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Spatial memory averaging, the landmark attraction effect, and representational gravity

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Abstract The effect of a large stationary landmark on memory for the location of a stationary target was examined. Memory for a stationary target was displaced toward the landmark, and targets that were larger, further from, or above the landmark exhibited greater magnitudes of displacement. Displacement was generally larger when the landmark vanished prior to judgment than when the landmark was visible during judgment. Memory for stationary targets offset from the major vertical or horizontal cardinal axis of the landmark was also displaced toward that cardinal axis. The data support the hypotheses that spatial memory averaging of the locations of a target and landmark occurs, and that this averaging may be combined with representational gravity in determining the remembered position of a stationary target.

Introduction

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 reviews see Hubbard, 1995b, 1999). For example, memory for the final position of a moving target that vanishes without warning is distorted forward in the direction of implied motion and downward in the direction of implied gravitational attraction, and these biases have been referred to as "representational momentum" (e.g., Freyd & Finke, 1984; Kelly & Freyd, 1987) and "representational gravity" (Hubbard, 1995b, 1997), respectively. A second type of bias distorts memory by decreasing the remembered distance between a target and a landmark (e.g., McNamara & Diwadkar, 1997; Nelson & Chaiklin, 1980; Sadalla, Burroughs, & Staplin, 1980), and this bias has been referred as a "landmark attraction effect" (Bryant & Subbiah, 1994). These biases of spatial memory result in a displacement of the remembered position of a previously perceived target stimulus; in other words, the remembered final position of a target stimulus is not the same as the actual final position of that target stimulus – the remembered position is displaced from the actual position.

Given that distortions arising from implied environmentally invariant physical principles and distortions arising from landmark attraction effects both result in a displacement of the remembered position of a target, it is possible that these distortions may interact or combine with each other to determine the ultimate displacement of a target. In one early example, a rotating target was enclosed within a larger square frame (Hubbard, 1993). When the frame was stationary and at an orientation slightly beyond the final orientation of the target, or when the frame rotated in the same direction as the target, then forward displacement of the target increased. When the frame was stationary and at an orientation slightly behind the final orientation of the target, or when the frame rotated in the direction opposite to the rotation of the target, then forward displacement of the target decreased. These displacement patterns may have resulted from a combination of representational momentum and landmark attraction: when representational momentum and landmark attraction operated in the same direction (i.e., a stationary frame was oriented beyond the final orientation of the target or a moving frame rotated in the same direction as the target), they combined and the resultant forward displacement of the target increased, whereas when representational momentum and landmark attraction operated in opposite directions (i.e., a stationary frame was oriented behind the final orientation of the target or a moving frame rotated in the direction opposite to the target), they partially canceled out and the resultant forward displacement of the target decreased.

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The effect of a surrounding or enclosing frame illustrates that landmark attraction can indeed influence the displacement of a moving target. Similar displacements in memory for a stationary stimulus within a larger enclosing framework have also been noted (e.g., Huttenlocher, Hedges, & Duncan, 1991; Nelson & Chaiklin, 1980). However, a larger enclosing framework is not typical of the traditional usage of the notion of "landmark," which usually refers to a distinctive location, point, or object along a particular route or at a specific distance and direction from the individual or target (e.g., Lynch, 1960). Hubbard and Ruppel (1999) recently investigated the effects of a more traditional landmark on the displacement of a target that moved toward or away from that landmark. Forward displacement increased if the target moved toward the landmark, but forward displacement decreased if the target moved away from the landmark. This pattern might be accounted for with the same mechanisms used to account for the effects of an enclosing frame on the displacement of the target: when representational momentum and landmark attraction operated in the same direction (i.e., when the target moved toward the landmark), they combined and the resultant forward displacement of the target increased, whereas when representational momentum and landmark attraction operated in opposite directions (i.e., when the target moved away from the landmark), they partially canceled out and the resultant forward displacement of the target decreased.

Additional evidence of the effects of landmark attraction on memory for a moving target may be found in a consideration of the displacement along the axis orthogonal to target motion for vertically or horizontally moving targets. For example, when a vertically moving target appeared to slide along the left or right edge of a larger stationary object, memory for the position of the target was also displaced along the orthogonal axis toward that larger stationary object (Hubbard, 1998). Similarly, when a horizontally moving target appeared to slide along the top or bottom edge of a larger stationary object, memory for the position of the target was also displaced along the orthogonal axis toward that larger stationary object (Hubbard, 1995a). Intriguingly, the magnitude of downward displacement when targets slid along the top edge of a larger stationary object was much greater than the magnitude of upward displacement when targets slid along the bottom edge of a larger stationary object, and this asymmetry was consistent with a combination of landmark attraction and representational gravity: when representational gravity and landmark attraction operated in the same direction (i.e., when the target was above the landmark), they combined and the net displacement of the target increased, whereas when representational gravity and landmark attraction operated in opposite directions (i.e., when the target was below the landmark), they partially canceled out and the net displacement of the target decreased.

The landmark attraction effect is reminiscent of spatial memory averaging. Hubbard (1995b) distinguished two senses of memory averaging: a temporal sense in which memory for the final position of a target is influenced by the perception of prior positions of that target, and a spatial sense in which memory for the final position of a target is influenced by the perception of nontarget stimuli presented concurrently with that target. The combination of temporal memory averaging with representational momentum was first described by Freyd and Johnson (1987), who demonstrated that the forward displacement of a rotating target decreased after a few hundred milliseconds, and they attributed this decrease to an averaging in memory of the final position of the target with the previous positions of the target. However, unless prior positions of the target are considered to function as landmarks, it is not clear how such a temporal memory averaging could contribute to landmark attraction per se. The combination of spatial memory averaging with representational momentum was first described by Hubbard (1993, 1995a, 1998) and Hubbard and Ruppel (1999), who demonstrated that the forward displacement of a target was influenced by the presence of nontarget stimuli that were presented either concurrently with the target or after the target had vanished.

When we consider how memory for a target may be influenced by a landmark, spatial memory averaging and landmark attraction are difficult to empirically disentangle; indeed, both spatial memory averaging and landmark attraction predict that memory for a target should be displaced toward a landmark, and the terms have seemingly been used interchangeably. However, spatial memory averaging is a broader notion than landmark attraction, and it may be that the landmark attraction effect is a special case of spatial memory averaging in which memory for a target is displaced toward a special type of contextual element, namely, a landmark. In other words, spatial memory averaging may provide a more basic mechanism by which landmark attraction effects occur. By considering landmark attraction as a specific case of a more general spatial memory averaging, we may be able to broaden theories of displacement and begin to locate ideas regarding displacement within the broader literature on cognitive mapping and spatial representation. Indeed, a first step in the integration of displacement within the broader literature on spatial representation has already been taken, and involved the proposal that representational momentum and boundary extension were both special cases of a more general displacement mechanism that distorted memory in ways consistent with past experience (Hubbard, 1996).

The studies reviewed to this point support the hypothesis that the effects of landmark attraction can combine with the effects of representational momentum or the effects of representational gravity, and that the ultimate displacement of a target reflects influences from landmark attraction and from implied invariant physical principles. Such an apparent combination of influences is consistent with previous proposals that the ultimate displacement of a target reflects a combination of influences (e.g., see Hubbard, 1995b). In previous studies of memory averaging in the representational momentum literature, the target was always undergoing motion, and so it is possible that the apparent effects of memory averaging may have been an artifact of that motion and not due to memory averaging per se. In previous studies of memory averaging in which stationary targets were presented, the target was always surrounded by a larger enclosing framework. To have more confidence in the existence of spatial memory averaging per se, and in the possibility that spatial memory averaging might occur in the absence of motion, it is desirable to examine how memory for a stationary target is influenced by a landmark that is a specific single direction and distance from the target.

