THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY
2005, 58A (6), 961–979

An effect of context on whether memory for initial position exhibits a Fröhlich effect or an onset repulsion effect

Timothy L. Hubbard and Michael A. Motes
Texas Christian University, Fort Worth, TX, USA

Memory for the initial and final positions of moving targets was examined. When targets appeared adjacent to the boundary of a larger enclosing window, memory for initial position exhibited a Fröhlich effect (i.e., a displacement forward), and when distance of initial position from the boundary increased, memory for initial position exhibited a smaller Fröhlich effect or an onset repulsion effect (i.e., a displacement backward). When targets vanished adjacent to the boundary of a larger enclosing window, memory for final position was displaced backward, and when distance of final position from the boundary increased, memory for final position did not exhibit significant displacement. These patterns differed from previously reported displacements of initial and final positions of targets presented on a blank background. Possible influences of attention and extrapolation of trajectory on whether memory for initial position exhibits a Fröhlich effect or onset repulsion effect and on backward displacement in memory for final position are discussed.

Observers asked to indicate where a previously perceived moving target appeared or vanished often exhibit systematic biases in their judgements. Memory for the initial (onset) position may be displaced forward in the direction of target motion, and this has been referred to as the *Fröhlich effect* (e.g., Müsseler & Aschersleben, 1998); alternatively, memory for the initial position may be displaced backward in the direction opposite to target motion, and this has been referred to as the *onset repulsion effect* (e.g., Thornton, 2002). Thornton pointed out that an important focus of future studies on memory for the initial position of a moving target should be to determine when memory exhibits a Fröhlich effect and when memory exhibits an onset repulsion effect, and so a primary purpose of the studies reported here is to examine a potential variable, spatial context, that influences whether memory for

Correspondence should be addressed to Timothy Hubbard, Department of Psychology, TCU Box 298920, Texas Christian University, Fort Worth, TX 76129, USA. Email: t.hubbard@tcu.edu

The authors thank Jane Montgomery for assistance in data collection and Dirk Kerzel and an anonymous reviewer for comments on a previous draft of the manuscript.

Portions of these data were presented at the Second Annual Meeting of the Vision Sciences Society (Sarasota, Florida, May 2002) and at the European Conference on Visual Perception (Glasgow, Scotland, August 2002).

Michael Motes is now at Department of Psychology, Rutgers University-Newark, Newark, NJ 07102, USA.

http://www.tandf.co.uk/journals/pp/02724987.html DOI:10.1080/02724980443000368

initial position exhibits a Fröhlich effect or an onset repulsion effect. Memory for the final (offset) position of a moving target is often displaced in the direction of anticipated target motion, and this has been referred to as *representational momentum* (e.g., Freyd & Finke, 1984). A secondary purpose of the studies reported here is to consider how biases in memory for initial position may be related to biases in memory for final position.

Kerzel and Gegenfurtner (2004) suggested that whether a Fröhlich effect or an onset repulsion effect occurred was influenced by a combination of an attentional delay and a bias in motor judgements, and Thornton (2002) and Kerzel (2002c) each speculated on a number of other variables that might influence whether memory for initial position exhibited a Fröhlich effect or an onset repulsion effect. One possible influence on whether memory for initial position exhibits a Fröhlich effect or an onset repulsion effect that has not yet been extensively investigated is the spatial context within which target motion is embedded, although Kerzel and Müsseler (2002) noted that the presence of a nontarget cue aligned with the initial position of the target could reduce the magnitude of the Fröhlich effect. It is well known that spatial context consisting of nontarget stimuli to one side of (Hubbard & Ruppel, 1999; Kerzel, 2002b), on opposite sides of (Gray & Thornton, 2001), or surrounding (Hubbard, 1993) a target influences displacement in memory for the final position of that target. Given that memory for final position is influenced by spatial context, perhaps memory for initial position may be similarly influenced. Our focus here is on a narrow type of spatial context involving the presence of a larger enclosing window within which target motion occurs.

In studies that reported an onset repulsion effect, the target would typically appear in relative isolation on a blank background, whereas in studies that reported a Fröhlich effect, the target would typically emerge into a window from behind an apparently occluding surface. Thus, whether memory for initial position exhibited an onset repulsion effect or a Fröhlich effect might be influenced by whether the target appeared within an enclosing window (or close to an apparently occluding boundary) or appeared in relative isolation on a blank background (or far from an apparently occluding boundary): Targets that appeared within an enclosing window and adjacent to the boundary would exhibit a Fröhlich effect, whereas targets that appeared on a blank background or within an enclosing window but some distance from the inner edge of the window would exhibit an onset repulsion effect.[1] Given that memory for the final position of a moving target may be influenced by the presence of a larger window within which target motion occurs—for example, forward displacement in memory for the final position of a rectangle undergoing implied rotation is increased if a larger surrounding frame (a) is stationary but aligned with an orientation slightly beyond the final orientation of the target or (b) rotates in the same direction as the

[1]There are two studies that initially appear to be exceptions to this general pattern, but which upon closer examination may not be exceptions. Müsseler and Aschersleben (1998) reported a robust Fröhlich effect for horizontally moving targets presented on a blank background or moving between background scales (i.e., rulers). However, the target always appeared at either one of two highly predictable locations, and when this trial context was eliminated, the Fröhlich effect was also eliminated (see Müsseler & Kerzel, 2004). It may be that the predictability of target location provided a "functional window" within the display, which influenced remembered position much as did a real window. Thornton (2002) reported a robust onset repulsion effect for targets that moved across a grid pattern. However, this grid pattern covered the extent of the background and so may have acted more like a textured background rather than as a spatial context (i.e., rather than as a nontarget stimulus object) per se.

target (Hubbard, 1993)—it would not be surprising to see influences of a larger enclosing window on displacement in memory for initial position.

The relationship between displacement in memory for initial position and displacement in memory for final position is not clear. Memory for both initial position and final position of the same (type of) stimulus has been measured in only a few studies (e.g., Actis Grosso & Stucchi, 2003; Hubbard & Motes, 2002; Thornton, 2002), and in most studies an onset repulsion effect and representational momentum were usually reported, and a Fröhlich effect was usually not reported. Also, studies that reported a Fröhlich effect have typically not measured memory for final position (although see Müsseler, Stork, & Kerzel, 2002). This pattern suggests that displacement in memory for initial position and displacement in memory for final position may be inversely related, and on this basis it could be predicted that a backward displacement in memory for final position should be observed if memory for initial position exhibits a Fröhlich effect. Alternatively, memory for initial position and memory for final position may be relatively independent, in which case it could be predicted that a forward displacement in memory for final position should be observed regardless of whether memory for initial position exhibited a Fröhlich effect or an onset repulsion effect. Thus, whether memory for the final position of a target that also exhibits a Fröhlich effect (in memory for initial position) is displaced forward or backward may be of considerable theoretical interest.

