis showed that order was not significant, nor did order interact with any other variables, so subsequent analyses collapsed across order. The probabilities of a *same* response for each probe position are shown in Figure 3, and weighted mean estimates of displacement were calculated as in Experiment 1.

The weighted means were analyzed in a 2 (Relevance: high, low) $\times$ 2 (Cue: present, absent) repeated-measures ANOVA. Presentation of a low-relevant cue ($M = 0.61$, $SE = 0.18$) resulted in marginally smaller forward displacement than did presentation of

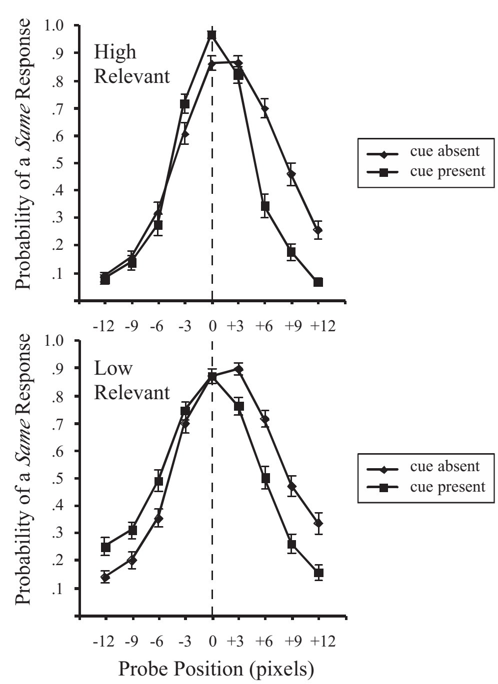

Figure 3. The probability of a *same* response as a function of probe position in Experiment 2. The top panel shows responses in the high-relevant block, and the bottom panel shows responses in the low-relevant block. In each panel, responses when the cue was present are shown by filled squares, and responses when the cue was absent are shown by the filled diamonds. Error bars indicate standard error of the mean.

a high-relevant cue ($M = 1.03$, $SE = 0.14$), $F(1, 28) = 2.85$, $MSE = 3.47$, $p < .10$. When a cue was present ($M = -0.83$, $SE = 0.14$) forward displacement was significantly less than when a cue was absent ($M = 1.73$, $SE = 0.13$), $F(1, 28) = 67.63$, $MSE = 2.87$, $p < .001$. Interpretation of these main effects was tempered by a marginal Relevance × Cue interaction, $F(1, 28) = 3.27$, $MSE = 1.16$, $p < .08$. As shown in Figure 3, there was a trend for a larger decrease in forward displacement of the target when a low-relevant cue was present than when a high-relevant cue was present (the distribution of *same* responses for the former is slightly more symmetrical than is the distribution of *same* responses for the latter).

In the high-relevant block, the weighted means when the cue was present ($M = 0.26$, $SE = 0.12$), $t(29) = 2.16$, $p < .04$, and when the cue was absent ($M = 1.81$, $SE = 0.21$), $t(29) = 7.66$, $p < .0001$, were significantly larger than zero. In the low-relevant block, the weighted means when the cue was present ($M = -0.42$, $SE = 0.24$), $t(29) = -1.57$, $p = .12$, did not differ from zero, and the weighted means when the cue was absent ($M = 1.64$, $SE = 0.17$), $t(29) = 8.34$, $p < .0001$, were significantly larger than zero.

To examine whether the decrease in forward displacement when a cue was present was influenced by whether the cue was present during the retention interval (as in Experiment 2) or during target motion (as in Experiment 1), we carried out a combined ANOVA using data from Experiments 1 and 2. Forward displacement in Experiment 2 ($M = 0.82$, $SE = 0.11$) was significantly less than in Experiment 1 ($M = 2.14$, $SE = 0.13$), $F(1, 57) = 27.38$, $MSE = 7.42$, $p < .0002$. Of greater interest, experiment interacted with relevance, $F(1, 57) = 8.04$, $MSE = 2.69$, $p < .007$, and with Relevance × Cue, $F(1, 57) = 13.26$, $MSE = 1.46$, $p < .0007$. The difference between the weighted means of the cue present and cue absent conditions in Experiment 2 (2.56) is larger than the difference between the weighted means of the cue present and cue absent conditions in Experiment 1 (1.11). Thus, a cue present during the retention interval decreased forward displacement more than did a cue present during target motion. Also, and not surprisingly, forward displacement when a cue was present ($M = 0.56$, $SE = 0.10$) was significantly less than when a cue was absent ($M = 2.41$, $SE = 0.12$), $F(1, 57) = 139.42$, $MSE = 2.93$, $p < .0001$. Relevance was not significant.