The following experiments examined displacements in remembered spatial position, and all stimuli were computer-generated and displayed on a CRT monitor. Experiment 1 presented a stationary square target to one side of a large square landmark, and target size and distance from the landmark were varied. Experiment 2 presented the target to one side of a landmark, and landmark size and target distance from the landmark were varied. In Experiments 1 and 2 the landmark was larger than the target, and so in Experiment 3 the landmark was smaller than the target and consisted of a small cross-hair at the coordinates corresponding to the center of the landmark in Experiments 1 and 2. Experiment 4 was a control experiment in which no landmarks were presented, and was designed to rule out an alternative hypothesis that the results of the previous experiments were due to a bias toward the center of the display. In Experiments 1, 2, and 3, the target was aligned with one of the cardinal axes of the landmark (i.e., the target was aligned with the vertical or horizontal axis of symmetry of the landmark), and so in Experiment 5 the target was a constant distance from the nearest edge of the landmark but varied in distance from the nearest cardinal axis of the landmark. In all of the experiments, observers used a computer mouse to position the cursor at the remembered position of the target after the target had vanished, and in Experiments 1, 2, 3, and 5, the landmark either vanished when the target vanished or remained visible until the observer responded.

Experiment 1

In this experiment, a small stationary target was briefly presented above, below, right of, or left of a larger stationary landmark. The size of the target and the proximity of the target to the landmark varied across trials. After the target vanished, observers indicated the remembered position of the target. If a landmark attraction effect occurs, then memory for the target should be displaced toward the landmark. Additionally, on half of the trials, the landmark vanished at the same time the target vanished, and on half of the trials, the landmark remained visible until the observer responded. If effects of the landmark are larger during judgment, then displacement of the target toward the landmark should be larger when the landmark remains visible. This possibility is consistent with findings that the orientation of a surrounding frame had a larger effect on displacement in the remembered orientation of a rotating target when the frame was visible only during judgment than when the frame was visible only prior to judgment (Hubbard, 1993). Alternatively, a visible landmark could provide a stable reference point which could diminish the magnitude of any such displacement. This latter possibility is consistent with findings that landmark attraction effects are often weaker in perception than in memory (e.g., Bryant & Subbiah, 1994; Tversky & Schiano, 1989).

Method

Participants. The observers were 16 undergraduates from Texas Christian University who participated in return for partial course credit in an introductory psychology course. All observers were naïve to the hypothesis until after their data had been collected.

Apparatus. The stimuli were displayed upon and data collected by an Apple Macintosh IIsi microcomputer equipped with an Apple RGB color monitor.

Stimuli. The target and landmark stimuli were filled black squares presented on a white background. The target square was either 20, 40, or 60 pixels (approximately 0.83°, 1.67°, or 2.50°) in diameter, and the landmark square was always 120 pixels (approximately 5.00°) in diameter. Both the target and the landmark were oriented such that each edge was either horizontal or vertical. For targets above or below the landmark, the centers of the target and landmark were at the same horizontal coordinates; for targets left or right of the landmark, the centers of the target and the landmark were at the same vertical coordinates. The closest edges of the target and landmark were separated by either 40, 90, or 140 pixels (approximately 1.67°, 3.75°, or 5.83°). Targets were displayed for 1 s; on half of the trials, the landmark vanished when the target vanished, and on half of the trials, the landmark remained visible until the observer responded. Each participant received 360 trials (2 landmark visibilities × 3 target proximities × 4 target directions × 3 target sizes × 5 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. The landmark immediately appeared, and after a 1-s pause, the target appeared. The target and landmark remained visible for 1 s. On half of the trials, the target then vanished and the landmark remained visible; on half of the trials, the target and the landmark then simultaneously vanished. The cursor, in the form of a plus sign, appeared at a random location, and observers were instructed to position the center of the cursor over where the center of the target had been when the target vanished. The cursor was positioned via the 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 differences between the true vanishing point and the judged vanishing point (in pixels) along the x- and y-axes were calculated for each target. The differences along the axis between the target and the landmark (i.e., the x axis for targets left or right of the landmark, and the y axis for targets above or below the landmark) were referred to as "T displacement" ("toward" the nearest edge of the landmark). The differences along the axis parallel to the surface of the landmark (i.e., the y axis for targets left or right of the landmark, and the x axis for targets above or below the landmark) were referred to as "P displacement" ("parallel" to the nearest edge of the landmark). Positively signed T displacements indicated judged vanishing points displaced toward the landmark, and negatively signed T displacements indicated judged vanishing points displaced away from the landmark. Positively signed P displacements indicated judged vanishing points above (for targets left or right of the landmark) or right (for targets above or below the landmark) of the true vanishing point, and negatively signed P displacements indicated judged vanishing points below (for targets left or right of the landmark) or left (for targets above or below the landmark) of the true vanishing point.

The mean T and P displacements are illustrated in Fig. 1. Displacements for trials in which the landmark was visible during judgment are shown in the top panel (in which the location of the landmark is indicated by a black square), and displacements for trials in which the landmark was not visible during judgment are shown in the bottom panel (in which the previous location of the landmark is indicated by an outline square). The arrows indicate the direction and extent of displacement. The distances of the near, intermediate, and far targets are indicated by the inner, middle, and outer dashed contours, respectively. Displacements for small, medium, and large targets are indicated by S, M, and L, respectively (although for each direction and proximity condition the coordinates of the target edge closest to the landmark were the same and the coordinates of the center of each target were along an extension of the axis of symmetry of the landmark, in Fig. 1 the base of the displacement arrows are offset along the dashed contour line for the purpose of clarity). The T and P displacements were analyzed in separate 2 (visibility) × 3 (proximity) × 4 (direction) × 3 (size) repeated measures analyses of variance (ANOVAs).

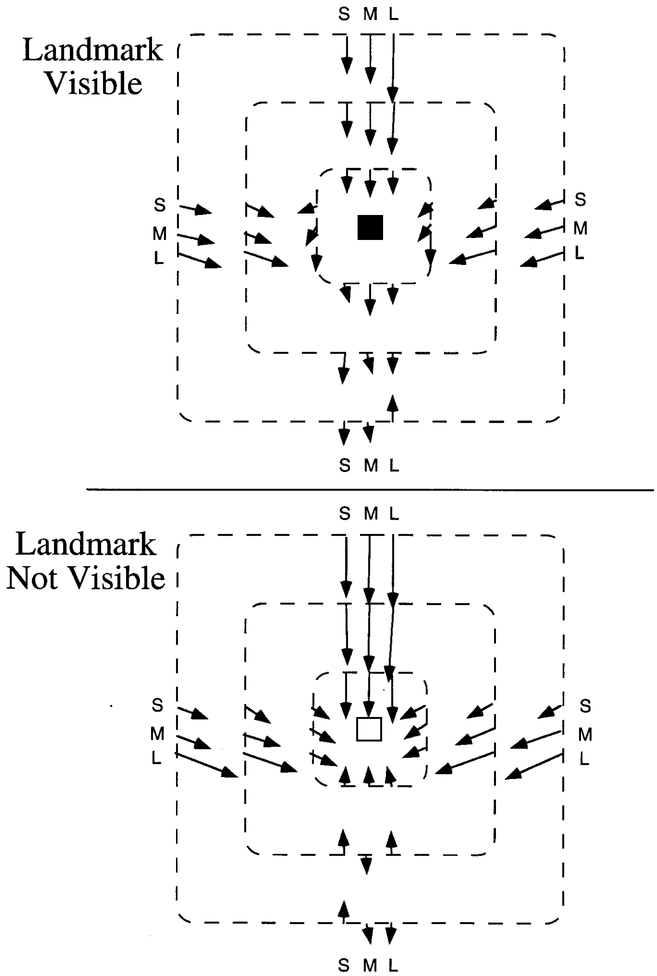

Fig. 1 Displacement as a function of target size and proximity to the landmark in Experiment 1 (see text for explanation)

T displacement

Landmark visibility influenced T displacement, $F(1, 15) = 21.12$, $MSE = 78.84$, $p < 0.0005$; the magnitude of positive T displacement was larger when the landmark was not visible ($M = 4.50$) than when the landmark was visible ($M = 2.10$) during judgment. Landmark visibility also interacted with Direction, $F(3, 45) = 3.14$, $MSE = 32.44$, $p < 0.04$, and with Proximity, $F(2, 30) = 7.60$, $MSE = 30.81$, $p < 0.005$. As may be seen in Fig. 1, there were larger effects of direction when the landmark was not visible during judgment, and larger effects of proximity when the landmark was visible during judgment.