One study that examined memory for initial position and memory for final position, but that did not report an onset repulsion effect, was carried out by Müsseler et al. (2002). Observers viewed a target that traversed approximately 86 degrees of arc along the perimeter of a circular path. A stationary stimulus was briefly flashed near the initial position when the target appeared or near the final position when the target vanished. When the flashed stimulus was relevant to the task (i.e., when observers were instructed to judge target position at the time of the flash), a robust Fröhlich effect in memory for initial position and a backward displacement in memory for final position (in the direction opposite to representational momentum) were exhibited. When the flashed stimulus was irrelevant to the task (i.e., when observers were instructed to ignore the flash and to judge the initial position or the final position of the target), a reduced Fröhlich effect and a reduced representational momentum were exhibited. When the same targets were presented in the absence of the flashed stimulus, there was no displacement in memory for initial position (i.e., neither a Fröhlich effect nor an onset repulsion effect occurred), and a robust forward displacement in memory for final position was exhibited. Thus, context in the form of a nearby flashed stationary stimulus may influence both memory for initial position and memory for final position.

It is possible that the flashed stationary stimulus in Müsseler et al. (2002) may have activated orientation mechanisms or otherwise interfered with the normal encoding of target position. In the studies reported here, a more permanent spatial context in the form of a frame or window within which target motion occurred was presented, and such a frame is similar to that presented in early studies of the Fröhlich effect (e.g., see illustrations in Kirschfeld & Kammer, 1999; Müsseler & Neumann, 1992) and in early studies of effects of context on representational momentum (e.g., Hubbard, 1993; Hubbard & Bharucha, 1988). In addition to examining how such context influences memory for initial position, two of the studies reported here allow examination of the relationship between displacement in memory for initial position and displacement in memory for final position. In Experiment 1, translating targets appeared and vanished adjacent to the inner edge of an enclosing window.

In Experiment 2, whether the initial position or the final position of a translating target was adjacent to or separated from the inner edge of an enclosing window varied. Immediately after the target vanished in Experiments 1 and 2, an auditory cue instructed observers to indicate remembered initial position or remembered final position. In Experiment 3, observers viewed the same targets as those in Experiment 2, but always indicated remembered initial position. In all experiments, observers indicated remembered initial position or remembered final position of the target by using a computer mouse to position the cursor at the appropriate display coordinates.

EXPERIMENT 1

Hubbard and Motes (2002) presented a vertically or horizontally moving target and measured displacement in memory for initial position and displacement in memory for final position. In that study, targets were presented in isolation and on a blank background, and a robust onset repulsion effect and a robust representational momentum were exhibited. Experiment 1 presented the same stimuli as those used in Hubbard and Motes, but with one crucial difference: A square window was drawn on the display, and visible motion of the target was entirely within the confines of the window. The target appeared adjacent to one side of the window and vanished as soon as it contacted the opposite side of the window. Given the similarity of this display to displays used in early studies of the Fröhlich effect, memory for initial position could be predicted to be displaced forward, but given that observers would not expect to view a target outside the boundaries of the window, memory for final position should not be displaced forward. Indeed, given the inverse relationship between displacement in memory for initial position and displacement in memory for final position noted in Hubbard and Motes, it could be predicted that memory for final position might even be displaced backward. Differences from the displacement patterns observed in Hubbard and Motes would demonstrate an effect of spatial context on memory for initial position and memory for final position.

Method

Participants

Observers were 14 undergraduates from Texas Christian University who participated for partial course credit in an introductory psychology course.

Apparatus

The stimuli were generated by and responses collected upon an Apple Macintosh IIsi computer connected to an Apple RGB colour monitor, and the auditory cue was presented over stereo headphones (Kenwood #KPM-210) connected directly to the computer. The viewing distance was approximately 60 cm.

Stimuli

The target stimulus was a filled black square approximately 0.83 degrees (20 pixels) in width and was presented on a white background approximately 26.67 deg (640 pixels) in width and 19.17 deg

(460 pixels) in height. Motion of the target was left to right (LR), right to left (RL), top to bottom (TB), or bottom to top (BT); motion of LR or RL targets was aligned with the approximate vertical midpoint of the display, and motion of TB or BT targets was aligned with the approximate horizontal midpoint of the display. The window within which target motion occurred was a large square, and the lines denoting the sides of the window were 1 pixel in width. The centre of the square was located at the centre of the display, and the lengths of the sides of the square varied across trials from 8.33 to 12.08 deg (200 to 290 pixels). The initial position of the target was adjacent to the inner edge of one of the sides of the window near the approximate midpoint of that side, and this was generally consistent with previous studies of the Fröhlich effect in which targets appeared at the edge of the window. The final position of the target was adjacent to the inner edge of the side of the window directly opposite to where the target had appeared. Target velocity was manipulated by varying the distance between successive presentations of the target; for the relatively slow velocity (approximately 5 deg/s), the target shifted 1 pixel between successive presentations, and for the relatively fast velocity (approximately 15 deg/s), the target shifted 3 pixels between successive presentations. Given previous findings that observers mislocalize objects toward the fovea (Kerzel, Jordan, & Müsseler, 2001; Müsseler, van der Heijden, Mahmud, Deubel, & Ertsey, 1999), coupled with a desire for a more ecologically valid response, a fixation point was not used, and observers were allowed to visually track the target.[2] The auditory cue was a 250-Hz or 2,000-Hz tone that played for one second. Each observer received 128 trials in a different random order: 2 (auditory cues: 250, 2,000 Hz) $\times$ 4 (directions: LR, RL, TB, BT) $\times$ 2 (velocities: 5, 15 deg/s) $\times$ 8 (replications).

Procedure

Observers received 10 practice trials (drawn randomly from experimental trials) at the beginning of the session. Observers initiated each trial by pressing a designated key. There was a one-second pause, and then the target and window simultaneously appeared, and the target immediately began moving in a straight line across the display. Observers were instructed to watch the target. The target vanished when it reached the opposite side of the window, and the window vanished at the same time that the target vanished. Immediately after the target vanished, the auditory cue was presented. A high tone (2,000 Hz) instructed observers to indicate where the target appeared; a low tone (250 Hz) instructed observers to indicate where the target vanished. Observers indicated the judged initial position or judged final position of the target by using a computer mouse to position the cursor at the appropriate display coordinates and then pressing the button on the mouse. Observers then initiated the next trial by pressing a designated key.