Discussion

When a cue was present during the retention interval, forward displacement was decreased relative to when a cue was absent. However, such a decrease in forward displacement does not uniquely distinguish between the accounts of Hayes and Freyd (2002) and of Kerzel (2003a), as both accounts predict a decrease in forward displacement if a cue is present during the retention interval; an account based on Hayes and Freyd suggests that the cue decreased forward displacement because of an increased allocation of attention to the final location of the target, whereas an account based on Kerzel suggests that the cue decreased forward displacement because of a disruption in the allocation of attention to the final location of the target. The decrease in forward displacement when a cue was present in Experiment 2 was larger than the decrease in forward displacement when a cue was present in Experiment 1, and this is not consistent with the hypothesis that the cue functioned as a landmark. Unlike in Experiment 1, cue relevance did not significantly influence displacement; indeed, the trend in Experiment 2 was in the opposite direction from the pattern in Experiment 1. The lack of an effect of cue relevance in Experiment 2 is also not consistent with the hypothesis that the cue functioned as a landmark, as a landmark hypothesis predicts that a high-relevant cue would produce a larger decrease in forward displacement than would a low-relevant cue.

One possible explanation for the differing effects of cue relevance in Experiments 1 and 2 is that cues in Experiment 1 (presented before the target reached its final position) functioned as *primes*, whereas cues in Experiment 2 (presented during the retention interval between when the target vanished and the probe appeared) functioned as *distractors*. Why might the cues have such different effects? One possibility is that the representation of the final location of the target was more fragile in memory (Experiment 2) than in perception (Experiment 1) and, therefore, was more easily disrupted by presentation of a cue during the retention interval than by presentation of a cue during target motion. A second possibility is that in Experiment 2, the allocation of additional attention to the final location of the target was limited by an inhibition of return (i.e., a bias against returning attention to a recently attended location; for review, see Klein, 2000). Such a notion would predict a greater inhibition of return for high-relevant cues than for low-relevant cues, and this is consistent with the finding that in Experiment 2 high-relevant cues were not as effective in decreasing forward displacement of the target as were low-relevant cues. Regardless, the results of Experiments 1 and 2 suggest that the same nontarget stimulus presented at different times or for different durations relative to target motion could have different effects upon the displacement of a target.

Experiment 3

In Experiments 1 and 2, presentation of a cue led to a decrease in forward displacement relative to control trials, in which no cue was present. The durations of the cues in Experiments 1 and 2 were very different: In Experiment 1, the cue was present for a relatively long period (2,250 ms) during target motion, and in Experiment 2, the cue was present for a briefer period (250 ms) during the retention interval. However, a more meaningful comparison of the effects of the cue during target motion or during the retention interval requires that the duration of cue presentation with different cue types be held constant. Also, given that cues present during target motion or during the retention interval decreased forward displacement, it would be useful to examine whether effects of cues present during both target motion and the retention interval combine to produce a larger decrease in forward displacement. Alternatively, if a cue is visible for some minimal duration at any time during target motion or during the retention interval, then any additional visibility of that cue might not result in further decrease in displacement. Accordingly, in Experiment 3, participants received three blocks of trials. In the target block, the cue was concurrent with the final inducing stimulus. In the retention block, the cue was concurrent with the retention interval. In the Target + Retention block, the cue was concurrent with both the final inducing stimulus and the retention interval. As in Experiments 1 and 2, half the trials in each block were control trials in which the cue was absent.

Method

Participants. The participants were 49 undergraduates from the same participant pool used in Experiments 1 and 2, and none had participated in the earlier experiments.

