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Mental Extrapolation and Cognitive Penetrability: Reply to Ranney and Proposals for Evaluative Criteria

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We propose three criteria for establishing that mentally extrapolated motions are impenetrable with respect to one's knowledge, beliefs, or expectations about the nature of corresponding physical motions, and we review recent findings on mental extrapolation and representational momentum that appear to meet these criteria. We also respond to some arguments recently proposed by Ranney (1989) and Hubbard and Bharucha (1988) that representational momentum is cognitively penetrable. We conclude that mental extrapolations are governed to at least some extent by the inherent properties of the underlying internal mechanisms.

Identifying the inherent characteristics of cognitive processes has been a fundamental problem in experimental psychology. The main difficulty lies in distinguishing aspects of cognitive processes that are due to conceptual influences (such as a person's knowledge, expectations, and beliefs) from constraints imposed by the structure of the underlying cognitive mechanisms (e.g., Finke, 1980; Freyd, 1987; Shepard, 1984).

Pylyshyn (1981, 1984) introduced the term *cognitive penetrability* to refer to conceptual influences on cognitive processes. If performance on a task depends arbitrarily on one's knowledge and expectations, then the process is cognitively penetrable. For example, suppose that one imagined blending together the colors yellow and red and reported mentally "seeing" the color orange. Would this reflect an inherent characteristic of the internal mechanisms that are activated when one imagines color combinations, or simply the knowledge that yellow and red are supposed to make orange when combined? Pylyshyn thus raised the following challenge for cognitive scientists: to discover those characteristics of a cognitive process that are not affected or penetrated by a person's knowledge, beliefs, or expectations.

The perceptual/representational system may be hierarchically organized (as argued, e.g., by Finke, 1980, and Shepard, 1984) in such a way that lower processes are more automatic and impenetrable, whereas higher processes are more influenced by cognitive penetration. Mental extrapolation and representational momentum most likely involve both lower and higher processes, which suggests that cognitive penetrability for these phenomena is a matter of degree and cannot be decided as all or none. We thus take our challenge to be twofold: First, we hope to show that at least some characteristics of mental extrapolation and representational momentum are impenetrable so as to ensure that we are investigating the inherent structure of the mind and not simply a set of modifiable beliefs; second, we hope to gain some insight into the perceptual/representational hierarchy by distinguishing between those aspects of extrapolation and momentum that are or are not penetrable. We begin by proposing three criteria for ruling out cognitive penetration, and then we review evidence from recent studies on mental extrapolation and representational momentum that appear to meet these criteria.

Criteria for Ruling Out Cognitive Penetrability

Rapid, Spontaneous Instantiation

First, mental extrapolations that occur rapidly and spontaneously are less likely to be governed by cognitive penetration than those that occur with delayed onset or only after lengthy training procedures; it ought to take time to acquire, organize, or apply the appropriate knowledge. For example, in traditional experiments on mental image scanning, subjects receive extensive training in learning the scanning distances and in mentally simulating an actual scan (e.g., Kosslyn, Ball, & Reiser, 1978); they would thus have ample opportunity to use their knowledge about distance–time relations to control their responses when performing the image-scanning task (Pylyshyn, 1981).

The criterion that an effect should occur rapidly or spontaneously is, of course, one of plausibility; in the absence of explicit, quantitative models of cognitive penetrability, we do not know the upper limit on how quickly penetration might take place. This is therefore the weakest of our three criteria. However, demonstrations of such effects would at least be consistent with current proposals concerning rapidity requirements for modularity in cognitive processes (e.g., see Fodor, 1983) and would tend to shift the burden of proof to those arguing for penetrability of a process.

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Insensitivity to Task Demands

A stronger criterion is that mental extrapolations should not be influenced by attempts to manipulate task demands and expectancies. Advocates for the cognitive penetration position have criticized previous studies on imagined motions for precisely this reason: that the task itself creates demands (either explicit or implicit) for applying one's knowledge of a particular physical process to performing a mental simulation of the process (Mitchell & Richman, 1980; Pylyshyn, 1981). Accordingly, if mental extrapolations still occurred even when the task demands were contrary to those expectations, it would be difficult to explain the extrapolations as having resulted from any kind of cognitively penetrable influences.

