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Conceptual Effects on Representational Momentum

Catherine L. Reed
University of Denver

Norman Guy Vinson
Carnegie Mellon University

Four experiments addressed the question of whether prior knowledge of an object's typical movement in the real world affects the representation of motion. Representational momentum (RM) is the tendency for the short-term memory representation of an object to undergo a transformation corresponding to the object's trajectory. Using the standard RM paradigm, the RM elicited by objects with different typical motions was compared. Results indicate that conceptual knowledge about an object's typical motion affects the magnitude of RM and, as such, the representation of motion.

We investigated the effects of an object's typical real-world motion on that object's representation in short-term memory. Our experiments show that representational momentum (RM) is affected by conceptual knowledge about an object's typical, real-world motion. This is inconsistent with the view that RM results exclusively from innate processes (Freyd, 1987; Freyd, 1992), and, therefore, we present a quite different explanation of RM. We also discuss how our results would be interpreted in the context of an interactive theory of mind.

Freyd and Finke (1984) found that short-term visual memories, or representations, of an object are distorted along the direction of that object's implied path of motion. RM refers to this unintended mental extrapolation of the stimulus' implied trajectory. The motion and trajectory are implied because only static images of the stimulus are displayed; no real (or apparent) motion is perceived. Nonetheless, the inducing sequence of images is constructed to suggest a particular type of motion, such as rotation. For instance, one can present a series of rectangles, in which each rectangle is oriented slightly farther away from the vertical than the previous rectangle. This is similar to looking at a few time-lapse photographs of a truly rotating rectangle. This type of display induces the viewer to unintentionally extrapolate the rotation such that the mental representation of the rectangle undergoes a slight distortion corresponding to the continued rotation of the real rectangle.

Catherine L. Reed, Department of Psychology, University of Denver; Norman Guy Vinson, Department of Psychology, Carnegie Mellon University.

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Correspondence concerning this article should be addressed to Catherine L. Reed, Department of Psychology, University of Denver, 2155 South Race Street, Denver, Colorado 80208. Electronic mail may be sent via Internet to creed@du.edu.

This phenomenon's resemblance to physical momentum prompted the name *representational momentum* (Freyd & Finke, 1984; Finke, Freyd, & Shyi, 1986). A moving object has (physical) momentum that carries it along its trajectory. To stop the object, an opposing force must be applied to it, but unless the force is strong enough, the object keeps moving for a certain amount of time, over a certain distance. Similarly, the mental representation of an object continues to "move" along the implied trajectory after the moving object itself is abruptly stopped. Just as a moving object has physical momentum, a representation has RM.

However, some basic conditions must be met to produce the effect. First, the implied motion must be coherent. That is, the positions of the successive stimuli in the inducing sequence must follow a discernible trajectory (Freyd & Finke, 1984). For complex trajectories, this requires increasing the number of frames in the inducing sequence (as in Verfaillie & d'Ydewalle, 1991). Also, one must use the same stimulus from frame to frame. Minor changes in the appearance of the stimulus will reduce the effect and substantial changes will eliminate it altogether (Kelly & Freyd, 1987). This also shows that, in the viewer's mental representation, the implied trajectory is closely associated to the object's identity.

Freyd and Finke (1984) point out that the relatively long interstimulus intervals (ISIs) and relatively sizable changes in stimulus position from frame to frame preclude any motion perception. They, therefore, conclude that sensory mechanisms involved in motion perception or in the production of afterimages or motion aftereffects are unlikely to be involved in RM. In any case, motion aftereffects would produce effects opposite to those of RM (Finke & Freyd, 1985; Freyd & Finke, 1984; see Anstis & Gregory, 1964; Masland, 1969). Other control experiments indicate that RM does not result from a general tendency to overestimate position changes (Finke & Shyi, 1988), or from changes in eye position (Finke & Freyd, 1985; Finke, Freyd, & Shyi, 1986).

In our experiments, we investigated the impact of knowledge about an object's typical motion on RM. Most of the prior findings can be classified into one of two groups: those indicative of internalized general constraints and those suggesting that the characteristics of displayed objects and situations have an impact. The first category of results is consistent with Shepard's views on the perceptual system and mental imagery (Shepard, 1981, 1984; Shepard & Cooper, 1982). Shepard theorizes that through the course of evolution, the perceptual system has internalized the general constraints operating on the real-world motion of objects. Specifically, these constraints take the form of a preference for object rigidity and extend to kinematic geometry and to the laws of motion (dynamics). In addition, he proposes that mental imagery relies on the same representational mechanisms as perception and, as a result, is governed by the same constraints. These constraints manifest themselves when the perceptual–imagery system is called on to fill in incomplete representations resulting from impoverished external stimulation. This includes nighttime and obstructions to viewing, and can be simulated in the laboratory with displays inducing apparent motion or RM.

Freyd and Finke (1985) developed a method of estimating the magnitude of the memory distortion or memory shift. Applying this method revealed that the magnitude of the memory shift is related to the stimulus' implied acceleration. If there is no implied acceleration, then the magnitude of the memory shift is proportional to the stimulus' implied velocity (Finke, Freyd, & Shyi, 1986; Freyd & Finke, 1985). Moreover, the representational extrapolation unfolds continuously (or in extremely small steps) over time. Freyd and Johnson (1987) examined the memory shifts taking place over delays of less than 30 ms after the last image in the inducing sequence was presented. They found that the size of the memory shift is only slightly less than the product of the delay and the implied velocity. This product equals the distance a moving object (with a real velocity) would travel in that time period. These quantitative correspondences between representational and physical momentum indicate that factors affecting physical momentum (velocity, acceleration, forces, and time) affect RM in a very similar way. The analogy between these two types of momentum is thereby strengthened.

The results are also quite consistent with Shepard's (1981, 1984; Shepard & Cooper, 1982) views regarding the internalization of real-world constraints on motion. It is important to note that these are general constraints of motion, in that they determine the motion of any object in any situation. Shepard (1981, 1984; Shepard & Cooper, 1982) does not believe that the particular properties of an object or situation will be reflected in the constraints governing the functioning of the perceptual–imagery system.

However, researchers have found that RM can be affected by the specific context presented and by the characteristics of the stimulus objects. Using the apparent (rather than implied) motion of a ball, Hubbard and Bharucha (1988) showed that the direction in which the mental distortions occurred depended on the ball's expected trajectory given the context of the display. When the ball was expected to bounce off of a barrier, the distortion was consistent with the trajectory following the bounce, rather than the incident trajectory. However, when the context was of a ball crashing through the barrier, the distortion was consistent with the trajectory going through the barrier. They concluded that the viewer's knowledge of the trajectory determined the direction of the distortion. Here, the context provided by the display influenced RM.