Apparatus. The apparatus was the same as in Experiment 1.

Stimuli. The inducing stimuli, probes, and cues were the same as in Experiments 1 and 2, with the following exceptions: Cues were always located at the coordinates of the final inducing stimulus (i.e., were the same as high-relevant cues in Experiments 1 and 2), and the duration of the cue was either 250 ms (in the target block and in the retention block) or 500 ms (in the Target + Retention block). In each block, each participant received 216 trials (2 cues [present, absent] × 9 probes [−12, −9, −6, −3, 0, +3, +6, +9, +12] × 2 directions [leftward, rightward] × 6 replications) in a different random order.

Procedure. The procedure was the same as in Experiment 1, with the following exceptions: Cue type was blocked, with target trials in one block, retention trials in a second block, and Target + Retention trials in a third block. There was a 3- to 7-day separation between the first and second blocks, and a 3- to 7-day separation between the second and third blocks. For trials in the target block in which a cue was present, the cue appeared when the final inducing stimulus appeared and vanished when the final inducing stimulus vanished. For trials in the retention block in which a cue was present, the cue appeared immediately after the final inducing stimulus vanished and vanished when the probe appeared. For trials in the Target + Retention block in which a cue was present, the cue appeared when the final inducing stimulus appeared, remained visible during the retention interval, and then vanished when the probe appeared.

Results

A preliminary analysis showed that order was not significant, nor did order interact with any other variables, so subsequent analyses collapsed across order. The probabilities of a *same* response for each probe position are shown in Figure 4, and weighted mean estimates of displacement were calculated as in Experiment 1.

Overall analysis. The weighted means were analyzed in a 3 (Timing: target, retention, Target + Retention) × 2 (Cue: present, absent) repeated-measures ANOVA. Timing was significant, $F(2, 96) = 5.04$, $MSE = 1.52$, $p < .01$, and least squares comparisons revealed forward displacement was smaller in the retention block ($M = 1.31$, $SE = 0.12$) and Target + Retention block ($M = 1.31$, $SE = 0.13$) than in the target block ($M = 1.65$, $SE = 0.12$). When a cue was present ($M = 0.64$, $SE = 0.08$) displacement was significantly less than when a cue was absent ($M = 2.21$, $SE = 0.10$), $F(1, 48) = 88.72$, $MSE = 4.11$, $p < .0001$. Interpretation of these main effects was tempered by a Timing × Cue interaction, $F(2, 96) = 7.94$, $MSE = 0.89$, $p < .001$. As shown in Figure 4, differences between the cue present and cue absent conditions were smaller in the target block than in the retention block and in the Target + Retention block.

Target block. When a cue was present ($M = 1.08$, $SE = 0.14$), displacement was significantly less than when a cue was absent ($M = 2.23$, $SE = 0.17$), $F(1, 48) = 41.60$, $MSE = 1.55$, $p < .0001$. The weighted means when the cue was present, $t(48) = 7.51$, $p < .0001$, and when the cue was absent, $t(48) = 11.04$, $p < .0001$, were significantly larger than zero.

Retention block. When a cue was present ($M = 0.45$, $SE = 0.12$) displacement was significantly less than when a cue was absent ($M = 2.16$, $SE = 0.18$), $F(1, 48) = 57.41$, $MSE = 2.49$, $p < .0001$. The weighted means when the cue was present, $t(48) = 3.54$, $p < .001$, and when the cue was absent, $t(48) = 10.73$, $p < .0001$, were significantly larger than zero.

