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A structural dynamic of form: Displacements in memory for the size of an angle

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Memory for the angular size of a chevron (V) shaped target was examined in four experiments. When the target was stationary, memory was displaced inwards (i.e., towards a smaller angle), and the magnitude of displacement increased with increases in absolute angle size. When the target moved vertically or horizontally, memory was displaced inwards, but the effect of absolute angle size was weakened, and displacement was not influenced by whether the direction of motion and the direction in which the angle pointed were the same or different. When the target expanded or contracted (i.e., increased or decreased in angular size), memory for expanding targets was displaced inwards more than was memory for contracting targets, and displacement was not influenced by whether motion was coherent or incoherent. Implications of the data for the possibility of dynamic aspects of mental representation based on the shape of a stimulus are discussed.

The appearance of a shape or form often reflects the forces that created or operated on that shape; for example, visual shapes as complex as sculptures and paintings (Arnheim, 1974, 1988) or as simple as handwritten letters (Babcock & Freyd, 1988) contain information that specifies the direction and magnitude of the forces used in the creation of those shapes. The notion that mental representations preserve such dynamic information has received increasing attention (e.g., Freyd, 1987; Hubbard, 1995b). The majority of empirical investigations of potential dynamic information have focused on physical principles that operate upon an object (e.g., momentum, Freyd & Finke, 1984, and Hubbard, 1995b; weight, Hubbard, 1997, Runeson & Frykholm, 1983, and Valenti & Costall, 1997; mass, Gilden & Proffitt, 1989, and Proffitt & Gilden, 1989), but both psychologists (e.g., Attneave, 1968) and art theorists (e.g,

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Arnheim, 1974, 1988) have speculated that dynamic properties may also arise from more structural properties inherent in the shape of an object. Both Arnheim (1974, 1988) and Freyd (1992, 1993) have further speculated that such dynamic properties may be involved in aesthetic effects in works of art.

One shape that has received considerable investigation of its structural dynamics is the triangle. Attneave (1968) observed that a stationary equilateral triangle could be seen to point in any one of three different directions at a given time, and that the direction in which the triangle appeared to point could be influenced by contextual factors. For example, such a triangle would be perceived as pointing in one direction if a base was aligned with the bases of other nearby triangles, whereas that same triangle would be perceived as pointing in a different direction if an axis of symmetry was aligned with similar axes of other triangles (see Figure 1). Arnheim (1974) suggested that visual figures possessed a structural skeleton and that dynamics consisted in part of the "directed tensions" specified by the structural skeleton. In the case of a stationary triangle, these directed tensions operate by pushing outward against the sides adjacent to apical angles (i.e., by "opening up" the angle) and by pointing outward along the axes of symmetry (see Figure 2). The effects of directed tension outward along an axis of symmetry are consistent with Attneave's demonstration that a triangle may be perceived as pointing in a particular direction, but the

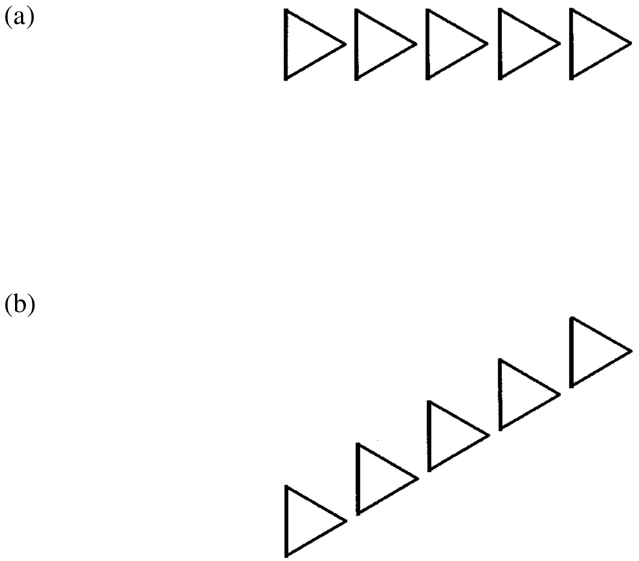

Figure 1. The direction of perceived pointing as a function of whether triangles are (a) axis-aligned or (b) base-aligned. Even though the orientation of each of the homologous lines composing the triangles in both panels are the same, the triangles in (a) are more easily perceived as pointing to the right, whereas the triangles in (b) are more easily perceived as pointing to the upper left (adapted from Attneave, 1968, and Palmer, 1980).

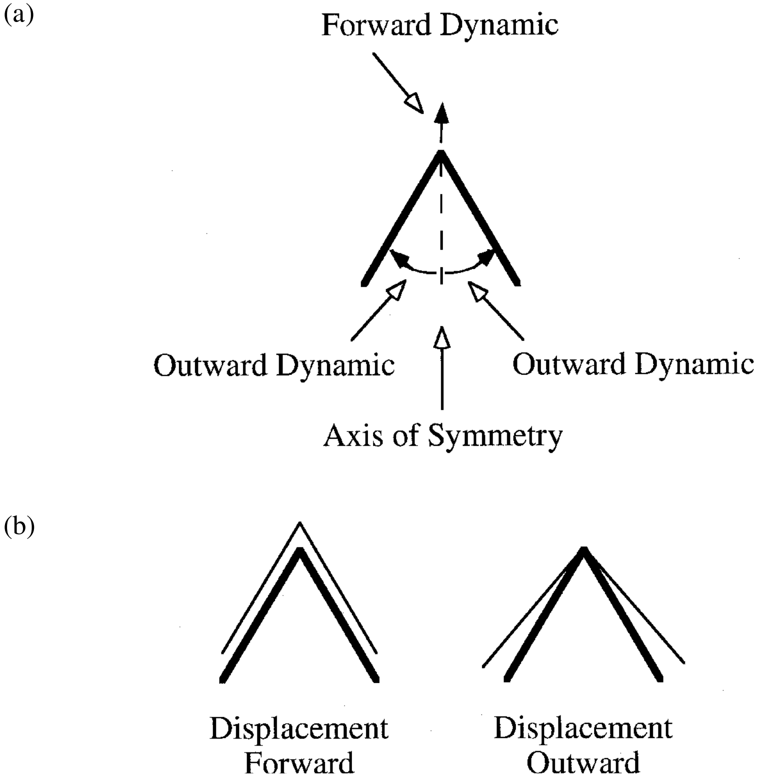

Figure 2. An illustration of the structural dynamics hypothesized to operate on a pointing shape. (a) The directions of forward and outward dynamics on a single pointing target. The pointing target is drawn in a thicker line; the directions of the dynamics are indicated by black arrows, and the labels that identify the dynamics are indicated by white arrows. (b) The left side illustrates memory displacement forward, and the right side illustrates the direction of memory displacement outward. The actual size and location of targets are drawn in a thicker line, and the remembered size and location of targets are drawn with a thinner line.

effects of the postulated directed tension outward against the sides adjacent to the apical angle have not yet been addressed within the empirical literature.