In other cases, researchers have argued that RM involves the representation of forces acting on objects, as in the compressibility of springs (Freyd, Pantzer, & Cheng, 1988). Placing a box on a spring led to a representational distortion corresponding to a compression of the spring, whereas displays showing the removal of the box led to distortions consistent with a (vertical) expansion of the spring. An alternative explanation is that knowledge of a spring's particular properties, as opposed to forces operating on a spring, influenced RM.

We interpret the above findings as showing that learned knowledge of object-specific properties, such as the object's typical motion, have an impact on RM. Therefore, two objects with different typical motions should induce different RM effects. For instance, in this study, the magnitude of the RM effect for a rising rocket is compared to that of a rising weight. The reasoning is that the magnitude should be greater for the rocket because rockets tend to rise, whereas weights tend to fall. The alternative hypothesis that the phenomenon is regulated exclusively by general internalized constraints of the laws of motion, predicts that all objects should show the same effects regardless of their typical motions. The experiments presented in this article systematically investigate whether RM treats all inanimate objects equally, regardless of their typical motion.

Experiment 1

In Experiment 1, we investigated whether conceptual factors can influence the magnitude of RM. Using the standard RM paradigm (Freyd & Finke, 1984), we examined conceptual effects on RM through the use of an ambiguous stimulus. Two groups of participants received the same experimental treatment. The groups differed only by the label assigned to the stimulus. One group was told that the ambiguous stimulus was a "rocket" and the other group was told that the same stimulus was a "steeple." The stimulus was given a label to keep participants from imposing their own conceptual interpretations, introducing an uncontrolled factor. If prior knowledge about an object's motion influences RM, there should be a main effect for group because rockets move and steeples do not.

This stimulus also permitted us to test for stimulus-specific RM effects over and above the effects that may have been induced by the stimulus' pointed top. Recent investigations suggest that a sharp angle can induce apparent motion perception more easily and produce memory distortions (similar to RM) in the direction in which the angle is pointing. McBeath, Morikawa, and Kaiser (1992) demonstrated that participants were biased to perceive apparent motion in the direction of a stimulus' forward-facing attribute. A pointed feature conveyed an impression of forward orientation. Thus, pointedness indirectly biased participants to perceive apparent motion. Also, Freyd and Pantzer (reported in Freyd, 1992) presented participants with arrows and isosceles triangles and found memory distortions in the direction in which the stimuli pointed. If pointedness has an effect on RM, its effect will have been the same for both participant groups because they both saw the same pointed stimulus; only its label differed.

We also examined the effects of typical and atypical motion. The effects for vertical implied motion were compared with those for horizontal implied motion. Because upright rockets tend to travel vertically but not horizontally, we also predicted a group effect for vertical implied motion, but not for horizontal implied motion.

Method

Participants

Forty University of Pennsylvania undergraduates received extra course credit for their participation in this experiment.

Stimuli and Apparatus

The stimulus was a MacPaint file of an object designed to be ambiguous in that it looked as much like a rocket as it did a steeple (see Figure 1; dimensions for the rocket/steeple are listed in Table 1). Stimuli in all experiments were stored in a PICT file that shared the dimensions of the image and were positioned on the screen based on the center of the PICT file.

The stimuli were displayed on a Macintosh Classic, 9 in., high resolution, monochrome monitor. Viewing distance was approximately 60 cm. Responses and response times (RTs) were recorded by the computer. Participants responded by pressing the "z" key with their left index finger to indicate that the test-frame object's position was the same as that of the memory frame, or by pressing the "m" key with their right index finger to indicate that the positions differed. A cardboard mask was placed over the keyboard to shield all but the response keys and to label their functions. Because the keyboard was used to record responses, the precision of the RTs is 16 ms. The PsychLab Macintosh application was used to implement the experiment.

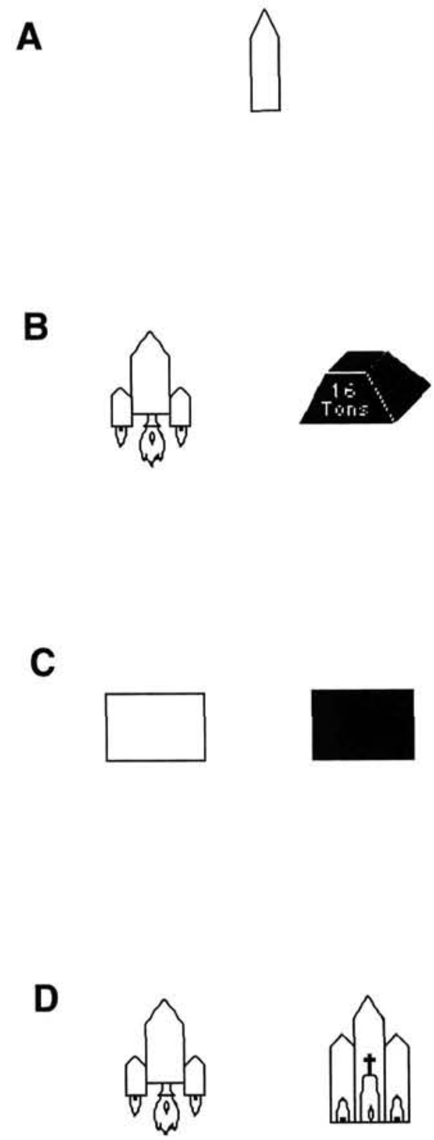

Figure 1. Stimuli used in Experiments 1–4. A: An ambiguous figure identified as either a rocket or a steeple, used for Experiment 1. B: A rocket and a 16-ton weight, used for Experiment 2. C: A black box and a white box, used for Experiment 3. D: A rocket and a church, used for Experiment 4.

Design

A mixed design was used with group (stimulus label) as a between-participant factor, and implied motion (vertically upward, downward or horizontally leftward, rightward) and displacement (−0.75 cm, −0.20 cm, 0.00 cm, +0.20 cm, +0.75 cm) as within-participant factors.

Group factor. Participants were randomly assigned to one of two groups. One group was told that the stimulus was a rocket, of the type used in NASA Apollo missions. The other group was told that the stimulus was a steeple or the Washington Monument. During the experiment, the stimulus was referred to either as a rocket or a steeple; otherwise instructions were identical for both groups. At the end of the experimental session, we conducted a manipulation check: Participants were asked whether they ever considered the stimulus to be something other than what they were told it was.

