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Brief article

Does representational momentum reflect a distortion of the length or the endpoint of a trajectory?☆

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Abstract

Observers viewed a moving target, and after the target vanished, indicated either the initial position or the final position of the target. In Experiment 1, an auditory tone cued observers to indicate either the initial position or the final position; in Experiment 2, different groups of observers indicated the initial position or the final position. Judgments of the initial position were displaced backward in the direction opposite to motion, and judgments of the final position were displaced forward in the direction of motion. The data suggest that the remembered trajectory is longer than the actual trajectory, and the displacement pattern is not consistent with the hypothesis that representational momentum results from a distortion of memory for the location of a trajectory. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Representational momentum; Fröhlich effect; Onset replusion effect; Dynamics; Length; Trajectory

1. Introduction

Memory for the final position of a moving target is often displaced in the direction of implied motion, and this has been referred to as *representational momentum*

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(Freyd & Finke, 1984; for review, see Hubbard, 1995). Early theories of representational momentum suggested that this displacement resulted from an internalization of the principles of momentum; much as a moving physical object possessed momentum, so too did the mental representation of that moving physical object possess an analogous form of momentum (e.g. see Finke, Freyd, & Shyi, 1986). A literal momentum metaphor has subsequently been abandoned by researchers, and a number of alternative mechanisms have been proposed including spatiotemporal coherence (Freyd, 1987, 1993), implicit knowledge of physical principles (Hubbard, 1998), second-order isomorphism between mental representation and subjective aspects of momentum (Hubbard, 1999), belief in naive impetus (Kozhevnikov & Hegarty, in press), pursuit eye movements (Kerzel, 2000), and properties of image schema (Gibbs & Berg, in press).

Regardless of the mechanism involved, representational momentum is usually considered to reflect bias in memory for the final position of a moving target. In the absence of any discussion regarding memory for prior positions of a target, theories of representational momentum may be read as suggesting that prior positions of the target are represented veridically (or that bias in memory for prior positions is not related to bias in memory for the final position; see top of Fig. 1). However, previous investigators reported that memory for the initial position of a moving target may be displaced forward, and this has been referred to as the *Fröhlich Effect* (e.g. Kirschfeld & Kammer, 1999; Müsseler & Aschersleben, 1998). Consideration of the Fröhlich Effect raises the possibility that forward displacement in memory for the final position of a moving target might reflect displacement of the entire trajectory rather than displacement of just the final position (see bottom of Fig. 1). Different mechanisms would presumably underlie displacement of the entire trajectory and displacement of just the final position, and so whether a Fröhlich Effect accompanies representational momentum is of interest for theories of representational momentum.

Studies of the Fröhlich Effect usually present faster target velocities than do studies of representational momentum. Within the range of velocities used in studies on the Fröhlich Effect (i.e. typically $>20°/s$), the magnitude of the Fröhlich Effect decreases with decreases in target velocity (Müsseler & Aschersleben, 1998; Müsseler & Neumann, 1992), and so it is not clear that a Fröhlich Effect would be exhibited within the range of slower velocities used in studies on representational momentum (i.e. typically $<20°/s$). Indeed, with such slower velocities memory for initial position exhibits a backward displacement (e.g. Actis Grosso, Stucchi, & Vacario, 1996), and this has been referred to as the *Onset Repulsion Effect* (e.g. Thornton, in press). If an Onset Repulsion Effect were found in memory for the initial position of a target, then a forward displacement in memory for the final position of a target could not result from a forward displacement in memory for the entire trajectory.

Previous investigations of the Fröhlich Effect, Onset Repulsion Effect, and representational momentum usually focused only on memory for either initial position or final position. Therefore, it has not been possible to determine how these displacements might be related to each other or to memory for the entire trajectory. Thornton (in press) recently assessed memory for initial position and

