Some Effects of Representational Friction, Target Size, and Memory Averaging on Memory for Vertically Moving Targets

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Abstract Observers viewed an animated ascending or descending target that varied in size and velocity across trials and appeared either (a) in isolation, (b) to slide along one side of a single larger stationary object, or (c) to slide between two larger stationary objects. Targets vanished without warning, and displacements (i.e., differences between actual and remembered final position) along the axis of motion and orthogonal axis were measured. Forward displacement (a) decreased with increases in implied friction, (b) increased with increases in target size for descending targets, and (c) decreased with increases in target size for ascending targets. When a larger stationary object was to one side of the target, orthogonal displacement was toward that object; when no object or objects on both sides were present, orthogonal displacement was near zero. Results are consistent with previous findings and speculation on the effects of representational friction, memory averaging, and target size on memory.

Résumé Les observateurs visionnaient une cible animée ascendante ou descendante qui variait en taille et en vélocité au cours des essais. Elle était (a) isolée, (b) glissait le long d'un plus gros objet stationnaire, ou (c) glissait entre deux plus gros objets stationnaires. Les cibles disparaissaient sans avertissement et les déplacements le long de l'axe du mouvement et de l'axe perpendiculaire étaient mesurés (c'est-à-dire les différences entre la position actuelle et la position finale retenue). Le déplacement vers l'avant (a) diminuait à mesure que la friction implicite augmentait, (b) augmentait à mesure que la taille des cibles descendantes augmentait, et (c) diminuait à mesure que la taille des cibles ascendantes augmentait. Lorsqu'un plus gros objet stationnaire se trouvait d'un côté de la cible, le déplacement perpendiculaire se faisait en direction de cet objet; lorsqu'il n'y avait aucun objet ou pas d'objet des deux côtés, le déplacement perpendiculaire était presque nul. Les résultats confirment les précédentes conclusions et hypothèses sur les effets de la friction représentationnelle, de la mise en moyenne de la mémoire et de la taille de la cible sur la mémoire.

An observer who perceives a target moving in a consistent direction will, when subsequently asked to indicate the remembered final position of that target, usually indicate a position that suggests that the target is remembered as having traveled further than it actually did. In other words, memory for the final position of a target is usually shifted in the direction of anticipated target motion. Early explanations of this shift drew upon parallels between the physical momentum of the target and an analogous momentum within the representational system, and so the shift was referred to as *representational momentum* (e.g., Finke, Freyd, & Shyi, 1986; Freyd & Finke, 1984). More recent investigations suggest shifts may occur in directions other than the direction of target motion and reflect more than just an internalization of the laws of momentum. For example, memory for horizontally moving targets is also shifted downward slightly in the direction of implied gravitational attraction, a shift referred to as *representational gravity*. These types of shifts are now referred to by the general term *displacement*, and the overall displacement for a given target may be influenced by several different factors (for a review, see Hubbard, 1995b).[1]

Displacement is influenced by whether the target interacts with other stimuli in its surroundings; for example, the forward displacement of a horizontally moving target is decreased if the target slides along the surface of a larger stationary object (Hubbard, 1995a). A physical object that slid along the surface of a larger

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[1] One type of factor involves environmentally invariant physical principles such as momentum, gravity, and friction, and Hubbard (1995b, 1998) suggested that the representational system may have been selected or shaped to automatically extrapolate spatial memory in ways consistent with such invariant environmental physical principles. Such an automatic extrapolation would be tantamount to an incorporation of such physical principles (or the subjective consequences of such physical principles, see Hubbard, 1997) into the representational system. An incorporation of invariant physical principles into the representational system could allow an organism to anticipate the effects of those physical principles on a predator or prey, and such anticipation could lead to a selective advantage (see Hubbard, 1998).

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stationary object would experience friction, and so such decreases in forward displacement are referred to as *representational friction*. If representational friction results from an internalization of the laws of physical friction, and not from some unspecified factor unique to motion along the horizontal axis, then effects of representational friction should be found whenever there is contact between a moving target and some other object; for example, a vertically moving target that slides along the surface of an adjacent stationary object should exhibit less forward displacement than an equivalent vertically moving target that does not slide along the surface of an adjacent stationary object. However, whether representational friction occurs with vertical (or any other non-horizontal) motion has not been examined.