Implied motion factor. A trial consisted of a sequence of four frames, each containing the same stimulus object in various screen locations. The first three frames formed the inducing sequence, and the third frame was the memory frame. In one set of trials, the object would move vertically either up or down the screen (vertical implied motion) and in the other set of trials, the object would move horizontally, either leftward or rightward across the screen (horizontal implied motion). An example of a trial for a upward vertical motion condition is illustrated in Figure 2. For vertical implied motion conditions, the object was positioned in the center of the screen's horizontal dimension and its vertical position varied from frame to frame. An upward or downward change in location from the first to the third frame produced implied motion. For upward implied motion, the object was first positioned 3.81 cm below the center of the screen and then moved up 1.9 cm in the

Table 1
Approximate Dimensions of Stimuli Used In Experiments 1–4

Stimulus	Width (cm)	Height (cm)	Area (cm^2)
Rocket/steeple	0.4	1.3	0.52
Rocket	1.3	2.3	2.99
Weight	2.2	1.2	2.64
White box	1.6	1.1	1.76
Block box	1.6	1.1	1.76
Church	1.3	2.3	2.00

second and third frames.[1] For downward implied motion, the object was first positioned 3.81 cm above the center of the screen and then moved down 1.9 cm in both the second and third frames.

For horizontal implied motion conditions, the object was positioned in the center of the screen's vertical dimension, but the object's horizontal position varied from frame to frame. A leftward or rightward change in location from the first to the third frame constituted implied motion. For leftward implied motion, the object was first positioned 3.81 cm to the right of screen center and then moved to the left 1.9 cm in the second and third frames. For rightward implied motion, the object was first positioned 3.81 cm to the left of screen center and then moved to the right 1.9 cm in the second and third frames.

The object in the first three frames was presented for 300 ms with an ISI of 150 ms. The ISI between the third and fourth frames was 250 ms (for a stimulus onset asynchrony of 450 ms). The fourth frame was displayed until the participant responded. When viewed, the display did not induce any apparent motion.

Displacement factor. The memory frame was positioned exactly in the middle of the screen, regardless of whether the implied motion was upward, downward, leftward, or rightward. The position of the object in the fourth frame, the test frame, differed from the position of the memory frame object along either the vertical dimension (for vertical implied motion) or horizontal dimension (for horizontal implied motion) by one of five displacements: −0.75 cm, −0.20 cm, 0 cm (i.e., no displacement), +0.20 cm, or +0.75 cm. The displacement values were selected on the basis of a pilot study. For each direction of implied motion, two of the test frame displacements are in the same direction as the implied motion (consistent with the implied motion direction), and the other two displacements are in the opposite direction (inconsistent with the implied motion direction). In our notation, the "−" sign indicates a displacement in the opposite direction of the implied motion. For example, in a condition in which the stimulus appears to move vertically upward, −0.20 cm indicates that the test frame's position on the screen was 0.20 cm lower than the memory frame's position on the screen. The "+" sign indicates a displacement continuing the direction of the implied motion. In the above condition, a +0.20-cm displacement indicates that the test frame position was 0.20 cm higher than the memory test frame position.

The task-demand characteristics of the RM paradigm induce the participants to refrain from producing responses indicative of RM (Finke & Freyd, 1985; Freyd & Finke, 1984; Kelly & Freyd, 1987). A distortion of their memory of the stimulus position would lead to an error in this paradigm, and of course, the participants are encouraged to avoid errors. Consequently, they are implicitly encouraged to avoid producing or showing any RM. To determine whether the participants are indeed trying to minimize their errors, we included the 0.75-cm displacements as controls. These displacements are nearly four times greater than the smaller test displacements (0.20 cm). If participants respond according to the task instructions (which emphasize accuracy), they should make few errors for the large displacements. On the other hand, if they intentionally extrapolated the implied motion, error rates for the large test displacements would be equal to, if not greater than, errors for the small test displacements. Consequently, we expect the effects of our manipulations to manifest themselves primarily in those trials involving the 0.20-cm displacements. The 0.75-cm displacements are simply used as controls.

In this first experiment, the between-groups factor also prevents the participants from tailoring their responses to create an object-specific effect. To create such an effect, each participant would have to know that there is another group; what stimulus label this other group would be shown; and how the participants in this other group would respond. Because the participants cannot know this, they cannot tailor their responses accordingly.

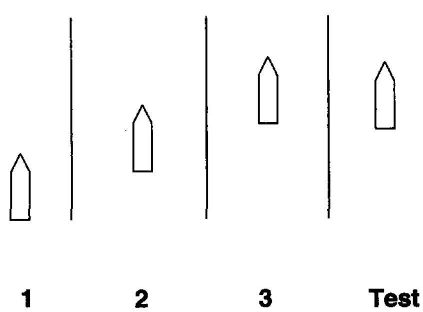

Figure 2. Example of display sequences used in Experiments 1–4 to suggest the vertical upward motion of an object. A stimulus is presented sequentially in three different locations, implying vertical upward motion. The third location is called the memory frame stimulus because the participant must compare its location with the location of the next test stimulus. The test stimulus is presented in one of five locations above, below, or identical to the third vertical location of the stimulus. The test stimulus illustrated on the right is an example of a "different" trial in which the test stimulus is not in the same vertical location as the memory frame's stimulus.

Procedure

The participants' task was to indicate with a key press, as fast and as accurately as possible, whether the stimulus in the test frame (fourth frame) was in the same position as the stimulus in the memory frame (third frame). It was stressed that they should attend to all four frames and respond within 1.5 s of the onset of the test frame. They were not informed of the proportion of same and different trials. Participants were prompted to attend to each trial with a "Ready?" signal displayed in the center of the screen for 300 ms.

Before each set of experimental trials, the participants performed 10 practice trials that sampled from all displacement positions. No error feedback was given. Subsequently, any questions were answered and the experimental trials began. Each participant

[1] The stimuli were intended to start 4 cm below the center of the screen and move up in 2-cm increments. However, we found that with our apparatus, 1 cm in real on-the-screen size equaled 1.05 cm in PsychLab position measurement. This is true for other programs as well, such as SuperPaint. This problem may be related to the variation in pixel size between the monitors of different types of Macintosh computers.

performed 10 trials for each displacement combination and implied motion, for a total of 200 trials. Trials were blocked by type of implied motion, therefore, in any block, participants either saw the stimulus moving vertically (up and down) or horizontally (left and right.) Blocking by implied motion typically increases the RM distortion (Finke & Shyi, 1988). Within blocks, the trials were presented in one of four random orders. Order was counterbalanced over participants. Error and RT data were collected. A typical session lasted approximately 35 min.

Results and Discussion

Participants with an overall error rate of 40% or more were eliminated from the analyses to ensure that any effects were not a result of guessing. Three participants exceeded 40% error and one in the rocket group reported perceiving the object as a house. To eliminate trials in which the participants lost their attention or inadvertently pressed the response key, individual participant data sets were trimmed in two steps: trials in which RTs exceeded 3,000 ms or were less than 150 ms were eliminated, and trials in which the RTs were 3 *SD*s away from the participant's mean were eliminated. The percentage of trials eliminated did not exceed 2% for any participant (i.e., no more than 4 trials out of 200). Excluded data did not vary as a function of stimulus or displacement. Mean proportion error for each condition was calculated for the trimmed data sets.