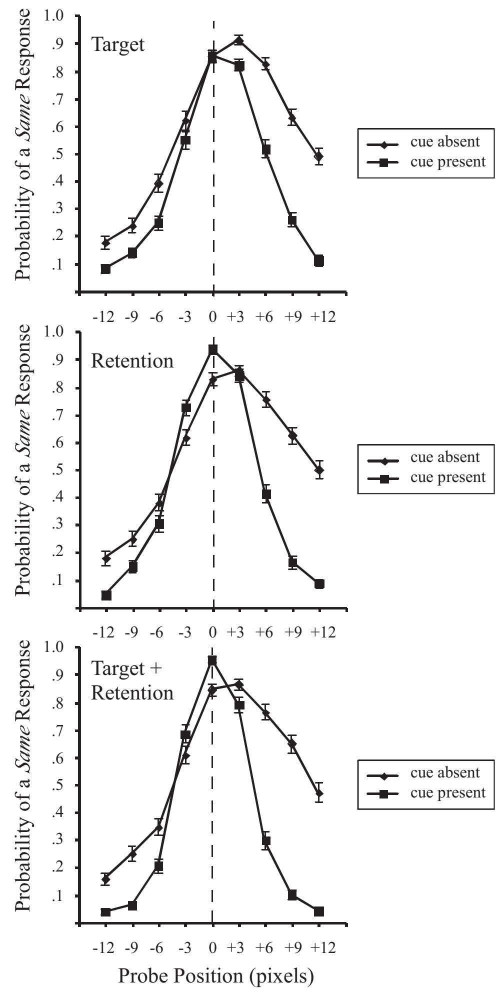

Figure 4. The probability of a *same* response as a function of probe position in Experiment 3. The top panel shows responses in the target block, the middle panel shows responses in the retention block, and the bottom panel shows responses in the Target + Retention block. In each panel, responses when the cue was present are shown by filled squares, and responses when the cue was absent are shown by the filled diamonds. Error bars indicate standard error of the mean.

Target + Retention block. When a cue was present ($M = 0.38$, $SE = 0.10$), displacement was significantly less than when a cue was absent ($M = 2.24$, $SE = 0.17$), $F(1, 48) = 92.93$, $MSE = 1.85$, $p < .0001$. The weighted means when the cue was present, $t(48) = 3.65$, $p < .001$, and when the cue was absent, $t(48) = 9.44$, $p < .0001$, were significantly larger than zero.

Discussion

Consistent with Experiments 1 and 2, forward displacement of the target decreased when a cue was present relative to when a cue was absent. The decrease was larger when the cue was present only during the retention interval or present during both target motion and the retention interval than when the cue was present only during target motion. The smaller forward displacement during the retention block than during the target block (within-subjects) in Experiment 3 is consistent with the (between-subjects) combined ANOVA for Experiments 1 and 2. Also, the results of Experiment 3 suggest that the smaller weighted means when the cue was present in Experiment 2 than when the cue was present in Experiment 1 did not result from the shorter duration of the cue in Experiment 2 but, rather, resulted from the cue in Experiment 2 being present during the retention interval. This is consistent with the finding that forward displacement of the target in the retention block and forward displacement of the target in the Target + Retention block in Experiment 3 did not differ, even though the retention block and Target + Retention block presented the cue for different durations. Thus, timing of the cue relative to when the probe was present, rather than duration of the cue, determined the influence of the cue on displacement. Although this is consistent with the notion that differences between Hayes and Freyd (2002) and Kerzel (2003a) reflect when the attentional manipulations occurred, the decrease in forward displacement with cue presentation during target motion or during the retention interval suggests that differences in timing of the attention manipulations cannot be the sole cause of differences in their data and conclusions.

Experiment 4

In Experiment 3, the decrease in forward displacement of the target attributable to the cue was larger when the cue was present during the retention interval than when the cue was present only during target motion. However, it is not clear whether this difference resulted from (a) the presence of the target during cue presentation in the target block and the absence of the target during cue presentation in the retention block and during the later stage of cue presentation in the Target + Retention block or (b) a longer latency between when the cue vanished and the probe appeared in the target block than between when the cue vanished and the probe appeared in the retention block and the Target + Retention block. To examine the effect of latency in the absence of a confound with target visibility, in Experiment 4, we presented briefer cues at different times within the retention interval. If the smaller decrease in forward displacement in the target block in Experiment 3 was due to the greater latency between when the cue vanished and when the probe appeared, then there should have been a smaller decrease in forward displacement when a cue was present during only the first half of the retention interval than when a cue was present during only the second half of the retention interval. Accordingly, in Experiment 4 there were two blocks of trials; in the first-half block, the cue was present during the first half of the retention interval, and in the second-half block, the cue was present during the second half of the retention interval. As in Experiments 1, 2, and 3, half the trials in each block were control trials in which the cue was absent.