[2]Representational momentum for some types of stimuli may be influenced by whether the observer fixates a single location some distance from the target or is allowed to visually track the target, and this has led some researchers to suggest that displacement may result from pursuit eye movements and a bias toward the fovea (e.g., Kerzel, 2000). However, fixating a stationary point some distance away from a moving target that an observer has to respond to is not a useful strategy in everyday contexts, and it may be that the disruption of displacement with fixation in some experiments may result from a disruption in the flow of information regarding eye movement activity that is normally provided to higher order mechanisms that produce displacement rather than to any casual role of eye movements per se. Numerous studies suggest a role for higher order processes in displacement (for reviews, see Hubbard, 1995, 2004), and, coupled with the failure of an eye movement explanation to account for representational momentum in memory for "frozen action" photographs (e.g., as in Freyd, 1983; Futterweit & Beilin, 1994) and in memory for stimuli undergoing implied motion (e.g., as in Freyd & Finke, 1984), it is unlikely that eye movements are the primary causal mechanism for representational momentum and related displacements. Given this, a more useful methodology in the current experiments would allow observers to use whatever strategy they would normally use in tasks involving spatial memory.

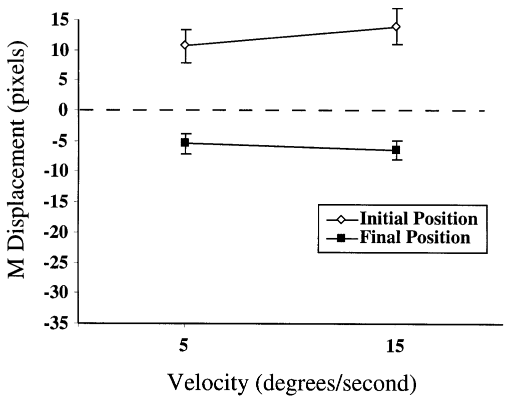

Figure 1. M displacement as a function of target velocity in Experiment 1. The open diamonds display data from judgements of initial position, and the filled squares display data from judgements of final position. Error bars reflect the standard error of the mean.

Results

Differences between the true initial position and the judged initial position, and between the true final position and the judged final position, were calculated along the axis of motion. As in previous reports, these differences were referred to as *M displacement*.[3] Positively signed M displacement indicated that the judged initial position or judged final position was beyond the true initial position or true final position (i.e., right of a LR target, left of a RL target, below a TB target, above a BT target), and negatively signed M displacement indicated that the judged initial position or judged final position was behind the true initial position or true final position (i.e., left of a LR target, right of a RL target, above a TB target, below a BT target).

M displacements were analysed in a 2 (judgement: initial position, final position) × 4 (direction: LR, RL, TB, BT) × 2 (velocity: slow, fast) repeated measures analysis of variance (ANOVA). Judgement influenced M displacement, $F(1, 13) = 7.95$, $MSE = 2{,}346.34$, $p < .02$; as shown in Figure 1 and in the top panel of Figure 2, judgement of initial position ($M = 12.38$) exhibited forward M displacement, and judgement of final position ($M = -5.88$) exhibited backward M displacement. The Judgement × Velocity interaction was marginally significant, $F(1, 13) = 4.23$, $MSE = 59.71$, $p < .07$. An analysis of all possible simple effects of the Judgement × Velocity interaction revealed that judgement of initial position exhibited more forward displacement than did judgement of final position at slow, $F(1, 13) = 6.33$, $MSE = 1{,}151.08$, $p < .03$, and fast, $F(1, 13) = 9.27$, $MSE = 1{,}254.00$, $p < .01$, velocities, and that for judgement of initial position, fast velocity led to a marginally larger forward displacement than did slow velocity, $F(1, 13) = 3.35$, $MSE = 86.97$, $p < .10$. Direction was also significant,

[3]Displacement may be measured along different axes (e.g., previous studies distinguished between displacement along the axis of motion, *M displacement*, and displacement along the axis orthogonal to motion, *O displacement*), and the "M" specifies displacement along the axis of motion. Even though no other displacements are of interest in the current study, the "M" qualifier is retained in order to be consistent with previous practice.

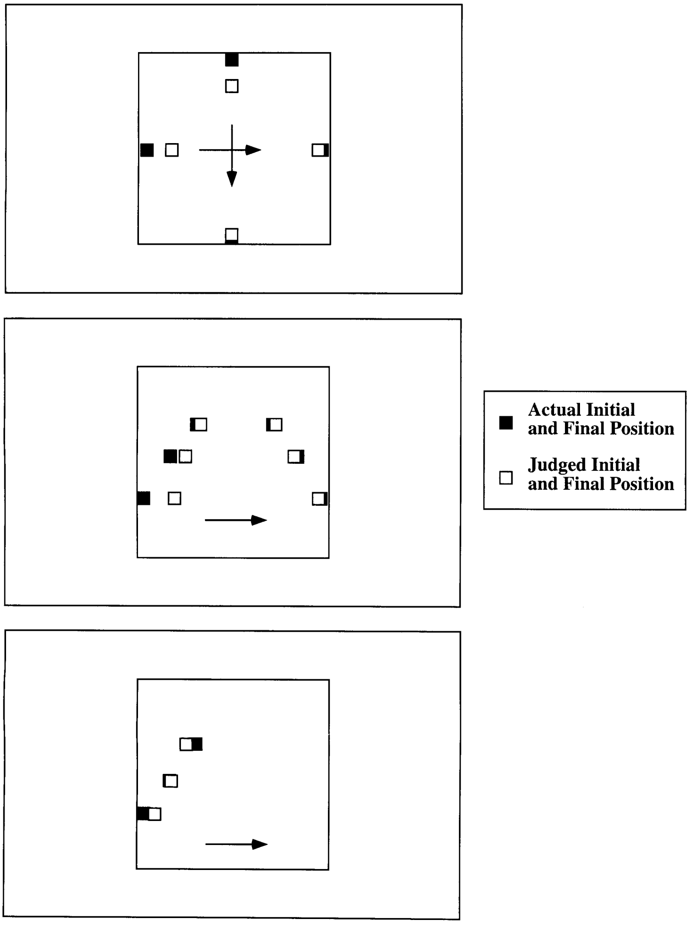

Figure 2. Examples of actual and judged initial and final positions in Experiments 1, 2, and 3. The filled squares indicate the actual initial and final positions, and the open squares indicate the judged initial and final positions; the arrows indicate the direction of motion. The top panel displays displacement of rightward and descending targets from Experiment 1; the middle panel displays displacement of rightward targets from Experiment 2, and the bottom panel displays displacement of rightward targets from Experiment 3. The vertical positions of targets adjacent to the window or separated from the window in the middle and bottom panels have been offset for clarity, but in the actual experiments, vertical position did not vary as a function of separation from the window. Displacement relative to target size is drawn to scale, but target size relative to display size is not to scale.

$F(3, 39) = 5.16$, $MSE = 233.95$, $p < .05$, and a post hoc Newman–Keuls test ($p < .05$) of all pairwise comparisons revealed that BT ($M = -3.52$) targets exhibited more backward displacement than did LR ($M = 5.53$), RL ($M = 4.13$), or TB ($M = 6.85$) targets. No other main effects or interactions were significant.