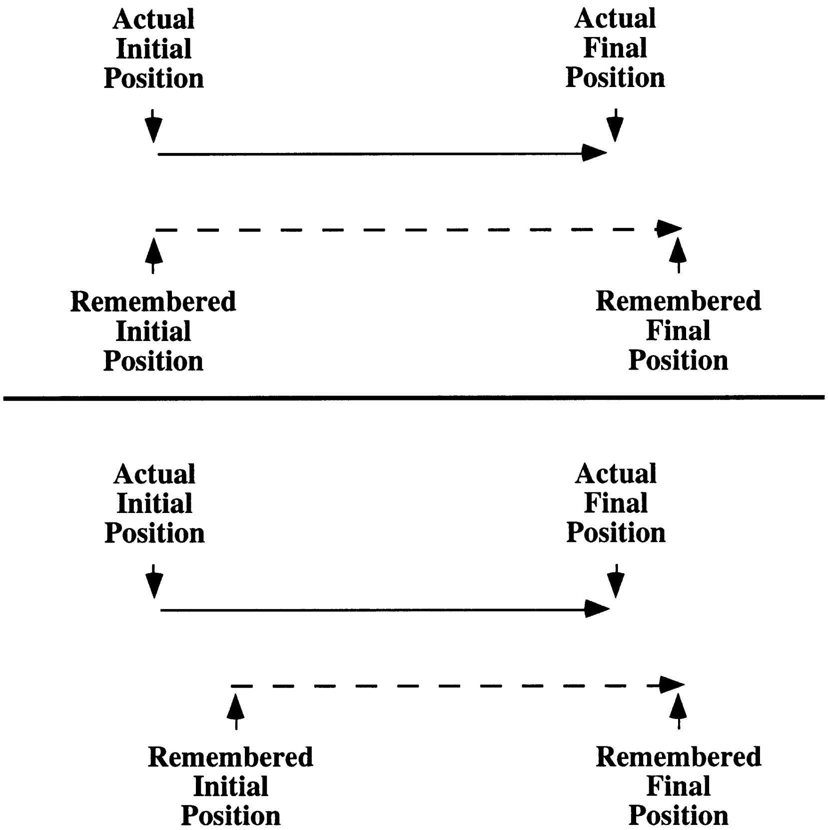

Fig. 1. Two possible accounts for the forward displacement of the remembered final position. The actual length of the target trajectory is indicated by the solid line, and the remembered length of the target trajectory is indicated by the dashed line. In the top panel, memory for the initial position is veridical, and forward displacement in memory for the final position results from a distortion in the remembered length of the trajectory. In the bottom panel, memory for the initial position is shifted forward, and forward displacement in memory for the final position results from a distortion in the remembered position of the trajectory. Adapted from Actis Grosso (1999).

final position of a moving target, and although judgments of initial position and judgments of final position were not directly compared, backward displacement for initial position and forward displacement for final position were reported. Such a pattern is not consistent with forward displacement of the entire trajectory or with forward displacement of only the final position. The purpose of the current experiments was to assess and directly compare memory for the initial position and the final position, and to determine whether displacement in memory for the final position reflects a displacement of the entire trajectory or of only the endpoint.

2. Experiment 1

Observers viewed a computer-generated image of a smoothly moving target that appeared and vanished at uncued locations, and immediately after the target vanished, an auditory cue instructed observers to indicate where the target had appeared or had vanished. Memory for final position should be displaced in the direction of motion. If a Fröhlich Effect in memory for initial position is exhibited, then that would suggest that representational momentum results from forward displacement of the entire trajectory rather than from forward displacement of just the final position of the target. However, if an Onset Repulsion Effect in memory for initial position is exhibited, or if memory for initial position is not systematically displaced, then that would suggest that representational momentum does not result from forward displacement of the entire trajectory.

2.1. Method

2.1.1. Participants

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

2.1.2. Apparatus

The stimuli were generated by and responses collected upon an Apple Macintosh IIsi computer connected to an Apple RGB color 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.

2.1.3. Stimuli

The target stimulus was a filled black square approximately 0.83° (20 pixels) in width and was presented on a white background approximately 26.67° (640 pixels) in width and 19.17° (460 pixels) in height. The target appeared between 4.67° and 8.00° from the nearest edge of the display and immediately began moving in a straight line toward the opposite edge of the display, and the target crossed between 9.5° and 12.1° of the display before vanishing without warning. Motion 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 approximately centered on the vertical axis of the display, and motion of TB or BT targets was approximately centered on the horizontal axis of the display. The target traveled at a relatively slow (5°/s) or fast (15°/s) velocity. The auditory cue was a 250 or 2000 Hz tone that played for 1 s. Each observer received 128 trials (2 auditory cues $\times$ 4 directions $\times$ 2 velocities $\times$ 8 replications) in a different random order.