Proximity influenced T displacement, $F(2, 30) = 5.54$, $MSE = 85.02$, $p < 0.01$, and a post hoc Newman-Keuls test ($p < 0.05$) revealed that near ($M = 2.02$) targets on average exhibited less T displacement than either intermediate ($M = 4.02$) or far ($M = 3.85$) targets. Proximity also interacted with Size, $F(4, 60) = 2.72$, $MSE = 19.79$, $p < 0.05$, and Direction, $F(6, 90) = 2.52$, $MSE = 26.64$, $p < 0.04$. As may be seen in Fig. 1, effects of proximity were slightly diminished for smaller targets and for targets below the landmark.

Direction influenced T displacement, $F(3, 45) = 9.86$, $MSE = 275.36$, $p < 0.001$. Planned comparisons revealed that T displacements for targets left ($M = 3.29$) or right ($M = 3.26$) of the landmark did not differ, $F(1, 15) = 0.0$, $p = 0.98$, and that T displacement for targets above ($M = 7.08$) the landmark was significantly larger than T displacement for targets below ($M = -0.44$) the landmark, $F(1, 15) = 15.81$, $p < 0.002$. The Direction × Size interaction was marginally significant, $F(6, 90) = 2.08$, $MSE = 24.55$, $p < 0.07$, with a larger effect of direction exhibited by larger targets.

Size influenced T displacement, $F(2, 30) = 5.43$, $MSE = 42.89$, $p < 0.01$; a post hoc Newman-Keuls test ($p < 0.05$) revealed that small ($M = 2.57$) targets exhibited less T displacement than large ($M = 4.12$) targets, and that neither small nor large targets differed from medium ($M = 3.21$) targets. No other main effects or interactions reached significance.

P displacement

Landmark visibility influenced P displacement, $F(1, 15) = 5.87$, $MSE = 7.34$, $p < 0.03$; the magnitude of negative P displacement was larger when the landmark was not visible ($M = -1.41$) than when the landmark was visible ($M = -1.02$) during judgment. P displacement was also influenced by direction, $F(3, 45) = 14.92$, $MSE = 75.90$, $p < 0.0005$, and the Direction × Size interaction was marginally significant, $F(6, 90) = 1.98$, $MSE = 9.61$, $p < 0.09$. As may be seen in Fig. 1, P displacement was negative (i.e., downward) when the target was to the left ($M = -3.09$) or right ($M = -2.63$) of the landmark, and P displacement was near zero (i.e., neither consistently to the left nor consistently to the right) when the target was above ($M = -0.05$) or below ($M = 0.97$) the landmark, and there was a trend for smaller targets to exhibit a greater range of the effects of direction. No other main effects or interactions reached significance.

Discussion

Memory for the target was displaced toward a large stationary landmark, and the magnitude of displacement was larger when the landmark was not visible during judgment. The displacement toward the landmark was consistent with both spatial memory averaging and landmark attraction. The decrease in displacement when the landmark remained visible might initially seem to suggest that the landmark had less influence when it was visible during judgment in Experiment 1 than when it was visible during judgment in Hubbard (1993). However, the landmark in Experiment 1 was in the same position during judgment as it had been prior to judgment, whereas the surrounding frame in Hubbard (1993) was not necessarily in the same orientation during judgment as it had been prior to judgment, nor was it necessarily aligned with the orientation of the target in the same way during judgment as it had been prior to judgment. If memory is biased toward the location (or orientation) of nearby context, then the effects of such a bias might have been more noticeable when the landmark was at a different location (or orientation) during judgment. Thus, memory for the target in Experiment 1 exhibited less displacement when the landmark was visible during judgment because the landmark was in the same spatial position before and after the target vanished. Such an account predicts that movements of the landmark during the retention interval should influence memory.

Memory for targets above the landmark exhibited larger displacement toward the landmark than did memory for targets below the landmark, and the range of displacement magnitudes was larger when the landmark was not visible. The effect of direction is consistent with the hypothesized combination of landmark attraction and representational gravity: if landmark attraction and representational gravity operated in the same direction (as would be the case when the target was above the landmark), then they would sum and produce a larger net displacement, whereas if landmark attraction and representational gravity operated in different directions (as would be the case when the target was below the landmark), then they would partially cancel and produce a smaller net displacement. The larger effect when the landmark was not visible during judgment is consistent with the hypothesis that the landmark might provide a more stable reference point, although it could be predicted that displacement would be influenced if the landmark appeared in a different position during judgment than during the initial target presentation. The relatively large negative P displacement for targets left or right of the landmark, and the relative absence of P displacement for targets above or below the landmark, are also consistent with the operation of representational gravity.

The proximity of the target to the landmark influenced displacement toward the landmark, and targets near to the landmark exhibited less displacement on average than did targets far from the landmark. This pattern is consistent with the greater accuracy in dot placement with increases in proximity to an enclosing frame reported by Nelson and Chaiklin (1980). The decrease in displacement for near targets may have resulted from a decrease in the strength of the landmark attraction effect, or it may have resulted from a ceiling effect on the possible magnitudes of displacement (after all, a target near the landmark has a smaller area in which it can shift toward the landmark before it would make contact with the landmark). One possibility is that displacement is some constant percentage of the distance between the target and the landmark, and if so, then the absolute magnitude of displacement may increase with increases in distance even though the percentage of change stays constant. However, this explanation is not completely consistent with the nonsignificant differences in T displacement between the near and intermediate targets and between the intermediate and far targets. Alternatively, it may be that the greater proximity of near targets to the landmark simply allowed for more accurate encoding of the spatial relationships between the target and landmark.

Experiment 2

In Experiment 1, large targets exhibited larger magnitudes of displacement toward the landmark than did small targets. It is possible that the magnitude of displacement was related to the difference or ratio of the sizes of the target and the landmark. However, it could be argued that a size-based account should predict that memory for a small target would exhibit greater displacement toward the landmark than would memory for a large target, because the center of mass of the landmark/target system would be closer to the landmark (i.e., further from the target) when the target was relatively small than when the target was relatively large. Similarly, a relatively small target might be less able than a relatively large target to resist the "pull" or "attraction" of the landmark, thus resulting in memory for relatively small targets exhibiting a larger displacement toward the landmark. However, such a pattern was not found in Experiment 1 or by Tversky and Schiano (1989). A further test of such a center of mass or size-based model would predict that if target size is held constant, then T displacement toward the landmark should decrease as landmark size decreased. Alternatively, if observers regard the landmark as merely indicating a direction, rather than as having a specific area, volume, or mass, then changes in the size of the landmark should not influence T displacement. Accordingly, in Experiment 2 observers were presented with a stationary target and landmark on each trial, and the size of the landmark varied across trials.