A set of four comparisons (2 judgement $\times$ 2 velocity) of displacement against zero were carried out, and a Bonferroni correction for $p < .05$ (.05/4 = .0125) was used. As shown in

Figure 1, memory for initial position exhibited significant positive displacement for slow, $t(55) = 3.85$, $p < .001$, and fast, $t(55) = 4.77$, $p < .001$, velocities, and memory for final position exhibited significant negative displacement for slow, $t(55) = -5.37$, $p < .002$, and fast, $t(55) = -4.20$, $p < .001$, velocities.

Discussion

M displacement in memory for initial position was positive; this is consistent with the Fröhlich effect and is not consistent with the onset repulsion effect. The forward displacement in memory for initial position observed in Experiment 1 is opposite to the direction of M displacement in memory for initial position in Hubbard and Motes (2002), and so the Fröhlich effect observed in Experiment 1 presumably resulted from the addition of the surrounding context to the display. M displacement in memory for final position was negative; this is not consistent with representational momentum per se, but it is consistent with previous studies that suggest memory for final position of a target is displaced in ways consistent with the anticipated behaviour of that target (e.g., Hubbard, 1994; Verfaillie & d'Ydewalle, 1991); given that observers never saw the target presented outside the window, they would not have expected the target to pass through the boundaries of the window, and such expectation might have been strong enough to result in negative displacement of targets that vanished adjacent to the boundary of the window. Indeed, the general expectation that the target would not be presented outside the window would presumably have influenced memory for initial position and memory for final position. Additionally, the relatively smaller magnitude of M displacement in memory for final position relative to M displacement in memory for initial position may in part reflect the predictability of the final position once the window was visible and the target had appeared.

The forward displacement in memory for initial position and the backward displacement in memory for final position are consistent with the pattern in Müsseler et al. (2002) when a flash was presented at target onset or at target offset, and observers indicated the position of the target at the time of the flash. The data in Experiment 1, Hubbard and Motes (2002), and the flash-relevant condition in Müsseler et al. (2002) all suggest that displacement in memory for initial position and displacement in memory for final position may be inversely related: Backward displacement in memory for initial position is accompanied by forward displacement in memory for final position, and forward displacement in memory for initial position is accompanied by backward displacement in memory for final position. However, in Experiment 1 and in Hubbard and Motes the spatial context near the initial position and that near the final position were highly similar, and a different relationship between memory for initial position and memory for final position might occur if the spatial contexts of initial position and final position were different (e.g., if the initial position was near the boundary within the "closed" end of a U-shaped structure and the final position was near the "open" end of that U-shaped structure). Also, in Müsseler et al. (2002) the inverse relationship between displacement in memory for initial position and displacement in memory for final position was not found when the flash (context) was irrelevant to the judgement of target position.

If having the initial position of the target contained within the larger enclosing window in Experiment 1 resulted in a Fröhlich effect, then why did having the target contained within the larger enclosing display screen in Hubbard and Motes (2002) not also result in a Fröhlich effect? More generally, why did the edges of the display not act as a "window"? The target appeared adjacent to the window in Experiment 1, but the target did not initially appear adjacent to the edge of the display in Hubbard and Motes (2002), and so it may be that initial adjacency to a boundary or surrounding context influences whether memory for initial position exhibits an onset repulsion effect or a Fröhlich effect. Of course, had the target appeared adjacent to the edge of the display, an onset repulsion effect could not have been measured because any location behind the target would have been beyond the edges of the display, and there would have been no visible location in which the cursor could have been positioned to directly reflect such a location. What would be necessary in order to further examine this notion would be to present a window that was well within the boundaries of the display (as in Experiment 1) so that a backward displacement outside the window could potentially be indicated, but then to vary the proximity of the initial position of the target so that the target was either adjacent to the inner edge of the window (as in Experiment 1) or separated from the inner edge of that window (as the target was separated from the edge of the display in Hubbard & Motes, 2002). This was done in Experiment 2.

EXPERIMENT 2

The data from Experiment 1 and from Hubbard and Motes (2002) suggested that whether memory for the initial position of a moving target exhibited a Fröhlich effect or an onset repulsion effect was influenced by whether the initial position of the target was adjacent to the edge of a window into which the target had just emerged or the initial position of the target was separated from such a boundary. If the presence or proximity of such a boundary influences whether memory for initial position exhibits a Fröhlich effect or an onset repulsion effect, then it could be predicted that displacement in memory for initial position should be influenced by the distance of the initial position of the target from the edge of an enclosing window: If the initial position of the target is adjacent to the inner edge of the window, then a robust Fröhlich effect should be exhibited, but if the initial position of the target is sufficiently separated from the inner edge of the window, then the Fröhlich effect should be reduced or an onset repulsion effect should be exhibited. Accordingly, the initial position of the target in Experiment 2 was either adjacent to the inner edge of the window or separated from the inner edge of the window. Also, the final position of the target was either adjacent to the inner edge of the window or separated from the inner edge of the window.

Method

Participants

Observers were 16 undergraduates from the same participant pool as that used in Experiment 1, and none had participated in the previous experiment.

Apparatus

The apparatus was the same as that in Experiment 1.

Stimuli

The target and window were the same as those in Experiment 1, with the following exceptions: The initial position of each target was adjacent (0 pixels) to, 1.25 deg (30 pixels) away from, or 2.50 deg (60 pixels) away from the inner edge of the window, and the final position of each target was 2.50 deg (60 pixels) away from, 1.25 deg (30 pixels) away from, or adjacent (0 pixels) to the inner edge of the window. Distance of initial position from the window was counterbalanced across distance of final position, and distance of final position from the window was counterbalanced across distance of initial position. In order to decrease the total number of trials, only LR targets and RL targets were presented. The auditory cue was the same as that in Experiment 1. Each observer received 144 trials in a different random order: 2 (auditory cues: 250, 2,000 Hz) × 2 (directions: LR, RL) × 3 (distances: 0, 30, 60 pixels) × 2 (velocities: 5, 15 deg/s) × 6 (replications).

Procedure

The procedure was the same as that in Experiment 1.

Results

M displacements were calculated as in Experiment 1. Judgements for each distance of initial position collapsed across all distances of final position, and judgements for each distance of final position collapsed across all distances of initial position.

M displacements were analysed in a 2 (judgement: initial position, final position) × 2 (direction: LR, RL) × 3 (distance: 0, 30, 60 pixels) × 2 (velocity: slow, fast) repeated measures ANOVA. Judgement influenced M displacement, $F(1, 15) = 9.56$, $MSE = 6{,}253.45$, $p < .01$; as shown in Figure 3 and in the middle panel of Figure 2, judgement of initial position ($M = 22.46$) exhibited forward M displacement, and judgement of final position ($M = -2.49$) exhibited backward M displacement. Distance, $F(2, 30) = 28.82$, $MSE = 190.56$, $p < .001$, and Judgement × Distance, $F(2, 30) = 79.74$, $MSE = 332.38$, $p < .001$, were significant. M displacement for initial position was positive and decreased with increases in the distance of the initial position from the inner edge of the window, and M displacement for final position was negative for targets adjacent to the window and less negative or not significantly different from zero for targets more distant from the inner edge of the window. The Judgement × Direction × Distance interaction was also significant, $F(2, 30) = 5.16$, $MSE = 206.94$, $p < .02$, such that differences between distances for initial positions were slightly greater for RL targets. No other main effects or interactions were significant.