Although this criterion is very plausible, it is not quite sufficient. For instance, it may be difficult to know what experimental subjects perceive to be the actual demands of the task, as their verbal reports may not be accurate. Also, it may be hard to tell whether the task demands have been effectively manipulated. Even so, this criterion would probably be acceptable to most critics of imagery studies.

Relevant Knowledge Not Available

The strongest of our criteria, and the one that is sufficient to rule out cognitive penetration, applies when mental extrapolations exhibit certain characteristics that are so unusual that no knowledge for those characteristics could have existed. In such cases, it would make no difference how much time a person had to mentally simulate a physical process; there would be insufficient prior knowledge for cognitive penetration to occur.

Such cases might be relatively rare. However, they need not be plentiful; even a single, uncontaminated case would suffice to rule out cognitive penetration as a complete explanation. Of course, for any pattern of results one can, post hoc, postulate tacit "knowledge" if misconceptions or overgeneralizations about how the world works can count as "knowledge." But in such cases, the burden of proof must fall on the proponent of the explanation.

Evidence for the Cognitive Impenetrability of Mental Extrapolations

Spontaneous Mental Extrapolation

Finke, Pinker, and their colleagues (Finke & Pinker, 1982, 1983; Pinker, Choate, & Finke, 1984) devised an image-scanning task in which subjects were presented with a dot pattern for a 5-s inspection period; the pattern was then removed, and an arrow was presented at some location in the viewing field 2 s later. Their task was to say whether the arrow was pointing at any of the dots in the pattern previously seen. Their verification times increased in proportion to the distance between the arrow and the dot, as in previous image-scanning experiments. In a control experiment, the subjects were given advance knowledge about the location of the arrow, in which case there was no increase in response time with increasing distance. The subjects who were shown the arrow from the unexpected locations reported that they had found it necessary to imagine extrapolating along the direction specified by the arrow in order to mentally "see" whether any of the dots would be encountered.

By our first two criteria, this "spontaneous" image scanning is unlikely to have resulted from cognitive penetrability. There would have been little time to make use of distance information to mentally simulate scanning motions because that information was not available until the very moment that the subjects were to respond. On the contrary, when subjects did have adequate time to make use of this information, and when the task demands encouraged them to do so (as in the control experiment), they did *not* carry out imagined simulations of a physical scan.

Representational Momentum

A more extensive source of evidence bearing on whether certain aspects of mental extrapolation are cognitively impenetrable comes from studies on *representational momentum* (Freyd & Finke, 1984, 1985). In these experiments, subjects are shown a sequence of displays in which a pattern appears in consecutive positions, implying that the pattern is moving, and the subjects' task is to remember the final position. A test pattern is then presented; this pattern can be in the same position as the pattern last observed or can be displaced in the forward or backward direction with respect to it. Subjects typically select test patterns that are shifted forward by small amounts as the pattern that they remember having seen. In analogy to a physical object's being stopped by friction, the size of the forward memory shifts increases as the implied velocity of the inducing sequence increases (Freyd & Finke, 1985), even when the sequence implies a constant acceleration or deceleration (Finke, Freyd, & Shyi, 1986).

Finke et al. (1986) proposed that the memory shifts results from a spontaneous tendency to mentally extrapolate the implied motions beyond the end of the inducing sequence at a rate corresponding to the final implied velocity. Freyd (1987) argued that representational momentum is characteristic of a representational system in which time is fully integrated with other dimensions, just as physical momentum is a property of objects embedded in a spatiotemporal world. According to both of these explanations, representational momentum results from the inherent structure of the mind. Is representational momentum cognitively impenetrable? Does it reflect the inherent properties of cognitive mechanisms underlying mental extrapolations, or is it simply an artifact of one's knowledge, beliefs, or expectations? In considering this question, we address the criticisms of Ranney (1989), wherever appropriate.[1]

With respect to our first criterion, these momentum effects are evidently established during time intervals so short that

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[1] Although Ranney (1989) focuses his criticisms primarily on Freyd, Pantzer, and Cheng's (1988) article, the issues that he raises bear on all representational momentum studies, and hence they are considered in this broader context.

cognitive penetration seems unlikely. Freyd and Johnson (1987) found that the memory shifts increased at a constant rate as the retention interval ranged from 10 to 90 ms, the rate of increase being proportional to the implied velocity of the inducing displays. As Kelly and Freyd (1987) noted, it is hard to conceive of conceptual influences such as knowledge about distance–time relations' governing memory shifts that occur during such brief times. Instead, these findings appear more consistent with the view that the mental extrapolations are elicited spontaneously and follow a continuous trajectory.