Two sets of analyses are presented below. The first set uses proportion error data to demonstrate that RM did occur with this paradigm and stimuli. The second set compares the sizes of the RM effects for the various conditions.

Error Analyses

Mean proportion error for each group and displacement is displayed in Table 2. As in Freyd et al. (1988), mean proportion error for the smaller displacements (i.e., 0.20 cm) is used to establish the presence of RM. A Group (rocket, steeple) × Implied Motion (upward, downward, leftward, rightward) × Consistency (consistent [+], inconsistent with implied motion [−]) Analysis of variance (ANOVA) was performed and significant main effects were found. The group effect, $F(1, 34) = 4.71, p < .04$, indicated that the rocket group produced more errors overall than the steeple group. The implied motion effect, $F(3, 102) = 3.43, p < .02$, indicated that some implied motions produced more errors than others. Most important, the consistency effect, $F(1, 34) = 94.60, p < .0001$, established that RM did occur in that consistent displacements produced more errors than inconsistent ones.[2] No interactions were significant.

To determine whether participants were indeed trying to minimize their errors, we analyzed the mean proportion error scores for the 0.75-cm displacements (control condition). The mean error rate for these displacements was much lower than for the 0.2-cm displacements (2.7% vs. 20.2%, respectively). In addition, a Group × Implied Motion × Consistency ANOVA showed there were no RM effects at the 0.75-cm displacements. Although a significant effect was found for consistency, $F(1, 34) = 13.77, p < .001$, there were more errors for the inconsistent than for the consistent displacements. The very low error rate and the lack of RM effects for these displacements indicate that participants were trying to minimize their errors and that they did not interpret the task as one in which they should produce RM.

Table 2
Mean Proportion Error for Each Condition in Experiment 1

Group & implied motion	Displacement (cm)				
	−0.75	−0.2	0.00	+0.2	+0.75
Rocket					
Left	0.02	0.27	0.07	0.61	0.03
Right	0.02	0.30	0.10	0.66	0.06
Up	0.01	0.33	0.03	0.72	0.01
Down	0.02	0.38	0.04	0.74	0.09
Steeple					
Left	0.02	0.13	0.13	0.55	0.03
Right	0.01	0.21	0.15	0.43	0.02
Up	0.02	0.29	0.11	0.47	0.03
Down	0.01	0.29	0.19	0.48	0.01

Note. The "−" sign indicates a displacement in the opposite direction of the implied motion. The "+" sign indicates a displacement in the direction of the implied motion.

RM Effect Analyses

We developed a summary measure to more clearly compare the magnitudes of RM. By incorporating the consistency factor in the new measure, we can directly compare stimulus-specific effects for different implied motions, thus, simplifying the interpretation of the data. The RM effect is determined by subtracting the proportion of errors for the 0.20-cm displacement inconsistent with the implied motion from the proportion of errors for the corresponding consistent displacement, that is, RM effect = $(\text{proportion error})_{\text{consistent}} - (\text{proportion error})_{\text{inconsistent}}$. Thus, a positive RM effect indicates that more errors occurred for the consistent displacement; that there was RM.

RM effects were calculated for each participant. Figure 3 illustrates the RM effects by group and implied motion. The vertical and horizontal implied motions could not be analyzed together using a factorial design because up and down directions could not arbitrarily be associated with left and right. As a result, separate analyses were performed for the

[2] The majority of participants produced RM effects (greater errors for consistent displacements than inconsistent displacements) in each vertical implied motion condition. For upward implied motion, 16 out of 18 participants in the rocket group and 13 out of 18 participants in the steeple group showed an RM effect. For downward implied motion, 17 participants in the rocket group and 12 participants in the steeple group showed an RM effect. RM effects were also found for horizontal implied motion. For leftward implied motion, 13 participants in the rocket group and 15 participants in the steeple group showed a positive RM effect. For rightward implied motion, 17 participants in the rocket group and 11 participants in the steeple group showed a positive RM effect.

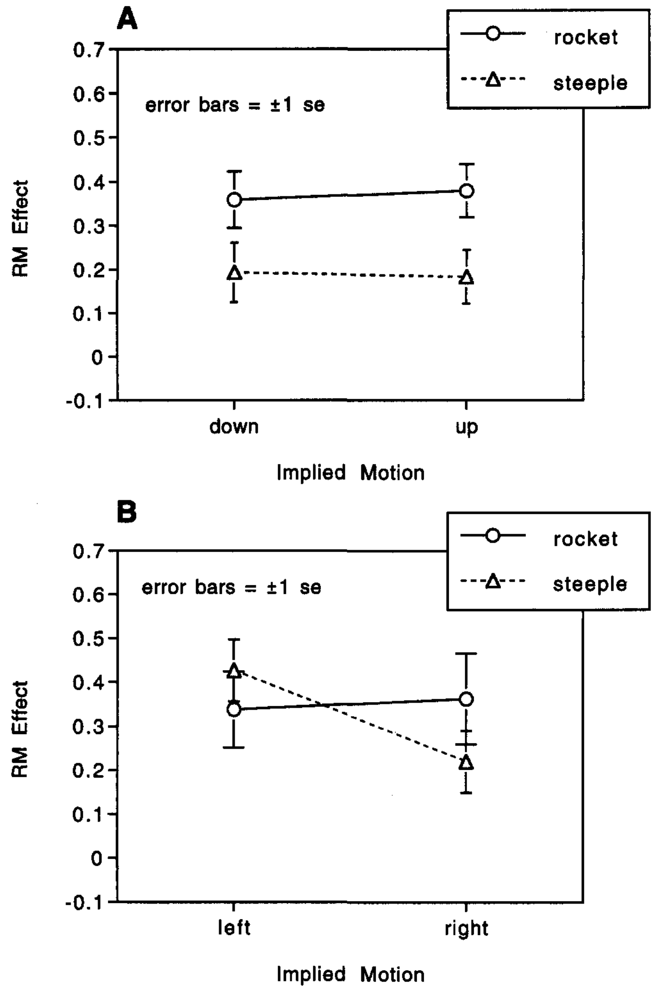

Figure 3. A: The size of the representational momentum effect, that is, RM effect = (proportion error)$_{consistent}$ − (proportion error)$_{inconsistent}$, on the 0.2-cm displacements for each group and direction for vertical implied motion in Experiment 1. The stimulus was an ambiguous figure, identified as either a rocket or a steeple. B: The size of the representational momentum effect, that is, RM effect = (proportion error)$_{consistent}$ − (proportion error)$_{inconsistent}$, on the 0.2-cm displacements for each group and direction for horizontal implied motion in Experiment 1. The stimulus was an ambiguous figure, identified as either a rocket or a steeple.

two types of implied motions. A Group (rocket, steeple) × Vertical Implied Motion (upward, downward) ANOVA was conducted using RM effects. As predicted, a significant effect was found for group, $F(1, 34) = 7.28$, $p < .02$: the rocket produced more RM than the steeple, over both implied motions. Post hoc Scheffé S tests revealed that RM for the rocket was significantly greater than for the steeple for upward implied motion $S = .196$, $p < .03$ and marginally greater for downward implied motion $S = .166$, $p < .09$. Neither the main effect of implied motion, $F(1, 34) < 1.0$, nor the interaction, $F(1, 34) < 1.0$, was significant. These effects are illustrated in Figure 3A.