A set of 12 comparisons, 2 (judgement) × 3 (distance) × 2 (velocity), of displacement against zero were carried out, and a Bonferroni correction for $p < .05$ (.05/12 = .0004) was used. As shown in Figure 3, memory for initial position exhibited significant positive displacement for adjacent slow, $t(31) = 7.78$, $p < .0001$, adjacent fast, $t(31) = 9.74$, $p < .0001$, 30-pixel slow, $t(31) = 4.20$, $p < .0002$, and 30-pixel fast, $t(31) = 4.35$, $p < .0001$, targets. Memory for initial position did not exhibit significant displacement for 60-pixel slow, $t(31) = 0.24$, $p > .81$, and 60-pixel fast, $t(31) = 0.65$, $p > .52$, targets. Memory for final position was marginally significantly negative for adjacent slow, $t(31) = -3.81$, $p < .0006$, and significantly negative for

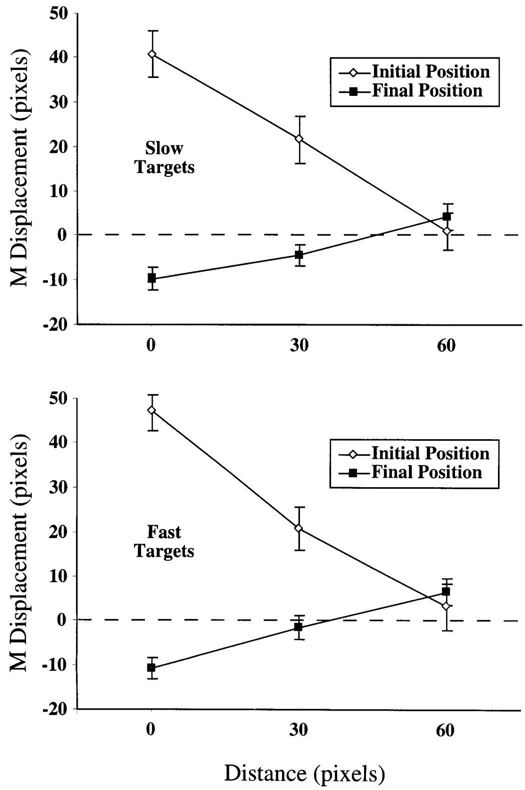

Figure 3. M displacement as a function of target distance from the frame in Experiment 2. Data from the slow-velocity condition are displayed in the upper panel, and data from the fast-velocity condition are displayed in the lower panel. The open diamonds display data from judgements of initial position, and the filled squares display data from judgements of final position. Error bars reflect the standard error of the mean.

adjacent fast, $t(31) = -4.53$, $p < .0001$, targets. Memory for final position did not exhibit significant displacement for 30-pixel slow, $t(31) = -1.79$, $p > .07$, 30-pixel fast, $t(31) = -0.49$, $p > .63$, 60-pixel slow, $t(31) = 1.39$, $p > .17$, and 60-pixel fast, $t(31) = 2.29$, $p > .02$, targets.

Discussion

When the initial position of the target was adjacent to the inner edge of a larger enclosing window, M displacement was forward and relatively large, and as the distance of the initial position of the target from the inner edge of the window increased, positive M displacement decreased. Inspection of Figure 3 reveals a robust Fröhlich effect in memory for targets that appeared adjacent to or 30 pixels from the inner edge of the window, but memory for targets that appeared 60 pixels from the inner edge of the window did not exhibit either a Fröhlich effect or an onset repulsion effect. Even though a negative M displacement consistent with an onset repulsion effect was not exhibited, the pattern observed in Experiment 2 was consistent with the broader hypothesis that the distance of the initial position of a target from the inner edge of the window influenced displacement in memory for initial position. Given that the initial position of the target in Hubbard and Motes (2002) was separated from the edge of the display by a distance larger than the largest (60-pixel) separation used in Experiment 2, it might be that an onset repulsion effect would be exhibited if an even larger separation of initial target position from the edge of the window were used.

When the final position of the target was adjacent to the inner edge of a larger enclosing window, M displacement was backward, but as the distance of the initial position of the target from the inner edge of the window increased, M displacement was nonsignificantly different from zero (although memory for 60-pixel fast targets would have been considered positively displaced if a Bonferroni correction had not been applied). Inspection of Figure 3 suggests that the effect of distance was not as large for judgements of final position as for judgements of initial position (i.e., the slope for judgements of initial position is much steeper), and, as in Experiment 1, the magnitude of M displacement for judgements of final position was not as large as the magnitude of M displacement for judgements of initial position. These differences may in part reflect the additional predictability of the final position once the window and the target were visible, although the predictability of the final position was not as great in Experiment 2 (in which distance of the initial position from the edge of the window on a given trial was counterbalanced across three different possible distances of the final position from the edge of the window) as in Experiment 1 (in which the final position was always adjacent to the edge of the window).

EXPERIMENT 3

As noted earlier, studies that reported a Fröhlich effect typically did not also examine memory for the final position of the target (but see Müsseler et al., 2002). Even though Thornton (2002) demonstrated that the occurrence of an onset repulsion effect did not depend upon whether observers also indicated the remembered final position of the target, it is desirable to replicate the distance effect obtained in Experiment 2 with a methodology more representative of studies that reported a Fröhlich effect (i.e., it is desirable to show a similar effect of the distance to the inner edge of a window on memory for initial position when only memory for initial position is measured). If memory for initial position is influenced by the distance of the initial position from the inner edge of an enclosing window as suggested by Experiment 2, then forward displacement in memory for initial position should decrease with increases in separation of the initial position from the inner edge of the window in Experiment 3. Indeed, to the extent that the Fröhlich effect relies on attention or on some other process that might be used in representing other parts of the trajectory, having observers judge only the initial position might influence the magnitude of the effect of distance. Accordingly, Experiment 3 presented the same targets as those in Experiment 2, but no auditory cue was presented, and on each trial observers indicated the initial position of the target.

Method

Participants

Observers were 15 undergraduates from the same participant pool as that used in Experiment 1, and none had participated in the previous experiments.

Apparatus

The apparatus was the same as that in Experiment 1.