Palmer (1980) expanded Attneave's observations and demonstrated that the direction in which a stationary equilateral triangle was perceived to point could be influenced by global (i.e., biases in particular directions), configural (i.e., collinearity of the triangle's base or axis of symmetry with the bases or axes of other triangles), and elemental (i.e., whether surrounding elements were perceived as pointing in a specific direction) factors (see also Palmer & Bucher, 1981). The internal texture and structure of a stationary triangle also influences the direction in which that triangle is perceived to point; for example, the presence of internal striping can increase the likelihood of a triangle being perceived to point in the direction of an axis of symmetry if the stripes are of low spatial frequency and parallel to the axis of symmetry (Palmer & Bucher, 1982). In addition, the relative size of the apical angle influences the extent to which a stationary triangle is perceived to point; isosceles triangles with smaller apical angles are judged as pointing (along the axis of symmetry that bisects the apical angle) more than are isosceles triangles with larger apical angles and more than are equilateral triangles (Freyd & Pantzer, 1995).

The perceived pointing of a triangle is also influenced by motion of that triangle; when the target translates along one of its axes of symmetry, the perceived pointing along that axis is enhanced (Bucher & Palmer, 1985). The effect of motion on the perceived direction of pointing suggests that dynamic factors arising from the shape or structure of a target stimulus may interact with dynamic factors arising from motion of that shape or structure. One dynamic that arises from motion of a target distorts memory in the direction of anticipated target motion (e.g., if observers are asked to indicate the final position of a previously observed moving target that vanished without warning, those observers are more likely to indicate a position slightly in front of the target's actual final position rather than a position slightly behind the target's actual final position; for review, see Hubbard, 1995b). This forwards distortion was initially attributed to an incorporation of the principles of momentum into the representation, and so was referred to as *representational momentum* (Freyd & Finke, 1984). However, subsequent research revealed that factors other than the implied momentum of the target could influence the distortion in remembered position, and so now the more neutral term *displacement* is preferred unless the distortion is attributable solely to the implied momentum of the target.

Freyd and Pantzer (1995) tested the hypothesis that the dynamics of perceived pointing could interact with representational momentum. Observers were presented with a computer-animated drawing of a moving arrow; the direction of motion and the direction of pointing were either congruent (i.e., the direction in which the arrow pointed was the same as the direction in which the arrow moved) or incongruent (i.e., the direction in which the arrow pointed was 180 degrees from the direction in which the arrow moved). Forwards displacement was greater when the direction in which the arrow pointed and the direction in which the arrow moved were congruent; in other words, memory for the location of the arrow was displaced in front of that arrow's actual location, and the magnitude of this displacement was greater when the direction of movement and the direction of pointing were the same. A vector model of displacement (Hubbard, 1995b) could easily account for this pattern: When the effects of pointing and implied momentum were in the same direction, these two influences combined and forwards displacement of the arrow was relatively larger. When the effects of pointing and implied momentum were in opposite directions, the weaker dynamic of pointing partially cancelled the stronger dynamic of representational momentum, and forwards displacement of the arrow was relatively smaller.

Although the extent to which a triangle may be perceived to point, and whether that pointing may influence memory for location, have received limited attention from investigators, the extent to which such a dynamic may influence memory for shape or angle size has not been empirically examined. A consideration of the dynamics due to pointing and of the dynamics due to target motion allow several predictions regarding the possible effects of those dynamics on memory for angle size. First, the hypothesis that a "directed tension" pushes outwards against the sides of an angle suggests that memory for a stationary angle should be displaced towards a larger angle size (i.e., the angle size will be remembered as slightly larger than it actually was). Second, possible perceived resistance or friction on a moving target (i.e., representational friction, see Hubbard, 1995a, b, 1998) could result in memory for the size of the leading angle of a moving target being displaced towards a smaller (more streamlined) angle when motion of the target is in the direction in which the angle points and towards a larger (more open) angle when motion of the target is in the direction opposite to that in which the angle points. Third, the notion of representational momentum predicts that expansion of an angular shape should displace memory for that shape towards a larger angle, whereas contraction of an angular shape should displace memory for that shape towards a smaller angle.

The majority of research examining the structural dynamics of pointing has employed closed or rigid stimuli such as triangles and arrows. However, the use of a closed or rigid target does not easily allow examination of the hypothesis that directed tensions would push outwards against the adjacent sides of an apical pointing angle or of the hypothesis that the representational momentum of a moving target could influence memory for the size of the leading angle of that target. In order to test such hypotheses, it is more useful to present a target angle in which the adjacent sides of the target angle are not rigidly anchored to a base, because such anchoring might potentially limit the degree to which effects of the dynamics involved in pointing could be observed. Also, in many studies the amount or direction of pointing was influenced by the alignment of the stimulus with surrounding objects. Given that displacement in remembered location is influenced by whether a target moves towards or away from a landmark, the distance of a target from a landmark, or whether a target is aligned with a horizontal or vertical axis of a landmark (Hubbard & Ruppel, 1999, in press), a potentially less confounded measure of the displacement in memory for angle size would be obtained if the target were presented in a blank field.

The experiments reported here examined displacement in memory for the angle size of a chevron (V) shaped target stimulus presented in a blank field. With such a shape, the angle between the sides of a target would be more free to vary and be influenced by any potential dynamics of pointing than would the angle(s) between the sides of a more rigid triangle. All stimuli were presented in a computer-generated display. Experiment 1 presented observers with stationary targets, and tested the hypothesis that a directed outwards tension would displace memory towards a larger angle size. Experiment 2 presented observers with targets that moved in the direction congruent with pointing or incongruent with pointing, and tested the hypothesis that motion in the direction of pointing would displace memory towards a smaller angle size and motion in the direction opposite to pointing would displace memory towards a larger angle size. Experiments 3 and 4 presented observers with targets in which the angle between the arms of the chevron increased or decreased in size, and tested the hypothesis that the remembered angle size would be displaced in the direction of implied motion. In all experiments, a stationary probe was presented after the target vanished, and observers judged whether the angle size of the probe was the same as the final angle size of the target. Displacements consistent with the predicted patterns would provide evidence in support of the hypothesized structural dynamics.

