The Effect of Height in the Picture Plane on the Forward Displacement of Ascending and Descending Targets

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Abstract The effect of height in the picture plane on the remembered location of ascending or descending targets was examined. Consistent with previous research, memory was displaced forward in the direction of motion. The magnitude of forward displacement was larger for targets low in the picture plane than for targets high in the picture plane, and this was observed with ascending motion and with descending motion. This pattern is consistent with the hypothesis that memory for the location of ascending or descending targets is biased by the effects of implied gravitational attraction on the velocity of those targets, and some implications of such a bias for issues in mental representation are noted.

Résumé Nous avons étudié l'effet de la hauteur dans le plan de l'image sur la mémorisation du site de cibles ascendantes ou descendantes. Conformément aux recherches antérieures, le site mémorisé s'est révélé décalé vers l'avant, dans la direction du mouvement. L'ampleur de ce décalage vers l'avant a été plus élevée dans le cas des cibles se trouvant dans la partie inférieure du plan de l'image que dans celui des cibles occupant la partie supérieure; cette différence a été observée, que le mouvement ait été descendant ou ascendant. Ce patron est conforme à l'hypothèse selon laquelle la capacité de mémorisation du site de cibles descendantes ou ascendantes est biaisée par les effets de l'attraction gravitationnelle implicite sur la vitesse des cibles; certaines implications d'un tel biais en regard des questions de représentation mentale, sont soulignées.

The remembered final position of a previously perceived moving target is often distorted in ways consistent with the operation of implied invariant physical principles. For example, when observers view a horizontally moving target, the remembered final position of that target is distorted forward in the direction of motion and downward in the direction of implied gravitational attraction (Hubbard, 1990), and this pattern is consistent with the operation of the physical principles of momentum and gravity. Distortion forward in the direction of motion has been referred to as *representational momentum* (e.g., Freyd & Finke, 1984), and distortion downward in the direction of implied gravitational attraction has been referred to as *representational gravity* (e.g., Hubbard, 1997). However, the magnitude of forward or downward distortion may be influenced by factors other than implied momentum or implied gravity (for review, see Hubbard, 1995), and so the more neutral term *displacement* is preferred unless the distortion in remembered position is attributable solely to the effects of implied momentum or the effects of implied gravity. The current experiment examines the extent to which displacement along the axis of motion of vertically moving targets is influenced by the height of the target in the picture plane.

Hubbard and Motes (2001) reported that memory for horizontally moving targets high in the picture plane of a stimulus display exhibited larger displacement in the direction of motion than did memory for otherwise identical horizontally moving targets low in the picture plane of a stimulus display. They suggested that height in the picture plane functioned as a depth cue, and that subsequent size constancy scaling resulted in targets high in the picture plane being represented as more distant than were targets low in the picture plane. Targets represented as more distant would have to travel a larger absolute (allocentric) distance in order to cross the same visual angle than would targets represented as closer, and travelling a larger absolute distance in an equivalent amount of time would require a faster absolute velocity. Faster velocities typically result in larger displacement in the direction of motion (Freyd & Finke, 1985; Hubbard & Bharucha, 1988), and so horizontally moving targets high in the picture plane exhibited larger displacement in the direction of motion than did horizontally moving targets low in the picture plane.

Although the use of height in the picture plane as a depth cue and the subsequent size constancy scaling may be appropriate in the representation of horizontally moving targets, such mechanisms do not seem as appropriate in the representation of vertically moving targets. Indeed, if such mechanisms were used, then ascending or descending targets would be represented as changing in distance (along the horizontal axis between the observer and the target) or as changing in size as they ascended or descended. What may be more salient or appropriate for vertically moving targets is the influence of gravitational attraction on the velocity of vertical motion: It is a common observation that ascending projectiles typically decrease in velocity during ascent and descending projectiles typically increase in velocity during descent. As a consequence of this, vertically moving targets high in the picture plane (i.e., at the end of an ascent or at the beginning of a descent) might be represented as traveling at a slower velocity than would vertically moving targets low in the picture plane (i.e., at the beginning of an ascent or at the end of a descent). A slower velocity would result in less momentum (and less representational momentum), and so it could be predicted that displacement in the direction of motion should be less for vertically moving targets high in the picture plane than for otherwise identical vertically moving targets low in the picture plane.