Stimuli

The target and window were the same as those in Experiment 2. Each observer received 72 trials in a different random order: 2 (directions: LR, RL) × 3 (distances: 0, 30, 60 pixels) × 2 (velocities: 5, 15 deg/s) × 6 (replications).

Procedure

The procedure was the same as that in Experiment 2, with the following exceptions: An auditory cue was not presented, and after the target vanished, observers always indicated the remembered initial position of that target.

Results

M displacements were calculated as in Experiment 1 and collapsed across all distances of final position as in Experiment 2.

M displacements were analysed in a 2 (direction: LR, RL) × 3 (distance: 0, 30, 60 pixels) × 2 (velocity: slow, fast) repeated measures ANOVA. As shown in Figure 4 and in the bottom panel of Figure 2, distance influenced M displacement, $F(2, 28) = 66.57$, $MSE = 218.55$,

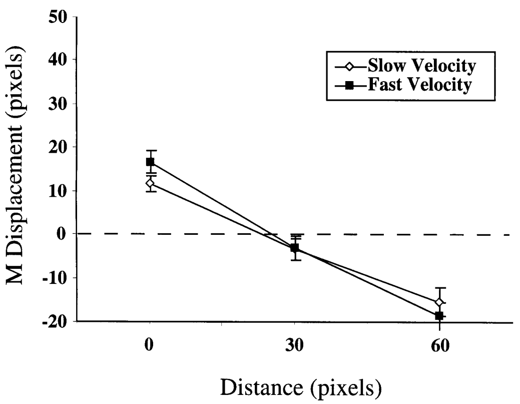

Figure 4. M displacement as a function of target distance from the frame in Experiment 3. The open diamonds display data from judgements of slow-velocity targets, and the filled squares display data from judgements of high-velocity targets. Error bars reflect the standard error of the mean.

$p < .0001$, such that M displacement was positive when targets appeared adjacent to the inner edge of the window and negative when targets appeared at the largest separation from the inner edge of the window. Distance also interacted with direction, $F(2, 30) = 5.64$, $MSE = 40.58$, $p < .01$, and velocity, $F(2, 30) = 4.37$, $MSE = 57.58$, $p < .05$, such that the effect of distance was greater for fast-velocity targets and for RL targets. No other main effects or interactions were significant.

A set of six comparisons (3 distance × 2 velocity) of displacement against zero were carried out, and a Bonferroni correction for $p < .05$ (.05/6 = .008) was used. As shown in Figure 4, memory for initial position exhibited a significant positive displacement for adjacent slow, $t(29) = 6.57$, $p < .001$, and fast, $t(29) = 6.19$, $p < .001$, velocities. Memory for initial position did not exhibit significant displacement for 30-pixel slow, $t(29) = -1.29$, $p > .21$, and fast, $t(29) = -1.04$, $p < .001$. Memory for initial position exhibited significant negative displacement for 60-pixel slow, $t(29) = -4.68$, $p < .001$, and fast, $t(29) = -5.76$, $p < .001$, velocities.

Discussion

When the initial position of the target was adjacent to the inner edge of a larger enclosing window, M displacement was positive, and when the initial position of the target was separated from the inner edge of the window, M displacement was near zero or was negative. This displacement pattern is broadly consistent with that found in memory for initial position in Experiment 2, and it is also consistent with the hypothesis that memory for initial position exhibits a Fröhlich effect if initial position is adjacent to the edge of a larger enclosing window and an onset repulsion effect if initial position is a sufficient distance from the edge of a larger enclosing window or the target is on a blank background. Alternatively, it might be argued that displacement in Experiment 3 reflected a regression-to-the-mean in which memory for initial position on any given trial was displaced toward an average of all possible initial positions. However, if displacement of initial position in Experiment 3 reflected a regression to the average initial position, then in Experiment 2 the displacement of targets with an initial position most distant from the inner edge of the window should have had approximately the same magnitude but the opposite sign as the displacement of targets adjacent to the window. Such a pattern did not occur in Experiment 2, and so it is not likely that effects of distance from the inner edge of the window in Experiment 3 are due to regression to the average initial position. Rather, the results of Experiments 2 and 3 replicated within subjects the different directions of displacement that had been reported in separate studies by previous investigators.

Although in Experiments 2 and 3 the forward displacement in memory for initial position decreased as the separation of the initial position of the target and the inner edge of the window increased, inspection of Figures 3 and 4 show that in Experiment 2 this decrease resulted in a nonsignificant displacement at the largest separation, whereas in Experiment 3 this decrease resulted in a significant negative displacement (i.e., an onset repulsion effect) at the largest separation. One potential explanation for this difference is that the possibility of being asked about the final position of the target in Experiment 2 might have focused relatively more attention on subsequent parts of the trajectory in Experiment 2 than was focused on those parts in Experiment 3, and the resultant greater salience of those subsequent parts of the trajectory might have shifted the general centre of activation of the representation of the target's trajectory forward (and thus the display coordinates at which a displacement in memory for initial position would change from positive to negative in Experiment 2 were shifted forward). Even if such a general forward shift of the represented trajectory occurred in Experiment 2, the largest separation condition in Experiment 3 still replicated Thornton's finding that an onset repulsion effect in memory for initial position can be observed when memory for final position is not measured. Also, in Experiment 3 a larger effect of distance for faster velocities was observed, and, as in Experiment 2, the effect of distance on memory for initial position was larger for RL targets.

GENERAL DISCUSSION

Memory for the initial position of a moving target was displaced forward when the initial position of the target was adjacent to the inner edge of a larger enclosing window, and this is consistent with the Fröhlich effect but not consistent with the onset repulsion effect (Experiment 1). Furthermore, the magnitude of forward displacement in memory for the initial position of a moving target within a larger enclosing window decreased as the distance of the initial position from the nearest inner edge of the enclosing window increased (Experiments 2 and 3). In contrast, Hubbard and Motes (2002) reported that memory for the initial position of a moving target presented in isolation on a blank background was displaced backward when the initial position of that target was separated from the edge of the display, and this is consistent with the onset repulsion effect but not consistent with the Fröhlich effect. In general, the data from Experiments 1, 2, and 3 and from Hubbard and Motes were consistent with the hypothesis that whether memory for the initial position of a target exhibited a Fröhlich effect or an onset repulsion effect was determined (at least in part) by the presence of a boundary (in this case, a larger enclosing window) and the distance of the initial position of the target from that boundary.