Method

Participants. The participants were 24 undergraduates from the same participant pool used in previous experiments, and none had participated in the earlier experiments.

Apparatus. The apparatus was the same as in Experiment 1.

Stimuli. The inducing stimuli, probes, and cues were the same as in the retention block in Experiment 3, with the following exceptions: The cue was present for only 125 ms, and the cue was visible only during the first half of the retention interval or only during the second half of the retention interval. In each block, each participant received 216 trials (2 cues [present, absent] × 9 probes [−12, −9, −6, −3, 0, +3, +6, +9, +12] × 2 directions [leftward, rightward] × 6 replications) in a different random order.

Procedure. The procedure was the same as in the retention block of Experiment 3, with the following exceptions: For trials in the first-half block in which a cue was present, the cue appeared immediately after the final inducing stimulus vanished and remained visible for 125 ms and then vanished. For trials in the second-half block in which a cue was present, there was a delay of 125 ms after the final inducing stimulus vanished before the cue appeared. The cue was visible for 125 ms and then vanished when the probe appeared.

Results

A preliminary analysis showed that order was not significant, nor did order interact with any other variables, so subsequent analyses collapsed across order. The probabilities of a *same* response for each probe position are shown in Figure 5, and weighted mean estimates of displacement were calculated as in Experiment 1.

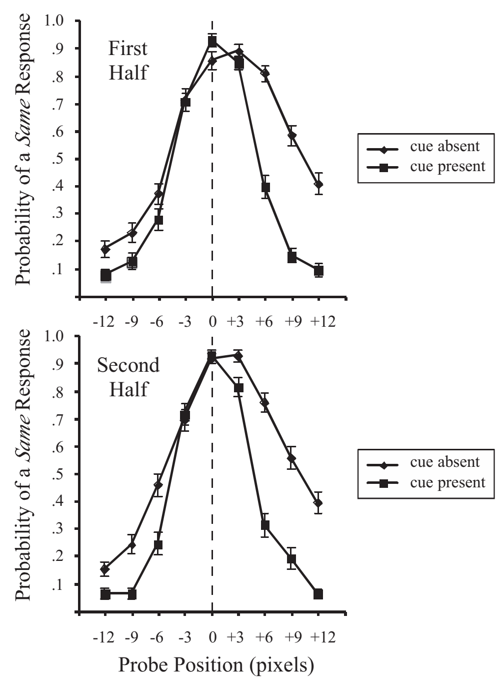

Figure 5. The probability of a *same* response as a function of probe position in Experiment 4. The top panel shows responses in the first-half block, and the bottom panel shows responses in the second-half block. In each panel, responses when the cue was present are shown by filled squares, and responses when the cue was absent are shown by the filled diamonds. Error bars indicate standard error of the mean.

The weighted means were analyzed in a 2 (Timing: first-half, second-half) × 2 (Cue: present, absent) repeated-measures ANOVA. When a cue was present (M = 0.50, SE = 0.12) forward displacement was significantly less than when a cue was absent (M = 1.78, SE = 0.15), $F(1, 22) = 26.66$, MSE = 2.89, $p < .0001$. Timing was not significant, nor did timing interact with cue, Fs < 2.61, ps $> .12$.

In the first-half block, the weighted means when the cue was present (M = 0.48, SE = 0.19), $t(23) = 2.27$, $p < .04$, and when the cue was absent (M = 1.88, SE = 0.23), $t(23) = 7.20$, $p <$ .0001, were significantly larger than zero. In the second-half block, the weighted means when the cue was present (M = 0.51, SE = 0.14), $t(23) = 4.19$, $p < .001$, and when the cue was absent (M = 1.68, SE = 0.21), $t(23) = 6.24$, $p < .0001$, were significantly larger than zero.