A Group (rocket, steeple) × Horizontal Implied Motion (left, right) ANOVA was conducted using RM effects. No significant effects were found for group, $F(1, 34) < 1.0$, implied motion, $F(1, 34) = 1.56$, or the interaction, $F(1, 34) = 2.55$. Post hoc Scheffé S tests revealed no significant differences between RM for the rocket or the steeple for leftward implied motion $S = 0.089$, or for rightward implied motion $S = 0.144$. These findings are illustrated in Figure 3B. Thus, no differential RM effects were found for atypical object motion.

In summary, despite the fact that two groups of participants received exactly the same stimulus and the same experimental paradigm, their performance differed as a function of the labeled identity of the stimulus and its associated motion. These results provide evidence that conceptions about real-world object motion influence the magnitude of RM. Experiments 2–4 show that the content of each particular trial influences RM, and provide further evidence that typical motion is at the root of the effects observed in Experiment 1.

Experiments 2, 3, and 4

General Method

In Experiments 2–4, we investigated the effects of various stimulus characteristics on the magnitude of RM. In contrast to Experiment 1, we examined vertical implied motion only.

Stimuli and Apparatus

The stimuli for Experiments 2–4 are illustrated in Figure 1 and their sizes are given in Table 1. They were approximately equal in area and subtended, on average, 1.92° of visual angle (Coren & Ward, 1989). The same apparatus was used as in Experiment 1.

Design and Procedure

In Experiments 2–4, a within-participant design was used by crossing three factors: stimulus (Experiment 2, rocket, weight; Experiment 3, black box, white box; Experiment 4, rocket, church), implied motion (vertically upward, downward), and displacement (−0.75 cm, −0.20 cm, 0.00 cm, +0.20 cm, +0.75 cm). Again, the larger displacements were included to show that participants were trying to minimize their errors and trying not to show RM. If this were so, errors at the smaller displacements would be more frequent and the RM effects would manifest themselves primarily at the smaller displacements.

The procedure was the same as in Experiment 1 except that all conditions were presented randomly with no blocking of trials.

Experiment 2

In Experiment 1, each participant saw only one stimulus. Consequently, the pattern of results could have been produced by the participant's adoption of a general, global, multitrial response strategy based on the stimulus object's typical real-world motion. That is, upon reading the instructions which labeled the stimulus as, say, a rocket, a participant could have adopted a response bias or strategy resulting in more errors, in general, for upward implied motion trials. Similar stimulus set effects have been observed in the RM paradigm. For instance, responses to a ball were seen to differ as a function of the other stimuli presented in other trials of the same experimental session (Halpern & Kelly, 1993).

Experiment 2 was designed to show that responses were a function of the content of the particular trials eliciting them. This was done by presenting each participant with two different stimuli, each with different typical motions. Because each participant saw both stimuli, the stimuli could not have been visually identical, as they were in Experiment 1. Consequently, we designed another rocket and a weight (see Figure 1). In addition, we did not block trials by implied motion (upward or downward) or stimulus (rocket or weight). By avoiding such blocking we eliminated the possibility that multitrial response strategies could develop within a block.

If the Experiment 1 effects resulted from the content of each individual trial, we should have found a stimulus by implied motion interaction in Experiment 2, such that the rocket produced more RM for upward implied motion than the weight, and vice versa for downward implied motion.

Participants

Sixteen Carnegie Mellon University undergraduates received partial course credit for their participation in this experiment.

Results

Error Analyses

Mean proportion error for each displacement and stimulus are displayed in Table 3. A Stimulus (rocket, weight) × Implied Motion (upward, downward) × Displacement Consistency (consistent, inconsistent with the implied motion) ANOVA was performed for the 0.20-cm displacements. The 0-cm displacement condition was not included. A significant effect of consistency, $F(1, 15) = 42.00, p < .0001$ indicated RM.[3] That is, displacements continuing the implied motion produced more errors than displacements opposing the implied motion. In addition, a three-way Stimulus × Implied Motion × Consistency interaction was found, $F(1, 15) = 5.00, p < .05$. This interaction corresponds to the two-way interaction of stimulus by implied motion presented in the RM Effect Analyses section below.

To determine whether participants were indeed trying to minimize their errors, mean proportion error scores for the 0.75-cm displacements (control condition) were analyzed. A Stimulus × Implied Motion × Consistency ANOVA was conducted. Although a main effect of consistency, $F(1, 15) = 6.65, p < .03$, and a Implied Motion × Consistency interaction, $F(1, 15) = 8.84, p < .01$, were found, a significant three-way interaction was required to indicate intentionally produced object-specific effects. However, it was not found, $F(1, 15) = 2.45, p > .10$. The fact that participants made virtually no errors for the 0.75-cm displacements indicates they were trying to avoid errors. In addition, when participants were debriefed at the end of the experiment, they reported that they did not know the purpose of the experiment or how many displacements had been included in the design.

Table 3
Mean Proportion Error for Each Condition in Experiment 2

Stimulus & implied motion	Displacement (cm)				
	−0.75	−0.2	0.00	+0.2	+0.75
Rocket					
Up	0.05	0.45	0.11	0.84	0.08
Down	0.04	0.57	0.08	0.84	0.08
Weight					
Up	0.05	0.51	0.04	0.68	0.03
Down	0.00	0.52	0.06	0.86	0.09

Note. The "−" sign indicates a displacement in the opposite direction of the implied motion. The "+" sign indicates a displacement in the direction of the implied motion.

RM Effect Analyses

RM effects were calculated for each participant, stimulus, and 0.20-cm displacement. An ANOVA was conducted for stimulus (rocket, weight) and implied motion (upward, downward, see also Figure 4). No significant main effects were found for stimulus, $F(1, 15) = 3.35, p < .10$, or implied motion, $F(1, 15) < 1.0$. However, there was a significant interaction, $F(1, 15) = 4.78, p < .05$. This finding indicates that the participants' expectations about each stimulus' typical motion influenced their representations. Post hoc comparisons tested our prediction of differential stimulus effects for each implied motion. As expected, the magnitude of the RM effect was significantly greater for the rocket than for the weight when implied motion was upward, $F = 5.65, p < .05$. However, there was no significant difference for downward implied motion.

This experiment has shown that the object-specific RM effects are produced by the particular content of each trial, and are not a function of a general or global set effect. Our prediction of a greater effect for the upward moving rocket was confirmed, with values quite similar to those of Experiment 1. However, contrary to our expectations, the downward moving weight did not produce significantly more RM than the downward moving rocket.