EXPERIMENT 1

In this experiment, memory for the angle size of a stationary pointing target was examined. Observers were briefly presented with a single target, and after the target vanished, a probe was presented. The target was a chevron (V) shape, and the angle between the arms of the chevron varied across trials. The probe was also a chevron shape; on each trial, the probe angle was either smaller than the target angle, the same size as the target angle, or larger than the target angle. The vertex of the probe was located at the same spatial coordinates as the vertex of the target. The target and the probe pointed in the same direction within a trial, and the direction of pointing varied across trials. Observers judged whether the angle size of the probe was the same as the angle size of the target, and the probability of a *same* judgement for each probe was used to estimate the magnitude and direction of any potential displacement in memory for the size of each target angle. If the hypothesis that a pointing triangle exhibits a directed tension outwards against the sides adjacent to the apical angle is correct, then it could be predicted that memory should be displaced towards a larger angle.

Method

Participants. The observers were 48 undergraduates at Texas Christian University who received partial course credit in an introductory or intermediate psychology course in return for participation. Each observer was randomly assigned to either an up, down, left, or right group ($N = 12$ in each group).

Stimuli. Targets and probes were composed of two white dotted lines presented against a black background, and each line formed one arm of a chevron (V) shape. If targets and probes had been formed of solid lines, then the limited resolution of the monitor would have resulted in each of the arms of the chevron exhibiting a jagged or staircase appearance, and changes in the appearance of the arms as a function of orientation could have served as a cue for observers; therefore, the arms were denoted by a series of spaced dots, and each dot was 1 pixel in diameter and was separated by 10 pixels from the dot adjacent to either side (a similar method of employing separated dots to indicate the sides of a target figure, and a similar argument for the use of such separated dots, was used by Verfaillie & d'Ydewalle, 1991, in a study of representational momentum in memory for the final orientation of a rotating target). The length of each arm was 100 pixels (approximately 4.17 degrees of visual angle). The angle between the arms of each target was either 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, or 165 degrees, and each target pointed either upwards, downwards, leftwards, or rightwards. The target was presented near the centre of the monitor screen for 250 ms and then vanished. The ISI between the disappearance of the target and the appearance of the probe was also 250 ms. On each trial, the probe pointed in the same direction as the target, and the vertex of the probe was at the same spatial coordinates as the vertex of the preceding target. The angle between the arms of each probe was either 86.67, 93.33, 100.00, 106.67, or 113.33% of the angle between the arms of the preceding target, and a complete listing of probe sizes is given in Table 1. The axis of symmetry for each probe had the same spatial coordinates as the axis of symmetry for the preceding target. Each participant received 385 trials (11 sizes × 5 probes × 7 replications) in a different random order.

Procedure. Observers were first given a set of practice trials consisting of 12 trials randomly chosen from the experimental trials. Observers pressed a designated key to begin each trial. The target immediately appeared and remained visible for 250 ms. After the target vanished, the screen remained blank for 250 ms, and then the probe appeared and remained visible until the observer responded. Observers judged whether the probe was the same as the target, and indicated their judgements by pressing either a key marked *S* (for same) or a key marked *D* (for different).

Results

Estimates of the magnitude and direction of displacement in remembered target angle size were determined by calculating the weighted mean (i.e., the sum of the products of the proportion of *same* responses and the distance of the probe [in degrees] from the actual angle size of the target, divided by the sum of the proportions of *same* responses) for each angle size for each observer, and the

TABLE 1
Sizes of probe stimuli in Experiments 1, 2, 3, and 4

	Probe size[a]				
	86.67[b]	*93.33*	*100.00*	*106.67*	*113.33*
Target size[c]					
15	13	14	15	16	17
30	26	28	30	32	34
45	39	42	45	48	51
60	52	56	60	64	68
75	65	70	75	80	85
90	78	84	90	96	102
105	91	98	105	112	119
120	104	112	120	128	136
135	117	126	135	144	153
150	130	140	150	160	170
165	143	154	165	176	187

[a] Probe sizes are indicated by specifying the angle size of the probe in degrees (e.g., a “13” indicates a probe in which the arms of the chevron are separated by 13 degrees).

[b] Probe levels are indicated by specifying the percentage of the target angle size exhibited by each probe (e.g., an “86.67” indicates a probe in which the angular extent of the probe is 86.67% that of the angular extent of the target).

[c] Target sizes are indicated by specifying the angle size of the target in degrees (e.g., a “15” indicates a target in which the arms of the chevron are separated by 15 degrees).

weighted means are displayed in Figure 3. Weighted means of the responses to probes placed in front of or behind the final position of a previously perceived moving target offer the most conservative method for estimation of the displacement of remembered target position (Faust, 1990), and so presumably weighted means of the responses to probes larger or smaller than the previously perceived target angle offer the most conservative method for estimation of the displacement of remembered angle size. A weighted mean of 1 suggests that the remembered target angle was the same as the actual target angle (i.e., no displacement); a weighted mean less than 1 suggests that the remembered target angle was smaller than the actual target angle (i.e., displacement inwards), and a weighted mean greater than 1 suggests that the remembered target angle was larger than the actual target angle (i.e., displacement outwards).

The weighted means were analysed in a 4 (Direction) × 11 (Size) repeated measures analysis of variance (ANOVA), with direction as a between-subjects variable and with size as a within-subjects variable. As shown in Figure 3, size was significant, $F(10, 410) = 16.43$, $MSE = .002$, $p < .0001$. A listing of significant pairwise differences based on a post hoc Newman-Keuls ($p < .05$) test is given in Table 2; generally, memory for larger angles was displaced inward

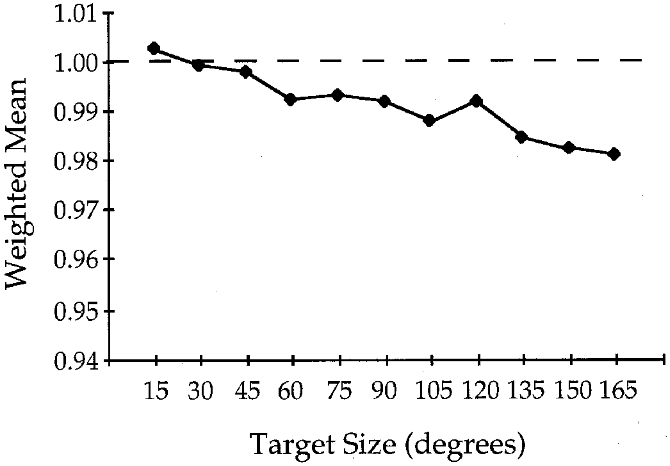

Figure 3. Displacement in remembered target angle size as a function of target angle size in Experiment 1.

more than was memory for smaller angles. Neither direction nor the Direction × Size interaction approached significance.