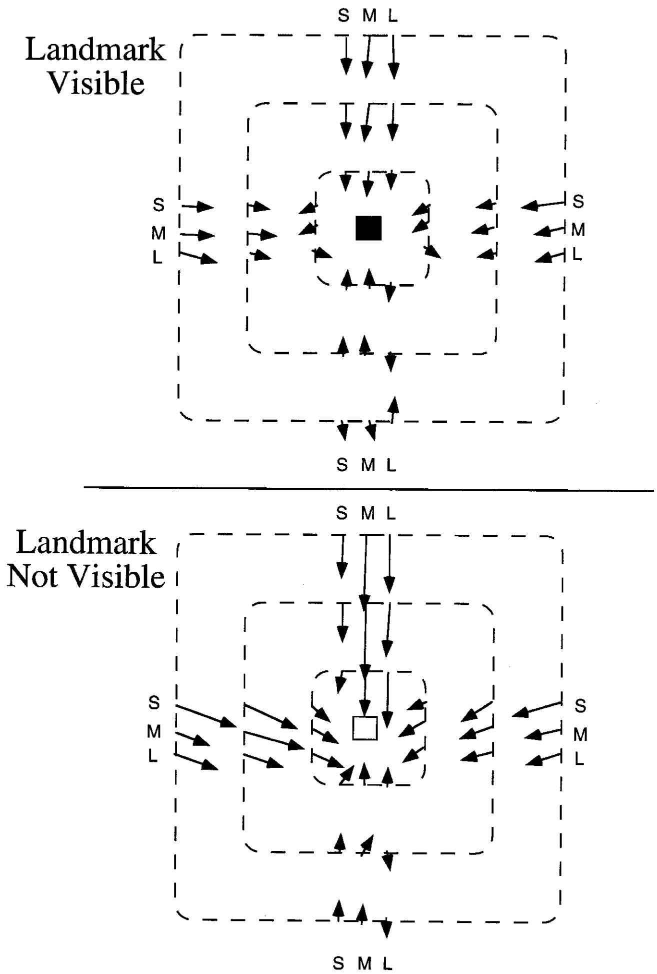

Fig. 2 Displacement as a function of landmark size and proximity of the target to the landmark in Experiment 2 (see text for explanation)

Method

Participants. The observers were 16 undergraduates from the same participant pool 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 target stimuli were filled black squares 20 pixels in diameter (the same as the "small" targets in Experiment 1). The landmark stimuli were the same as those used in Experiment 1, with the following exception: On each trial, the landmark was either 40, 80, or 120 pixels (approximately 1.67°, 3.33°, or 5.00°) in diameter. The spatial coordinates of the centers of the landmarks in Experiment 2 were the same as the spatial coordinates of the centers of the landmarks in Experiment 1. Each participant received 360 trials (2 landmark visibilities × 3 target proximities × 4 target directions × 3 landmark sizes × 5 replications) in a different random order.

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

Results

T and P displacements were calculated as in Experiment 1. The mean T and P displacements are illustrated in Fig. 2; the layout and symbols of Fig. 2 are the same as in Fig. 1, with the following exception: S, M, and L refer to small, medium, and large landmark sizes, respectively, rather than to small, medium, and large target sizes. T and P displacements were analyzed in separate 2 (visibility) × 3 (proximity) × 4 (direction) × 3 (size) repeated measures ANOVAs.

T displacement

Landmark visibility influenced T displacement, $F(1, 15) = 21.55$, $MSE = 54.41$, $p < 0.0004$; the magnitude of positive T displacement was larger when the landmark was not visible ($M = 3.67$) than when the landmark was visible ($M = 1.65$) during judgment. Landmark visibility also interacted with Proximity, $F(2, 30) = 4.15$, $MSE = 19.52$, $p < 0.005$. As may be seen in Fig. 2, differences in displacement as a function of proximity were generally larger when the landmark was visible during judgment than when the landmark was not visible during judgment.

Proximity influenced T displacement, $F(2, 30) = 10.90$, $MSE = 52.71$, $p < 0.0005$, and a post hoc Newman-Keuls test ($p < 0.05$) revealed that near ($M = 1.35$) targets exhibited less T displacement than either intermediate ($M = 2.86$) or far ($M = 3.77$) targets. Proximity also interacted with Direction, $F(6, 90) = 5.73$, $MSE = 27.26$, $p < 0.0005$. As may be seen in Fig. 2, effects of proximity were slightly diminished for targets below the landmark.

Direction influenced T displacement, $F(3, 45) = 7.29$, $MSE = 146.20$, $p < 0.0005$. Planned comparisons revealed that T displacements for targets left ($M = 2.97$) or right ($M = 2.46$) of the landmark did not differ, $F(1, 15) = 0.26$, $p = 0.62$, and that T displacement for targets above ($M = 4.94$) the landmark was significantly larger than T displacement for targets below ($M = 0.26$) the landmark, $F(1, 15) = 14.50$, $p < 0.002$. No other main effects or interactions reached significance.

P displacement

P displacement was influenced by direction, $F(3, 45) = 5.06$, $MSE = 69.89$, $p < 0.01$, and the Direction × Landmark Visibility interaction was significant, $F(3, 45) = 2.87$, $MSE = 12.30$, $p < 0.05$. As may be seen in Fig. 2, effects of direction were larger when the landmark was not visible. Additionally, landmark size influenced P displacement, $F(2, 30) = 5.20$, $MSE = 12.53$, $p < 0.02$; a post hoc Newman-Keuls test ($p < 0.05$) revealed that large ($M = -0.71$) landmarks resulted in larger negative P displacement than did small ($M = 0.11$) landmarks, and neither the small nor large landmarks differed from the medium ($M = -0.38$) landmarks. No other main effects or interactions reached significance.

Discussion

The main effect of landmark size on T displacement was not significant, nor did landmark size interact with any other variable in the T displacement data. The effects of landmark visibility, proximity, and direction on T displacement observed in Experiment 2 paralleled the effects of landmark visibility, proximity, and direction on T displacement observed in Experiment 1. The data from Experiment 2 were consistent with the general hypotheses that memory for a stationary target is displaced in the direction of a larger stationary landmark, and that the magnitude of this displacement is related to the proximity of the target to the landmark and to the direction of the landmark from the target. The data from Experiment 2 were also consistent with the more specific hypothesis that the landmark may be regarded as indicating a direction rather than a specific area, mass, or volume. The data from Experiment 2 were not consistent with a center of mass or size-based model in which displacement reflected some weighted average of the relative sizes of the target and the landmark. Landmark size influenced P displacement, with large landmarks producing slightly more negative displacement in memory for the targets, but the reason for this pattern is not clear. Additionally, the effects of direction on P displacement observed in Experiment 2 paralleled those in Experiment 1.

Experiment 3

Although changes in the magnitude of T displacement as a function of landmark size per se did not occur in Experiment 2, it is possible that memory for the target was displaced toward the landmark simply because the landmark was always larger than the target. Such a notion would predict that landmark attraction effects on the target would vanish if the landmark were smaller than the target. Alternatively, it may be that the size of the landmark relative to the size of the target is not a critical determinant of the magnitude of displacement of the target toward the landmark, and that the landmark served merely to indicate a direction. If the landmark merely indicates direction, then a robust landmark attraction effect should be found even when the landmark is denoted by a stimulus much smaller than the target, and we would also expect to observe effects of proximity, direction, and size similar to those observed in Experiments 1 and 2. Accordingly, in Experiment 3 the same targets that were shown in Experiment 1 were presented, but the landmark was denoted by a small cross-hair shape rather than by a large filled square. Given that the absence of a previously perceived larger landmark might be more salient than the absence of a previously perceived smaller landmark, it is also possible that differences in displacement as a function of whether the landmark was still visible at the time of judgment might be decreased if the landmark was relatively small.

Method

Participants. The observers were 16 undergraduates from the same participant pool 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 stimuli were the same as those used in Experiment 1. The landmark stimulus was a small cross-hair ("+") shape; each line of the cross-hair was one pixel thick, and each of the four line segments of the cross-hair was 5 pixels (approximately 0.21°) in length. The spatial coordinates of the centers of the cross-hair landmarks corresponded to the spatial coordinates of the centers of the square landmarks used in Experiment 1. Each participant received 360 trials (2 landmark visibilities × 3 target proximities × 4 target directions × 3 target sizes × 5 replications) in a different random order.

