
Representational Momentum and the Landmark Attraction Effect

TIMOTHY L. HUBBARD and SUSAN E. RUPPEL, Texas Christian University

Abstract The effect of a large stationary landmark on memory for the location of a smaller moving target was examined. Forward displacement of the target was larger when the target moved toward the landmark than when it moved away from the landmark. Target size and direction of motion also influenced displacement. When the target passed close by the landmark, forward displacement of the target was larger before the target passed by the cardinal axis of the landmark than after the target passed by the cardinal axis of the landmark. Memory for a target that passed by a landmark was also displaced toward the target along the axis orthogonal to motion. Control experiments ruled out biases toward the centre of the screen as causing the differences in displacement. The data support the hypotheses that representational momentum may combine with landmark attraction effects to influence the displacement of a target along the axis of motion.

Spatial memory exhibits a number of consistent biases. One type of bias distorts memory in ways consistent with the operation of environmentally invariant physical principles. For example, memory for the final position of a moving target that vanishes without warning is often distorted forward in the direction of anticipated future motion, and this bias has been referred to as *representational momentum* (e.g., Freyd & Finke, 1984; Hubbard, 1995b). A second type of bias distorts memory by decreasing the remembered distance between a target and a landmark (e.g., McNamara & Diwadkar, 1997; Sadalla, Burroughs, & Staplin, 1980; Tversky & Schiano, 1989), and this bias has been referred to as a *landmark attraction effect* (Bryant & Subbiah, 1994). These biases and distortions of memory result in a displacement of the remembered spatial position of a target; in other words, the remembered position of a previously perceived target stimulus is not the same as the actual position previously occupied by that target stimulus — the remembered position is displaced from the actual position.

Studies of representational momentum have suggested that memory for spatial location may be influenced by

memory averaging (e.g., Freyd & Johnson, 1987). Hubbard (1995b) distinguished between two senses of memory averaging: A temporal sense in which memory for the final position of a target is influenced by the memory of prior positions of the target, and a spatial sense in which memory for the final position of a target is influenced by the memory of nontarget stimuli that were presented concurrently with the target. It may be possible that remembered prior positions of a target could serve as landmarks, and via temporal memory averaging account for displacements of remembered position toward the average of those prior positions. However, it is more obvious and perhaps more commonplace that nontarget stimuli or context presented concurrently with the target may serve as landmarks. The presence of such concurrent nontarget stimuli or context could provide the opportunity for spatial memory averaging. Indeed, the landmark attraction effect as it is currently conceived may be a special case of a more general spatial memory averaging: Both landmark attraction effects and spatial memory averaging predict that memory for the position of a target should be displaced in the direction of a landmark.

Spatial memory averaging and landmark attraction effects are both consistent with a number of findings in the representational momentum literature. For example, if a rotating target is surrounded by a larger stationary square frame, forward displacement of the target is increased if the orientation of the frame is rotated slightly forward from the final orientation of the target, and forward displacement of the target is decreased if the orientation of the frame is rotated slightly backward from the final orientation of the target. Similarly, if the surrounding frame is in motion concurrently with the target, forward displacement of the target is increased if the frame is rotating in the same direction as the target, and forward displacement of the target is decreased if the frame is rotating in the direction opposite to the target (Hubbard, 1993). These displacement patterns may result from a combination of representational momentum and landmark attraction effects: When representational momentum and landmark attraction operate in the same direction

(i.e., when the frame is in front of the target or moving in the same direction as the target), they combine and the resultant displacement forward along the axis of motion is increased. When representational momentum and landmark attraction operate in opposite directions (i.e., when the frame is behind the target or moving in the direction opposite to the target), they partially cancel and the resultant displacement forward along the axis of motion is decreased.

Spatial memory averaging and landmark attraction effects are also found along the axis orthogonal to target motion. In addition to the displacement along the axis of motion, memory for the position of a horizontally moving target is also displaced toward a single larger surface presented above or below the path of target motion. Furthermore, the magnitude of upward displacement when a larger stationary object is above the target is smaller than the magnitude of downward displacement when a larger stationary object is below the target (Hubbard, 1995a). Such an asymmetry may be accounted for if a landmark attraction effect displaces memory toward the larger stationary object, and the landmark attraction effect also combines with *representational gravity* (i.e., with a displacement in the direction of implied gravitational attraction; see Hubbard, 1995b, 1997). When landmark attraction and representational gravity operate in the same direction (i.e., when the landmark surface is below the target), they combine and the resultant displacement along the orthogonal axis is increased, whereas when landmark attraction and representational gravity operate in opposite directions (i.e., when the landmark surface is above the target), they partially cancel and the resultant displacement along the orthogonal axis is decreased. Also, memory for the position of a vertically moving target is displaced toward a single larger surface presented on the left or right of the path of target motion (Hubbard, 1998), with the magnitudes of leftward or rightward displacement being very similar.

Given that landmark attraction effects influence displacement along the axis orthogonal to motion for horizontally or vertically moving targets, it is possible that landmark attraction effects might also influence displacement along the axis of motion for such targets. The frame studies previously discussed demonstrated effects of an enclosing frame on memory for the orientation of the target (and on displacement in the direction of motion), but a landmark is more traditionally considered to be offset in a single specific direction from a target rather than enclosing a target. On the basis of the previous studies, we may hypothesize that a landmark that is offset in a specific direction from a target should influence displacement for that target in the direction of the landmark, and we may adapt the vector notion of Hubbard (1995a, 1995b, 1998) to make explicit predictions. If the target moves directly toward a landmark, then both representational momentum and landmark attraction would bias memory in the direction of the landmark, and so they

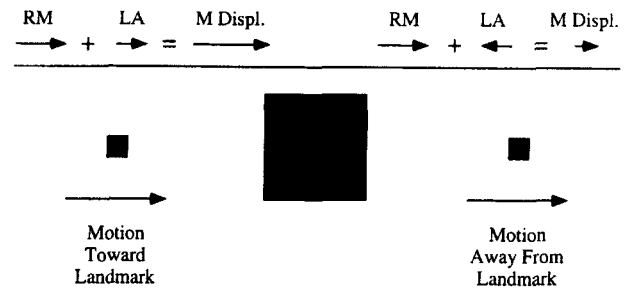


Figure 1. The contributions of representational momentum (RM) and landmark attraction effects (LA) to the displacement of the target along the axis of motion when the target moves directly toward or away from the landmark.

would combine to produce a larger displacement forward along the axis of motion (see Figure 1, left). If the target moves away from the landmark, then representational momentum would bias memory away from the landmark, and landmark attraction would bias memory toward the landmark, and so they would partially cancel and produce a smaller displacement forward along the axis of motion (see Figure 1, right).

Effects of a landmark on the displacement of a target along the axis of motion need not be limited to cases in which the target moves directly toward or away from the landmark, but might also be found if a target passes close by a landmark. Previous investigators reported that memory for a stationary target was displaced toward a cardinal axis (i.e., displaced toward a horizontal or vertical axis of symmetry; Huttenlocher, Hedges, & Duncan, 1991) or toward a diagonal line (Schiano & Tversky, 1992) of a larger enclosing figure or frame. If a cardinal axis of the landmark may also function as a landmark-like reference, then we may hypothesize an analogous combination of representational momentum and landmark attraction effects: If both landmark attraction effects and representational momentum operate in the same direction (i.e., a target moving toward the cardinal axis of the landmark), they should combine and the resultant displacement of the target forward along the axis of motion should be increased, whereas if landmark attraction and representational momentum operate in opposite directions (i.e., a target moving away from the cardinal axis of the landmark), they should partially cancel and the resultant displacement of the target forward along the axis of motion should be decreased (see Figure 2). Additionally, we should also observe effects of a landmark on the displacement of the target along the axis orthogonal to target motion: When a target passes close by a landmark, the displacement of that target along the axis orthogonal to target motion should be toward the landmark.