Displacement may be influenced by the size of the target, but effects of target size have previously only been observed along the axis aligned with implied gravitational attraction (Hubbard, 1997). In the terrestrial environment, size, mass, and weight are highly correlated, and differences in mass are usually experienced as differences in weight. Thus, observers may respond to the implied weight, rather than the implied mass, of the target. Indeed, weight is the product of mass and (the acceleration due to) gravity, and so effects of weight should be exhibited only along the axis aligned with implied gravitational attraction. Effects of target size on displacement along the axis aligned with gravitational attraction are influenced by the direction of target motion: Increases in target size (implied weight) produce decreases in forward displacement for ascending targets and increases in forward displacement for descending targets. This pattern may result from kinesthetic or motor components of visual displacement, and may reflect the amount of perceived effort or work needed to move or maintain the target (Hubbard, 1997). Such a suggestion is consistent with previous findings that observers are sensitive to dynamics of weight in visual stimuli (Runeson & Frykholm, 1983; Valenti & Costall, 1997). If observers are sensitive to dynamics involving implied weight and effort, then we would be more likely to expect them to be sensitive to the dynamics underlying friction and to exhibit representational friction.

Displacement is also influenced by memory averaging: That is, memory for a target may be shifted toward a nearby object. For example, representational momentum in memory for the final orientation of a rotating target is increased if a surrounding square frame is rotated slightly forward from the final orientation of the target and decreased if a surrounding square frame is rotated slightly backward from the final orientation of the target (Hubbard, 1993). In a more intriguing example, memory for a horizontally moving target is shifted slightly upward when a larger stationary object is above the target and relatively far downward when a larger stationary object is below the target (Hubbard, 1995a). This pattern may result from a combination of (a) memory averaging between the target and larger object, and (b) a downward shift attributable to representational gravity. When memory averaging and representational gravity operated in opposite directions (i.e., the object above the target), they nearly cancelled, and a slightly stronger memory averaging resulted in a slight displacement upward. When memory averaging and representational gravity operated in the same direction (i.e., the object below the target), they combined to form an even larger downward displacement. However, the larger stationary object was always above or below the target, and so it was not possible to confirm whether the direction and magnitude of memory averaging were independent of implied gravitational attraction.

Questions concerning the generalizability of representational friction and the extent to which memory averaging is independent of representational gravity remain. Accordingly, observers in this experiment viewed vertically moving targets that were displayed either (a) in isolation, (b) sliding along the surface of a larger stationary object on either the left or right, or (c) sliding between a larger stationary object on the left and a larger stationary object on the right. If representational friction occurs, then forward displacement should decrease as implied friction increases. If memory averaging occurs, then memory should be displaced horizontally toward a single object presented on either the left or right side of the target, and memory should not be displaced horizontally when either no objects or one object on each side of the target (which would cancel out) are presented.

METHOD

Participants. The observers were 13 undergraduates who participated in return for partial course credit in an introductory psychology course.

Apparatus. The stimuli were displayed upon and data collected by an Apple Macintosh IIsi microcomputer equipped with an Apple RGB color monitor. The monitor was approximately 60 cm from the participants, and participants could adjust this distance slightly in order to achieve maximal comfort.

Stimuli. The target stimulus was a filled black square on a white background, and on each trial the target was either 20, 40, or 60 pixels (approximately 0.83°, 1.67°, 2.50°) in width. There were four friction surface conditions: target only (TO), surface left (SL), surface right (SR), and two surfaces (TS). On TO trials, the target was the only element displayed. On SL and SR trials, a single larger stationary object was also displayed; on TS trials, two larger stationary objects were also displayed. On SL trials, the object

TABLE 1
Displacement Along the Axis of Target Motion (M displacement)

	Target Size[a]								
	20			40			60		
	Target Velocity[b]			Target Velocity			Target Velocity		
	2.5	5.0	7.5	2.5	5.0	7.5	2.5	5.0	7.5
Descending									
Target Only	2.47	4.53	5.46	6.42	7.86	5.01	5.14	6.95	9.36
Surface Left	2.97	0.77	-0.67	3.62	5.11	1.66	6.93	6.28	9.36
Surface Right	1.52	-1.31	-1.66	6.84	3.33	3.35	4.56	7.47	8.59
Two Surfaces	0.25	0.08	-1.81	0.63	3.45	2.04	5.47	6.84	4.08
Ascending									
Target Only	9.40	12.54	11.33	5.39	7.38	12.43	4.16	6.92	9.12
Surface Left	5.04	9.63	10.09	5.01	9.13	11.21	8.38	9.23	11.56
Surface Right	5.49	8.71	11.89	6.99	7.40	8.90	9.69	6.74	7.88
Two Surfaces	6.20	6.20	11.02	4.85	3.33	7.90	5.03	3.70	7.00

Note. Positively signed M displacements indicated judged vanishing points beyond the true vanishing point (i.e., below a descending target, above an ascending target), and negatively signed M displacements indicated judged vanishing points behind the true vanishing point (i.e., above a descending target, below an ascending target).