Discussion

Memory for larger angles was displaced inwards more than was memory for smaller angles. This pattern is not consistent with either the outwards displacement predicted by the directed tensions hypothesis or with a general regression-to-the-mean. However, the pattern is consistent with the general psychophysical finding that the exponent of the power function relating remembered area to physical area is smaller than the exponent of the power

TABLE 2
Pairwise comparisons in Experiment 1

	15	*30*	*45*	*60*	*75*	*90*	*105*	*120*	*135*	*150*	*165*
15	–										
30		–									
45			–								
60	*	*		–							
75	*	*			–						
90	*	*				–					
105	*	*	*				–				
120	*	*						–			
135	*	*	*	*	*	*		*	–		
150	*	*	*	*	*	*		*		–	
165	*	*	*	*	*	*	*	*			–

*$p < .05$.

function relating perceived area to physical area (for reviews, see Algom, 1992; Hubbard, 1994). Alternatively, the smaller inwards displacement for smaller angles could result from a floor effect (because smaller angles would have less potential area available for displacement inwards) or because the observers may not have been as able to successfully discriminate between the probes following smaller targets. It might be objected that the greater inwards displacement for the largest target resulted because the larger probes of the 165-degree target angle were actually greater than 180 degrees, and so perhaps easier to reject; however, even if the 165-degree target angle is excluded, the general pattern still holds: Memory for larger target angles exhibited a greater displacement inwards than did memory for smaller target angles.

EXPERIMENT 2

Given that motion of a triangular figure along an axis of symmetry facilitates perceived pointing along that axis (Bucher & Palmer, 1985), and given that smaller angles are perceived to point more (Freyd & Pantzer, 1995), it could be predicted that motion of a target in the direction of pointing would increase perceived pointing and thus decrease remembered angle size, whereas motion of a target in the direction opposite to pointing would decrease perceived pointing and thus increase remembered angle size. Also, any perceived resistance to motion could be predicted to decrease remembered angle size for motion in the direction of pointing and increase remembered angle size for motion in the direction opposite to pointing. Accordingly, in Experiment 2 the effect of horizontal or vertical translation on memory for angle size was examined. On each trial, observers were shown four sequential presentations of a target; these presentations were referred to as *inducing stimuli* and implied consistent movement upwards, downwards, leftwards, or rightwards. Movement was along the axis of symmetry of the inducing stimuli. On half of the trials, the direction of target motion was congruent with the direction of pointing, and on the other half of the trials, the direction of target motion was incongruent with the direction of pointing. After the final inducing stimulus vanished, a probe was presented, and observers judged whether the angle size of the probe matched the angle size of the final inducing stimulus.

Method

Participants. The observers were 48 undergraduates drawn from the same participant pool used in Experiment 1, and each observer was randomly assigned to either an up, down, left, or right group ($N = 12$ in each group). None of the observers had participated in the previous experiment.

Stimuli. Targets were the same as in Experiment 1 with the following exception: Instead of presenting a single stationary target, a series of four inducing target stimuli were presented. These inducing stimuli were composed of chevron shapes identical to the target angles used in Experiment 1. Within a given trial, each of the inducing stimuli had the same angle size and pointed in the same direction. The spatial coordinates of each inducing stimulus were shifted by 40 pixels (approximately 1.67 degrees of visual angle) along the axis of symmetry from the coordinates of the preceding inducing stimulus; each inducing stimulus was presented for 250 ms, and the ISI between inducing stimuli and between the final inducing stimulus and the probe was also 250 ms. Probes were the same as in Experiment 1. In congruent trials, the inducing stimuli and probe pointed in the same direction as the motion of the inducing stimuli; in incongruent trials, the inducing stimuli and probe pointed in the direction opposite to the motion of the inducing stimuli. Each participant received 440 trials (11 sizes × 5 probes × 2 congruencies × 4 replications) in a different random order.

Procedure. The procedure was the same as in Experiment 1, with the following exceptions: After observers pressed the designated key to begin a trial, four inducing stimuli were sequentially presented. After the final inducing stimulus vanished, there was a pause of 250 ms, and then the probe was presented and remained visible until the observer responded.

Results

Weighted means for each target angle size and congruency condition for each observer were calculated as in Experiment 1. The weighted means were analysed in a 4 (Direction) × 11 (Size) × 2 (Congruency) repeated measures ANOVA with direction as a between-subjects variable and with size and congruency as within-subjects variables. As shown in Figure 4, congruency did not influence displacement, $F(1, 29) = 1.45$, $p > .24$, nor did it interact with any other variables. As in Experiment 1, size influenced displacement, $F(10, 450) = 3.73$, $MSE = .002$, $p < .001$, although the pattern was less consistent than in Experiment 1, and only the difference between the 15- and 165-degree target angles was significant in a post-hoc Newman-Keuls test ($p < .05$). No other main effects or interactions approached significance.

Discussion

Whether the target angle moved in the direction of pointing or in the direction opposite to pointing did not influence remembered target angle size. It may be that motion of the target did not evoke sufficient changes in the amount of perceived pointing to decrease or increase the remembered target angle size. Similarly, it may be that motion of the target did not evoke sufficient perceived

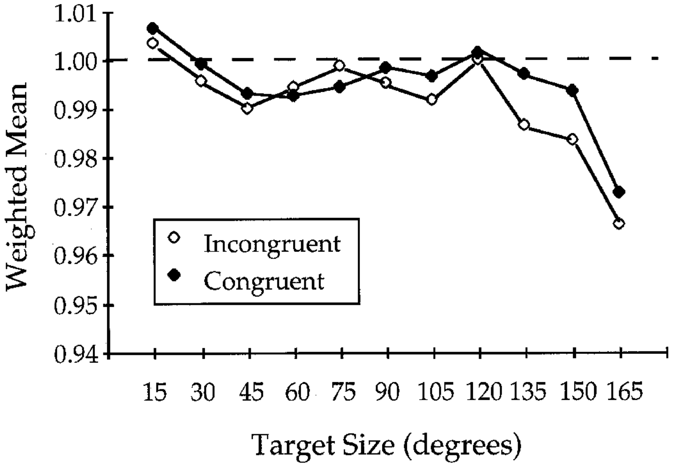

Figure 4. Displacement in remembered target angle size as a function of target angle size in Experiment 2.

resistance to decrease (for congruent motion) or increase (for incongruent motion) the remembered target angle size. The hypothesis of an insufficient resistance is consistent with the observation that any friction or resistance in Experiment 2 would have resulted from contact between the target and the background medium through which the target moved; prior studies found effects of implied friction on the forwards displacement of a target only when the target contacted another object (e.g., Hubbard, 1995a, 1998) and not when the target moved through a background medium (e.g., Cooper & Munger, 1993). The results of Experiment 2 do not seem consistent with the results of Freyd and Pantzer, and so it may be that the effects of congruity Freyd and Pantzer reported resulted from conceptual knowledge of the typical behaviour of an arrow rather than from any effect of pointing *per se* (cf. Reed & Vinson, 1996).