[3] The rocket induced an RM effect for 12 out of 15 participants for upward implied motion and 13 participants for downward implied motion. The weight induced an RM effect for 11 participants for upward implied motion and 12 participants for downward implied motion.

Experiment 3

In Experiment 3, we investigated whether a stimulus feature unrelated to expectations about typical motion, namely color, influences the size of RM. According to Arnheim (1974), artists often use black to imply physical weight and white to imply physical lightness. It is, therefore, possible that color, by itself, can produce different RM effects. To test the possible effects of color, stimuli without typical motions, a black and a white box, were used so as not to confound the typical motion and color factors. A significant interaction between stimulus and implied motion for the RM effect would verify the influence of object color.

Participants

Twelve Carnegie Mellon University undergraduates received partial course credit for their participation in this experiment.

Results

Error Analyses

Table 4 lists the mean proportion error for stimulus, implied motion, and displacement. A Stimulus (white box, black box) × Implied Motion (upward, downward) × Consistency (consistent, inconsistent with implied motion) ANOVA was performed for the 0.20-cm displacements. A significant consistency effect, $F(1, 11) = 11.32, p < .007$, established that there were more errors when displacement was consistent with the implied motion, indicating a significant occurence of RM.[4] A significant interaction between implied motion and consistency, $F(1, 11) = 7.90, p < .02$, suggests a bias for downward implied motion: Downward implied motion produced more consistent displacement errors than upward implied motion.

Table 4
Mean Proportion Error for Each Condition in Experiment 3

Stimulus & implied motion	Displacement (cm) −0.75	−0.2	0.00	+0.2	+0.75
Black box					
Up	0.01	0.48	0.07	0.58	0.08
Down	0.06	0.36	0.10	0.73	0.07
White box					
Up	0.06	0.49	0.10	0.61	0.08
Down	0.03	0.36	0.08	0.79	0.08

Note. The "−" sign indicates a displacement in the opposite direction of the implied motion. The "+" sign indicates a displacement in the direction of the implied motion.

To determine whether participants were indeed trying to minimize their errors, we analyzed the mean proportion error scores for the 0.75-cm displacements (control condition) (5.7% vs. 54.9% for the 0.20-cm condition). An ANOVA was performed as above and showed that RM did not occur at the control displacements, consistency main effect, $F(1, 11) < 1.0$, nor was there a replication of the significant downward bias found above, Motion × Consistency, $F(1, 11) = 3.08, p > .10$. In addition, the Stimulus × Consistency interaction did not reach significance. Consequently, the effects found at the 0.20-cm displacements were not intentionally produced.

RM Effects Analyses

RM effects were analyzed to determine whether the box stimuli were differently affected by the two implied motions. An ANOVA was conducted on factors stimulus (black box, white box) and implied motion (upward, downward) for the critical 0.20-cm displacement. The analysis revealed a significant effect of implied motion, $F(1, 11) = 4.78, p < .02$, due to a larger RM effect for downward motion than for upward motion. No significant effects were found for stimulus, $F(1, 11) < 1.0$, or for the interaction, $F(1, 11) < 1.0$ (Figure 5). That the experimental manipulation had a similar effect on both black and white boxes, indicates that stimulus color does not influence the magnitude of the RM effect.

Although we are concluding that the null hypothesis is true (i.e., that the white box and black box do not produce significantly different results), the means for each stimulus are almost identical. Thus, it is unlikely that we are com-

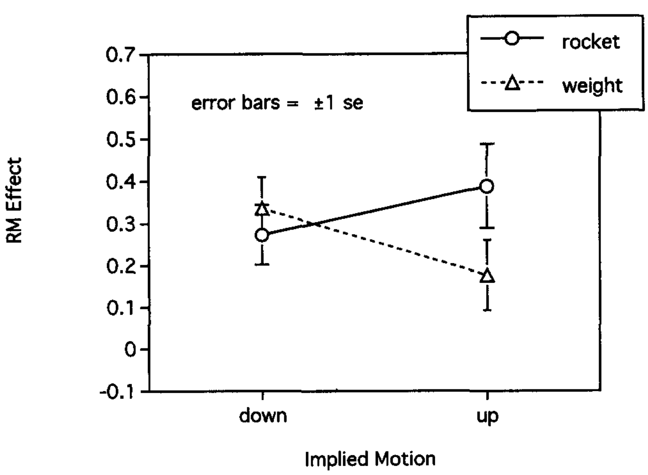

Figure 4. Size of the representational momentum effect, that is, RM effect = $(\text{proportion error})_{\text{consistent}} - (\text{proportion error})_{\text{inconsistent}}$, on the 0.2-cm displacements for each stimulus and implied motion in Experiment 2. The stimuli were a rocket and a 16-ton weight.

[4] The black box induced an RM effect for 12 out of 12 participants in the upward implied motion condition and 11 participants for downward implied motion. The white box induced an RM effect for 11 participants for upward implied motion and 11 participants for downward implied motion.

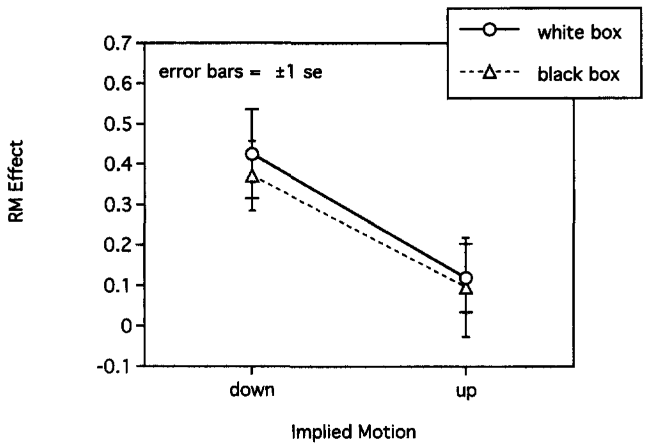

Figure 5. Size of the representational momentum effect, that is, RM effect = (proportion error)$_{\text{consistent}}$ − (proportion error)$_{\text{inconsistent}}$, on the 0.2-cm displacements for each stimulus and implied motion in Experiment 3. The stimuli were a black box and a white box.

mitting a Type II error. Nonetheless, we performed two post hoc comparisons combining the data from Experiments 2 and 3. For upward implied motion, the rocket was significantly different from both the white box, $t(26) = 1.87, p < .05$, and the black box, $t(26) = 1.97, p < .05$. No other comparisons were significant. This is the same significance pattern we obtained in Experiment 2 when comparing the RM for the rocket against that for the weight.