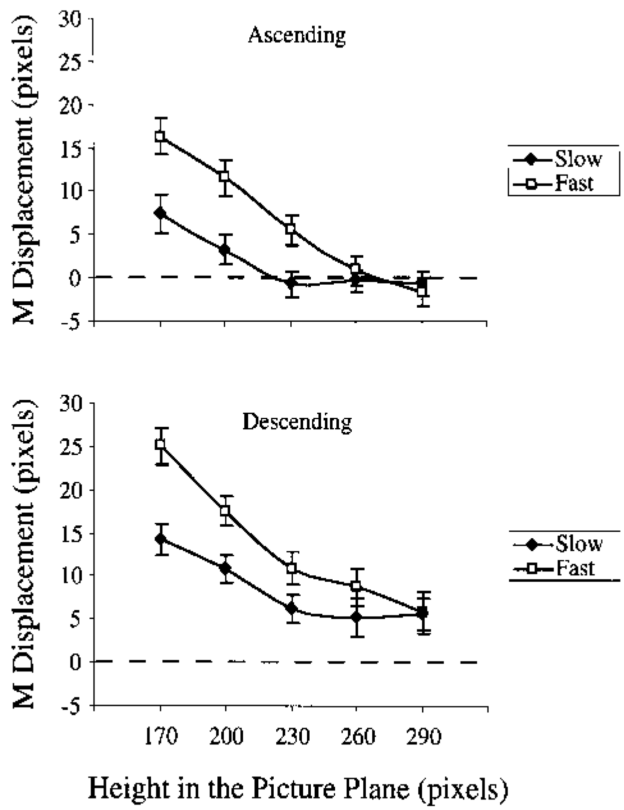

Figure 1. M displacement as a function of distance travelled. Data for ascending targets are displayed in the top panel, and data for descending targets are displayed in the bottom panel. Data for targets moving at a fast velocity are plotted using open squares, and data for targets moving at a slow velocity are plotted using filled diamonds. The vertical bars represent standard errors.

Method

PARTICIPANTS

The observers were 14 undergraduates who participated in return for partial course credit in an Introductory Psychology course.

APPARATUS

The stimuli were displayed upon and the data were collected by an Apple Macintosh IIsi microcomputer equipped with an Apple RGB colour display monitor.

STIMULI

The target stimulus was a filled black square presented on a white background. On each trial, the target was either 20, 40, or 60 pixels (approximately 0.83, 1.67, or 2.50 degrees of visual angle) in width, and the background was 640 pixels in width and 460 pixels in height (approximately 26.67 x 19.17 degrees of visual angle). The target emerged from either the (a) bottom edge of the display and moved upward, or (b) top edge of the display and moved downward. The target vanished without warning at one of five heights: 170, 200, 230, 260, or 290 pixels (approximately 7.08, 8.33, 9.58, 10.83, or 12.08 degrees of visual angle) from the bottom of the display. The 170- and 200-pixel heights were below the vertical midpoint of the display, the 230-pixel height was at the vertical midpoint of the display, and the 260- and 290-pixel heights were above the vertical midpoint of the display. The target was always within the middle 20% of the horizontal extent of the display. Target velocity was controlled by shifting the target 1 or 3 pixels between successive presentations, thus resulting in an apparent velocity of approximately 5 or 15 degrees per second. Each participant received 360 trials (5 heights [170, 200, 230, 260, 290 pixels] x 2 directions [ascending, descending] x 2 velocities [5°/s, 15°/s] x 3 sizes [20, 40, 60 pixels] x 6 replications) in a different random order.

PROCEDURE

Observers received 12 practice trials (randomly drawn from the experimental trials) at the beginning of the session. The observers initiated each trial by pressing a designated key, and after a one-second pause, the target emerged from the top or bottom edge of the dis-

TABLE 1
M Displacement (in Pixels)