Memory for the final position of a moving target was displaced backward when the final position of the target was adjacent to the inner edge of a larger enclosing window (Experiment 1). Furthermore, the magnitude of backward displacement in memory for the final position of a moving target within a larger enclosing window decreased and became nonsignficantly different from zero as the distance of the initial position from the nearest inner edge of the enclosing window increased (Experiment 2). In contrast, Hubbard and Motes (2002) reported that memory for the final position of a moving target presented in isolation on a blank background was displaced forward when the final position of that target was separated from the edge of the display, and this is consistent with representational momentum. The data on memory for final position from Experiments 1 and 2 were not consistent with a literal momentum metaphor (which predicted forward displacement regardless of the proximity of surrounding nontarget stimuli), but given that many theorists have rejected such a literal explanation of representational momentum (e.g., Cooper & Munger, 1993; Freyd, 1987; Hubbard, 1995; Kozhevnikov & Hegarty, 2001), such an inconsistency is not surprising. The data were consistent with findings that displacement in memory for final position is diminished or even reversed when observers expect a target to stop or change direction (Finke, Freyd, & Shyi, 1986; Hubbard & Bharucha, 1988; Verfaillie & d'Ydewalle, 1991).

Why might a surrounding spatial context have such an impact on displacement in memory for initial location? Part of the answer may relate to how the spatial context is interpreted. The language used in early studies of the Fröhlich effect is that a target "emerges" into a window, and this suggests the surrounding frame provides a window into a scene beyond the picture plane. Elements of the scene that are outside the area visible through the window would be occluded, and so if a target travelled through those occluded areas prior to its emergence into the window, then that target would not be visible prior to its emergence into the window. Indeed, use of the term "window" to describe the context may increase the likelihood of this type of interpretation. Alternatively, the window may be seen as a container, and so if a target approached the inner surface, it might be expected to bounce off the side of that container rather than pass behind or beneath an occluding surface. However, observers in Experiments 1, 2, or 3 never saw the target bounce off the inner edge of the window, and so a "container" interpretation might be less likely. Regardless of the specific interpretation, the data from Experiments 1, 2, and 3 convincingly demonstrate that one variable that influences whether memory for initial position exhibits a Fröhlich effect or an onset repulsion effect is the presence and proximity of spatial context (e.g., in the case of Experiments 1, 2, and 3, the distance to a boundary of a larger enclosing window).

One possible explanation for the effect of the window on memory for initial position involves whether observers retrospectively extrapolate a possible prior trajectory of the target. In Experiments 1, 2, and 3, the boundary of the window limited the maximum extent of the visible trajectory; observers knew the target could not be perceived before entering the window. If the target appeared adjacent to the window, then occlusion by the plane containing the window offered a ready explanation for why the target was not previously visible. In this case, observers would have no reason to extrapolate a previous visible history of the target because that previous history would not have been visible. This lack of extrapolation is consistent with previous accounts of the Fröhlich effect (e.g., time to shift attention, Müsseler & Aschersleben, 1998; metacontrast masking, Kirschfeld & Kammer, 1999). In all of these cases, the memory trace for the actual trajectory would be significantly stronger for positions in front of the actual initial position of the target (i.e., further in the direction of target motion), and so memory for the initial position of the target would be displaced forward (i.e., a Fröhlich effect would be exhibited). Even though the Fröhlich effect and representational momentum both involve forward displacement in memory for the position of the target, the Fröhlich effect may involve a lack of extrapolation of potential trajectory, whereas representational momentum has often been attributed to an extrapolation of potential trajectory.

If the target appeared on a blank background (as in Hubbard & Motes, 2002), or if the target appeared sufficiently far enough inside the window, observers would not be able to assume that the target had previously been occluded and would not have a ready explanation for why the target was not previously visible. In this case, observers might more actively extrapolate a previous (and potentially perceivable) history of the target than they would if the previous history of the target were behind an obvious occluding surface (and not potentially perceivable), and this more active extrapolation of a possible history would create a stronger backward trace for the target through the area in which the target would have most likely moved prior to its being perceived by the observer (cf. Thornton, 2002).[4] This backward trace might become blended or integrated with memory for the actual trajectory, and so memory for the initial location of the target would be displaced backward, and an onset repulsion effect would be exhibited. Such an idea predicts that a larger potentially visible trajectory should result in a larger backward displacement, and just such a pattern was found in Experiments 2 and 3. Such an extrapolation of a potentially visible trajectory and a blending or integration of that extrapolation with memory for the actual trajectory may also underlie representational momentum, and so the onset repulsion effect and representational momentum may involve similar mechanisms that operate on different parts of the represented trajectory.

Once a target appears, observers presumably attend to the target until that target vanishes or until they expect the target to vanish (unless instructed to do otherwise, e.g., fixate an arbitrary stationary point some distance away from the target, e.g., Kerzel, Jordan, & Müsseler, 2001). When the target is in isolation on an otherwise blank background, there is no obvious boundary (inside the display) beyond which observers know the target will not pass; therefore, when the target vanishes, attention is still focused on the target, and so memory for the target is extrapolated forward, and memory exhibits forward displacement (as in Hubbard & Motes, 2002). However, when target motion is entirely within a larger enclosing window, there is an obvious boundary beyond which observers know the target will not pass, and so there is no a priori reason to extrapolate beyond the boundaries of the window. As the target approaches the boundary of the window, observers might begin to disengage attention from the target because they expect the target to stop (or at least not remain visible), and so the magnitude of forward extrapolation decreases as the final position of the target approaches the boundary of the window (as in Experiments 1 and 2). Such a notion is consistent with findings that representational momentum is reduced when the final position corresponds to a stable or a good "stopping point" (e.g., Munger, Solberg, & Horrocks, 1999; see also Kelly & Freyd, 1987) and that attention is necessary for the extrapolation that produces forward displacement (e.g., Kerzel, 2002a).

The combination of a Fröhlich effect in memory for initial position and a backward displacement in memory for final position that were observed in Experiments 1 and 2 results in a net decrease in the remembered length of the trajectory of the target. This decrease is reminiscent of the *tandem effect*, a decrease in the distance between two targets that sequentially

---

[4]Such an account might seem inconsistent with the robust Fröhlich effect that Müsseler and Aschersleben (1998) reported for horizontally moving targets. However, in Müsseler and Aschersleben's study one endpoint of the trajectory was always 5.5–6.5 deg from the central fixation, and the distance travelled by the target was always 5.5 deg, and, consistent with the speculation earlier, the use of a constant trajectory length might have imposed a "functional window" on the display, which then influenced attention and remembered position much as a real window did in Experiments 1, 2, and 3. The notion of such a "functional window" may also be consistent with the observation of Kerzel and Müsseler (2002) that memory for the orientation of a rotating stimulus did not exhibit a Fröhlich effect unless context was present on both sides of that target. In contrast, trajectory lengths in Hubbard and Motes (2002) and in Thornton (2002) were more variable, and so observers would have been less able to impose such a functional window because the trajectory length in any given trial was much less predictable. Such an account is consistent with Müsseler and Kerzel's (2004) findings that Fröhlich effects in the Müsseler and Aschersleben paradigm did not occur if targets appeared at unpredictable locations.

enter a window (see Müsseler & Neumann, 1992). The tandem effect is consistent with a Fröhlich effect for the trailing target, and, most relevant to our purpose here, the direction of the tandem effect may be reversed if attention is shifted to a location behind the trailing stimulus (Müsseler & Neumann, 1992). The reversal of the tandem effect is consistent with the possibility that a reversal of the Fröhlich effect (i.e., an onset repulsion effect) may occur if attention is directed toward a location behind the initial position (as would occur if observers could not assume that the target was occluded prior to their perception of it). Such a possibility is consistent with observations that an onset repulsion effect is more likely if a target appears in an otherwise blank background: When a target emerges into a window, observers would not need to direct attention to areas behind the initial position as those areas would be occluded by the plane containing the window and would not have been visible, whereas when a target appears in a blank background, observers might be more likely to direct attention to areas behind the initial position as those areas might have contained a potentially visible target.