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

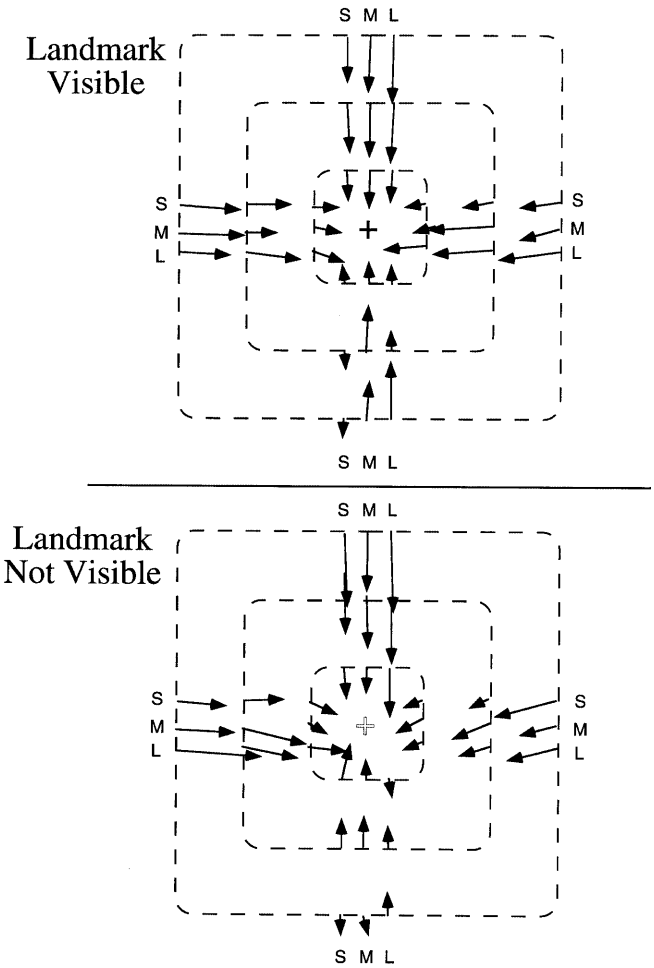

Fig. 3 Displacement as a function of target size and proximity to the landmark in Experiment 3 (see text for explanation)

Results

T and P displacements were calculated as in Experiment 1. The mean T and P displacements are illustrated in Fig. 3; the layout and symbols of Fig. 3 are the same as in Fig. 1, with the following exception: the landmark is indicated by a solid black cross-hair (top panel) or an outline cross-hair (bottom panel). T and P displacements were analyzed in separate 2 (visibility) × 3 (proximity) × 4 (direction) × 3 (size) repeated measures ANOVAs.

T Displacement

Proximity influenced T displacement, $F(2, 30) = 6.25$, $MSE = 182.59$, $p < 0.006$, and a post hoc Newman Keuls test ($p < 0.05$) revealed that near ($M = 2.70$) targets on average exhibited less T displacement than either intermediate ($M = 5.01$) or far ($M = 6.07$) targets. Proximity also interacted with Size, $F(4, 60) = 2.65$, $MSE = 32.44$, $p < 0.05$, and with Direction, $F(6, 90) = 2.46$, $MSE = 50.14$, $p < 0.03$. Consistent with the results observed in Experiment 1, effects of proximity were generally diminished for smaller targets and for targets below the landmark.

Direction influenced T displacement, $F(3, 45) = 6.76$, $MSE = 151.82$, $p < 0.001$. A post hoc Newman-Keuls test ($p < 0.05$) revealed that T displacements for targets left ($M = 4.37$), right ($M = 6.18$), or above ($M = 5.81$) the landmark were significantly larger than T displacement for targets below ($M = 2.01$) the landmark. Finally, size influenced T displacement, $F(2, 30) = 5.20$, $MSE = 47.72$, $p < 0.02$; a post hoc Newman-Keuls test ($p < 0.05$) revealed that small ($M = 3.86$) targets exhibited less T displacement than either medium ($M = 4.47$) or large ($M = 5.45$) targets. No other main effects or interactions reached significance.

P displacement

Direction influenced P displacement, $F(3, 45) = 3.64$, $MSE = 48.69$, $p < 0.02$, and also interacted with landmark visibility, $F(3, 45) = 5.78$, $MSE = 15.47$, $p < 0.005$. As may be seen in Fig. 3, targets left or right of the landmark were displaced slightly downward, and targets above or below the landmark were displaced slightly to the right; the range of displacements was larger when the landmark was not visible.

Discussion

The effects of proximity and direction on T displacement, and the effect of direction on P displacement, were consistent with the data of Experiments 1 and 2. The effect of target size on T displacement, and the interaction of direction and landmark visibility on P displacement, were consistent with the data of Experiment 1. Memory for the target was displaced toward the landmark, and the magnitude of displacement decreased for targets that were smaller, nearer, or below the landmark. The same general pattern of displacement occurred regardless of whether the landmark was larger (Experiments 1 and 2) or smaller (Experiment 3) than the target. The combined data of Experiments 1, 2, and 3 are not consistent with the notion that spatial memory averaging reflects either the center of mass of the landmark/target system or a weighted average of the sizes of the target and the landmark; the combined data are more consistent with the notion that observers encode the landmark as indicating a direction rather than as indicating a singular object consisting of a specific area, mass, or volume.

Landmark visibility did not influence T displacement in Experiment 3, and in conjunction with the effects of landmark visibility observed in Experiments 1 and 2, this suggests that differences between the influence of a perceived or a remembered landmark may be important only when the landmark is more visually detectable, dominant, or salient. However, the proximity, direction, and target size effects observed in Experiment 3, in conjunction with similar effects observed in Experiments 1 and 2, suggest that landmark size per se is not a critical determinant of whether or not displacement toward the landmark occurs. This is consistent with Bryant and Subbiah's (1994) findings that landmarks do not have to be physical objects or marks (which would necessarily be of a specific size and extent), and that an empty region of space may function as a landmark if that region is made sufficiently salient. It may be the case that if observers fixate the target, then a relatively large landmark is more easily perceived in peripheral vision than is a relatively small landmark, and hence more able to serve as a reference point. However, even if the landmark is not easily visible in peripheral vision, observers may still remember the general direction toward the landmark, and hence displacement is observed regardless of whether or not a remaining landmark is easily visible. Thus, effects of landmark visibility (i.e., whether the landmark is present or not present during judgment) are observed with larger landmarks (Experiments 1 and 2), but not with smaller landmarks (Experiment 3).

Experiment 4

Although the general displacement of the target toward the landmark that was observed in Experiments 1, 2, and 3 is consistent with the hypothesis that memory for the target is shifted in the direction of the landmark, it is also consistent with an alternative hypothesis: that memory for the target is biased toward the center of the display. If the patterns of displacement observed in Experiments 1, 2, and 3 were due to such a bias, then memory for the target should exhibit displacement toward the center of the display even when the target is presented in the absence of a landmark, and the proximity of the target to the center should influence displacement, such that a target near the center would exhibit less displacement toward the center than would a target far from the center. If, however, the patterns of displacement observed in Experiments 1, 2, and 3 were due to a landmark attraction effect, then no displacement toward the center of the display should be observed when a target is presented in absence of the landmark, nor should the proximity of a target to the center of the display influence displacement. Accordingly, in Experiment 4 the same targets used in Experiments 1 and 3 were presented, but the targets were presented in the absence of a landmark (i.e., targets were shown on an otherwise blank display).

Methods

Participants. The observers were 15 undergraduates from the same participant pool 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.

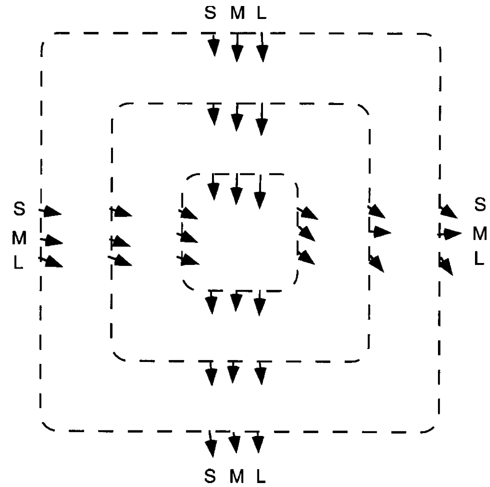

Fig. 4 Displacement as a function of target size and proximity to the center of the screen in Experiment 4 (see text for explanation)

Stimuli. The target stimuli were the same as those used in Experiment 1, and no landmarks were presented. Each participant received 180 trials (3 target proximities × 4 target directions × 3 target sizes × 5 replications) in a different random order.

Procedure. The procedure was the same as in Experiment 1, with the following exception: a landmark was not drawn on the monitor screen after participants initiated a trial.