			Height in the Picture Plane (in pixels)									
Direction	Size	Velocity	170		200		230		260		290	
Ascending												
	Small											
		Slow	7.36	(3.05)	3.73	(3.21)	-2.66	(2.68)	-1.53	(2.02)	-1.12	(2.60)
		Fast	16.17	(2.70)	13.94	(3.57)	5.91	(2.81)	0.23	(2.87)	-0.35	(3.28)
	Medium											
		Slow	5.96	(4.45)	3.06	(3.30)	-1.16	(2.78)	0.27	(2.07)	-0.14	(1.66)
		Fast	14.76	(3.90)	8.91	(3.55)	5.27	(2.71)	1.01	(3.41)	-1.77	(2.48)
	Large											
		Slow	9.15	(4.23)	3.24	(2.75)	1.80	(2.75)	0.48	(2.81)	-0.63	(2.93)
		Fast	18.26	(4.58)	12.01	(3.84)	5.78	(3.53)	1.78	(2.78)	-2.41	(2.75)
Descending												
	Small											
		Slow	14.74	(3.05)	8.04	(2.13)	4.11	(2.54)	1.88	(4.09)	3.92	(3.88)
		Fast	26.04	(3.69)	18.28	(2.40)	11.46	(2.75)	5.83	(3.93)	5.80	(3.69)
	Medium											
		Slow	13.71	(3.12)	12.61	(2.84)	6.45	(2.72)	6.50	(3.49)	6.42	(2.67)
		Fast	24.00	(3.20)	17.86	(2.73)	10.59	(2.70)	9.56	(2.76)	4.36	(4.66)
	Large											
		Slow	14.27	(3.37)	11.84	(3.14)	8.11	(3.07)	7.20	(3.91)	6.70	(3.28)
		Fast	25.29	(4.20)	16.66	(3.79)	10.82	(4.28)	11.01	(4.14)	7.54	(4.34)

Note. Positively signed displacements indicate a judged vanishing point slightly beyond the actual vanishing point (i.e., above an ascending target, below a descending target), and negatively signed displacements indicate a judged vanishing point slightly behind the actual vanishing point (i.e., below an ascending target, above a descending target). The standard error for each M displacement is given in parentheses following that M displacement.

play and moved vertically across the display. The target vanished without warning, and after the target vanished, the cursor (in the form of a plus sign) appeared near the centre of the display. Observers were instructed to position the centre of the cursor at the coordinates where the centre of the target had been when the target vanished. The cursor was positioned by the movement of a computer mouse, and after positioning the mouse, the observers clicked a button on the mouse in order to record the coordinates of the cursor. Observers then initiated the next trial.

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 DISPLACEMENT

The M displacement scores were analyzed using a 5 (height) x 2 (direction) x 2 (velocity) x 3 (size) repeated measures analysis of variance, and are listed in Table 1. Height influenced M displacement, $F(4,56) = 11.15$, $MSE = 503.80$, $p < .0001$, and interacted with Velocity, $F(4,56) = 21.62$, $MSE = 34.05$, $p < .0001$. As shown in Figure 1, displacement in the direction of motion decreased with increases in height in the picture plane, and this decrease was larger for targets moving at the fast velocity. M displacement was larger for faster (M = 10.16) than for slower (M = 5.14) targets, $F(1,14) = 28.92$, $MSE = 195.55$, $p < .001$, and marginally larger for descending (M = 11.06) than for ascending (M = 4.20) targets, $F(1,14) = 3.10$, $MSE = 3{,}365.14$, $p < .10$. No other effects reached significance.

O DISPLACEMENT

The O displacement scores were analyzed using a 5 (height) x 2 (direction) x 2 (velocity) x 3 (size) repeated measures analysis of variance. No effects approached significance, and mean O displacement scores did not differ from zero.

Discussion

Vertically moving targets high in the picture plane exhibited smaller displacement in the direction of motion than did vertically moving targets low in the picture plane, and this was observed with ascending targets and with descending targets. This pattern is consistent with everyday experience of the typical behaviour of projectile objects: Ascending projectiles decelerate as they ascend and descending projectiles accelerate as they descend, and as a consequence, both ascending and descending projectiles typically exhibit slower velocities when relatively high in the picture plane and faster velocities when relatively low in the picture plane. Given that faster target velocities result in larger displacement in the direction of motion, targets low in the picture plane therefore exhibited larger displacement in the direction of motion than did targets high in the picture plane. Thus, the data are consistent with the hypothesis that the representation of a target incorporates effects of the implied gravitational attraction on the velocity of that target. Also, the effect of velocity and the marginally significant effect of direction on displacement in the direction of motion, and the lack of any effects on displacement along the axis orthogonal to motion, were consistent with previous findings (e.g., Hubbard, 1990).