Ranney (1989) points out that the rapid onset of the memory shifts does not rule out the possibility that some sort of "postperceptual processing" could occur before the subject's response. Although postperceptual processing could conceivably allow penetration, the extremely short retention intervals used by Freyd and Johnson (1987) presumably allow only 10–90 ms for the mental extrapolation itself; once the distractor position is presented, it is available for comparison with the position in memory. Furthermore, it seems unlikely that cognitively penetrable processing would lead to memory shifts increasing at a strikingly constant rate ($r = .98$) over retention intervals ranging from 10 to 90 ms (Freyd & Johnson, 1987). Having subjects give rapid, immediate "same"–"different" responses to the test patterns is the most conservative procedure that one could use; the subject's response time in these experiments was typically on the order of 700–900 ms. Also, the momentum effects occur regardless of whether the test pattern is left on throughout the response period (Finke & Freyd, 1985; Finke et al., 1986). Ranney's criticisms would apply better to studies involving long-term retention or prolonged inspection of the stimuli.

Our second criterion for ruling out penetrability is satisfied because the experimental procedures do not create task demands for mentally simulating momentumlike effects. The task used in representational momentum experiments is objective in that there is a correct answer and an incorrect answer. Furthermore, the task demands oppose any tendency to mentally simulate momentumlike effects, as subjects are motivated to remember the final positions in order to perform accurately. Indeed, the memory shifts are not eliminated when error feedback is given repeatedly or when subjects are shown the very same pattern to remember on every trial (e.g., Finke & Freyd, 1985). Thus the momentum effects persist despite efforts to discourage or suppress them.

Ranney (1989) raises the concern that the momentum effects tend to be much smaller than one would have expected had the extrapolations continued unimpeded. He concludes, therefore, that the memory shifts may not be mandated by impenetrable properties of the extrapolation process. The magnitude of representational momentum effects has been a source of much confusion, which we will attempt to dispel.

The analogy that we have found useful for representational momentum is of a physical object's being *stopped* by friction or air resistance; that is, the subject's attempt to remember the final position of the object is considered roughly analogous to a physical stopping force. Physical objects being stopped by friction do not halt abruptly, nor do they indefinitely continue to move at their initial rate. Although the exact details of the stopping function depend on particular characteristics of the physical situation (see Freyd & Johnson, 1987), the object eventually slows to a stop. This means that the analogy predicts that representational momentum will produce smaller memory distortions than would be expected had the extrapolations continued unimpeded.

In relation to this issue, we distinguish between what subjects are trying to do in a *memory* task and in an *extrapolation* task. In representational momentum experiments, subjects are not supposed to extrapolate the implied motions at all. In fact, had the memory shifts been equivalent to forward extrapolations out to the next step in the inducing sequence, one could make a case that the subjects *were* responding to subtle task demands, that they erroneously believed that they were supposed to anticipate the pattern corresponding to the next inducing step. On the contrary, the fact that the memory shifts were only a small fraction of the fully extrapolated distances provides further evidence that they are not simply due to task demands (Finke & Freyd, 1985; Finke et al., 1986; Freyd & Johnson, 1987).[2]

If the momentum effects were due solely to one's knowledge about the actual properties of physical momentum, then the memory shifts should also be affected by procedures that manipulate one's *conception* of the mass of the moving objects. Because physical momentum is proportional to an object's mass, but the stopping force may not be, one might expect the distance that a stopping object travels to vary with mass. Indeed, given the intuition that heavy cars are harder to stop than light ones, a cognitive penetration account of representational momentum might more likely predict an effect of mass than of velocity. However, as Pantzer and Freyd (1989) found, conceptual manipulations of implied mass do not affect representational momentum. Accordingly, any account of the memory shifts based on prior knowledge about physical momentum would be strained to explain why implied velocity affects the memory shifts but not implied mass. However, this finding is consistent with the idea that the memory shifts reflect properties of cognitive mechanisms having to do specifically with the speed and efficiency with which the mental extrapolations are carried out (e.g., Finke et al., 1986). Thus if an analogue to physical mass exists for representational momentum, it may be something, such as stimulus salience, removed from common conceptual knowledge of physical momentum.