Results

T and P displacements were calculated as in Experiment 1. The mean T and P displacements are illustrated in Fig. 4; the layout and symbols of Fig. 4 are the same as in Fig. 1, with the following exceptions: given that a landmark was not presented, only one data panel is necessary, and no landmark is indicated. T and P displacements were analyzed in separate 3 (proximity) × 4 (direction) × 3 (size) repeated measures ANOVAs.

T displacement

Direction influenced T displacement, $F(3, 42) = 4.72$, $MSE = 84.56$, $p < 0.0001$, and post hoc Newman-Keuls tests ($p < 0.05$) revealed all pairwise comparisons between left ($M = 1.59$), right ($M = -1.25$), above ($M = 3.60$), and below ($M = -2.27$) targets were significant except for the right versus below comparison and the above versus left comparison. As may be seen in Fig. 4, this pattern reflects a slight rightward displacement for targets left or right of the center of the display and a downward displacement for targets above or below the center of the display. Additionally, the Direction × Size interaction, $F(6, 84) = 2.06$, $MSE = 6.99$, $p < 0.07$, was marginally significant, suggesting a trend for the effects of direction to be slightly larger with increases in target size. No other main effects or interactions reached significance.

P displacement

Direction influenced P displacement, $F(3, 42) = 14.81$, $MSE = 42.16$, $p < 0.0001$. As may be seen in Fig. 4, targets left ($M = -2.39$) or right ($M = -2.07$) of the center of the display were displaced downward, and targets above ($M = 1.50$) or below ($M = 1.48$) the center of the display were displaced slightly rightward. No other main effects or interactions reached significance.

Discussion

In both T and P displacement data, memory for the position of the target was displaced slightly rightward and downward. The strong and consistent T displacements toward the center of the display (i.e., toward the landmark) observed in Experiments 1, 2, and 3 were absent in Experiment 4. Similarly, the consistent effects of proximity observed in Experiments 1, 2, and 3 were absent in Experiment 4. The slight rightward bias in T displacement for targets left or right of the center is consistent with the slight rightward P displacement for targets above or below the landmark in Experiments 1, 2, and 3. Also, the downward T displacement for targets above or below the center, coupled with the downward P displacement for targets left or right of the center, is consistent with the hypothesized influence of representational gravity. Overall, the T and P displacements observed in Experiment 4 support previous hypotheses about the roles of landmark attraction and representational gravity in the displacement in remembered position of stationary targets, and do not support the hypothesis that the displacement patterns observed in Experiments 1, 2, and 3 were due to a bias toward the center of the display.

Experiment 5

In Experiments 1, 2, and 3, the focus was on the displacement of the target toward the landmark, but previous investigators have also demonstrated that memory for a target may be displaced toward a cardinal axis of a larger enclosing framework. For example, Huttenlocher et al. (1991) reported that memory for the location of a dot within a larger circle was displaced toward a cardinal axis of that larger circle, and Schiano and Tversky (1992; Tversky & Schiano, 1989) reported that memory for the orientation of a line within a graph was displaced toward the 45° diagonal of the graph. In Experiments 1, 2, and 3, the targets were always aligned with either the horizontal or vertical cardinal axis (i.e., the horizontal or vertical axis of symmetry) of the landmark, but it could be predicted that memory for targets offset from either the horizontal or vertical cardinal axis of the landmark should also be displaced toward that cardinal axis. Accordingly, in Experiment 5 targets were presented at a constant distance from the landmark, but targets varied in their proximity to (an imaginary extension outward from the landmark along) the horizontal or vertical cardinal axis of the landmark (i.e., targets varied in location along the P displacement axis: the x axis for targets above or below the landmark, and the y axis for targets left or right of the landmark).

Method

Participants. The observers were 16 undergraduates from the same participant pool 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 landmark was the same as in Experiment 1. The targets were the same as in Experiment 1, with the following exception: The center of the target was offset from an imaginary extension of the nearest horizontal or vertical cardinal axis of the landmark (henceforth, the "imaginary extension" qualification should be understood as present, but for reasons of brevity, it will not be stated). All targets were presented at the same distance from the landmark; the distance between the nearest edges of the target and the landmark was always 40 pixels (approximately 1.67°; the same distance from the landmark as the "near" targets in Experiment 1). There were four target positions on each side of the landmark. For targets to the left or right of the landmark, two positions were above the horizontal axis of symmetry of the landmark, and two positions were below the horizontal axis of symmetry of the landmark; for targets above or below the landmark, two positions were to the left of the vertical axis of symmetry of the landmark, and two positions were to the right of the vertical axis of symmetry of the landmark. The distance between a cardinal axis of the landmark and the nearest parallel edge of the two inner positions (nearest the cardinal axis) was 10 pixels (approximately 0.42°), and the distance between a cardinal axis of the landmark and the nearest parallel edge of the two outer positions (farthest from the cardinal axis) was 50 pixels (approximately 2.08°). Each participant received 384 trials (2 landmark visibilities × 4 proximities × 4 target directions × 3 target sizes × 4 replications) in a different random order.

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

Results

T and P displacement were calculated as in Experiment 1, with the following exception: P displacement was positive if the displacement was toward the nearest vertical or horizontal cardinal axis of the landmark, and P displacement was negative if displacement was away from the nearest vertical or horizontal cardinal axis of the landmark. The mean T and P displacements are illustrated in Fig. 5; the layout and symbols of Fig. 5 are the same as in Fig. 1, with the following exceptions: All targets were presented at the same distance from the nearest edge of the landmark (and so only one distance

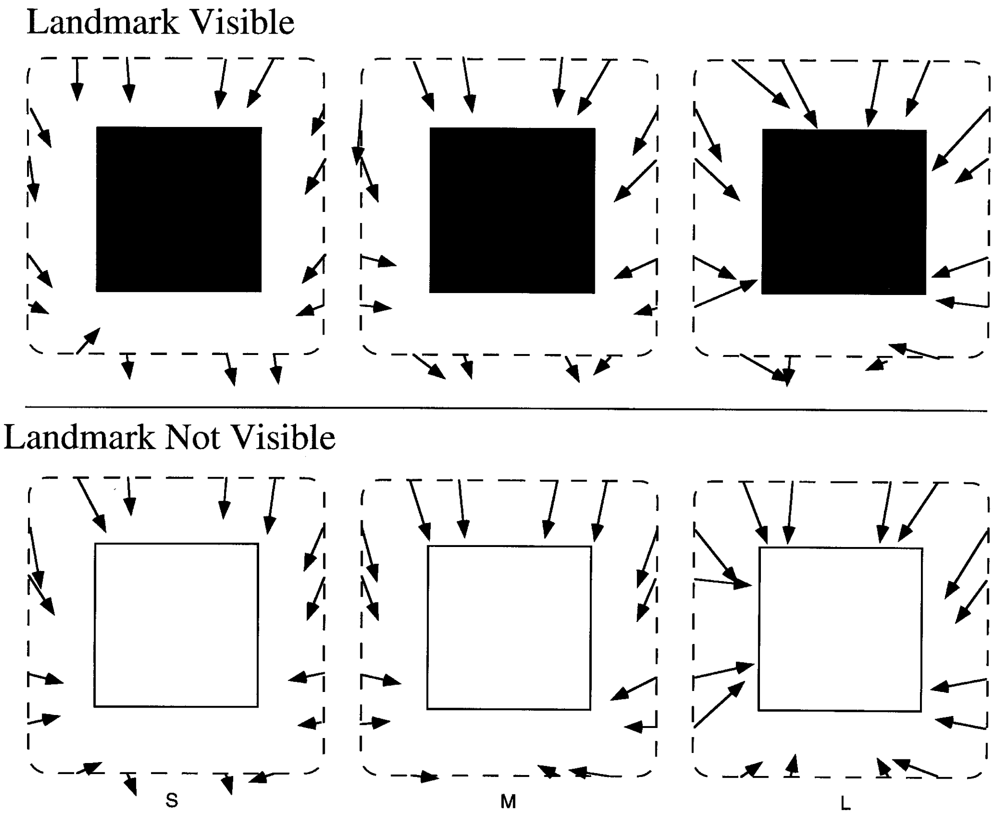

Fig. 5 Displacement as a function of target size and proximity to a cardinal axis of the landmark in Experiment 5 (see text for explanation)

is indicated by a dashed contour), and displacements for the different distances from the cardinal axis correspond to the different locations of the bases of the arrows along the dashed contour. Displacements for small targets are indicated in the left column; displacements for medium targets are indicated in the middle column, and displacements for large targets are indicated in the right column. T and P displacements were analyzed in separate 2 (visibility) × 4 (proximity) × 4 (direction) × 3 (size) repeated measures ANOVAs.