Discussion

Consistent with Experiments 2 and 3, forward displacement of the target decreased when a cue was present during the retention interval. However, the decreased forward displacement when a cue was present was not influenced by whether the cue was present during only the first half of the retention interval or was present during only the second half of the retention interval. The lack of a timing effect in Experiment 4 is consistent with the hypotheses that the smaller forward displacement in Experiment 2 than in Experiment 1, and the smaller forward displacement in Experiment 3 for the retention block and Target + Retention block than for the target block, were not solely a function of the latency between when the cue vanished and when the probe appeared. Also, the data of Experiment 4 do not uniquely distinguish between the accounts of Hayes and Freyd (2002) and of Kerzel (2003a). As noted in Experiment 2, a decrease in forward displacement when a cue is present during the retention interval is consistent with either a cue-driven increase in the allocation of attention to the final location of the target (cf. Hayes & Freyd, 2002) or a disruption in the processing of the final location of the target (cf. Kerzel, 2003a).

Given that the magnitude of representational momentum increases during the first few hundred milliseconds after the target vanishes (cf. Freyd & Johnson, 1987; Kerzel, 2000), if the cue was displaced by the representational momentum of the target, then cues present in the first half of the retention interval would have exhibited less forward displacement than did cues present in the second half of the retention interval. If displacement of the target was based on a potential displacement of the cue, then displacement of the target should have been smaller when cues were present in the first half of the retention interval than when cues were present in the second half of the retention interval. The lack of a timing effect suggests that the decrease in forward displacement of the target when a cue was present was not due to any potential displacement of the cue. Also, consistent with Experiment 3 and with the high-relevant cue condition of Experiment 2, presentation of a cue at the final location of the target during the retention interval in Experiment 4 did not eliminate forward displacement, again underscoring the robustness of representational momentum and suggesting that at least one component of representational momentum is automatic.

General Discussion

Spatial cueing of the final location of a target influenced forward displacement in memory for the final location of that target. When a cue indicating the location at which a currently visible target would vanish was present during the entirety (Experiment 1) or final portion (Experiment 3) of target motion, forward displacement of the target decreased. When a cue indicating the location at which a previously visible target vanished was present during the entirety (Experiments 2 and 3) or first half or second half (Experiment 4) of the retention interval between when that target vanished and a probe appeared, forward displacement of the target decreased. Furthermore, cues present during the retention interval resulted in a larger decrease in forward displacement than did cues present during target motion (comparison of Experiments 1 and 2; Experiment 3). Also, the relevance of a cue present during target motion or present during the retention interval influenced forward displacement in memory for that target. A high-relevant cue (presented at the location at which the target vanished or would vanish) decreased forward displacement more than did a low-relevant cue (presented above or below the location at which the target vanished or would vanish) when the cue was present during target motion (Experiment 1), whereas there was a marginally significant trend for a low-relevant cue to decrease forward displacement more than would a high-relevant cue when the cue was present during the retention interval (Experiment 2).

Presentation of a high-relevant cue or a low-relevant cue decreased forward displacement of the target, but cueing the final location of the target did not, in general, eliminate forward displacement of the target. The inability to eliminate representational momentum, even when a high-relevant cue spanned the entire retention interval (i.e., even in the condition that should have been most likely to eliminate representational momentum), is consistent with hypotheses that (a) displacement is at least partly automatic (Hayes & Freyd, 2002), (b) representational momentum might involve both modular and nonmodular components (Hubbard, 2005; see also Finke & Freyd, 1989), and (c) attention can modulate but not eliminate representational momentum (Kerzel, 2004). Furthermore, the inability of such a cue to eliminate representational momentum is consistent with findings that participants receiving explicit feedback about their response on a target-localization task (Ruppel, Fleming, & Hubbard, in press) or explicitly informed about representational momentum prior to participation in experimental trials and asked to compensate for its effect (Courtney & Hubbard, 2008) still exhibit significant forward displacement. The only exception to the inability of a cue to eliminate forward displacement is in the low-relevant cue condition in Experiment 2 (in which the final location of the target was not actually cued) and the elimination of displacement in this condition is consistent with the data of Kerzel (2003a).