Evidence for representational momentum has also been reported for implied transformations that have no direct analogue to physically moving objects; this bears on our third and most stringent criterion. Kelly and Freyd (1987), for example, found that memories for the final shape of a rectan-

[2] Ranney (1989) notes that in Freyd, Pantzer, and Cheng's (1988) study, none of the forward distractors produced more "same" responses than the actual same pattern, even though the distributions as a whole were shifted forward. The implied motions in that study, however, were much less explicit than in previous studies on representational momentum. On the contrary, small, forward distractors typically do yield the greatest number of "same" responses in representational momentum studies, particularly when the distractors are closely spaced with respect to the actual same pattern (e.g., Freyd & Finke, 1985).

gle were shifted forward when the inducing sequence implied smooth changes in the rectangle's width while leaving its height unchanged, implying that the rectangle was growing thinner or fatter. Of more significance, they found that memories for the final tone in a sequence of computer-generated tones were shifted forward in pitch when the tonal sequence was increasing or decreasing in pitch. These findings suggest that representational momentum is not simply restricted to implied motions of physical objects, but it can apply to more general types of transformations in which the implied changes are smoothly depicted and can be easily extrapolated. It is unlikely that one would have prior knowledge about momentumlike effects involving shape changes or tonal sequences.

One might argue that the tacit knowledge affecting memory for position, shape, and pitch is a more general sort of knowledge: that movement or change tends to continue in this world. Of course, if this "knowledge" is embedded in the perceptual system, it would not be the sort of tacit knowledge held responsible for *cognitive* penetration; instead, it would be part of the inherent structure of the mind. Indeed, depending on how such knowledge is represented in the perceptual system, the proposal that movement or change tends to continue may be very compatible with Freyd's (1987) account of representational momentum. If, instead, one argues that such tacit knowledge is acquired from prior experience, the explanation runs into difficulty with the finding that memory for pitch is not just shifted forward but is also a function of the implied final velocity of the inducing sequence (Freyd, Kelly, & DeKay, 1989). Thus the memory shifts for pitch are specifically momentumlike, yet changes in pitch in the world do not usually exhibit momentumlike properties, which makes it difficult to see where such tacit knowledge could have been acquired.

Still, one might wonder whether subjects would show an "overshoot" type of error in any task involving extrapolated motions, simply because they expect the motions to continue. Finke and Shyi (1988), using identical inducing sequences, addressed this question by comparing performance on the memory task with that on a pure extrapolation task. In the memory task, the subjects were instructed to remember the final positions, as in previous studies. In the extrapolation task, they were instructed to imagine continuations of the implied motions all the way to the next step in the inducing sequence and then to judge the test patterns according to whether the patterns were in the correct future positions, had they continued to move exactly as depicted. Finke and Shyi created forward and backward distractors for the extrapolation trials by varying the positions of the test patterns about their correct forward-extrapolated positions. The results for the memory task were similar to those of previous studies of representational momentum. In the extrapolation task, the extrapolations were performed accurately as the implied velocity increased to 1.0°/s, but then they fell behind at higher implied velocities. Errors that occurred on the extrapolation task were thus in the backward direction with respect to what would have been the correct extrapolated positions. This argues against the possibility that the momentum effect is simply due to some general tendency to err in the forward direction, as a result of expectancies that the motions ought to continue beyond the final positions. Such results are difficult to explain in terms of cognitive penetration, especially given that accurate performance was required on both tasks.