[a] Target size was specified in pixels.

[b] Target velocity was specified in degrees per second.

was a filled black area to the left of the path of motion; on SR trials, the object was a filled black area to the right of the path of motion. On SL trials, the left edge of the screen marked the left edge of the object; on SR trials, the right edge of the screen marked the right edge of the object. The width of the object was 308, 298, and 288 pixels (approximately 12.83°, 12.42°, 12.00°) on the small, medium, and large target trials, respectively. The width of the object(s) decreased as target size increased because the constant width of the RGB monitor resulted in larger targets occupying a larger percentage of the horizontal extent of the screen and leaving a smaller percentage of the horizontal extent of the screen for the object(s). The height of the object was 320 pixels (approximately 13.33°), and the object was centred between the top and bottom of the screen (and occupied 67% of the vertical extent of the screen). On SL or SR trials, the target slid along the right (SL) or left (SR) surface of the object. On TS trials, both the SL and SR objects were displayed, and the target slid between the objects. On SL, SR, and TS trials, no background was visible between the target and the object(s), nor did the target and the object(s) overlap. Target velocity was constant within a trial and varied between trials. Target velocity was controlled by shifting the target either 1, 2, or 3 pixels between successive presentations, thus resulting in an apparent velocity of approximately 2.5°/sec, 5.0°/sec, or 7.5°/sec. Target motion appeared smooth and continuous, and targets crossed between 45-75% of the vertical extent of the screen before vanishing without warning. Each participant received 288 trials (2 directions x 4 surfaces x 3 sizes x 3 velocities x 4 replications) in a different random order.

Procedure. Observers received 12 practice trials (randomly drawn from experimental trials) at the beginning of the session. Observers initiated each trial by pressing a designated key. If a friction surface was presented on that trial, that object was immediately drawn on the screen. There was then a one second pause before the target emerged from the approximate midpoint of either the top or bottom edge of the screen and traveled toward the opposite edge. The target vanished without warning, and if a friction surface had been presented on that trial, that object vanished at the same time the target vanished. The cursor, in the form of a plus sign, then appeared near the center of the screen, and observers positioned the center of the cursor over where the center of the target had been when the target vanished. The cursor was positioned via movement of a computer mouse, and after positioning the mouse, the observers clicked a button on the mouse to record the screen coordinates of the cursor. Observers then initiated the next trial.

TABLE 2
Displacement Along the Axis Orthogonal to Target Motion (O displacement)

	Target Size[a]								
	20			40			60		
	Target Velocity[b]			Target Velocity			Target Velocity		
	2.5	5.0	7.5	2.5	5.0	7.5	2.5	5.0	7.5
Descending									
Target Only	1.37	0.71	1.81	0.71	1.10	1.54	0.11	0.92	0.50
Surface Left	-2.02	-1.39	-1.23	-3.66	-3.18	-4.64	-3.35	-4.51	-4.32
Surface Right	2.10	2.29	4.02	5.26	2.16	3.91	6.05	5.62	6.82
Two Surfaces	-0.08	0.77	-0.14	-0.19	1.54	0.27	1.13	0.44	-0.23
Ascending									
Target Only	-0.19	0.58	0.35	0.40	0.31	-0.19	0.09	-0.31	-0.06
Surface Left	-2.00	-2.37	-0.91	-2.43	-2.97	-3.31	-5.51	-5.11	-6.57
Surface Right	2.46	1.98	0.17	4.87	3.91	4.00	6.47	7.43	5.68
Two Surfaces	-0.73	-1.12	0.23	-0.46	-0.98	0.90	-0.52	1.02	-0.29

Note. Positively signed O displacements indicated judged vanishing points to the right of the true vanishing point, and negatively signed O displacements indicated judged vanishing points to the left of the true vanishing point.