The current data address two potential resolutions of Hayes and Freyd (2002) and Kerzel (2003a) regarding the relationship of attention and representational momentum. One potential resolution is that differences in the timing of the presentation and duration of the attentional manipulations in Hayes and Freyd and in Kerzel accounted for differences in the apparent effects of attention on forward displacement of the target. Some of the current data appear consistent with an effect of timing on displacement. For example, forward displacement when a cue was present in Experiment 1 was larger than forward displacement when a cue was present in Experiment 2, and Experiment 3 found a larger decrease in forward displacement when the cue was present during the retention interval than when the cue was present during only target motion. In these data, the decrease in forward displacement increased when the latency between when the cue vanished and when the probe appeared decreased. However, forward displacement in Experiment 4 was not consistent with a timing hypothesis. Similarly, cues in the target block and cues in the retention block were the same duration in Experiment 3, but cues in the retention block led to larger decreases in forward displacement. Indeed, given that, in the experiments reported here, presentation of a cue decreased forward displacement regardless of when the cue was present, the timing of the attentional manipulation cannot solely account for differences between Hayes and Freyd's findings and Kerzel's findings.

Another potential resolution of Hayes and Freyd (2002) and of Kerzel (2003a) is that a nontarget stimulus can have different effects on the representation of the target. The concurrent task (stimulus) in Hayes and Freyd decreased attention allocated to the target but did not significantly disrupt processing of the final location of the target when the target vanished. In contrast, the subsequent distractor in Kerzel might have significantly disrupted processing of the final location of the target when the target vanished. If processing of the final location of the target was not disrupted (as in Hayes & Freyd), then normal consequences of such processing (e.g., representational momentum) would occur. However, if processing of the final location of the target was disrupted (as in Kerzel), then normal consequences of such processing (e.g., representational momentum) would not occur. Kerzel's data might reflect not a decrease in the allocation of attention to a functioning representation of the final location of the target per se, but instead might reflect a significant disruption to or even elimination of the representation of the final location of the target. Indeed, Kerzel's suggestion that memory averaging could account for the backward displacement he observed is consistent with the distractor disrupting representation of the final location of the target and leaving representations of previous positions (presented sufficiently prior to the appearance of the distractor) intact. Such an account is also consistent with suggestions that the cue in the current experiments functioned as a prime when presented prior to when the target vanished but as a distractor when presented after the target vanished.

Spatial cueing of the final location of a target decreases forward displacement in memory for that target. This finding is consistent with Hayes and Freyd's (2002) hypothesis that attention is required to stop a dynamic process and suggests the spatial cue can facilitate allocation of additional attention to the target or to the location corresponding to the final location of the target. A possible resolution of the differences between Hayes and Freyd (2002) and Kerzel (2003a) regarding the relationship of attention and representational momentum is that Hayes and Freyd's results reflect the allocation of attention, and Kerzel's results reflect a more general disruption of processing. In this latter case, not only was attention withdrawn from the target but processing of the target representation was also disrupted; this disruption, rather than effects of attention per se, resulted in the backward displacement in Kerzel's experiments. Alternative hypotheses involving landmark attraction or displacement of the cue as sole causes for the decrease in forward displacement of the target when a cue was presented were ruled out. Even though cueing the final location reduced forward displacement, cueing did not eliminate forward displacement, and this is consistent with suggestions that displacement is at least partially modular or automatic. The allocation of attention can influence but not eliminate displacement and, more broadly, could be involved in inhibiting or disengaging dynamic processes such as representational momentum.

References

Bryant, D. J., & Subbiah, I. (1994). Subjective landmarks in perception and memory for spatial location. *Canadian Journal of Experimental Psychology, 48,* 119–139.

Courtney, J. R., & Hubbard, T. L. (2004). Possible asymmetries and effects of attention in boundary extension. Paper presented at the 45th Annual Meeting of the Psychonomic Society, Minneapolis, MN.

Courtney, J. R., & Hubbard, T. L. (2008). Spatial memory and explicit knowledge: An effect of instruction on representational momentum. *Quarterly Journal of Experimental Psychology, 61,* 1778–1784.

Finke, R. A., & Freyd, J. J. (1989). Mental extrapolation and cognitive penetrability: Reply to Ranney and proposals for evaluative criteria. *Journal of Experimental Psychology: General, 118,* 403–408.

Freyd, J. J., & Finke, R. A. (1984). Representational momentum. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10,* 126–132.