The absolute size of the target angle influenced the magnitude of displacement in remembered target angle size, and this is consistent with the results of Experiment 1. Although fewer individual pairwise comparisons of the displacements of different target angle sizes were significant in Experiment 2 than in Experiment 1, the largest target angle in Experiment 2 exhibited significantly greater inwards displacement than did the smallest target angle, and this paralleled Experiment 1. In the discussion of Experiment 1, it was suggested that the general pattern of larger stationary angles exhibiting greater displacement inwards held even if the 165-degree target angle (in which larger probes were greater than 180 degrees) was excluded. However, closer examination of Figure 4 suggests that the general pattern of larger translating angles exhibiting greater displacement inwards does not hold in Experiment 2 as clearly as in

Experiment 1, especially if the 165-degree target angle is excluded. A more appropriate conclusion regarding the data of Experiment 2 would be that the effect of the absolute size of the target on the magnitude of displacement in remembered target angle size was due to the difference between the 165-degree target angle and all the other target angles, and that a consistent increase in the magnitude of the displacement with general increases in target angle size was not observed.

The addition of motion to the target may have decreased sensitivity for remembered target angle size, and this may have led to fewer of the pairwise comparisons between different angle sizes reaching significance in Experiment 2 than in Experiment 1. One possible explanation for such a decreased sensitivity is that moving targets required more attention than stationary targets, and if observers in Experiment 2 monitored both angle location and angle size, then they presumably would have been able to devote less attention or other cognitive resources to the processing of angle size information *per se* than were observers in Experiment 1. Less attention might result in less displacement; however, Hayes and Freyd (1995) reported the magnitude of representational momentum of a target increased when attention was divided, and so attributing a decreased sensitivity to increases in attentional demands is less plausible. A second possible explanation for such a decreased sensitivity is that representational momentum in memory for the location of the target might have led observers to look for the probe at spatial coordinates slightly in front of where the probe was actually presented. By thus not focusing directly on the final location of the target, observers were not as able to discriminate as well between the probes, and so the overall variance of the differences between target sizes was increased, thus diminishing the statistical significance of the comparisons.

EXPERIMENT 3

A consideration of representational momentum would predict that memory should be displaced towards a larger angle size when a target angle expands (i.e., increases in angle size) across a sequence of inducing stimuli and that memory should be displaced towards a smaller angle size when a target angle contracts (i.e., decreases in angle size) across a sequence of inducing stimuli; such displacements would be in the direction of implied target motion. However, if the target angle has an outwards dynamic (i.e., directed tension pushing outwards against the sides adjacent to the apical angle), then it could be predicted that memory for the angle size of the final inducing stimulus would be displaced towards a larger angle size regardless of whether the target angle expanded or contracted across the sequence of inducing stimuli. Accordingly, in Experiment 3 displacements in remembered angle size were assessed for target angles that expanded or contracted across each sequence of inducing stimuli. The vertices of the inducing stimuli and of the probe within each trial were all located at the same spatial coordinates, and the inducing stimuli and the probe within a given trial all pointed in the same direction. Memory for the angle size of the final inducing stimulus was measured.

Method

Participants. The observers were 52 undergraduates drawn from the same participant pool used in Experiment 1, and each observer was randomly assigned to either an up, down, left, or right group ($N = 13$ in each group). None of the observers had participated in the previous experiments.

Stimuli. Targets were the same as in Experiment 1 with the following exceptions: Instead of presenting a single stationary target, a series of four inducing stimuli were presented. The inducing stimuli were composed of chevron shapes similar to the targets in Experiment 1; the final inducing stimuli were identical to the targets in Experiment 1, and the preceding inducing stimuli on each trial implied either consistent expansion or consistent contraction of angle size. Within a given trial, all of the inducing stimuli pointed in the same direction, and the vertices of the inducing stimuli were located at the same spatial coordinates. In the expanding condition, the first, second, and third inducing stimuli were 70, 80, and 90%, respectively, of the angular size of the final inducing stimulus; in the contracting condition, the first, second, and third inducing stimuli were 130, 120, and 110%, respectively, of the angular size of the final inducing stimulus. A complete listing of the sizes of the inducing stimuli is given in Table 3. Each inducing stimulus was presented for 250 ms, and the ISI between inducing stimuli and between the final inducing stimulus and the probe was also 250 ms. Probes were the same as in Experiment 1.On each trial, the probe pointed in the same direction as the inducing stimuli, and the vertex of the probe was presented at the same spatial coordinates as the vertices of the inducing stimuli. Each participant received 440 trials (11 sizes × 5 probes × 2 motions × 4 replications) in a different random order.

Procedure. The procedure was the same as in Experiment 2.

Results

Weighted means for each target angle size and motion condition for each observer were calculated as in Experiment 1 (i.e., weighted means less than 1 reflect displacement towards a smaller angle size, and weighted means greater than 1 reflect displacement towards a larger angle size). The weighted means were analysed in a 4 (Direction) × 11 (Size) × 2 (Motion) repeated measures ANOVA with direction as a between-subjects variable and with size and motion as within-subjects variables. As shown in Figure 5, motion significantly

TABLE 3
Sizes of inducing stimuli in Experiment 3

	Inducing stimulus size[a]		
	1	*2*	*3*
Expanding targets:			
15[b]	10.5	12.0	13.5
30	21.0	24.0	27.0
45	31.5	36.0	40.5
60	42.0	48.0	54.0
75	52.5	60.0	67.5
90	63.0	72.0	81.0
105	73.5	84.0	94.5
120	84.0	96.0	108.0
135	94.5	108.0	121.5
150	105.0	120.0	135.0
165	115.5	132.0	148.5
Contracting targets:			
15	19.5	18.0	16.5
30	39.0	36.0	33.0
45	58.5	54.0	49.5
60	78.0	72.0	66.0
75	97.5	90.0	82.5
90	117.0	108.0	99.0
105	136.5	126.0	115.5
120	156.0	144.0	132.0
135	175.5	162.0	148.5
150	195.0	180.0	165.0
165	214.5	198.0	181.5

[a] Inducing stimuli are numbered sequentially (i.e., the first is "1", the second is "2", and the third is "3"); the final (fourth) inducing stimulus is the target.