The data from the current experiments, in conjunction with data from previous studies, suggest that memory for the initial position of a moving target exhibits a Fröhlich effect when the target appears adjacent to the inner edge of a window and an onset repulsion effect when the target appears some distance from such a boundary. Of course, the current data do not rule out the possibility that other influences on whether memory for initial position of a moving target exhibits a Fröhlich effect or an onset repulsion effect might be found, and so it is certainly possible that future research may uncover additional influences (e.g., as in Kerzel & Gegenfurtner, 2004). In the present case, the importance of the proximity of the initial position of the target to a boundary to the direction and magnitude of displacement in memory for initial position is consistent with the notion that whether a Fröhlich effect or an onset repulsion effect occurs may be determined by the extent to which an observer attends to locations in front of or behind the initial position of the target and extrapolates the trajectory that the target would have had prior to becoming visible. Such an extrapolation of probable trajectory information is consistent with many theories of representational momentum, and so an automatic extrapolation of trajectory may provide a single mechanism capable of accounting for (at least some types of) displacement in memory for the position of either end of a target's trajectory.

REFERENCES

Actis Grosso, R., & Stucchi, N. (2003). Shifting the start: Backward mislocalization of the initial position of a motion. *Journal of Experimental Psychology: Human Perception and Performance*, *29*, 675–691.

Cooper, L. A., & Munger, M. P. (1993). Extrapolations and remembering positions along cognitive trajectories: Uses and limitations of analogies to physical momentum. In N. Eilan, R. McCarthy, & B. Brewer (Eds.), *Spatial representation: Problems in philosophy and psychology* (pp. 112–131). Cambridge, MA: Blackwell.

Finke, R. A., Freyd, J. J., & Shyi, G. C. W. (1986). Implied velocity and acceleration induce transformations of visual memory. *Journal of Experimental Psychology: General*, *115*, 175–188.

Freyd, J. J. (1983). The mental representation of movement when static stimuli are viewed. *Perception & Psychophysics*, *33*, 575–581.

Freyd, J. J. (1987). Dynamic mental representations. *Psychological Review*, *94*, 427–438.

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

Futterweit, L. R., & Beilin, H. (1994). Recognition memory for movement in photographs: A developmental study. *Journal of Experimental Child Psychology*, *57*, 163–179.

Gray, R., & Thornton, I. M. (2001). Exploring the link between time to collision and representational momentum. *Perception*, *30*, 1007–1022.
Hubbard, T. L. (1993). The effects of context on visual representational momentum. *Memory & Cognition*, *21*, 103–114.
Hubbard, T. L. (1994). Judged displacement: A modular process? *American Journal of Psychology*, *107*, 359–373.
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. (2004). *Representational momentum and related displacements in spatial memory: A review of the findings.* Manuscript submitted for publication.
Hubbard, T. L., & Bharucha, J. J. (1988). Judged displacement in apparent vertical and horizontal motion. *Perception & Psychophysics*, *44*, 211–221.
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 the landmark attraction effect. *Canadian Journal of Experimental Psychology*, *53*, 242–256.
Kelly, M. H., & Freyd, J. J. (1987). Explorations of representational momentum. *Cognitive Psychology*, *19*, 369–401.
Kerzel, D. (2000). Eye movements and visible persistence explain the mislocalization of the final position of a moving target. *Vision Research*, *40*, 3703–3709.
Kerzel, D. (2002a). Attention maintains mental extrapolation of target position: Irrelevant distractors eliminate forward displacement after implied motion. *Cognition*, *88*, 109–131.
Kerzel, D. (2002b). Attention shifts and memory averaging. *Quarterly Journal of Experimental Psychology*, *55A*, 425–443.
Kerzel, D. (2002c). Different localization of motion onset with pointing and relative judgements. *Experimental Brain Research*, *145*, 340–350.
Kerzel, D., & Gegenfurtner, K. R. (2004). Spatial distortions and processing latencies in the onset repulsion and Fröhlich effects. *Vision Research*, *44*, 577–590.
Kerzel, D., Jordan, J. S., & Müsseler, J. (2001). The role of perception in the mislocalization of the final position of a moving target. *Journal of Experimental Psychology: Human Perception and Performance*, *27*, 829–840.
Kerzel, D., & Müsseler, J. (2002). Effects of stimulus material on the Fröhlich illusion. *Vision Research*, *42*, 181–189.
Kirschfeld, K., & Kammer, T. (1999). The Fröhlich effect: A consequence of the interaction of visual focal attention and metacontrast. *Vision Research*, *39*, 3702–3709.
Kozhevnikov, M., & Hegarty, M. (2001). Impetus beliefs as default heuristics: Dissociation between explicit and implicit knowledge about motion. *Psychonomic Bulletin & Review*, *8*, 439–453.
Munger, M. P., Solberg, J. L., & Horrocks, K. K. (1999). On the relation between mental rotation and representational momentum. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 1557–1568.
Müsseler, J., & Aschersleben, G. (1998). Localizing the first position of a moving stimulus: the Fröhlich effect and an attention-shifting explanation. *Perception & Psychophysics*, *60*, 683–695.
Müsseler, J., & Kerzel, D. (2004). *The trial context determines adjusted localization of stimuli: Reconciling the Fröhlich and onset repulsion effects.* Manuscript submitted for publication.
Müsseler, J., & Neumann, O. (1992). Apparent distance reduction with moving stimuli (tandem effect): Evidence for an attention-shifting model. *Psychological Research/Psychologische Forschung*, *54*, 246–266.
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.
Müsseler, J., van der Heijden, A. H. C., Mahmud, S. H., Deubel, H., & Ertsey, S. (1999). Relative mislocalization of briefly presented stimuli in the retinal periphery. *Perception & Psychophysics*, *61*, 1646–1661.
Thornton, I. M. (2002). The onset repulsion effect. *Spatial Vision*, *15*, 219–243.
Verfaillie, K., & d'Ydewalle, G. (1991). Representational momentum and event course anticipation in the perception of implied periodical motions. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 302–313.

Original manuscript received 19 June 2003
Accepted revision received 3 May 2004
PrEview proof published online 24 September 2004