It is surprising to see a main effect of implied motion, which indicates a bias for downward RM for both boxes. Because these stimuli were thought to have no associated typical motions, we expected them to produce equal RM effects for downward and upward implied motion. Note that such a downward bias did not occur for the steeple in Experiment 1, and this was consistent with the steeple's typical immobility. The boxes' downward RM effects are more similar in magnitude to those of the weight, and Experiments 1 and 2 rockets. This suggests (albeit weakly) that an object will reflect a downward RM bias unless the object is typically immobile. In other words, there is a default bias for downward RM that can be overridden by an object's property of typical immobility. Similar downward biases have appeared in other RM studies (Freyd et al., 1988; Hubbard, 1990; Hubbard & Bharucha, 1988) as well as in scene recognition (Biederman, Mezzanotte, & Rabinowitz, 1982). The issue of a downward bias is investigated further in Experiment 4.

Experiment 4

Our goals for Experiment 4 were (a) to replicate the general findings of Experiment 1 in a within-participant paradigm, showing a typical motion effect over and above any pointedness effects; and (b) to replicate the specific pattern of results for downward implied motion from Experiment 1, suggesting that objects that typically do not move (e.g., a steeple or a church) will show weaker RM effects for downward implied motion. This latter finding is consistent with the typical motion hypothesis because it suggests that the property of typical immobility overrides a general bias for downward RM.

We examined RM effects for two stimuli with similarly pointed tops but different associated types of motion: the rocket which typically travels upward and a church which does not move. In each stimulus, we combined two factors, shape and typical motion, for two reasons. First, pointedness has been found to have some effect in general. Second, we feared participants would impose their own conceptual interpretations on the stimuli, if we did not impose them ourselves. Consequently, we determined whether knowledge of typical motion affected RM over and above the potential effects of the perceptual feature of pointedness.

Participants

Twelve University of Pennsylvania undergraduates received extra course credit for their participation.

Results

Error Analyses

Table 5 lists mean proportion error for stimulus, implied motion, and displacement. A Stimulus (rocket, church) × Implied Motion (upward, downward) × and Consistency (consistent, inconsistent with implied motion) ANOVA was performed. A significant consistency effect, $F(1, 11) = 68.34, p < .0001$, indicated that more errors occurred in consistent conditions and established RM.[5] A significant effect was also found for stimulus, $F(1, 11) = 8.15, p < .02$, with the church producing higher raw error rates than the rocket. The Stimulus × Consistency interaction, $F(1, 11) = 7.52, p < .02$, indicated that the rocket induced more RM overall than did the church.

We performed a similar ANOVA with the 0.75-cm displacement data, for which the error rate was only 4.8% (vs. 52.3% for the 0.20-cm displacement). This low error rate shows that participants were trying to minimize their errors. The only significant effect was for consistency, $F(1, 11) = 8.47, p < .02$, indicating that more errors were made for large displacements that continued the implied motion. This main effect is evidence of RM, however, there were no interactions of consistency with stimulus or implied motion. Consequently, we can be relatively certain that the 0.20-cm stimulus effects were not intentionally produced.

RM Effect Analyses

RM effects were analyzed to determine whether the two stimuli were differently affected by the implied motions. A

[5] The rocket induced an RM effect for 11 out of 12 participants in the upward implied motion condition and 12 participants for downward implied motion. The church induced an RM effect for 11 participants for upward implied motion and 11 participants for downward implied motion.

Table 5
Mean Proportion Error for Each Condition in Experiment 4

Stimulus & implied motion	Displacement (cm) −0.75	−0.2	0.00	+0.2	+0.75
Rocket					
Up	0.05	0.24	0.18	0.72	0.07
Down	0.01	0.22	0.21	0.80	0.11
Church					
Up	0.03	0.39	0.16	0.73	0.05
Down	0.03	0.35	0.22	0.75	0.04

Note. The "−" sign indicates a displacement in the opposite direction of the implied motion. The "+" sign indicates a displacement in the direction of the implied motion.

Stimulus (rocket, church) × Implied Motion (upward, downward) ANOVA was conducted for the critical 0.20-cm displacements. A significant effect was found for stimulus, $F(1, 11) = 7.52, p < .02$; the church produced less RM than the rocket over both implied motions. This finding is not surprising because rockets typically move and churches do not. Neither the main effect of implied motion, $F(1, 11) = 1.09, p > .10$, nor the interaction, $F(1, 11) < 1.0$, was significant. These effects are illustrated in Figure 6.

The critical comparison involved the RM effects of the rocket and church for upward implied motion. A post hoc analysis confirmed that the rocket had a greater RM effect for implied upward motion than the church, $F(1, 11) = 5.15, p < .05$. There was no significant difference between stimuli for implied downward motion, $F(1, 11) = 4.12, p > .05$, although there was a trend for the rocket to induce more RM than the church. These results are consistent with the typical motions of rockets and churches: Rockets tend to move up, but churches do not move at all.

This experiment also replicated the results found in Experiment 1; significantly more RM induced by the rocket, especially for upward implied motion. However, the magnitude of RM effects in Experiment 4 were greater than those from Experiment 1. Even so, these results support the hypothesis that there is a general bias for downward RM that can be overridden by an object's typical immobility.

General Discussion

Experiment 1 indicated that RM (representational momentum) is affected by the typical, real-world motion of objects. In this experiment, a single stimulus induced different patterns of RM that were consistent with the typical motion of the objects corresponding to the stimulus' different labels. The participants who were told that the stimulus was a steeple produced smaller RM effects than those who were told that the stimulus was a rocket, especially for upward implied motion. This is consistent with the typical motions of rockets, which tend to go up, and steeples, which tend not to move at all.

The results of the next, within-participant experiments with the rocket and weight, the two boxes, and the rocket and church showed that the object-specific RM effects stem from the content of each particular trial eliciting the response rather than from a global, cross-trial response bias elicited by the stimulus label, or labels. Such global stimulus set effects have been found elsewhere (Halpern & Kelly, 1993), but if they manifested themselves in our experiments, they were overridden by the object-specific effects.

In addition, the results of Experiments 1, 3, and 4 indicate that knowledge about the typical motion of an individual object impacts the magnitude of the RM effect over and above any potential effects of the perceptual features of pointedness (Experiments 1 and 4) and color (Experiments 1, 3, and 4).

On a more speculative note, we also suspect that there is a general bias for downward implied motion to elicit relatively strong RM effects, suggesting that participants expect objects to fall with gravity. Similar gravity biases have appeared in other studies (Biederman et al., 1982; Freyd et al., 1988; Hubbard, 1990; Hubbard & Bharucha, 1988). As argued in Freyd et al. (1988), the gravity effect is consistent with the view that RM is the result of internalized physical constraints. However, it is also consistent with the hypothesis that RM may be influenced by cognitive processes, because knowledge of gravity could lead to gravitylike RM effects. However, this bias seems to be overridden by the effects of typical motion on RM, in that typically stationary objects (i.e., the steeple of Experiment 1 and the church from Experiment 4) do not elicit more downward than upward RM. This issue of a downward bias should receive more study.