[a] Target size was specified in pixels.

[b] Target velocity was specified in degrees per second.

RESULTS

Differences between the true vanishing point and the judged vanishing point (in pixels) along the *x*- and *y*-axes were calculated for each target. Consistent with previous reports, differences along the axis of motion (the *y*-axis) were referred to as *M displacement*, and differences along the axis orthogonal to motion (the *x*-axis) were referred to as *O displacement*. Positively signed M displacements indicated judged vanishing points beyond the true vanishing point (i.e., below a descending target, above an ascending target), and negatively signed M displacements indicated judged vanishing points behind the true vanishing point (i.e., above a descending target, below an ascending target). Positively signed O displacements indicated judged vanishing points to the right of the true vanishing point, and negatively signed O displacements indicated judged vanishing points to the left of the true vanishing point. M and O displacements were analysed in separate 2 (direction) × 4 (surface) × 3 (size) × 3 (velocity) repeated measures ANOVAs, and are listed in Tables 1 and 2.

M Displacement. Surface influenced M displacement, $F(3,36) = 4.98$, $MS_e = 78.84$, $p < .01$, and also interacted with size, $F(6,72) = 2.35$, $MS_e = 39.78$, $p < .05$. Planned comparisons revealed that targets encountering friction on two surfaces ($M = 4.24$) exhibited less M displacement than targets encountering friction on one surface ($M = 6.16$), $F(1,36) = 7.36$, $p < .01$, or targets not encountering friction ($M = 7.32$), $F(1,36) = 14.16$, $p < .001$. There was also a trend for targets encountering friction on one surface to exhibit less M displacement than targets not encountering friction, $F(1,36) = 2.70$, $p < .10$. Additionally, the decrease in M displacement with increases in friction was greater for smaller targets than for larger targets.

Size significantly influenced M displacement, $F(2,24) = 3.93$, $MS_e = 88.97$, $p < .05$, and also interacted with direction, $F(2,24) = 16.92$, $MS_e = 61.27$, $p < .01$. A post-hoc Newman-Keuls test ($p < .05$) of all pairwise comparisons between 20 ($M = 5.01$), 40 ($M = 5.80$), and 60 ($M = 7.10$) pixel targets revealed that, on average, 60 pixel targets exhibited larger M displacement than 20 pixel targets, but this main effect was driven by the strong effect of size on descending targets. Although increases in size produced relatively large increases in M displacement for descending targets (1.05, 4.11, and 6.75 pixels for 20, 40, and 60 pixel targets, respectively), increases in size produced relatively small decreases in M displacement for ascending targets (8.96, 7.50, 7.45 pixels for 20, 40, and 60 pixel targets, respectively).

Velocity significantly influenced M displacement, $F(2,24) = 3.37$, $MS_e = 73.01$, $p = .05$, and also interacted with direction, $F(2,24) = 3.94$, $MS_e = 82.38$, $p < .05$, and with Direction × Size, $F(4,48) = 4.22$, $MS_e = 23.99$, $p < .01$. A post-hoc Newman-Keuls test ($p < .05$) of all pairwise comparisons between slow ($M = 5.10$), medium ($M = 5.93$), and fast ($M = 6.88$) targets revealed that on average fast targets exhibited larger M displacement than slow targets, but this main effect was driven by ascending targets and by large descending targets. Although increases in velocity produced increases in M displacement for ascending targets and for large descending targets, increases in velocity produced less consistent effects in M displacement for small and medium descending targets. No other main or interaction effects approached significance.

O *Displacement*. Surface significantly influenced O displacement, $F(3,36) = 28.47$, $MS_e = 77.04$, $p < .001$, and also interacted with size, $F(6,72) = 18.38$, $MS_e = 10.04$, $p < .01$, and with Size × Direction, $F(6,72) = 2.43$, $MS_e = 5.77$, $p < .05$. A post-hoc Newman-Keuls test ($p < .05$) revealed all pairwise comparisons between TO ($M = 0.54$), SL ($M = -3.30$), SR ($M = 4.18$), and TS ($M = 0.09$) were significant except for the TO-TS comparison. When a single larger stationary object was present on either side of the target, O displacement was in the direction of that object; when either no object or objects on both sides were present, O displacement was closer to zero. Also, increases in target size produced larger O displacement when a single object was present on either side of the target, and this effect was larger for ascending motion than for descending motion. No other main or interaction effects approached significance.