Three potential explanations for the increase in displacement in the direction of motion for vertically moving targets low in the picture plane may be ruled out. First, the increase in displacement did not reflect a generally larger displacement for all targets low in the picture plane, as displacement in the direction of motion is decreased for horizontally moving targets low in the picture plane (Hubbard & Motes, 2001). Second, the increase in displacement was not a function of the distance travelled by the target, because increases in distance travelled increased displacement for descending targets but decreased displacement for ascending targets. However, it should be noted that the current experiment presented a special case in which the initial height of the target for each direction of motion was constant; it is possible that the distance travelled by a target might influence displacement if the initial height of the target varied and the final height was constant (e.g., a falling object near the ground might be represented as travelling at a faster velocity, and memory might exhibit larger displacement, if that object had fallen from a higher height). Third, the increase in displacement was not a function of the proximity of the vanishing point of the target to the edge of the display or of observers' potential use of the edge of the display as a landmark, as the lowest and highest vanishing points (i.e., 170 and 290 pixels) were equally distant from the nearest edge of the display.

It is somewhat surprising that target size did not influence displacement in the direction of motion, as target size was previously linked with decreases in displacement for smaller descending targets and increases in displacement for smaller ascending targets (see Hubbard, 1997). Inspection of Table 1 suggests a slight trend for smaller descending targets to exhibit less displacement in the direction of motion than did larger descending targets when targets vanished before reaching vanishing points relatively low in the display, and this is consistent with previous findings that stronger effects of target size were observed for descending motion than for ascending motion. In previous studies of target size, the target usually vanished after crossing approximately half of the display and there were a larger number of target sizes, and this may have made height in the picture plane less salient and target size more salient. In the current experiment, there was a larger number of potential vanishing points and a smaller number of target sizes, and this may have made height in the picture plane more salient and target size less salient. It might be that when height in the picture plane is more salient and target size is less salient, then effects of height in the picture plane are larger than and obscure effects of target size. Alternatively, it might be that effects of target size are generally more subtle than effects of height in the picture plane, and so effects of target size were obscured in the data reported here.

The data are consistent with the notion that displacement reflects a combination of influences (see Hubbard, 1995, 1999). For vertically moving targets, such influences include representational momentum and representational gravity. For descending targets, representational momentum and representational gravity operate in the same direction, and so they sum and displacement in the direction of motion is relatively large; for ascending targets, representational momentum and representational gravity operate in opposite directions, and so they partially cancel and displacement in the direction of motion is relatively small. In such an account, decreases in displacement in the direction of motion of vertically moving targets with increases in height in the picture plane may result from decreases in representational momentum or from decreases in representational gravity. The current data cannot discriminate between these possibilities, but given that everyday experience involves changes in the momentum of objects and does not involve changes in the overall level of gravitational attraction, it could be suggested that height in the picture plane influences representational momentum rather than representational gravity. A change in representational momentum due to changes in represented velocity would be consistent with effects of height in the picture plane on displacement in the direction of motion of horizontally moving targets in Hubbard and Motes (2001).

The effect of height in the picture plane on displacement in the direction of motion for vertically moving targets is consistent with the velocity and momentum changes specified by implied gravitational attraction on vertically moving physical objects. Interestingly, effects of height on displacement were observed even though targets were simple animations that would not have experienced gravity or momentum per se and that did not vary in velocity within a given trial. This underscores the robustness of the influence of expectations regarding implied gravitational attraction and implied momentum on spatial representation: Effects of gravity per se and concomitant changes in velocity that gravitational attraction produce were not present, yet observers responded as if targets were subject to gravity and to changes in momentum resulting from effects of implied gravitational attraction on target velocity. This sensitivity to implied gravitational attraction is consistent with previous findings that the representation of a target reflects the implied weight of that target (e.g., Hubbard, 1997; Intons-Peterson & Roskos-Ewoldsen, 1989; Runeson & Frykholm, 1981, 1983; Valenti & Costall, 1997). More broadly, the data support the hypothesis that the functional architecture of mental representation incorporates subjective aspects of invariant physical principles such as momentum and gravity.

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