[b] Target sizes are indicated by specifying the angle size of the target in degrees (e.g., a "15" indicates a target in which the arms of the chevron are separated by 15 degrees).

influenced displacement, $F(1, 48) = 25.87$, $MSE = .001$, $p < .0001$, with memory for expanding angles ($M = 0.995$) exhibiting greater inwards displacement than memory for contracting angles ($M = 1.003$). No other main effects or interactions approached significance.

Discussion

Expansion and contraction of the target influenced displacement in remembered target angle size, but the obtained displacements are in the direction

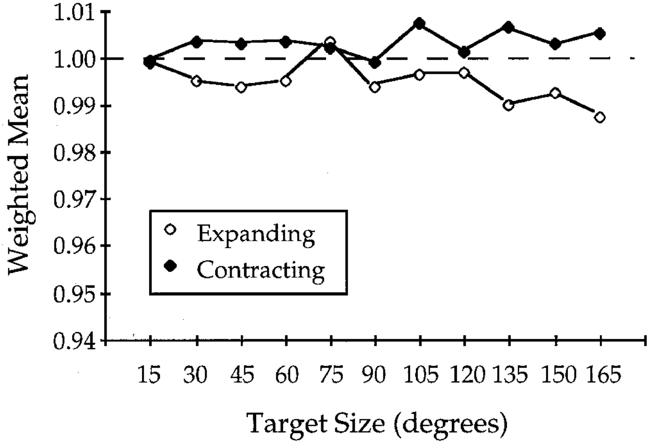

Figure 5. Displacement in remembered target angle size as a function of target angle size in Experiment 3.

opposite to those predicted by a consideration of representational momentum: Memory for expanding target angles was displaced towards a relatively smaller target angle size and memory for contracting target angles was displaced towards a relatively larger target angle size. The backwards displacement is similar to the memory averaging that occurs after a more rapid representational momentum initially displaces memory forwards (cf. Freyd & Johnson, 1987). Memory averaging is not dependent upon a prior occurrence of representational momentum (Hubbard & Ruppel, in press) and, in the case of a moving target presented on a blank field, memory averaging would bias memory for the final location of the target towards an average of the previous locations of that target. Previous locations of the target were behind the target, and so memory averaging would displace memory backwards. It may be that observers in Experiment 3 did not perceive expanding or contracting motion *per se* (and hence did not exhibit representational momentum), but did experience memory averaging (and hence exhibited backwards displacement).

The absolute size of the target angle did not influence the magnitude of displacement in Experiment 3, and this differed from the significant effect of angle size in Experiments 1 and 2. One possible reason why the absolute size of the target angle was more important in Experiments 1 and 2 than in Experiment 3 is that targets in Experiments 1 and 2 may have more clearly involved pointing. The expansion and contraction of inducing stimuli in Experiment 3 occurred behind the vertex, and so attention may have been redirected from in front of the target (in the direction of pointing) in Experiments 1 and 2 to behind the target (contained within the arms of the target angle and not in the direction of pointing) in Experiment 3. Alternatively, it may be that changes in angle size resulted in observers more explicitly encoding angle size information, or it may be that absolute size is less important when angles are changing in size than when angles are stationary or translating. Also, the data from Experiment 3, in conjunction with the data from Experiments 1 and 2, suggest that the displacement of remembered target angle size is influenced by the immediate past behaviour and context of that target angle. Such an influence is consistent with reports that the magnitude and direction of displacement in memory for location is influenced by the past behaviour, current context, and future expectations regarding the target (reviewed in Hubbard, 1995b).

EXPERIMENT 4

The backwards displacements in Experiment 3 may have resulted if observers did not perceive the implied expansion or contraction across the inducing stimuli on each trial as consistent motion. One way to examine this more closely is to reverse the presentation order of the first and second inducing stimuli, while still having observers compare the probe and the final inducing stimulus; reversing the presentation order of the first and second inducing stimuli should eliminate any sense of continuous expansion or contraction that might have been present. An example of this strategy was used in Freyd and Finke's (1984) studies on memory for the orientation of a rotating target: When the presentation order of inducing stimuli implied consistent motion (e.g., a sequence in which the inducing stimuli were 17, 34, and 51 degrees from the upright), representational momentum was obtained, whereas when the presentation order of inducing stimuli implied inconsistent motion (e.g., a sequence in which the inducing stimuli were 34, 17, and 51 degrees from the upright), representational momentum was not obtained. Accordingly, the inducing stimuli in Experiment 4 implied either consistent or inconsistent motion. If displacements resulting from consistent sequences do not differ from displacements resulting from inconsistent sequences, then that would be consistent with the hypothesis that representational momentum was not obtained in Experiment 3 because observers did not perceive those stimuli to be in consistent motion.

Method

Participants. The observers were 52 undergraduates drawn from the same participant pool used in Experiment 1, and each observer was randomly assigned to either an up, down, left, or right group ($N = 13$ in each group). None of the observers had participated in the previous experiments.

Stimuli. Targets were the same as in Experiment 3 with the following exceptions: only the 15, 45, 75, 105, 135, and 165 degree target angle sizes were used. The number of target angle sizes was decreased in order to avoid a high number of trials and subsequent observer fatigue, but the range of target angle sizes remained the same as in Experiment 3. The initial inducing stimulus from each trial was deleted, and only the second inducing stimulus, third inducing stimulus, and the target angle (henceforth referred to as the first, second, and final inducing stimulus, respectively) from Experiment 3 were displayed prior to the appearance of the probe; the use of three inducing stimuli and a probe more precisely paralleled the methodology of Freyd and Finke (1984). The inducing stimuli on half of the trials implied either consistent expansion or consistent contraction of target angle size; these trials were the same as in Experiment 3, and consistent with Freyd and Finke (1984) were referred to as *coherent* trials. The inducing stimuli on the other half of the trials implied inconsistent changes of target angle size; the inconsistent trials were created by reversing the presentation order of the first and second inducing stimuli from the consistent trials, and consistent with Freyd and Finke (1984) were referred to as *incoherent* trials. For example, coherent trials presented a consistent expansion towards a 60-degree target angle by presenting inducing stimuli of 48, 54, and 60 degrees, and incoherent trials presented an inconsistent expansion towards a 60-degree target by reversing the first two stimuli and presenting inducing stimuli of 54, 48, and 60 degrees. Probes were the same as in Experiment 1. On each trial, the probe pointed in the same direction as the inducing stimuli, and the vertex of the probe was presented at the same spatial coordinates as the vertices of the inducing stimuli. Each participant received 480 trials (6 sizes × 5 probes × 2 motions × 2 coherences × 4 replications) in a different random order.