The following experiments tested these predictions regarding the effects of a landmark on the displacement of a moving target. In Experiment 1, the path of target motion was either directly toward or away from a larger stationary

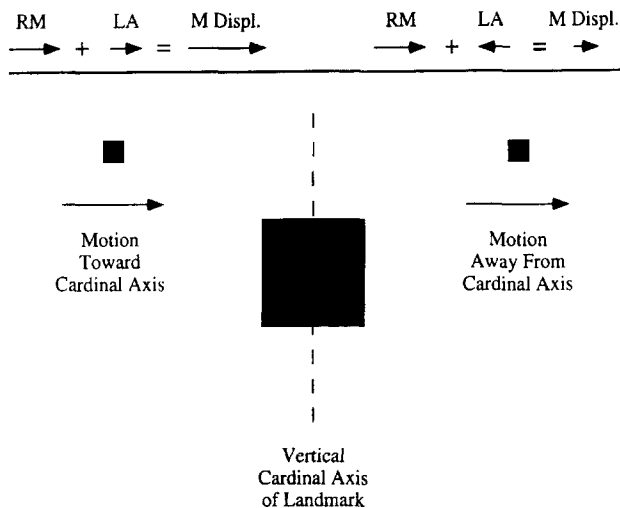


Figure 2. The contributions of representational momentum (RM) and landmark attraction effects (LA) to the displacement of the target along the axis of motion when the target passes near a landmark (and toward or away from a cardinal axis of the landmark).

landmark. In Experiment 2, the same targets used in Experiment 1 were displayed, but the landmark was not visible. In Experiment 3, the target passed close to a larger stationary landmark, and the path of target motion paralleled the nearest edge of that landmark. In Experiment 4, the same targets used in Experiment 3 were displayed, but the landmark was not visible. Experiments 1 and 3 examined possible effects of landmarks on displacement along the axis of motion (and in Experiment 3, on displacement along the axis orthogonal to target motion), and Experiments 2 and 4 provided control conditions that ruled out a bias toward the centre or cardinal axis of the screen as an explanation for the displacement patterns observed in Experiments 1 and 3.

Experiment 1

In this experiment, observers viewed a small moving target and a larger stationary landmark. The target appeared above, below, to the right, or to the left of the landmark; immediately after the target appeared, it moved directly toward or away from the landmark. The size of the target varied across trials, but was constant within a trial, whereas the size of the landmark was constant across trials. The target vanished without warning, and after the target vanished, observers indicated the location at which the target vanished. If representational momentum and landmark attraction combine in influencing displacement along the axis of motion, then forward displacement of targets that moved toward the landmark should be larger than forward displacement of targets that moved away from the landmark. Alternatively, if representational momentum and landmark attraction do not combine in influencing displacement along the axis of motion, then forward displacement should not be influenced by whether targets moved toward or away from

the landmark.

METHOD

Participants. The observers were 16 undergraduates from Texas Christian University who participated in return for partial course credit in an introductory psychology course.

Apparatus. The stimuli were displayed and data collected by an Apple Macintosh IIsi microcomputer equipped with an Apple RGB colour monitor (with a vertical refresh rate of 66.7 Hz). The monitor was located approximately 60 cm from the observer, and was presented in normal room illumination.

Stimuli. The target and landmark stimuli were filled black squares presented on a white background. The targets were either 20, 40, or 60 pixels (approximately 0.83°, 1.67°, or 2.50° of visual angle) in width, and the landmark was 120 pixels (approximately 5.00° of visual angle) in width. The display area of the monitor screen was 640 × 460 pixels (approximately 26.67° × 19.16° of visual angle). The target and the landmark were oriented such that each edge was either horizontal or vertical, and the centres of the target and landmark were at the same horizontal (for targets above or below the landmark) or vertical (for targets left or right of the landmark) coordinates. Targets appeared either above, below, left of, or right of the landmark, and targets were either relatively close (40 pixels; approximately 1.67° of visual angle) or relatively far (140 pixels; approximately 5.83° of visual angle) from the landmark. Targets that were close to the landmark moved away from the landmark, and targets that were far from the landmark moved toward the landmark. Target motion was always in a straight line toward or away from the landmark and orthogonal to the nearest edge of the landmark. Targets traveled 100 pixels (approximately 4.17° of visual angle) before vanishing, and target velocity was approximately 5.9° of visual angle per second. On half of the trials, the landmark vanished when the target vanished, and on the other half of the trials, the landmark remained visible until the observer responded. Each participant received 336 trials (4 target directions [ascending, descending, leftward, rightward] × 3 target sizes [20, 40, 60 pixels] × 2 target approaches [toward the landmark, away from the landmark] × 2 landmark visibilities [visible during judgment, not visible during judgment] × 7 replications) in a different random order.

Procedure. Observers were first given 12 practice trials (drawn randomly from the experimental trials) at the beginning of the session. The observers initiated each trial by pressing a designated key, and the landmark immediately appeared. After a one-second pause, the target appeared (a) close to the landmark and moved away from the landmark, or (b) far away from the landmark and moved toward the

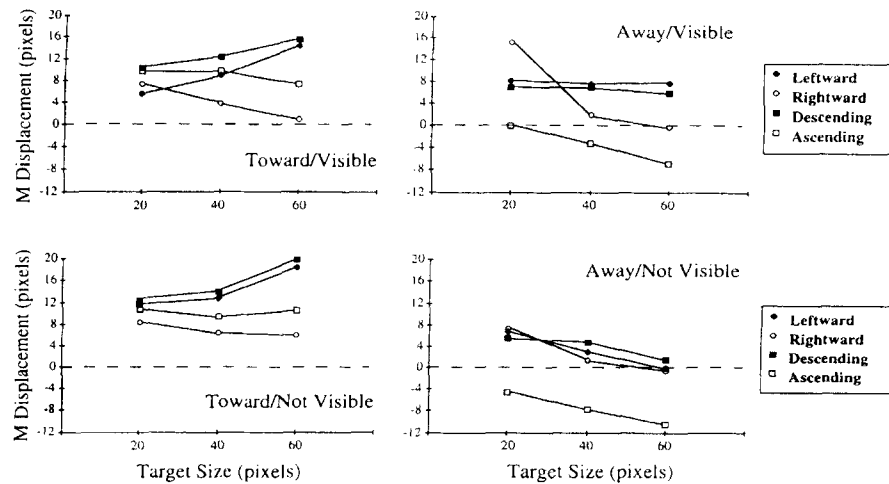


Figure 3. M displacement as a function of target size, approach, direction, and landmark visibility in Experiment 1.

landmark. Observers were instructed to watch the target. After the target vanished, the cursor (in the form of a plus sign) appeared near the centre of the screen, and observers were instructed to position the centre of the cursor over where the centre of the target had been when the target vanished. The cursor was positioned by movement of a computer mouse, and after positioning the mouse, the observers clicked a button on the mouse in order to record the screen coordinates of the cursor. Observers then initiated the next trial.

RESULTS

The mean differences between the true vanishing point of the target and the judged vanishing point of the target (in pixels) along the x - and y -axes were calculated for each observer for each condition. Consistent with previous reports, differences along the axis of motion (the x axis for leftward or rightward motion, the y axis for ascending or descending motion) were referred to as *M displacement*, and differences along the axis orthogonal to motion (the y axis for leftward or rightward motion, the x axis for ascending or descending motion) were referred to as *O displacement*. Positively signed *M* displacements indicated judged vanishing points beyond the true vanishing point (e.g., left of a target moving leftward), and negatively signed *M* displacements indicated judged vanishing points behind the true vanishing point (e.g., right of a target moving leftward). Positively signed *O* displacements indicated judged vanishing points above (for targets left or right of the landmark) or to the right (for targets above or below the landmark) of the true vanishing point, and negatively signed *O* displacements indicated judged vanishing points below (for targets left or right of the landmark) or to the left (for targets above or below the landmark) of the true vanishing point.

M and *O* displacements were analyzed in separate 4 (target

direction) \times 3 (target size) \times 2 (target approach) \times 2 (landmark visibility) repeated measures analyses of variance, and are displayed in Figures 3 and 4, respectively.

M displacement. Targets moving toward the landmark ($M = 10.23$) exhibited much larger *M* displacement than did targets moving away from the landmark ($M = 2.44$), $F(1,15) = 17.62$, $MSE = 661.57$, $p < .001$. Approach also interacted with direction, $F(3,45) = 17.42$, $MSE = 89.11$, $p < .0005$, size, $F(2,30) = 43.58$, $MSE = 24.97$, $p < .0005$, and Direction \times Size, $F(6,90) = 3.64$, $MSE = 15.78$, $p < .003$. When motion was toward the landmark, increases in target size led to (a) increases in *M* displacement for leftward and descending targets, and (b) decreases or no change in *M* displacement for rightward and ascending targets. When motion was away from the landmark, increases in target size were linked with decreases in displacement regardless of the direction of target motion.