T displacement

Landmark visibility influenced T displacement, $F(1, 15) = 19.56$, $MSE = 47.94$, $p < 0.0005$; the magnitude of positive T displacement was larger when the landmark was not visible ($M = 2.87$) than when the landmark was visible ($M = 1.30$) during judgment. Landmark visibility also interacted with Direction, $F(3, 45) = 3.06$, $MSE = 19.72$, $p < 0.05$. As may be seen in Fig. 5, there were slightly larger effects of direction when the landmark was not visible during judgment.

Direction influenced T displacement, $F(3, 45) = 4.58$, $MSE = 340.54$, $p < 0.001$. Planned comparisons revealed that T displacements for targets left ($M = 1.81$) or right ($M = 2.50$) of the landmark did not differ, $F(1, 15) = 0.57$, $p = 0.46$, and T displacement for targets above ($M = 4.45$) the landmark was significantly greater than T displacement for targets below ($M = -0.43$) the landmark, $F(1, 15) = 5.89$, $p < 0.03$. Direction also interacted with proximity, $F(9, 135) = 1.91$, $MSE = 11.59$, $p = 0.05$. As may be seen in Fig. 5, effects of proximity were slightly diminished for smaller targets and for targets below the landmark.

Size influenced T displacement, $F(2, 30) = 18.40$, $MSE = 20.55$, $p < 0.0001$; post hoc Newman-Keuls tests ($p < 0.05$) revealed that small ($M = 1.41$) and medium ($M = 1.79$) targets exhibited less T displacement than large ($M = 3.05$) targets. No other main effects or interactions reached significance.

P displacement

Landmark visibility influenced P displacement, $F(1, 15) = 8.89$, $MSE = 55.37$, $p < 0.01$; the magnitude of positive P displacement was larger when the landmark was not visible ($M = 1.78$) than when the landmark was visible ($M = 0.65$) during judgment. Landmark visibility also interacted with Direction × Proximity, $F(9, 135) = 2.59$, $MSE = 12.39$, $p < 0.01$, and marginally interacted with Direction, $F(3, 45) = 2.61$, $MSE = 11.94$, $p < 0.07$. As may be seen in Fig. 5, targets above the horizontal axis of the landmark exhibited positive (i.e., toward a cardinal axis) displacement, targets slightly below the horizontal axis of the landmark exhibited negative (i.e., away from a cardinal axis) displacement, and targets further below the horizontal axis of the landmark exhibited a small positive (i.e., toward a cardinal axis) displacement or a negligible displacement. Furthermore, these patterns were stronger when the target was not visible during judgment.

Proximity to a cardinal axis influenced P displacement, $F(3, 45) = 6.04$, $MSE = 133.02$, $p < 0.002$, and a planned comparison revealed that targets further from a cardinal axis exhibited larger positive P displacement toward that axis than did targets nearer to a cardinal axis, $F(1, 15) = 12.07$, $p < 0.005$. Proximity to a cardinal axis also interacted with size, $F(6, 90) = 5.38$, $MSE = 13.89$, $p < 0.0005$; as shown in Fig. 5, larger targets exhibited a larger effect of proximity to a cardinal axis than did smaller targets. Size influenced P displacement, $F(2, 30) = 5.27$, $MSE = 28.27$, $p < 0.02$; post hoc Newman-Keuls tests ($p < 0.05$) revealed small ($M = 0.80$) and medium ($M = 1.03$) targets exhibited less P displacement than large ($M = 1.83$) targets. No other main effects or interactions reached significance.

Discussion

Memory for targets was displaced toward the nearest horizontal or vertical cardinal axis of the landmark, and P displacement was larger for targets that were further from a horizontal or vertical cardinal axis of the landmark. The effect of proximity on P displacement paralleled the effect of proximity on T displacement in Experiments 1, 2, and 3: displacement was larger for targets further from the (cardinal axis of the) landmark. An analogous parallel of the effects of proximity on displacement for targets moving directly toward or away from the landmark and displacement for targets passing near to the landmark (but moving directly toward or away from an imaginary extension of a cardinal axis) was reported by Hubbard and Ruppel (1999). P displacement toward the cardinal axis was larger when the landmark was not visible during judgment in Experiment 5, and this paralleled effects of landmark visibility on T displacement toward the landmark observed in Experiments 1 and 2. Also, effects of landmark visibility and direction on T displacement in Experiment 5 replicated the patterns observed in Experiments 1, 2, and 3. Memory for the target was displaced toward a landmark, and this displacement occurred regardless of whether the landmark was visible during judgment. Targets above the landmark exhibited the largest T displacement, and targets below the landmark exhibited the smallest T displacement; furthermore, the range of displacement magnitudes was larger when the target was not visible.

Why might memory for the target exhibit P displacement toward a cardinal axis of the landmark? In Experiments 1, 2, and 3, the center of each target was always aligned with either the horizontal or vertical cardinal axis of the landmark; therefore, equal extents of the landmark extended left and right of the target (for targets above or below the landmark) or above and below the target (for targets right or left of the landmark). However, in Experiment 5, the center of each target was not aligned with either the horizontal or vertical cardinal axis of the landmark, and so a greater extent of the landmark's surface area or implied mass or volume extended beyond one side of the target. This asymmetry might result in the larger side of the landmark functioning as a "sub-landmark" or area of greater weight or concentration which might displace memory in the direction of that greater extent. Thus, displacement toward a cardinal axis might be a specific case of the more general landmark attraction effect. However, it is not clear that such an account is completely consistent with the suggestion of Experiments 1, 2, and 3 that the landmark is encoded as indicating a direction rather than as a singular object consisting of a specific area, mass, or volume. Alternatively, this apparent assimilation may reflect a combination of category information with an inexact but unbiased representation of target location (cf. Engebretson & Huttenlocher, 1996; Huttenlocher et al., 1991).

The P displacement data from Experiment 5 also provide evidence suggestive of a combination of landmark attraction and representational gravity, and this combination may be seen clearly when the target was above or below the horizontal cardinal axis of the landmark (i.e., when the target was to the left or right of the landmark). When the target was further above the horizontal cardinal axis, a relatively large downward bias due to landmark attraction combined with a relatively large downward bias due to representational gravity, and so a large displacement downward was observed. When the target was slightly below the horizontal cardinal axis, a relatively smaller upward bias due to landmark attraction combined with a relatively large downward bias due to representational gravity, and so a smaller displacement downward (slightly away from the horizontal axis of the landmark) was observed. When the target was further below the horizontal cardinal axis, a relatively large upward bias due to landmark attraction combined with a nearly equal downward bias due to representational gravity, thus reducing P displacement to a negligible level. Such an account is based in part on the ideas that (a) the landmark attraction effect is stronger for targets further from the landmark (or further from a cardinal axis of the landmark), a notion supported by the results of Experiments 1, 2, and 3 and by the findings in Hubbard and Ruppel (1999), and (b) the magnitude of representational gravity is relatively constant across target positions.

General discussion

Memory for the location of a stationary target was displaced toward a landmark, and the effects of landmark attraction were generally larger when the landmark was not visible at the time of judgment. Both the proximity of the target to the landmark and the direction from the target to the landmark influenced the magnitude of displacement, as displacement was larger for targets above the landmark or further from the landmark. When a stationary target was slightly offset from a vertical or horizontal cardinal axis of the landmark, memory for the location of the target was also displaced toward that cardinal axis, and the magnitude of this displacement was larger for targets further from that cardinal axis. All of these results are consistent with the hypothesis that spatial memory averaging occurs with stationary targets that are a specific direction and distance from a landmark. Previous studies suggestive of spatial memory averaging presented targets undergoing apparent or implied motion; the data reported here suggest that the memory averaging observed in those studies was not an artifact of target motion, and also support the notion that memory averaging is an important component of the overall displacement process. This allows us to consider displacement within a broader context, and to begin mapping out the potential relationship of displacement to other cognitive processes.