Freyd, J. J., & Johnson, J. Q. (1987). Probing the time course of representational momentum. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 259–269.

Freyd, J. J., & Jones, K. T. (1994). Representational momentum for a spiral path. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 968–976.

Hayes, A. E., & Freyd, J. J. (2002). Representational momentum when attention is divided. *Visual Cognition, 9,* 8–27.

Hubbard, T. L. (1990). Cognitive representation of linear motion: Possible direction and gravity effects in judged displacement. *Memory & Cognition, 18,* 299–309.

Hubbard, T. L. (1993). The effects of context on visual representational momentum. *Memory & Cognition, 21,* 103–114.

Hubbard, T. L. (1995). Environmental invariants in the representation of motion: Implied dynamics and representational momentum, gravity, friction, and centripetal force. *Psychonomic Bulletin & Review, 2,* 322–338.

Hubbard, T. L. (1996). Displacement in depth: Representational momentum and boundary extension. *Psychological Research, 59,* 33–47.

Hubbard, T. L. (2005). Representational momentum and related displacements in spatial memory: A review of the findings. *Psychonomic Bulletin & Review, 12,* 822–851.

Hubbard, T. L. (2008). Representational momentum contributes to motion induced mislocalization of stationary objects. *Visual Cognition, 16,* 44–67.

Hubbard, T. L., & Motes, M. A. (2002). Does representational momentum reflect a distortion of the length or the endpoint of a trajectory? *Cognition, 82,* B89–B99.

Hubbard, T. L., & Ruppel, S. E. (1999). Representational momentum and landmark attraction effects. *Canadian Journal of Experimental Psychology, 53,* 242–256.

Jordan, J. S., & Knoblich, G. (2004). Spatial perception and control. *Psychonomic Bulletin & Review, 11,* 54–59.

Kerzel, D. (2000). Eye movements and visible persistence explain the mislocalization of the final position of a moving target. *Vision Research, 40,* 370–371.

Kerzel, D. (2002). Memory for the position of stationary objects: Disentangling foveal bias and memory averaging. *Vision Research, 42,* 159–167.

Kerzel, D. (2003a). Attention maintains mental extrapolation of target position: Irrelevant distractors eliminate forward displacement after implied motion. *Cognition, 88,* 109–131.

Kerzel, D. (2003b). Mental extrapolation of target position is strongest with weak motion signals and motor responses. *Vision Research, 43,* 2623–2635.

Kerzel, D. (2004). Attentional load modulates mislocalization of moving stimuli, but does not eliminate the error. *Psychonomic Bulletin & Review, 11,* 848–853.

Klein, R. M. (2000). Inhibition of return. *Trends in Cognitive Sciences, 4,* 138–147.

Munger, M. P., Solberg, J. L., Horrocks, K. K., & Preston, A. S. (1999). Representational momentum for rotations in depth: Effects of shading and axis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 157–171.

Müsseler, J., Stork, S., & Kerzel, D. (2002). Comparing mislocalizations with moving stimuli: The Fröhlich effect, the flash-lag, and representational momentum. *Visual Cognition, 9,* 120–138.

Posner, M. I., & Snyder, C. R. R. (1974). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola Symposium* (pp. 55–85). Hillsdale, NJ: Erlbaum.

Posner, M. I., & Snyder, C. R. R. (1975). Facilitation and inhibition in the processing of signals. In P. M. A. Rabbit & S. Dornic (Eds.), *Attention and performance* (Vol. 5, pp. 669–682). London: Academic Press.

Postma, A., Huntjens, R. J. C., Meuwissen, M., & Laeng, B. (2006). The time course of spatial memory processing in the two hemispheres. *Neuropsychologia, 44,* 1914–1918.

Ruppel, S. E., Fleming, C. N., & Hubbard, T. L. (in press). Representational momentum is not (totally) impervious to error feedback. *Canadian Journal of Experimental Psychology.*

Werner, S., & Diedrichsen, J. (2002). The time course of spatial memory distortions. *Memory & Cognition, 30,* 718–730.

Received January 4, 2008
Revision received October 14, 2008
Accepted October 21, 2008 ■