Direction influenced *M* displacement, $F(3,45) = 9.99$, $MSE = 240.71$, $p < .0005$: Post hoc Newman-Keuls ($p < .05$) tests revealed that all pairwise comparisons of leftward ($M = 8.65$), rightward ($M = 4.82$), descending ($M = 9.78$), and ascending ($M = 2.09$) motion were significant except for the rightward versus ascending and the leftward versus descending comparisons. The Direction \times Size interaction was significant, $F(6,90) = 20.86$, $MSE = 20.62$, $p < .001$, with increases in size producing increases in *M* displacement for leftward or descending motion, and decreases in *M* displacement for rightward or ascending motion. Size influenced *M* displacement, $F(2,30) = 3.81$, $MSE = 69.20$, $p < .04$: Post hoc Newman-Keuls ($p < .05$) tests revealed that small ($M = 7.51$) targets exhibited larger *M* displacement than did medium ($M = 5.76$) or large ($M = 5.73$) targets.

Landmark visibility during judgment did not significantly influence *M* displacement, but landmark visibility did interact with approach, $F(1,15) = 43.19$, $MSE = 43.59$, $p <$

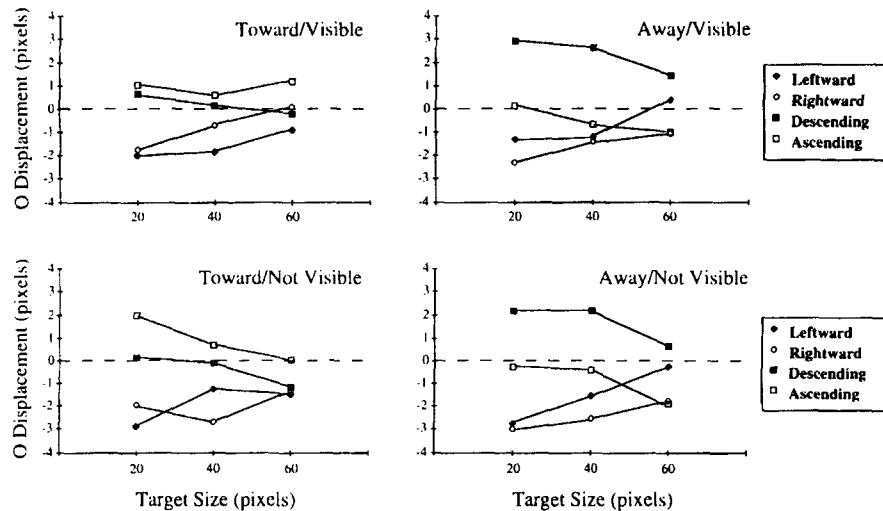


Figure 4. O displacement as a function of target size, approach, direction, and landmark visibility in Experiment 1.

.0005, and with Direction \times Size, $F(6,90) = 4.70$, $MSE = 16.09$, $p < .0005$. The effect of approach was stronger when the landmark was not visible, and increases in target size produced relatively larger decreases in M displacement for rightward motion when the landmark remained visible. No other main effects or interactions reached significance.

O displacement. Landmark visibility influenced O displacement, $F(1,15) = 12.09$, $MSE = 5.79$, $p < .005$: The magnitude of negative O displacement was greater when the landmark was not visible ($M = -0.89$) than when the landmark was visible ($M = -0.19$) during judgment. O displacement was influenced by direction, $F(3,45) = 7.32$, $MSE = 41.47$, $p < .0005$, and direction also interacted with approach, $F(3,45) = 8.83$, $MSE = 13.84$, $p < .0005$, and with size, $F(6,90) = 8.76$, $MSE = 4.43$, $p < .001$. Post hoc Newman-Keuls ($p < .05$) tests revealed that all pairwise comparisons for leftward ($M = -1.39$), rightward ($M = -1.69$), descending ($M = 0.96$), and ascending ($M = 0.13$) motion were significant except for the rightward versus leftward and the ascending versus descending comparisons. There were also trends for smaller targets and for targets moving away from the landmark to exhibit a greater range of direction effects. No other main effects or interactions reached significance.

DISCUSSION

Forward displacement along the axis of motion was larger when targets moved toward the landmark than when targets moved away from the landmark; this pattern is consistent with the hypothesis that landmark attraction combines with representational momentum in influencing the ultimate displacement of a target along the axis of motion. The main effect of whether the target approached or moved away from the landmark also interacted with effects of target size,

direction, and Size \times Direction. When the target moved away from the landmark, smaller targets exhibited larger magnitudes of M displacement. It may be that smaller targets were perceived as more likely to “escape” from the grip of the landmark. Alternatively, smaller targets were less similar in size to the landmark than were larger targets. Coupled with the fact that representational momentum decreases as the similarity between inducing stimuli decreases (Kelly & Freyd, 1987), perhaps smaller targets were also less strongly or less likely to participate in memory averaging with the landmark. Therefore, the forward displacement of smaller targets moving away from the landmark was reduced less by the landmark than was the forward displacement of larger targets moving away from the landmark. When the target approached the landmark, the displacement patterns were influenced by direction, with increases in target size linked with increases in forward displacement for leftward and descending targets.

The difference in the magnitude of M displacement between targets that moved toward the landmark and targets that moved away from the landmark was heightened when the landmark was not visible during judgment; this pattern is consistent with the generally larger landmark attraction effects found with memory than with perception (e.g., Bryant & Subbiah, 1994; Schiano & Tversky, 1992). When the landmark remained visible during judgment, and targets moved toward the landmark, then increases in target size led to increases in M displacement for leftward or descending targets, but decreases or no change in M displacement for rightward or ascending targets. When the landmark was not visible during judgment, there was a more consistent trend for increases in target size to lead to a slight decrease in M displacement or to no change in M displacement. Landmark visibility also influenced O displacement, as the magnitude

of negative O displacement was increased when the landmark was not visible during judgment, and there was a greater range of effects of direction, approach, and target size on O displacement when the target was not visible during judgment.

Larger horizontally moving targets exhibited greater displacement to the left regardless of whether the targets were moving toward the right or toward the left. Such a leftward bias for larger horizontally moving targets is not usually observed when targets are presented in isolation (e.g., Hubbard, 1997). One possible explanation is that the introduction of a landmark may have made hemifield differences in displacement more salient. Representational momentum is larger for targets in the left hemifield (Halpern & Kelly, 1993; White, Minor, Merrell, & Smith, 1993), and it may be that when observers divide attention (or other processing resources) between a target and a landmark, the differences in displacement magnitude (and perhaps in perceptual fluencies related to displacement) as a function of hemifield might become more pronounced. If observers fixate on a target moving toward the left, then the anticipated motion of that target is through the left hemifield; given the larger magnitudes of displacement generated by the left hemifield, targets moving toward the left therefore exhibit larger M displacement. This might also help account for the inconsistent effects of target size on displacement as a function of whether leftward moving targets moved toward or away from the landmark. This is because whether the landmark was in the left or the right hemifield, or whether the location of the landmark influenced whether the target was in the left or right hemifield, might influence processing of the target.

Descending targets exhibited greater M displacement than ascending targets, and this is a common pattern previously suggested to reflect a combination of representational momentum and representational gravity (e.g., Hubbard, 1990). When targets were above the landmark, size had a larger effect on displacement: For ascending motion away from the landmark, larger targets exhibited smaller forward displacement than did smaller targets, and for descending motion toward the landmark, larger targets exhibited larger forward displacement than did smaller targets. This pattern is consistent with previous studies of the effects of size on the displacement of vertically moving targets (Hubbard, 1997). When targets were below the landmark (i.e., in the descending away and the ascending toward conditions), size had a smaller effect on displacement. One possible explanation involves the naturalness of the displays. When targets were above the larger stationary landmark, those displays may have appeared more naturalistic (e.g., pictures in which a larger mass is near the bottom are judged as more balanced than are pictures in which a larger mass is near the top; Winner, Dion, Rosenblatt, & Gardner, 1987), and so effects of differences in implied weight were more likely to influ-

ence memory. When targets were below the larger stationary landmark, those displays may have appeared less naturalistic, and so effects of differences in implied weight were less likely to influence memory.