The displacement patterns in the current data, in conjunction with the displacement patterns from previous studies in which moving targets were presented (e.g., Hubbard, 1995a, 1998; Hubbard & Ruppel, 1999), support the hypothesis that spatial memory averaging may be combined with distortions arising from environmentally invariant physical principles (e.g., representational momentum, representational gravity) in determining the ultimate displacement in memory for a target. The increased T displacement for targets above the landmark and the decreased T displacement for targets below the landmark in Experiments 1, 2, and 3, as well as the relatively larger downward P displacement for targets left or right of the landmark in Experiments 1, 2, and 3 and above the horizontal cardinal axis of the landmark in Experiment 5, were consistent with a combination of spatial memory averaging and representational gravity. When spatial memory averaging and representational gravity operated in the same direction, they added together and resulted in a larger net displacement, whereas when spatial memory averaging and representational gravity operated in different directions, they partially canceled out and resulted in a smaller net displacement. This type of combination of spatial memory averaging and representational gravity is consistent with previous speculations regarding displacement, and could easily be instantiated within a spreading activation (e.g., see Hubbard, 1995b) or vector addition (e.g., see Hubbard & Ruppel, 1999) account of displacement.

Such an account may suggest that spatial memory averaging and representational gravity are distortions in memory. Representational momentum has been suggested to reflect an illusion of memory (Roediger, 1996), and presumably representational gravity also reflects an illusion or distortion of memory. However, it could be argued that spatial memory averaging reflects a distortion of perception similar to that found in visual illusions in which the stimulus is continuously available to perception (e.g., the Müller-Lyer). It is not necessary that spatial memory averaging result from a distortion of memory for the hypothesized combination of spatial memory averaging and representational gravity to occur; the mechanisms that produce memory distortion could use perceptually distorted information as input (e.g., size-distance invariance scaling is considered to influence perception, but Hubbard and Motes (2000) found that displacement of horizontally moving targets was influenced by the size, distance, and velocity relationships implied by the size-distance invariance hypothesis). In the current data, the occurrence of displacement when the landmark was visible during judgment, coupled with the generally stronger effect of displacement when the landmark was not visible during judgment, suggests spatial memory averaging may be present in perception but is stronger in memory than in perception; however, the current data cannot conclusively determine whether spatial memory averaging per se resulted from perceptual distortion or memory distortion.

The stimuli were computer-generated square shapes viewed on a flat two-dimension screen, and so it might be argued that the stimuli were too simplistic or nonecological and that the results might not, therefore, generalize to physical objects in three-dimensional space. However, aspects of the data clearly suggest that observers treated the displays as reflective of three-dimensional space. For example, the downward P displacements for targets left or right of the landmark, and the larger T displacement for targets above the landmark than for targets below the landmark, reflect a clear recognition of the direction of implied gravitational attraction in the three-dimensional world. Presumably, if the display were flat on the ground and observers viewed the display from above, then such patterns would not necessarily exist relative to an arbitrary horizontal and vertical axis on the picture plane of the flat display (cf. Nagai & Yagi, 1998). Also, previous studies have reported representational momentum for a variety of targets including drawings of animals and vehicles (Halpern & Kelly, 1993), rockets and cathedrals (Reed & Vinson, 1996), pyramids (Cooper & Munger, 1993) and cubes (Munger, Solberg, Horrocks, & Preston, 1999) that included depth and perspective information, and so the occurrence of displacement per se does not seem to be dependent upon the specific shape or identity of the target. Indeed, the use of simplistic and nonecological stimuli might actually be a strength, as the observation of displacement with such stimuli demonstrates the robustness of the biases which underlie displacement.

The effects of size on spatial memory averaging are not yet entirely clear. When the displacement of a stationary target toward the landmark or toward the nearest vertical or horizontal cardinal axis of a landmark was measured, larger targets exhibited larger magnitudes of displacement. This is not consistent with a model in which the remembered position of the target corresponds to a weighted average of the center of mass (or to an average of the two-dimensional surface areas of computer-generated stimuli such as those used here) of the landmark/target system, because such a model would predict smaller displacements for larger targets. If we consider, though, the displacement toward the landmark as analogous to an attraction or gravitational force, then the obtained pattern is reminiscent of the larger displacement along the axis of implied gravitational attraction previously demonstrated by larger targets (Hubbard, 1997). In general, the size of the target influenced displacement, but the size of the landmark did not influence displacement. It is possible that this pattern merely reflects which stimulus is judged – perhaps only the size of the judged stimulus, and not the size of any other element of the display, influences memory averaging.

The displacement of the target toward the landmark is consistent with findings in the literature on cognitive mapping that the remembered or perceived distance from some point to a landmark is typically less than the remembered or perceived distance from the landmark to that same point (e.g., Burroughs & Sadalla, 1979; McNamara & Diwadkar, 1997; Sadalla et al., 1980). The logic is as follows: when observers initially focus on the target, memory for the spatial location of that target is shifted in the direction of the landmark, and this has the consequence of decreasing the remembered distance between the target and the landmark. However, when observers initially focus on the landmark, memory for the spatial location of that landmark is presumably not shifted in the direction of the target, and so the remembered distance between the landmark and the target is not decreased. Therefore, when observers focus on the target, they remember the distance to the landmark as being relatively shorter, whereas when observers focus on the landmark, they remember the distance to the target as being relatively longer (cf. McNamara & Diwadkar, 1997). Such an asymmetry suggests spatial representation may not preserve a Euclidean metric, and this conclusion is consistent with numerous prior findings (e.g., Baird, Wagner, & Noma, 1982; Moar & Bower, 1983; Stevens & Coupe, 1978; Tversky, 1981).

The displacement patterns are also consistent with previous models of spatial memory and cognitive mapping. For example, the Weighted-Distortion model of Nelson and Chaiklin (1980) predicts that memory for a target should be biased toward a landmark and that the magnitude of this bias increases with increases in the distance between the target and the landmark; the effects of proximity observed in Experiments 1, 2, and 3 fit this pattern exactly. Similarly, the Contextual Scaling model of McNamara and Diwadkar (1997) predicts that the distance between a target and a landmark will be underestimated, and this pattern is consistent with displacement of the target toward the landmark. Furthermore, the absence of a clear and distinct landmark in Experiment 4 created a different context for the encoding and subsequent retrieval of the target, and hence resulted in a different pattern of displacement than that observed in Experiments 1, 2, and 3. Finally, the displacement of the target toward the nearest horizontal or vertical axis of the landmark in Experiment 5 is consistent with the perceptual/conceptual model of Tversky and Schiano (1989; Schiano & Tversky, 1992) and with the category adjustment model of Huttenlocher et al. (1991) and Engebretson and Huttenlocher (1996).

Displacements attributable to spatial memory averaging were found to occur in the absence of target motion, and although spatial memory averaging was previously linked with representational momentum, the data reported here clearly demonstrate that spatial memory averaging can occur in the absence of representational momentum. Furthermore, the data reported here suggest that distortions resulting from spatial memory averaging may combine with distortions resulting from representational gravity, and that the displacement of a stationary target is a weighted sum of spatial memory averaging and representational gravity. Of course, it is possible that factors not explicitly examined or controlled in the present experiments could also influence the displacement of stationary targets; the focus in the current experiments on spatial memory averaging and representational gravity was not meant to be exhaustive or exclusive. The apparent combination of influences arising from environmentally invariant physical principles and from spatial memory averaging is consistent with previous proposals that the ultimate displacement of a target reflects a combination of factors. In addition to serving as important reference points in spatial representation, and contributing to asymmetries or distortions in spatial representation, landmarks also appear to systematically influence the displacement in remembered position.

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