To summarize, Experiments 1–4 presented in this article show object-specific effects in RM. Furthermore, these effects were consistent with the real-world typical motions associated with the various stimuli presented. Rockets tend to move upward more than weights, boxes, churches, or steeples, and accordingly, the greatest RM for upward implied motion was induced by the rocket stimuli. It was further demonstrated that these effects did not result from a

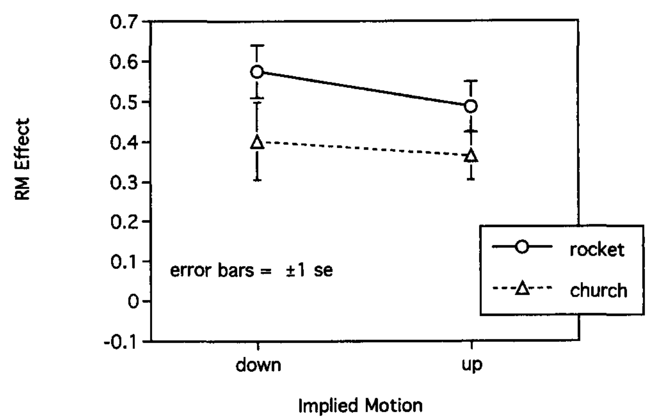

Figure 6. Size of the representational momentum effect, that is, RM effect = (proportion error)$_{\text{consistent}}$ − (proportion error)$_{\text{inconsistent}}$, on the 0.2-cm displacements for each stimulus and implied motion in Experiment 4. The stimuli were a rocket and a church.

global, cross-trial response bias, or differences in the visual features of each stimulus; differences such as color (white or black) or pointedness.

However, it is possible that these object-specific effects can be best detected by using objects that typically move more in one direction than another. For instance, we think of rockets as traveling upward more than traveling downward. Rockets have an asymmetrical typical motion for the vertical dimension of motion. In another study, which compared RM for different stimuli (Halpern & Kelly, 1993), the direction of implied motion was always consistent with the objects' typical motions: All objects studied—a rhinoceros, a fox, a motorcycle, a truck, and a ball—typically move from right to left as well as from left to right. In addition, the stimuli always faced the direction of implied motion. Thus, we would not expect any stimulus to show a pattern of effects that differed from the others'. Indeed, they found that the effects did not differ, except that the truck induced a greater effect than the other stimuli in Halpern and Kelly's first experiment. In addition, the peculiar results they obtained led them to question whether their experimental paradigm really had induced RM: They obtained negative RM effects for right-to-left implied motion, they were unable to replicate the effect of implied velocity on RM, and they were unable to affect RM by increasing the retention interval. Given these difficulties, it is unclear whether objects without asymmetrical typical motions could show object-specific effects. However, a set of objects with differing asymmetrical typical motions should induce object-specific effects.

Explanations of Apparent Conceptual Effects

We explain the above object-specific effects as a result of the viewer's expectations about the motion of these objects in the context of the displayed situations. These expectations derive from knowledge of the particular properties of those objects and situations. In our present experiments, this knowledge pertained to the typical motion of rockets, weights, churches, and steeples. Expectations regarding the objects' movements affect the representational distortions characteristic of RM. This would occur in the following way. First, we note that maintaining the object's identity throughout the inducing sequence is important for inducing RM (Kelly & Freyd, 1987). This indicates that the identity of the object depicted in each frame is attended to, recognized, and recorded. It also indicates that the implied motion is assigned to that object specifically; encoded in that particular object's short-term memory representation. Because the object is identified and recognized, information about its typical motion, stored in long-term memory, should be recalled and encoded in the short-term memory representation as well. Therefore, it is not unreasonable to expect conceptual information to interact with, or to affect, the representation obtained from the inducing sequence. Information from long-term memory could affect the rate of the representation's transformation, it could affect the point at which the transformation stops, or it could affect the path taken by the transformation. Thus, conceptual information about objects and motion held in long-term memory could influence many aspects of RM.

This view can account for the findings that the path of the mental extrapolation was due to both the participant's knowledge of object properties (i.e., the ball and the barrier) and to the participant's interpretation of the interaction of these objects (Hubbard & Bharucha, 1988). Additionally, it can account for representational distortion corresponding to a compression of a spring (Freyd et al., 1988). This is also similar to the finding that cognitive (conceptual) interpretations of stimuli can produce biases in the perception of apparent motion (McBeath et al., 1992).

Our conceptual view of RM can also account for those cases in which RM resembles physical momentum. This correspondence simply results from the expectation that objects behave according to the laws of physics. This expectation in turn is based on knowledge of motion that is acquired through real-world experience. On the other hand, people's beliefs about the motion of objects are sometimes inconsistent with the objects' actual, real motion (Kaiser, Proffitt, & McCloskey, 1985; McCloskey, 1983; McCloskey, Caramazza, & Green, 1980; McCloskey & Kohl, 1983). We predict that RM should reflect people's beliefs rather than the objects' actual motion. This presents the possibility that the nature of RM depends not on mental structure, but rather on knowledge of (a) the general regularities of motion (e.g., objects fall due to gravity), and (b) the specific typical motions of particular objects.

Analog Processing and Cognitive Penetrability

Whether RM is cognitively penetrable or perceptually modular has been a point of contention (Finke & Freyd, 1989; Freyd et al., 1988; Hubbard & Bharucha, 1988; Ranney, 1989). On one hand, conceptual effects such as ours suggest the processes underlying RM are cognitively penetrable and that RM results from tacit knowledge about the motion of objects (Pylyshyn, 1981). On the other hand, RM is resistant to the viewer's conscious attempts to control it, suggesting that it is not cognitively penetrable. This is only paradoxical if one assumes that the mind is modular (e.g., Fodor, 1983).

An alternate view is that the mind is interactive: Perceptual processes are not encapsulated from semantic knowledge of the world, and perceptual processes can be affected by beliefs or concepts. In this framework, processing constraints can be strong enough to prevent conscious control of RM. We have suggested that all these constraints are conceptual, but some could be learned and have little semantic content, and some could be innate. To the extent that this consistently produces mental transformations that correspond to real-world motion, one could say the processes underlying RM are analog. However, this should not be interpreted as revealing of innate mental structures. It only reveals the strength and nature of the constraints operating to produce RM, not how the constraints were acquired.

Within the interactive framework, there is no reason to think that prior results revealing strong processing constraints in RM should be discounted because of findings of conceptual influence. However, no assumption is made in the interactive model that analog-seeming processes reveal mental structures and that conceptual processing is arbitrary. Consequently, the debate over analog versus cognitively penetrable processing loses much of its importance. Here, the focus is on the more subtle question of identifying the constraints and measuring their relative strengths.

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