Horizontally moving targets exhibited a general downward displacement consistent with previous findings on representational gravity (e.g., Hubbard, 1997). Downward O displacement decreased with increases in target size, but this effect of target size was not consistent with an explanation in terms of the implied weight of the target. One possible explanation is that observers' memories may have been biased to also align the horizontal axes of the target and landmark (e.g., Tversky, 1981), and it may have been easier for observers to align the landmark and the target when the size of the target was closer to the size of the landmark. Such an alignment of the horizontal axes would have diminished the influence of representational gravity, and so increases in target size therefore resulted in a decrease in representational gravity. Ascending targets did not exhibit a consistent displacement toward either the left or the right, but descending targets exhibited a slight displacement toward the right when those targets moved away from the landmark. The very small rightward O displacement for descending targets moving away from the landmark was not predicted by a simple combination of representational momentum, representational gravity, or landmark attraction, and the reason for this displacement is not clear.

Experiment 2

In Experiment 1, the landmark was near the centre of the screen. It is possible that the larger M displacement observed when motion was toward the landmark and the smaller M displacement observed when motion was away from the landmark did not result from effects of landmark attraction per se, but rather from a general bias toward the centre of the screen. Therefore, we could interpret Experiment 1 as showing that M displacement was larger when the target moved toward the centre of the screen and smaller when the target moved away from the centre of the screen, and this would occur regardless of whether or not the landmark was visible. In order to help rule out a bias toward the centre of the screen, Experiment 2 presented the same targets in the same locations as in Experiment 1, but in the absence of a landmark. If the displacement patterns observed in Experiment 1 were due to a combination of representational momentum and landmark attraction effects, then the displacement patterns observed in Experiment 1 should not be observed in Experiment 2. However, if the displacement patterns observed in Experiment 1 were due to a bias toward the centre of the screen, or to a combination of representational momentum and a bias toward the centre of the screen, then the displacement patterns observed in Experiment 1 should also be observed in Experiment 2.

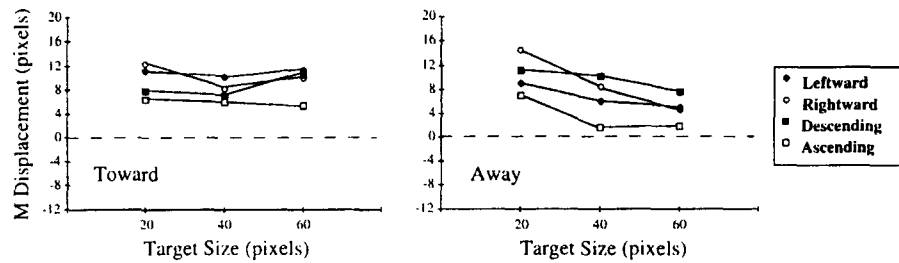


Figure 5. M displacement as a function of target size, approach, and direction in Experiment 2.

METHOD

Participants. The observers were 16 undergraduates from the same participant pool that was used in Experiment 1, and none of the observers had participated in the previous experiment.

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

Stimuli. The stimuli were the same as in Experiment 1, with the following exception: Landmarks were not drawn on the screen. Each participant received 168 trials (4 target directions [ascending, descending, leftward, rightward] \times 3 target sizes [20, 40, 60 pixels] \times 2 target approaches [toward the landmark, away from the landmark] \times 7 replications) in a different random order.

Procedure. The procedure was the same as in Experiment 1, with the following exception: The landmark was not visible at any time during the experiment.

RESULTS

M and O displacements were calculated as in Experiment 1, and were analyzed in separate 4 (target direction) \times 3 (target size) \times 2 (target approach) repeated measures analyses of variance. M displacements are shown in Figure 5, and O displacements are shown in Figure 6.

M displacement. The M displacement of targets moving toward the centre of the screen ($M = 8.84$) did not differ from the M displacement of targets moving away from the centre of the screen ($M = 7.21$), $F(1,14) = 0.49$, $MSE = 489.44$, $p > .49$. Approach interacted with direction, $F(3,42) = 3.44$, $MSE = 35.47$, $p < .03$, and with size, $F(2,28) = 8.34$, $MSE = 27.10$, $p < .002$. When targets moved toward the centre of the screen, increases in target size did not have a consistent effect on M displacement; when targets moved away from the centre of the screen, increases in target size led to a slight decrease in M displacement.

Direction influenced M displacement, $F(3,42) = 3.56$, $MSE = 129.52$, $p < .03$: Post hoc Newman-Keuls ($p < .05$) tests revealed that leftward ($M = 9.65$), rightward ($M = 8.73$), and descending ($M = 9.04$) motion all exhibited larger M displacement than did ascending ($M = 4.68$) motion. Size influenced

M displacement, $F(2,28) = 7.72$, $MSE = 41.04$, $p < .003$: Post hoc Newman-Keuls ($p < .05$) tests revealed that small ($M = 9.90$) targets exhibited larger forward M displacement than did medium ($M = 7.16$) or large ($M = 7.01$) targets. No other main effects or interactions reached significance.

O displacement. O displacement was influenced by direction, $F(3,42) = 23.16$, $MSE = 27.44$, $p < .0001$, and post hoc Newman-Keuls ($p < .05$) tests revealed all comparisons of leftward ($M = -1.65$), rightward ($M = -1.58$), descending ($M = 3.24$) and ascending ($M = 2.71$) motion were significant except for the leftward versus rightward and the ascending versus descending comparisons. No other main effects or interactions reached significance.

DISCUSSION

The overall magnitude of M displacement was not influenced by whether the target moved toward or away from the centre of the screen, and so we may reject the alternative hypothesis that the main effect of approach in Experiment 1 was due to a bias toward the centre of the screen. Similarly, we may also reject the related alternative hypothesis that the main effect of approach in Experiment 1 was due to a confound between the distance of a target's vanishing point from the centre of the screen and whether that target moved toward or away from the centre. The generally greater magnitude of leftward M displacement than rightward M displacement for larger horizontally moving targets that was observed in Experiment 1 was not present in Experiment 2, and this is consistent with the possibility that the difference observed in Experiment 1 may have resulted from additional processing demands or from increased hemifield effects created by the presence of the landmark. The effect of direction on both M and O displacement in Experiment 2 was consistent with patterns previously reported for targets presented in isolation (e.g., Hubbard, 1990). Also, the rightward O displacement that was observed for descending moving targets that moved away from the landmark in Experiment 1 was not present in Experiment 2.

M displacement was also influenced by the size of the target and by a Size \times Approach interaction: Larger targets moving away from the centre exhibited clearer decreases in M displacement. By equalizing the distance between the

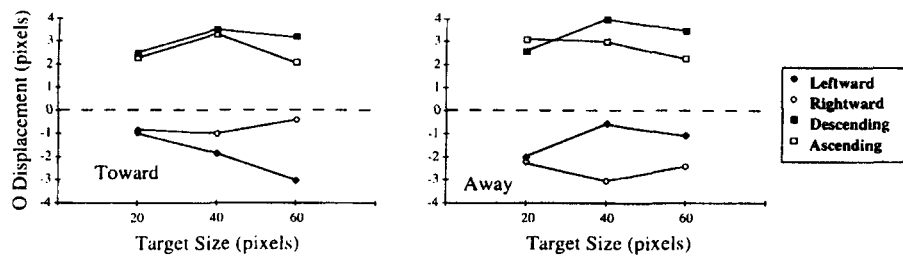


Figure 6. O displacement as a function of target size, approach, and direction in Experiment 2.

nearest edge of the target and the landmark, the finite extent of the monitor screen necessitated that the leading edge of a larger target moving away from the centre was closer to the edge of the screen when that larger target vanished than was the leading edge of a smaller target moving away from the centre of the screen when that smaller target vanished. The remembered location of a stationary target is displaced toward a landmark, and the magnitude of this displacement decreases with increases in proximity to the landmark (Nelson & Chaiklin, 1980) and with increases in target size (Hubbard & Ruppel, 1999). If the edge of the screen served as a landmark, and if proximity exhibits a similar effect on moving targets, then we might account for the observed decrease in forward displacement with increases in target size for targets that vanished closer to the edge of the screen (i.e., for targets that moved away from the centre).