Procedure. The procedure was the same as in Experiment 2.

Results

Weighted means for each target size, coherence, and motion condition for each observer were calculated as in Experiment 1 (i.e., weighted means less than 1 reflect displacement towards a smaller angle size, and weighted means greater than 1 reflect displacement towards a larger angle size). The weighted means were analysed in a 4 (Direction) × 6 (Size) × 2 (Coherence) × 2 (Motion) repeated measures ANOVA with direction as a between-subjects variable and with size, coherence, and motion as within-subjects variables. As in Experiment 3, motion significantly influenced displacement, $F(1, 48) = 7.50$, $MSE = .003$, $p < .01$, with memory for expanding angles ($M = 0.983$) exhibiting greater inwards displacement than memory for contracting angles ($M = 0.992$). As shown in Figure 6, size significantly influenced displacement, $F(5, 240) = 3.50$, $MSE = .014$, $p < .005$, but as in Experiment 2, only the difference between the 15- and 165-degree target angles was significant in a post hoc Newman-Keuls test ($p < .05$). Also, the Motion × Size × Direction interaction was significant, $F(15, 240) = 2.69$, $MSE = .003$, $p < .01$, such that the differences

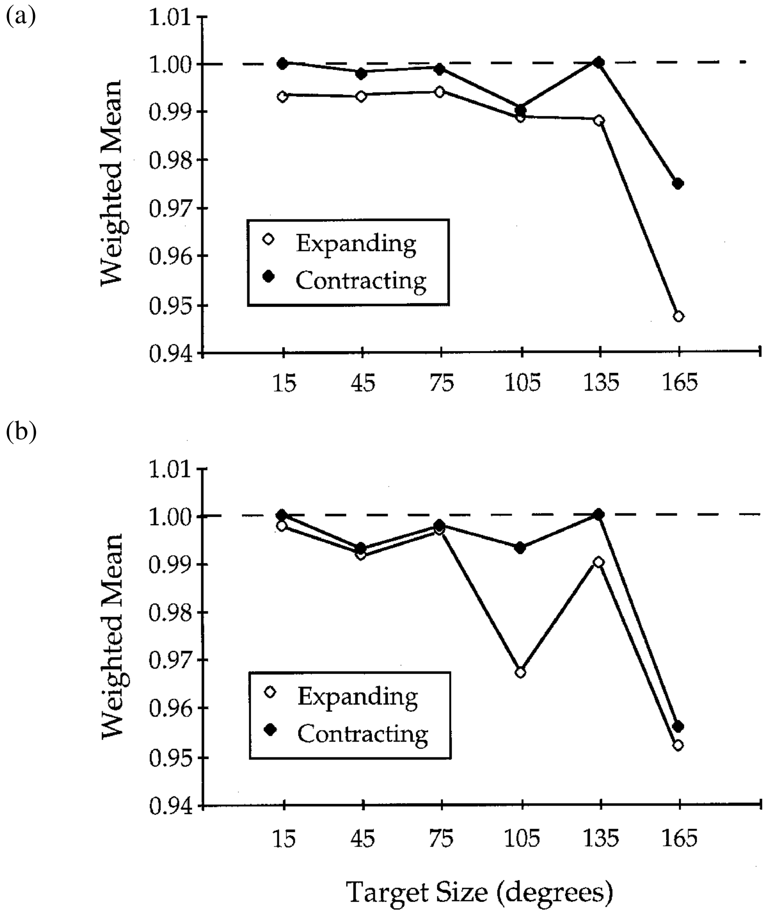

Figure 6. Displacement in remembered target angle size as a function of target angle size in Experiment 4. (a) Data from coherent trials. (b) Data from incoherent trials.

between the 165-degree target angle and the other target angles was largest for target angles pointing downwards or rightwards and for target angles pointing upwards and expanding. No other main effects or interactions approached significance.

Discussion

Whether expansion or contraction of a target angle was coherent or incoherent did not influence displacement in remembered target angle size, nor did the coherence of motion interact with any other factors. The failure of the coherence of motion to influence displacement suggests that observers may not have perceived inducing stimuli in coherent trials as portraying a single object undergoing a consistent expansion or contraction; rather, inducing stimuli in both coherent and incoherent trials were perceived as portraying separate and discrete stimuli. If the inducing stimuli were not integrated into a single object, then they would have appeared as three separate stationary objects of different sizes, and observers would not have perceived motion from one inducing stimulus to another inducing stimulus. Representational momentum for the memory of the final inducing stimulus does not occur if the inducing stimuli are sufficiently different from each other that a continuous transformation of a single object is not perceived (Kelly & Freyd, 1987), and so representational momentum for the target angles was not observed because observers did not perceive the inducing stimuli as portraying a continuous transformation of a single object that was consistently expanding or contracting on each trial.

If observers did not integrate the inducing stimuli into a representation of a single stimulus undergoing continuous transformation, then it is possible that a memory trace of the first or second inducing stimulus may have interfered with judgements of the probe. Such an interference would be reminiscent of a "response competition" or "flankers" task in which a stimulus presented adjacent to a target can influence the time to respond to that target (e.g., Eriksen & Eriksen, 1974; Eriksen, 1995). On each trial in Experiments 3 and 4, the vertex of each inducing stimulus and the vertex of the probe were all located at the same spatial coordinates, and so the arms of the inducing stimuli would indeed have flanked the outer (for contracting angles) or inner (for expanding angles) arms of the probe. However, the designs of Experiments 3 and 4 differed from a typical flankers task in that in Experiments 3 and 4 the inducing stimuli (i.e., the "flanking items") vanished before the target was presented, and it is not clear if a remembered flanker would exert the same interference as a perceived flanker. Alternatively, the remembered location of the first or second inducing stimulus may have functioned as a landmark for memory for the final inducing stimulus, and given that memory is biased towards a landmark (Hubbard & Ruppel, 1999, in press), memory for the final inducing stimulus was displaced toward the first or second inducing stimulus.