DISCUSSION

Effects of implied friction, target size, and memory averaging on displacement were observed. Forward displacement decreased with increases in implied friction; this pattern supports the hypothesis that an analogue of friction may be incorporated into the representation of the target, and also extends previous findings to include vertical motion. Additionally, the magnitude of decrease in forward displacement attributable to representational friction was slightly larger for smaller targets than for larger targets. Although it may be tempting to interpret this pattern as suggesting that smaller targets experienced more friction than larger targets, such an interpretation is misleading. Friction occurred along only one or two of a target's sides, and so even though the total amount of friction (based on height) may have increased as target size (and target height) increased, the total amount of momentum (based on size or implied mass, i.e., height × width) would have increased even faster. The ratio of momentum effects to friction effects increased with increases in target size, and so a relatively smaller magnitude of friction effects would have been observed in the displacements of larger targets.

Forward displacement increased with increases in target size for descending targets, but decreased with increases in target size for ascending targets, and this pattern is consistent with previous findings for vertically moving targets. These effects of size on displacement along the vertical axis appear to depend upon the presence of motion, because downward displacement of stationary targets is not influenced by target size (Hubbard, 1997). Surprisingly, there was a trend for forward displacement to be larger for ascending targets than for descending targets, and this trend is not consistent with previous findings (e.g., Hubbard, 1990). The lack of a standard direction main effect may be partially due to the presence of friction in three-fourths of the trials. It may be that friction reduces or attenuates the standard asymmetry between forward displacements for ascending and descending targets. Given that friction reduced the overall magnitude of forward displacement, the nonsignificant direction main effect may have resulted from a floor effect. Alternatively, friction may have been more salient, and hence larger, for descending targets. Forward displacement increased with increases in velocity for descending targets and large ascending targets, but the magnitude of increase as a function of velocity was diminished for small and medium-sized ascending targets.

Displacement along the orthogonal axis was influenced by the location of nearby larger stationary surfaces. When a single surface was present on either the left or right side of the target, memory for the target was displaced in the direction of that surface; when no surface or when surfaces on both the left and right sides of the target were presented, memory for the target was not displaced along the orthogonal axis. Furthermore, larger targets exhibited greater displacement than smaller targets when a single surface was presented. The magnitude of orthogonal displacement when a single surface was presented on the left was not significantly different from the magnitude of orthogonal displacement when a single surface was presented on the right.[2] These data demonstrated that memory averaging toward a larger stationary object occurs, and that the direction of memory averaging does not significantly influence the magnitude of memory averaging per se (although factors such as gravitational attraction that are related to direction may combine with memory averaging and influence overall displacement). This result is consistent with the hypothesis in Hubbard (1995a) that the slight upward displacement when a

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[2] The slight trend for a larger magnitude of displacement toward objects on the right side of the target is consistent with the larger representational momentum previously reported for rightward moving targets (Halpern & Kelly, 1993). Similarly, a surface on the right might result in the target being primarily in the left visual field, and the trend for a larger magnitude of displacement toward objects on the right side of the target is consistent with the larger representational momentum previously reported for stimuli in the left visual field (White, Minor, Merrell, & Smith, 1993).

friction surface was above a horizontally moving target and the large downward displacement when a friction surface was below a horizontally moving target resulted from a combination of memory averaging and representational gravity. Although the current experiment and previous experiments all used moving targets, there is no principled reason why memory averaging should not also occur for stationary targets.

Effects of representational friction, target size, and memory averaging on displacements in memory for ascending and descending targets were observed. The presence of increased implied friction decreased the magnitude of forward displacement, and this pattern is consistent with the hypothesis that representational friction occurs with non-horizontal motion. The displacement toward a single larger stationary target presented on either the right or left side of the target is consistent with the hypothesis that memory averaging processes may be relatively independent of the direction of implied gravitational attraction. Effects of target size on displacement were similar to previous findings: The presence of effects of target size along the axis aligned with the direction of implied gravitational attraction, coupled with the absence of effects of target size along the axis orthogonal to the direction of implied gravitational attraction, are consistent with the hypothesis that the representational system responds to implied mass as implied weight. These patterns extend previous findings, and are consistent with previous proposals that aspects of environmentally invariant principles may have become incorporated into the representational system.

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