Experiment 3

In Experiment 1, target motion was either directly toward or away from the landmark. Memory may also be displaced along the axis orthogonal to motion and toward a larger stationary stimulus adjacent to the target but to one side of the path of motion of the target (Hubbard, 1995a, 1998). However, it has not yet been examined whether displacement along the axis of motion may be similarly influenced when the landmark is some distance to one side of the path of motion of the target. Previous studies (e.g., Huttenlocher et al., 1991; Schiano & Tversky, 1992) reported that memory for the location of a static stimulus was displaced toward a cardinal or diagonal axis of a larger enclosing frame. As previously illustrated in Figure 2, we could therefore predict that M displacement should be relatively large if the target has not yet passed by the cardinal axis of the landmark, whereas M displacement should be relatively small if the target has already passed by the cardinal axis of the landmark. Also, we could predict that O displacement should be toward the landmark when the target is off to one side of the landmark. Accordingly, in Experiment 3 the path of the moving target was not directly toward or away from the landmark, but was slightly off to one side of that landmark.

METHOD

Participants. The observers were 16 undergraduates from the

same participant pool that was used in Experiment 1, and none of the observers had participated in the previous experiments.

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

Stimuli. The target was the same shape and size as the small target in Experiment 1. The landmark was a black square 60 pixels (approximately 2.50° of visual angle) in width. The size of the landmark was decreased from the size of the landmark in Experiment 1 so that neither the landmark nor the target would be too close to the edge of the screen (Hubbard & Ruppel, 1999, reported that landmark size did not influence displacement of stationary targets). As in Experiment 1, the edges of the target and the landmark were parallel with the horizontal and vertical axes of the screen. The target and the landmark were configured such that horizontally moving targets passed above or below the landmark and vertically moving targets passed to the left or right of the landmark. The distance between the closest edges of the landmark and target was 30 pixels. Targets vanished at one of five vanishing points relative to the cardinal axis of the landmark that was orthogonal to the path of target motion (i.e., the vertical axis of the landmark for targets moving horizontally, the horizontal axis of the landmark for targets moving vertically): -40, -20, 0, +20, or +40 pixels (a negative sign indicates a vanishing point before the target had passed by the cardinal axis, and a positive sign indicates a vanishing point after the target had passed by the cardinal axis; the unsigned [zero] vanishing point is on the cardinal axis). The different possible vanishing points were counterbalanced across trials. Target velocity was the same as in Experiment 1. On half of the trials, the landmark vanished when the target vanished, and on the other half of the trials, the landmark remained visible until the observer responded. On half of the ascending and descending trials, the target passed on the left side of the landmark, and on the other half of the ascending and descending trials, the target passed on the right side of the landmark. On half of the leftward and rightward trials, the target passed above the landmark, and on the other half of the leftward and rightward trials, the target passed below the landmark. Each participant received 320 trials (4 target directions [ascending,

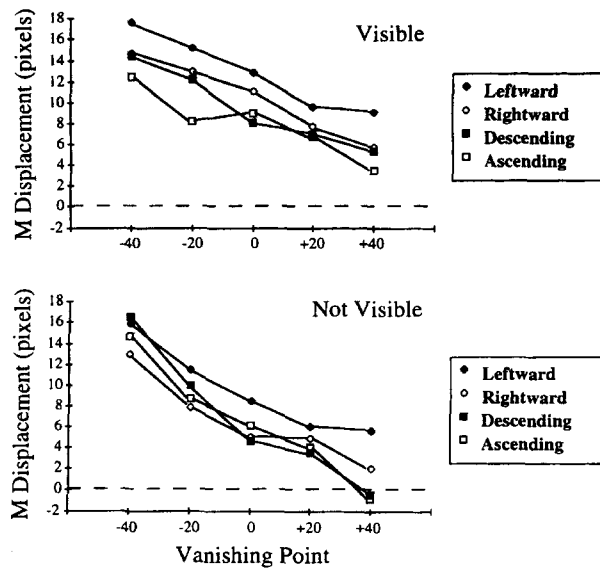


Figure 7. M displacement as a function of vanishing point, direction, and landmark visibility in Experiment 3.

descending, leftward, rightward] \times 2 configurations [above/left, below/right] \times 5 vanishing points [-40, -20, 0, +20, +40] \times 2 landmark visibilities [visible during judgment, not visible during judgment] \times 4 replications) in a different random order.

Procedure. The procedure was the same as in Experiment 1.

RESULTS

M displacement was calculated as in Experiment 1. O displacement was calculated as in Experiment 1, with the following exception: The sign convention was modified so that positively signed O displacements indicated judged vanishing points toward the landmark, and negatively signed

O displacements indicated judged vanishing points away from the landmark. M and O displacements were analyzed in separate 4 (target direction) \times 5 (vanishing point) \times 2 (landmark visibility) repeated measures analyses of variance, and are displayed in Figures 7 and 8, respectively.

M displacement. Vanishing point significantly influenced the magnitude of M displacement, $F(4,60) = 51.39$, $MSE = 92.69$, $p < .0001$. Post hoc Newman-Keuls ($p < .05$) tests comparing the first ($M = 14.86$), second ($M = 10.83$), third ($M = 8.16$), fourth ($M = 6.18$), and fifth ($M = 3.67$) vanishing points revealed that all pairwise comparisons were significant. Vanishing point also interacted with landmark visibility, $F(4,60) = 6.38$, $MSE = 32.07$, $p < .001$, and with direction, $F(12,180) = 1.89$, $MSE = 30.47$, $p < .05$. As shown in Figure 7, effects of vanishing point were larger when the landmark was not visible during judgment and for targets moving vertically. Direction influenced M displacement,

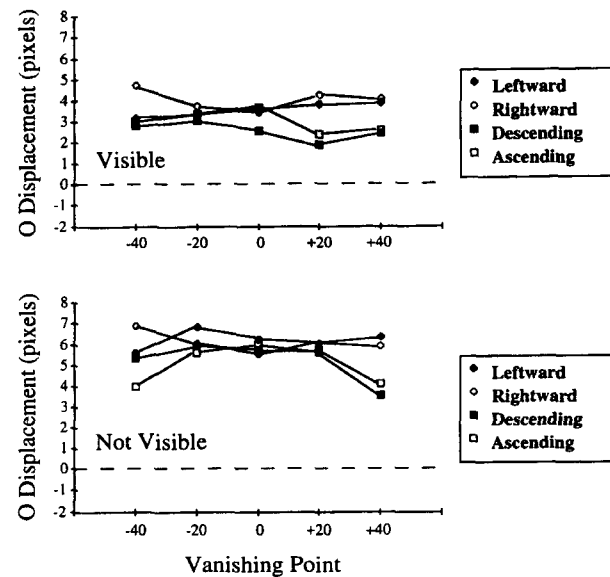


Figure 8. O displacement as a function of vanishing point, direction, and landmark visibility in Experiment 3.

$F(3,45) = 5.21$, $MSE = 174.36$, $p < .004$: Post hoc Newman-Keuls ($p < .05$) tests revealed that M displacement was larger for leftward ($M = 11.15$) motion than for rightward ($M = 8.47$), descending ($M = 8.07$), and ascending ($M = 7.27$) motion. Finally, M displacement was greater when the landmark was visible ($M = 10.16$) than when the landmark was not visible ($M = 7.32$), $F(1,15) = 39.76$, $MSE = 64.90$, $p < .0001$. No other main effects or interactions reached significance.

O displacement. Landmark visibility influenced O displacement, $F(1,15) = 30.12$, $MSE = 59.52$, $p < .0002$; O displacement was greater when the landmark was not visible ($M = 5.64$) than when the landmark was visible ($M = 3.27$) during judgment. O displacement was also influenced by direction, $F(3,45) = 4.22$, $MSE = 24.33$, $p < .02$, and a Direction \times Vanishing Point interaction, $F(12,180) = 1.81$, $MSE = 9.65$, $p < .05$. As shown in Figure 8, effects of vanishing point on O displacement were larger for targets moving vertically than for targets moving horizontally. No other main effects or interactions reached significance.