Shyi and Finke (1989) then varied the probability that subjects would have to make a memory judgment versus an extrapolation judgment. Whereas accuracy on the extrapolation task was affected by expectations for having to extrapolate the implied motions (in particular, "undershoot" errors were more common as the probability for having to make an extrapolation judgment decreased), the memory shifts were not affected by these manipulations. In other words, the memory shifts occurred independently of expectations that the implied motions would continue and were thus impenetrable with respect to those expectations.

In summary, the findings reviewed satisfy each of our criteria for ruling out cognitive penetrability. The momentum effects occur spontaneously over very short time intervals, they occur despite task demands to the contrary, they are not affected by conceptual manipulations, and they occur for implied transformations that are sufficiently unusual that one could not have drawn upon prior knowledge about them.

Penetrable Aspects of Mental Extrapolation

We have so far considered evidence that the spontaneous rate of extrapolation, the continuity of the extrapolation process, and the inability to instantaneously halt the extrapolation process are all characteristics of mental extrapolation that are not cognitively penetrable. Are there any aspects of mental extrapolation that *are* cognitively penetrable?

Maintaining the Mental Extrapolations

Although mental extrapolations may be elicited spontaneously, people can, within limits, control how long an extrapolation is continued; that is, even though mental extrapolations may not be *instantly* halted, as experiments on representational momentum have shown, this does not mean that the extrapolations must continue on indefinitely. Rather, the extent to which a mental simulation is maintained would be determined by penetrable factors such as task demands and whether alternative cognitive strategies would be more appropriate (e.g., Jagacinski, Johnson, & Miller, 1983; Kosslyn, 1980; Rosenbaum, 1975; Shyi & Finke, 1989).

Determining the Path of Extrapolation

It also appears that the selection of a representational "pathway" for carrying out the mental extrapolation is cognitively penetrable. Hubbard and Bharucha (1988) found that when subjects expected a moving dot to rebound off a barrier, their memory shifts were in the direction opposite that of the inducing motion. A control experiment showed that the barrier itself was not responsible; when subjects previously observed the moving dot passing through the barrier, the memory shifts were in the same direction as the dot's motion. In a related study, Shyi and Finke (1989) compared memory shifts by using inducing displays depicting either a consistent motion in one direction (e.g., left to right), or an alternating, back-and-forth motion. They found that the direction of the memory shifts was determined by whether the earlier displays had suggested a forward or a backward continuation of the implied motions. Again, this suggests that the particular direction of the momentum effects is cognitively penetrable.

With regard to the findings of Hubbard and Bharucha (1988) and the related arguments of Ranney (1989), we must distinguish between those aspects of representational momentum that are influenced by higher level controlling mechanisms for the direction of the memory shifts and those aspects that are likely to be impenetrable with respect to those mechanisms. Granted that the direction of the memory shifts is cognitively penetrable, this does not mean that representational momentum itself is a cognitively penetrable phenomenon. To use a physical analogy, imagine a train running along a track. One could easily change the direction of the train by switching the track ahead of it; this would be a penetrable aspect of the train's motion. However, the train would still carry its momentum along the chosen track, whichever one that might be.

This distinction helps to resolve an apparent contradiction between the results of studies on representational momentum and those on "naive physics" reported by McCloskey and his colleagues. McCloskey and Kohl (1983), for example, found that people often fail to predict the correct paths of continuation when forces constraining objects are suddenly removed. For instance, when a ball rolls out of a spiral tube, people often predict that the ball will continue to move along a curved path, even though the constraining force no longer exists. We would expect that such misconceptions about the direction of future motion would affect which path is selected in carrying out the mental extrapolations. However, momentum effects should still occur, independently of these misconceptions, along the extrapolated paths.

Concluding Remarks

We have proposed that certain aspects of mental extrapolation, such as the inability to abruptly halt the extrapolation, are not the result of cognitive penetration. We have also attempted to identify those aspects of mental extrapolation, such as the determination of the extrapolation path, that *are* likely to be cognitively penetrable, in the hope that these distinctions will help avoid future misunderstandings of the phenomenon. Although this issue is by no means completely resolved, we believe that our evidence strongly suggests that at least some characteristics of mental extrapolation—in particular, representational momentum—are better accounted for in terms of the properties of the internal mechanisms themselves.

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