2.1.4. Procedure

Observers received ten 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 1 s pause, and then the target appeared and immediately began moving in a straight line across the display. Observers were instructed to watch the target, and a fixation point was not presented. The target vanished without warning. Immediately after the target vanished, the auditory cue was presented. A high tone (2000 Hz) instructed observers to position the cursor where the target had appeared; a low tone (250 Hz) instructed observers to position the cursor where the target had vanished. The cursor was positioned by movement of a computer mouse; the cursor was initially invisible, but became visible after the target vanished. After positioning the mouse, observers clicked a button on the mouse in order to record the display coordinates of the cursor. Observers then initiated the next trial.

2.2. Results

Differences (in pixels) between the true initial position and the judged initial position, and between the true vanishing position and the judged vanishing position, were calculated along the axis of motion. Consistent with previous reports, these differences were referred to as *M displacement*.[1] Positively-signed *M* displacement indicated that the judged initial or final position was beyond the true initial or 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 or final position was behind the true initial or final position (i.e. left of a LR target, right of a RL target, above a TB target, below a BT target).

M displacement scores were analyzed in a 2 (judgment) $\times$ 4 (direction) $\times$ 2 (velocity) repeated measures analysis of variance. Judgment influenced *M* displacement ($F(1, 13) = 20.82$, MSE $= 2924.06$, $P < 0.0005$); as shown in Fig. 2, judgment of initial position ($M = -21.01$) exhibited backward *M* displacement, and judgment of final position ($M = 11.96$) exhibited forward *M* displacement. Additionally, judgment interacted with velocity ($F(1, 13) = 4.78$, MSE $= 207.81$, $P < 0.05$). An analysis of the simple effects of this interaction revealed that judgment of final position exhibited larger *M* displacement for fast targets than for slow targets ($F(1, 13) = 5.94$, MSE $= 134.84$, $P < 0.04$), and that judgment of final position exhibited larger forward *M* displacement than did judgment of initial position for both slow ($F(1, 13) = 11.14$, MSE $= 2078.99$, $P < 0.006$) and fast ($F(1, 13) = 36.77$, MSE $= 1052.88$, $P < 0.001$) velocities. For each observer, the average *M* displacement for initial position and the average *M* displacement for final position were negatively correlated ($r = -0.57$, $t(12) = -2.41$, $P < 0.02$); observers who exhibited larger backward displacements for initial position exhibited larger forward displacements for final position.

[1] 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 usage.

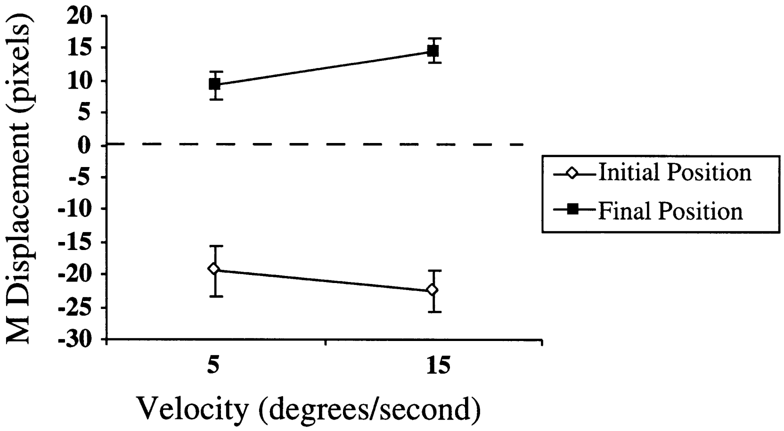

Fig. 2. *M* displacement as a function of velocity in Experiment 1. Data for judgments of initial position are plotted with open diamonds, and data for judgments of final position are plotted with filled squares. The vertical bars represent standard error.

2.3. Discussion

Memory for final position was displaced forward in the direction of target motion, and the magnitude of displacement increased with increases in target velocity. This is consistent with previous findings in the representational momentum literature (e.g. Freyd & Finke, 1985; Hubbard & Bharucha, 1988). Memory for initial position was displaced backward in the direction opposite to target motion, and this is consistent with an Onset Repulsion Effect but not consistent with a Fröhlich Effect. Backward displacement of initial position, coupled with forward displacement of final position, suggests that the remembered length of the trajectory was larger than the actual length of the trajectory, and this pattern is consistent with displacements reported by Thornton (in press). Also, observers who exhibited larger backward *M* displacement in judgment of initial position exhibited larger forward *M* displacement in judgment of final position. Overall, memory for the length of the trajectory was not veridical, and representational momentum did not result from displacement of the trajectory in the direction of motion.