DISCUSSION

M displacement was larger when targets vanished before passing by the cardinal axis of the landmark than when targets vanished after passing by the cardinal axis of the landmark; this pattern is consistent with the hypothesis that landmark attraction toward the cardinal axis combines with representational momentum in determining the ultimate displacement of a target along the axis of motion. Furthermore, the magnitude of M displacement changes as a function of the distance of the target from the cardinal axis. If we presume the magnitude of representational momentum to be

constant for a specific direction and velocity condition, then the data suggest a gradient in the strength of the landmark attraction effect such that attraction is increased when the target is further from the cardinal axis (such a gradient is also consistent with the decreases in displacement toward the cardinal axis with increases in proximity to that axis for stationary targets reported by Hubbard & Ruppel, 1999). Such a gradient would be a V-shaped (or possibly U-shaped) curve symmetrical about the cardinal axis, and the combination of a V-shaped landmark attraction gradient and a constant magnitude of representational momentum could produce the approximately linear decline in forward displacement across vanishing points observed in Experiment 3.

The approximately linear decrease in forward displacement of the target was obtained using a range of vanishing point distances which were relatively close to the cardinal axis of the landmark. Even though landmark attraction may exhibit a V-shaped gradient within the range of distances studied in Experiment 3, it is reasonable to assume that there are distances beyond which the arms of the V-shaped gradient turn down and beyond which landmark attraction effects become negligible. Along these lines, it should be noted that the distance traveled by the target before vanishing varied across trials in Experiment 3, whereas the distance traveled by the target before vanishing did not vary across trials in Experiment 1. Although Experiment 3 might be interpreted as suggesting that displacement decreases with distance, such a conclusion is not consistent with Experiment 1, because targets in Experiment 1 traveled the same distance regardless of whether they moved toward or away from the landmark. Both Experiments 1 and 3 converged on the conclusion that the direction of target motion relative to the landmark (or to the cardinal axis of the landmark) influenced displacement. Also, forward displacement was larger for targets moving toward the left than for targets moving toward the right, and this is consistent with the pattern for larger horizontally moving targets in Experiment 1.

M displacement was larger when the landmark was visible than when the landmark was not visible, and landmark visibility did not interact with any other factors. This pattern is different from that observed in Experiment 1, and is also different from that observed in previous studies that examined the effects of a landmark on memory for stationary objects (e.g., Bryant & Subbiah, 1994; Hubbard & Ruppel, 1999). It may be that when the direction of the path between the target and the landmark does not change over time (e.g., when a target is stationary or moves directly toward or away from the landmark), then a relatively stronger or more focused memory trace corresponding to that path is encoded, whereas when the direction of the path between the target and the landmark does change over time (e.g., when a target moves past a landmark), then a relatively

weaker or more diffuse memory trace corresponding to the path is encoded.¹ Thus, landmark attraction effects are stronger in memory than in perception for targets that are stationary or move directly toward or away from the landmark, whereas landmark attraction effects are stronger in perception than in memory for targets that pass close by the landmark. Alternatively, the differences in the effect of landmark visibility might reflect differences in observer strategies (cf. Schiano & Tversky, 1992; Tversky & Schiano, 1989) as a function of target behaviour relative to the landmark.

O displacement was positive regardless of the direction of target motion; in other words, targets were displaced toward the landmark regardless of the direction of target motion or the direction of implied gravitational attraction. This pattern is consistent with the predicted displacement toward the landmark along the orthogonal axis, with the notion of spatial memory averaging, and with data from previous studies (e.g., Hubbard, 1995a, 1998). The magnitude of O displacement in Experiment 3 was larger than that typically reported for horizontally or vertically moving targets presented in isolation, and this is consistent with the displacement along the orthogonal axis noted in Hubbard (1995a, 1998) and with the hypothesis of an active bias toward the landmark. O displacement was also larger for targets moving vertically than for targets moving horizontally, and this is consistent with the generally larger displacements along the horizontal axis than along the vertical axis noted previously (e.g., Hubbard, 1990). Finally, displacement along the orthogonal axis was also larger when the landmark was not visible than when the landmark was visible: This pattern is inconsistent with the effects of landmark visibility on M displacement, but is consistent with the larger effects of landmark attraction reported with remembered stimuli than with perceived stimuli previously noted.

Experiment 4

Experiment 2 demonstrated that a bias toward the centre of the screen did not significantly influence M displacement for targets presented in isolation, and so the larger M displacement for targets that moved toward a landmark in Experiment 1 did not result from a bias toward the centre of the screen. It is desirable to eliminate the possibility of a similar bias in accounting for the results of Experiment 3 — more specifically, to eliminate the possibility that the displacements observed in Experiment 3 resulted from a bias toward

¹ Along these lines, it is even possible that the memory trace of the direction of the path between the target and the landmark might itself experience representational momentum as the direction of that path (relative to the cardinal axes of the landmark) is constantly changing, and given that a single pathway would not receive as strong an activation, the effects of the landmark in memory would be less than in perception.

the cardinal axis (either horizontal or vertical) of the screen that was orthogonal to the direction of target motion. Accordingly, Experiment 4 presented the same targets in the same locations as in Experiment 3, but the targets were displayed in the absence of a landmark. If the patterns of M or O displacement were the same as those in Experiment 3, then those patterns may have resulted from biases toward a cardinal horizontal or vertical axis of the screen. However, if the patterns of M and O displacement were different from those in Experiment 3, then the hypothesis that those patterns resulted from a bias toward a cardinal horizontal or vertical axis of the screen could be rejected.

METHOD

Participants. The observers were 15 undergraduates from the same participant pool that was used in Experiment 1, and none of the observers had participated in the previous experiments.

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

Stimuli. The stimuli were the same as in Experiment 3, with the following exception: Landmarks were not drawn on the screen. Each participant received 160 trials (4 target directions [ascending, descending, leftward, rightward] \times 2 configurations [above/left, below/right] \times 5 vanishing points [-40, -20, 0, +20, +40] \times 4 replications) in a different random order.

Procedure. The procedure was the same as in Experiment 1, with the following exception: The landmark was not visible at any time during the experiment.

RESULTS

M and O displacements were calculated as in Experiment 3, and M and O displacements were analyzed in separate 4 (target direction) \times 5 (vanishing point) repeated measures analyses of variance. M displacements are shown in Figure 9, and O displacements are shown in Figure 10.

M displacement. Vanishing point significantly influenced the magnitude of representational momentum, $F(4,60) = 3.68$, $MSE = 37.91$, $p < .01$. Post hoc Newman-Keuls ($p < .05$) tests comparing the first ($M = 9.87$), second ($M = 9.23$), third ($M = 7.98$), fourth ($M = 7.42$), and fifth ($M = 7.77$) vanishing points revealed that the first vanishing point was significantly different from the third, fourth, and fifth vanishing points. Direction influenced M displacement, $F(3,45) = 7.56$, $MSE = 205.56$, $p < .0004$: Post hoc Newman-Keuls ($p < .05$) tests revealed that all pairwise comparisons of leftward ($M = 11.71$), rightward ($M = 10.01$), descending ($M = 7.54$), and ascending ($M = 4.55$) motion were significant except for the leftward versus rightward and the ascending versus descending comparisons. No other main effects or interactions

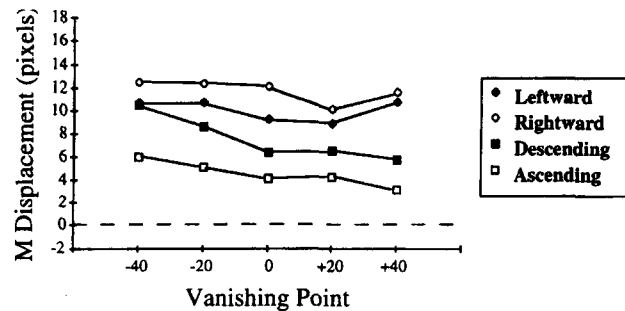


Figure 9. M displacement as a function of vanishing point and direction in Experiment 4.

reached significance.