The absolute size of the target angle influenced the magnitude of displacement in remembered angle size, and this is consistent with the results of Experiments 1 and 2. Inspection of Figure 6 (as well as of the post hoc Newman-Keuls tests) suggests that the effect of size in Experiment 4 was driven solely by differences between the 165-degree target angle and the other target angles. However, inspection of Figure 5 suggests that a similar pattern did not occur in Experiment 3. The primary difference between Experiments 3 and 4 is that in Experiment 3 inducing stimuli exhibited only coherent motion, whereas inducing stimuli in Experiment 4 exhibited either coherent or incoherent motion. It may be that the possibility of an incoherent trial changed the perceptual set of observers in Experiment 4, thereby making them even more likely to perceive the inducing stimuli as separate and stationary targets; thus, observers in Experiment 4 (like the observers in Experiment 1) were more likely to exhibit greater displacement inwards for the 165-degree target angle. Alternatively, perhaps the presence of an additional inducing stimulus on each trial in Experiment 3 diminished the importance of absolute angle size, but confidence in this possibility is weakened by the earlier finding that absolute angle size influenced the magnitude of displacement for translating target angles in Experiment 2 in which four inducing stimuli had been presented on each trial.

GENERAL DISCUSSION

When observers viewed a stationary target angle, memory for the angular size of that target angle was displaced inwards towards a smaller angle, and the magnitude of displacement was larger with larger target angles. When observers viewed a target angle that translated horizontally or vertically, memory for the size of that target angle was displaced towards a smaller angle, but whether horizontally or vertically moving target angles moved in the direction of pointing or in the direction opposite to pointing did not influence the magnitude of displacement in remembered angle size. When observers viewed a target angle that consistently expanded or contracted, memory for the size of that target angle was displaced backwards towards an average of the angle sizes of the previous inducing stimuli (i.e., memory for an expanding angle was displaced towards a smaller size, memory for a contracting angle was displaced towards a larger size). Lastly, when observers viewed angles that consistently or inconsistently expanded or contracted, memory for expanding angles was displaced towards a smaller size more than was memory for contracting angles. Somewhat surprisingly, across experiments the magnitude of displacement was not influenced by whether a given target angle was a more common or prototypical angle size (e.g., 90 degrees), nor was the magnitude of displacement of angle size influenced by the direction in which the target angle pointed.

Even though these changes in remembered angle size achieved statistical significance, they were quite small in overall magnitude, and generally amounted to less than 1% of angle size. Ranney (1989; but see Finke & Freyd, 1989) criticized research on representational momentum and other dynamic forms of displacement because the magnitude of displacement is typically much smaller than the magnitude of the analogous physical principle that would be exhibited by a physical object. The magnitude of the changes in remembered angle size reported here are even smaller than the typical magnitude of representational momentum, but it could be argued that the effects of structural dynamics might not be as visually obvious or observable as effects of representational momentum and other dynamic forms of displacement arising from physical principles. For cases of structural dynamics that arise from an object's shape and in which observers might have more visual evidence of dynamics, we could predict relatively larger displacements (e.g., memory for a compressed spring is displaced in the direction of decompression, Freyd, Pantzer, & Cheng, 1988). Also, floor effects limit the amount of potential inwards displacement, and data from the 165-degree target angles suggest that a ceiling effect with a 180-degree angle may limit the amount of potential outwards displacement.

The data of Experiments 1 and 2 do not initially seem consistent with the directed tension hypothesis. Stationary angles in Experiment 1 and translating angles in Experiment 2 may not have been displaced as predicted if observers did not perceive each arm of the chevron as being a solid body (e.g., outward tension in Exp. 1 and resistance in Exp. 2 may have "passed through the spaces between the dots", thus reducing the influence of any outwards tension or resistance). However, confidence in this alternative is weakened by prior studies that reported representational momentum for a single target constructed of spaced dots (Verfaillie & d'Ydewalle, 1991). The data of Experiments 1 and 2 might be reconciled with the notion of a directed tension outwards if such a dynamic was hypothesized to develop in response to a mismatch of the angle size specified by the current fixation and the angle size specified by the memory of a previous fixation. Specifically, if an observer initially fixated a section of the target angle, shifted fixation to another section of the angle or to another stimulus, and subsequently refixated the previously viewed section of the target angle, then the remembered angle size would be smaller than the subsequently perceived angle size. A subsequently perceived angle would thus look larger than it was remembered to be, and this apparent increase in angle size might suggest an outwards dynamic. Such a mechanism would be similar to that proposed by Freyd (1992) to more generally account for effects of implied dynamics in art and aesthetics.

The contracting or expanding angles in Experiments 3 and 4 may not have been displaced as predicted if observers did not perceive the sequence of inducing stimuli on a single trial as representing a single object that was undergoing a continuous transformation. In Experiments 3 and 4, the observers may have perceived the inducing stimuli as a series of discrete and isolated stationary stimuli, and so representational momentum was not evoked. The backwards displacement might then be interpreted as reflecting memory averaging, landmark attraction effects, or interference based on response competition from the first and second inducing stimuli. The backwards displacement in Experiments 3 and 4 is also similar to the backwards displacement in memory for luminance reported by Brehaut and Tipper (1996), who suggested that representational momentum-like displacement would not occur unless the dimension along which stimulus change occurred corresponded to "motion in the real world". Given that the change in angle size did not result in a change in the average spatial coordinates of the target, the change in angle size might not have been interpreted as corresponding to motion in the real world. Therefore, representational momentum along the dimension of change was not evoked, and memory for angle size was not displaced in the direction of target angle expansion or contraction.

Angle size is a structural property of a target stimulus, and so the displacements in memory for angle size represent a type of dynamic that influences memory—dynamics arising from the shape or structure of the target. These dynamics operate in addition to dynamics that arise from properties external to the target or that reflect an internalization or incorporation of invariant physical principles (e.g., momentum, gravity; see Hubbard, 1995b). Dynamics based on structural properties and dynamics based on invariant physical principles exhibit intriguing similarities; for example, both types bias memory for the stimulus and may be assessed using very similar methodologies (indeed, the forced-choice methodology used in Experiments 1, 2, 3, and 4 is similar to the methods used in many investigations of representational momentum). Furthermore, these two types of dynamics may appear relatively independent (e.g., the non-significant congruency effect on memory for angle size in Experiment 2) or may influence each other (e.g., the significant congruency effect on representational momentum for position reported by Freyd & Pantzer, 1995). The principles governing such interaction, as well as the range of other possible structural dynamics and the effects of those dynamics on perception and representation, remain issues for further investigation.

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