3. Experiment 2

In Experiment 1, observers did not know until after the target vanished whether they would report initial position or final position, and so they needed to maintain the entire trajectory (or at least the initial and final positions) in memory until the auditory cue was presented. However, in studies of the Fröhlich Effect and in studies of representational momentum, observers are usually aware that memory for just initial position or just final position will be examined, and so there is no need for them to hold the entire trajectory in memory. It may be that the displacement pattern in Experiment 1 resulted from memory demands of encoding an entire trajectory rather than from separate biases in encoding either initial position or final position. Accordingly, observers were presented with the same targets used in Experiment 1, but measurement of remembered initial position or remembered final position was a between-subjects variable. A replication of the displacement pattern from Experiment 1 would strengthen confidence in the proposal that forward displacement in memory for final position does not result from forward displacement of the entire trajectory.

3.1. Method

3.1.1. Participants

The observers were 28 undergraduates from the participant pool used in Experiment 1, and none had participated in Experiment 1. Fourteen observers participated in the Initial condition, and 14 observers participated in the Final condition.

3.1.2. Apparatus

The apparatus was the same as in Experiment 1.

3.1.3. Stimuli

The stimuli were the same as in Experiment 1, with the following exception: no auditory cue was presented. Each observer received 64 trials (4 directions $\times$ 2 velocities $\times$ 8 replications) in a different random order.

3.1.4. Procedure

The procedure was the same as in Experiment 1, with the following exception: after the target vanished, observers were not presented with an auditory cue. Observers in the Initial condition positioned the cursor at the location at which the target appeared, and observers in the Final condition positioned the cursor at the location at which the target vanished.

3.2. Results

M displacements were calculated as in Experiment 1, and were analyzed in a 2 (judgment) $\times$ 4 (direction) $\times$ 2 (velocity) analysis of variance in which judgment was a between-subjects variable and direction and velocity were within-subjects variables. Judgment influenced *M* displacement ($F(1,27) = 43.04$, MSE = 2049.49, $P < 0.0001$); as shown in Fig. 3, judgment of initial position ($M = -25.92$) exhibited backward *M* displacement, and judgment of final position ($M = 13.10$) exhibited forward *M* displacement. Additionally, judgment interacted with velocity ($F(1,27) = 5.69$, MSE = 88.72, $P < 0.05$). An analysis of the simple effects of this interaction revealed that judgment of final position exhibited larger *M* displacement for fast targets than for slow targets ($F(1,27) = 5.94$, MSE = 88.72, $P < 0.03$). Also, the simple effects analysis revealed that judgment of final position exhibited larger forward *M* displacement than judgment of initial position at both slow ($F(1,27) = 35.25$, MSE = 1069.11, $P < 0.001$) and fast ($F(1,27) = 47.73$,

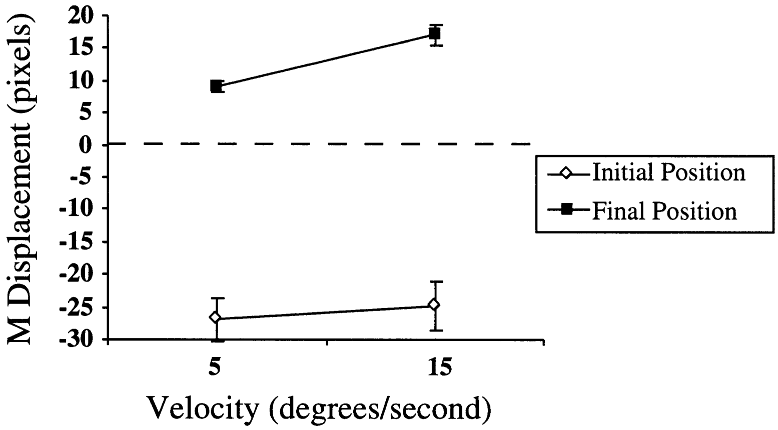

Fig. 3. *M* displacement as a function of velocity in Experiment 2. Data for judgments of initial position are plotted with open diamonds, and data for judgments of final position are plotted with filled squares. The vertical bars represent standard error.