O displacement. Direction influenced O displacement, $F(3,45) = 6.72$, $MSE = 7.79$, $p < .001$: Post hoc Newman-Keuls ($p < .05$) tests revealed that all pairwise comparisons of leftward ($M = 0.82$), rightward ($M = 0.96$), descending ($M = -0.15$), and ascending ($M = -0.02$) motion were significant except for the leftward versus rightward and the ascending versus descending comparisons. No other main effects or interactions reached significance.

DISCUSSION

Vanishing point significantly influenced M displacement, but comparisons of the data in Figures 7 and 9 (as well as the corresponding F and p values) reveals the magnitude of the effect of vanishing point was much greater in Experiment 3 than in Experiment 4. Although a weak bias toward a cardinal axis of the screen might contribute to the effects observed in Experiment 3, such a bias is certainly not solely responsible for the strong pattern observed in Experiment 3; therefore, the weak effect observed in Experiment 4 is not strong enough to require rejection of the hypothesis from Experiment 3 of a V-shaped gradient for the landmark attraction effect. The slight bias toward a cardinal axis when the target passed near the centre of the screen in Experiment 4 is different from the lack of a bias in Experiment 2 when the target moved directly toward or away from the centre of the screen. It may be that the bias toward a cardinal axis of the screen is stronger than any bias toward the centre per se. Alternatively, the slight trend toward a decrease in M displacement for more distant vanishing points in Experiment 4 is also consistent with the pattern found with slow velocities in Hubbard and Bharucha (1988; Experiment 2), and may reflect Runeson's (1974, 1975) finding that a uniform velocity is perceived as a fast velocity followed by a deceleration.

The asymmetry in the magnitude of M displacement between leftward motion and rightward motion observed in Experiment 3 was absent in Experiment 4. This pattern parallels a similar asymmetry in the magnitude of M displacement between leftward motion and rightward motion that

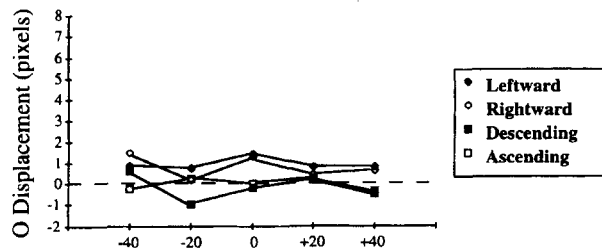


Figure 10. O displacement as a function of vanishing point and direction in Experiment 4.

was observed with larger targets in Experiment 1 but was absent in Experiment 2. The presence of the asymmetry in Experiments 1 and 3, coupled with the absence of the asymmetry in Experiments 2 and 4, is consistent with the hypothesis that the asymmetry results from the presence of the landmark. Why the presence of the landmark introduces such an asymmetry is not clear, but as discussed earlier, it is possible that the presence of the landmark highlights or amplifies hemifield differences in displacement. Also, the magnitude of O displacement in Experiment 4 was greatly reduced from that in Experiment 3: Without the landmark being presented, memory was not displaced toward the centre of the screen along the axis orthogonal to target motion. This lack of a bias toward the centre of the screen along the axis orthogonal to target motion in Experiment 4 paralleled the lack of a bias toward the centre of the screen along the axis of motion in Experiment 2, and supported the hypothesis that the effects of the landmark on displacement in Experiments 1 and 3 were not due to a bias toward the centre of the screen.

General Discussion

The forward displacement of a moving target was greatly influenced by the presence and location of a landmark and by the spatial relationship between the target's location and direction of motion and the landmark. When a target moved directly toward a landmark, forward displacement of that target was increased, whereas when a target moved directly away from a landmark, forward displacement of that target was decreased. When the path of target motion was such that the target passed near a landmark, forward displacement of the target was increased if the target had not yet passed by the cardinal axis of the landmark, whereas forward displacement of the target was decreased if the target had already passed by the cardinal axis of the landmark. When the path of motion was directly toward or away from a landmark, no clear effects of that landmark were observed upon displacement of the target along the axis orthogonal to motion, whereas if the target passed close to a landmark, displacement of the target along the original axis was toward the landmark. These findings are consistent with previous findings on the effects of nontarget context on the displace-

ment of a target and with claims that memory is biased toward landmarks and other reference points.

The effect of a landmark on the displacement of a target along the axis of motion is similar if the target directly approaches or moves away from the landmark or if the target passes close by the landmark. In both cases, the magnitude of forward displacement increases as the target approaches and decreases as the target moves away. Such a similarity in displacement patterns suggests that similar mechanisms may be involved in producing displacements in the two different cases, and a comparison of the combination of representational momentum and landmark attraction effects illustrated in Figures 1 and 2 highlights this similarity. Indeed, it may be that moving directly toward a landmark is just a special case of moving toward a cardinal axis of a landmark in which the target happens to also be moving along a different cardinal axis of that same landmark. Also, the combination of landmark attraction effects with representational momentum along the axis of motion in Experiments 1 and 3 or of landmark attraction effects with representational gravity along the axis orthogonal to target motion in Hubbard (1995a) is consistent with the hypotheses that these individual biases may combine with each other (and with other information) in producing the ultimate displacement in the remembered position of the target.

The similarity in the displacements resulting from motion of the target directly toward the landmark or toward a cardinal axis of the landmark also suggests that the amount of mass directly in front of the target (i.e., along the axis of motion) may not be a critical component in the determination of the magnitude of the landmark attraction effect. After all, when the target moves toward or away from the cardinal axis of the landmark (i.e., when the target passes by a landmark), the mass of the landmark is in a direction different from that of the motion of the target. This lack of an effect of mass of the landmark on the forward displacement of the target is consistent with the lack of mass effects per se in studies of representational momentum (Cooper & Munger, 1993) and the failure of landmark size to influence the magnitude of the displacement of a stationary target toward that landmark (Hubbard & Ruppel, 1999). Conclusive study of the effects of landmark size on the forward displacement of a moving target awaits further research, but results thus far are suggestive: It may be that landmarks function more as a point or a direction, and so the surface area, mass, or volume of the landmark would not contribute to the magnitude of any displacement effect exhibited by a target.

The effects of a landmark on displacement that have been observed thus far are easily accounted for within the framework of a vector model (as previously illustrated in Figures 1 and 2). Although the bulk of the explanation of the displacement patterns from Experiments 1, 2, 3, and 4 has been couched in terms of representational momentum

and landmark attraction effects, a vector model of displacement is not limited to those particular quantities (e.g., contributions of representational friction and representational gravity to displacement may be easily incorporated). Indeed, the ultimate displacement of a target may be a weighted combination of any number of quantities. The ultimate remembered location of a target will reflect the final combination of quantities, regardless of the number of elements. Also, the interactions of target size, direction of target motion, and of whether the target moved toward or away from the landmark that were observed in the current data suggest that the combination of representational momentum and landmark attraction effects may not be additive; alternatively, such interactions could reflect the presence of factors that have not yet been documented.

Such a vector approach might be realizable within a network model (see also Hubbard, 1995b). If we posit a network in which different nodes correspond to different locations in space, then it is possible that the presence of a target and a landmark would activate the corresponding nodes. Activation from the stationary landmark nodes would prime surrounding nodes, and activation from a moving target would preferentially spread into the areas of anticipated future target motion (such a preferential spread would produce representational momentum for that target). Regardless of whether the target was moving toward or away from the landmark (or a cardinal axis of the landmark), at least some of the region between the target and the landmark would have been primed by the landmark. If the target was moving toward the landmark (or a cardinal axis of the landmark), then priming from the landmark would allow target activation to more easily or more rapidly flow forward, thus increasing the magnitude of forward displacement. If the target was moving away from the landmark, then perhaps relatively more activation might flow back in the direction of the nodes primed by the landmark, thus reducing the magnitude of forward displacement. Similarly, if the landmark is to one side of the target, then the region corresponding to the orthogonal axis closest to the landmark would have been primed by the landmark, thus facilitating displacement toward the landmark.

The data are consistent with suggestions that spatial memory averaging influences memory for target location. As noted at the outset, landmark attraction effects and spatial memory averaging both predict displacement in remembered location toward the landmark, and it was suggested that landmark attraction may be a special case of spatial memory averaging. The vector and network approaches discussed here suggest an even tighter relationship between landmark effects and spatial memory averaging — spatial memory averaging may be the mechanism that produces landmark attraction effects. Furthermore, such a mechanism relates landmark attraction effects to other common cognitive processes that might not otherwise be

seen as similar (e.g., memory averaging of exemplars may result in the abstracting of a prototype), and allows a clearer way of conceptualizing how landmark effects may interact with other factors. Regardless of the ultimate scope of memory averaging, the data reported here reveal that the ultimate remembered location of a target may be influenced by spatial memory averaging and how spatial memory averaging may combine with representational momentum.

The authors thank Patrick McCormick and two anonymous reviewers for comments. Portions of these data were presented at the 39th Annual Meeting of the Psychonomic Society, Dallas, Texas, November 1998. Correspondence should be addressed to Timothy Hubbard, Department of Psychology, TCU Box 298920, Texas Christian University, Fort Worth, TX 76129, USA (E-mail: thubbard@gamma.is.tcu.edu).

References

- Bryant, D. J., & Subbiah, I. (1994). Subjective landmarks in perception and memory for spatial location. *Canadian Journal of Experimental Psychology*, *48*, 119-139.
- Cooper, L. A., & Munger, M. P. (1993). Extrapolating and remembering positions along cognitive trajectories: Uses and limitations of analogies to physical motion. In N. Eilan, R. McCarthy, & B. Brewer (Eds.), *Spatial representation: Problems in philosophy and psychology* (pp. 112-131). Cambridge, MA: Blackwell.
- 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.
- Halpern, A. R., & Kelly, M. H. (1993). Memory biases in left versus right implied motion. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 471-484.
- 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. (1995a). Cognitive representation of motion: Evidence for friction and gravity analogues. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 241-254.
- Hubbard, T. L. (1995b). 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. (1997). Target size and displacement along the axis of implied gravitational attraction: Effects of implied weight and evidence of representational gravity. *Journal of Experimental Psychology: Learning, Memory, and Cognition*,

- 23, 1484-1493.
- Hubbard, T. L. (1998). Some effects of representational friction, target size, and memory averaging on memory for vertically moving targets. *Canadian Journal of Experimental Psychology*, 52, 44-49.
- Hubbard, T. L., & Bharucha, J. J. (1988). Judged displacement in apparent vertical and horizontal motion. *Perception & Psychophysics*, 44, 211-221.
- Hubbard, T. L., & Ruppel, S. E. (1999). Spatial memory averaging, the landmark attraction effect, and representational gravity. *Manuscript submitted for publication*.
- Huttenlocher, J., Hedges, L. V., & Duncan, S. (1991). Categories and particulars: Prototype effects in estimating spatial location. *Psychological Review*, 98, 352-376.
- Kelly, M. H., & Freyd, J. J. (1987). Explorations of representational momentum. *Cognitive Psychology*, 19, 369-401.
- McNamara, T. P., & Diwadkar, V. A. (1997). Symmetry and asymmetry of human spatial memory. *Cognitive Psychology*, 34, 160-190.
- Nelson, T. O., & Chaiklin, S. (1980). Immediate memory for spatial location. *Journal of Experimental Psychology: Human Learning and Memory*, 6, 529-545.
- Runeson, S. (1974). Constant velocity — Not perceived as such. *Psychological Research*, 37, 3-23.
- Runeson, S. (1975). Visual prediction of collision with natural and non-natural motion functions. *Perception & Psychophysics*, 18, 261-266.
- Sadalla, E. K., Burroughs, W. J., & Staplin, L. J. (1980). Reference points in spatial cognition. *Journal of Experimental Psychology: Human Learning and Memory*, 6, 516-528.
- Schiano, D. J., & Tversky, B. (1992). Structure and strategy in encoding simplified graphs. *Memory & Cognition*, 20, 12-20.
- Tversky, B. (1981). Distortions in memory for maps. *Cognitive Psychology*, 13, 407-433.
- Tversky, B., & Schiano, D. J. (1989). Perceptual and conceptual factors in distortions in memory for graphs and maps. *Journal of Experimental Psychology: General*, 118, 387-398.
- White, H., Minor, S. W., Merrell, J., & Smith, T. (1993). Representational-momentum effects in the cerebral hemispheres. *Brain and Cognition*, 22, 161-170.
- Winner, E., Dion, J., Rosenblatt, E., & Gardner, H. (1987). Do lateral or vertical reversals affect balance in paintings? *Visual Arts Research*, 13, 1-9.

Date of acceptance: April 19, 1999

Sommaire

Le souvenir de la position finale d'une cible en déplacement traduit habituellement la direction du mouvement anticipé, donc vers l'avant, ce qu'on appelle le *momentum représentationnel* (voir Hubbard, 1995b). Le souvenir que l'on a d'une distance entre une cible et un point de repère est souvent celui d'une distance plus courte qu'en réalité, ce qu'on appelle *l'effet d'attraction du point de repère* (Bryant et Subbiah, 1994). Les expériences mentionnées ici ont permis d'étudier la façon dont le momentum représentationnel et les effets d'attraction du point de repère se combinent pour déterminer la position mémorisée d'une cible qui soit se déplaçait vers un point de repère soit s'en éloignait. Les déplacements entre les points de fuite perçus et les points de fuite réels ont été mesurés sur l'axe du mouvement et sur l'axe cartésien par rapport au mouvement. Dans l'expérience 1, un vaste point de repère était affiché et la cible se trouvait soit directement au-dessus, en-dessous, à gauche ou à droite de ce point, et se déplaçait directement vers lui ou s'en éloignait. Un déplacement vers l'avant sur l'axe du mouvement était plus grand quand la cible se dirigeait vers la cible que lorsqu'elle s'en éloignait. Cet effet était également assujéti à la direction de la cible, à sa taille et au fait que le point de repère demeure visible durant l'observation. Dans l'expérience 2, on montrait les mêmes cibles que celles utilisées durant l'expérience 1, toutefois le point de repère

n'était pas visible, ce qui écartait l'hypothèse voulant que les données issues de l'expérience 1 soient l'effet d'une polarisation vers le centre de l'écran. Dans l'expérience 3, la cible est passée près du point de repère. Le déplacement vers l'avant était plus grand quand la cible approchait de l'axe cardinal du point de repère que lorsqu'elle dépassait cet axe. Cet effet était lui aussi assujéti à la direction de la cible, à sa taille et au fait que le point de repère demeure visible durant l'observation. De plus, l'observateur gardait le souvenir d'une cible se déplaçant vers le point de repère, sur l'axe cartésien par rapport à la direction du mouvement. Les utilisées pour l'expérience 4 étaient les mêmes que pour l'expérience 3, sauf que le point de repère n'était pas visible à l'écran et les résultats ont écarté l'autre hypothèse voulant que les données issues de l'expérience 3 soient l'effet d'une polarisation vers un axe cardinal de l'écran. Dans l'ensemble, les résultats ont corroboré l'hypothèse voulant que la présence d'un point de repère ait influé sur le déplacement mémorisé d'une cible proche. La matrice des déplacements traduisait une perspective vectorielle où le déplacement d'une cible était la somme du momentum représentationnel de cette cible et de l'attraction d'un point de repère à proximité. Lorsqu'une cible se déplaçait directement vers un point de repère ou vers l'axe cardinal d'un point de repère, et le momentum représentationnel et l'attraction du point

de repère convergeaient dans la même direction, ce qui engendrait un long déplacement vers l'avant sur l'axe directionnel. Par contre, lorsque la cible s'éloignait d'un point de repère ou de l'axe cardinal d'un mouvement, le momentum représentationnel et l'attraction exercée par le point de repère opéraient dans des directions opposées, ils avaient donc un effet d'invalidation partielle, d'où un déplacement résultant sur l'axe directionnel plus limité. De

la même façon, lorsque la cible passait près du point de repère, on constatait un déplacement vers le point de repère sur l'axe cartésien par rapport au mouvement de la cible. Une telle perspective vectorielle peut être instanciée à l'intérieur d'un modèle de diffusion de l'activation où les zones adjacentes à un point de repère ou sur l'axe du mouvement anticipé de la cible obtiennent la préférence.