MSE = 1069.11, $P < 0.001$) velocities. Velocity influenced *M* displacement ($F(1,27) = 16.45$, MSE = 88.72, $P < 0.001$), with slow targets ($M = -8.92$) exhibiting larger backward *M* displacement than fast targets ($M = -3.90$). Direction influenced *M* displacement ($F(3,81) = 3.53$, MSE = 281.38, $P < 0.03$), and a post-hoc Newman–Keuls test ($P < 0.05$) of LR ($M = -5.32$), RL ($M = -1.20$), TB ($M = -8.30$), and BT ($M = -10.82$) found that RL motion led to less backward *M* displacement than BT motion. Interpretation of velocity and direction effects are tempered by a Velocity × Direction interaction ($F(3,81) = 3.21$, MSE = 47.29, $P < 0.03$). An analysis of the simple effects of this interaction revealed that effects of direction were larger at fast velocities (F(3,81) = 4.54, MSE = 194.52, $P < 0.006$) than at slow velocities ($F(3,81) = 194.52$, MSE = 134.16, $P > 0.12$) and that velocity influenced *M* displacement for both LR ($F(1,27) = 8.91$, MSE = 105.93, $P < 0.007$) and RL ($F(1,27) = 16.18$, MSE = 50.40, $P < 0.0001$) motion.

3.3. Discussion

Memory for initial position was displaced backward and memory for final position was displaced forward. Although the main effect of velocity was significant, the interaction of judgment and velocity revealed that this effect was driven by differences in judgments of final position and that velocity did not influence *M* displacement in memory for initial position. These displacements paralleled those observed in Experiment 1. Also, horizontal motion was influenced more by velocity than was vertical motion, and there was a trend for vertical motion to exhibit less forward (more backward) *M* displacement than did horizontal motion; these patterns are consistent with previous findings in the representational momentum literature (e.g. Hubbard, 1990; Hubbard & Bharucha, 1988). Specification of judgment as a between-subjects variable seemed to increase differences in *M* displacement across conditions (e.g. resulting in the velocity effect reaching significance). The results of Experiment 2 suggest that the displacement pattern in Experiment 1 did not result from observers having to remember the entire trajectory.

4. General discussion

Memory for the initial position of a moving target was displaced in the direction opposite to target motion, and memory for the final position of a moving target was displaced in the direction of target motion. This pattern lets us reject the hypothesis that forward displacement in memory for final position results from forward displacement of the entire trajectory. However, observers who exhibited larger forward displacement of final position also exhibited larger backward displacement of initial position, and so displacement in memory for final position is not completely independent of displacement in memory for initial position. Backward displacement of initial position coupled with forward displacement of final position suggests that the remembered length of the trajectory was longer than the trajectory's actual length. Given that memory for static targets is usually displaced toward a smaller size (e.g. boundary extension, Intraub, Gottesman, & Bills, 1998; memory psychophysics of length and area, Algom, 1992; Hubbard, 1994), the longer remembered length of the trajectory of a moving target might reflect differences in the (implied) dynamics of stationary targets and of moving targets, and suggests that moving targets may be encoded or processed differently than are static targets.

Discussion of the mechanism of the backward displacement of initial position is beyond the scope of this paper (but see Thornton, in press), but at least two hypotheses may be rejected. The hypothesis that backward displacement resulted from memory averaging (i.e. from a backward displacement toward previous positions of the target that occurs after the initial rapid representational momentum; see Freyd & Johnson, 1987) and that a forward displacement might be observed if memory for initial position were sampled at an earlier time may be rejected because in Experiments 1 and 2 the target was never located at positions corresponding to a backward displacement of initial position. The hypothesis that displacement patterns resulted from a bias toward either the center or the edge of the display may be rejected as neither the Onset Repulsion Effect (Thornton, in press) nor representational momentum (Hubbard & Ruppel, 1999; Experiment 2) is influenced by whether the target moves toward or away from the center of the display.

The displacement of memory for the initial position of a target in the direction opposite to target motion is not consistent with the Fröhlich Effect, but is consistent with the Onset Repulsion Effect, and so the data reported here offer a useful replication and extension of Thornton (in press). The net result of the forward displacement of final position and the backward displacement of initial position is that the trajectory is remembered as longer than it actually was, and this is consistent with more direct assessments of memory for trajectory in which observers reconstructed previously viewed trajectories (e.g. Thornton, 1999). Determination of criteria for whether memory for initial position of a moving target exhibits a Fröhlich Effect or an Onset Repulsion Effect remains for future research, although differences in the velocities used in studies of the Fröhlich Effect and the velocities used in studies of the Onset Repulsion Effect suggest that velocity may be such a criterion. Regardless of the ultimate explanation for the backward displacement of initial position, the occurrence of such backward displacement is evidence against the hypothesis that representational momentum results from forward displacement of the entire trajectory.

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