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Representational momentum: New findings, new directions

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Our visual experience of the world often takes the form of events in which objects and/or other aspects of a scene (e.g., the layout) move or change over time. Understanding how the brain processes such "dynamic events" poses a major challenge for theories of perception, memory, and cognition. This Special Issue presents a series of papers related to one topic in this area—*representational momentum*—the systematic tendency for observers to remember an event as extending beyond its actual ending point. For example, when observers view a moving target, that target is typically remembered as having travelled a little farther than it actually did.

Representational momentum was first documented by Freyd and Finke (1984), and in their original paradigm, observers viewed three discrete presentations of a rotating rectangle. A brief retention interval (e.g., 250 ms) followed this *inducing display* and then a fourth, *probe,* rectangle was presented. Observers were asked to judge if the probe was at the same orientation as the third inducing rectangle. As long as the inducing display implied rotation in a consistent direction, observers were more likely to judge "same" when the probe was actually rotated a little further in the direction of motion. Using a different paradigm, Hubbard and Bharucha (1988) presented smooth continuous motion of a target travelling either vertically or horizontally. The target would vanish without warning and observers indicated the judged

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vanishing point using a computer mouse. Typically, the judged vanishing point was slightly in front of the actual vanishing point. Similar dynamic effects have been observed even with completely static stimuli, such as individual images or photographs, when motion is implied within the depicted scene (e.g., Bertamini, 1993; Freyd, 1983; Freyd & Pantzer, 1995; Freyd, Pantzer, & Chang, 1988; Futterweit & Beilin, 1994; Kourtzi & Kanwisher, 2000; Senior et al., 2000).

Subsequent investigation revealed a number of variables that influence representational momentum. For example, the implied acceleration (Finke, Freyd, & Shyi, 1986), velocity (Freyd & Finke, 1985; Hubbard & Bharucha, 1988), and direction of motion (Halpern & Kelly, 1993; Hubbard, 1990; Munger, Solberg, Horrocks, & Preston, 1999) of a target modulate representational momentum for that target. The implied weight of a target (Hubbard, 1997) and the implied friction experienced by a target (Hubbard, 1995a, 1998b) also modulate the effect. Information and expectations regarding target identity (Kelly & Freyd, 1987; Reed & Vinson, 1996) or behaviour (Freyd & Finke, 1984; Hubbard, 1994; Hubbard & Bharucha, 1988; Nagai & Yagi, 2001; Verfaillie & d'Ydewalle, 1991) appear to exert an influence on representational momentum, as do aspects of the physical surroundings, such as the presence or behaviour of nearby objects (Hubbard, 1993, 1995a, 1998b; Hubbard, Blessum, & Ruppel, 2001) or landmarks (Hubbard & Ruppel, 1999). Finally, the length of the retention interval between the disappearance of the target and the probing of memory also influences the extent of representational momentum (Freyd & Johnson, 1987).

Several explanations of representational momentum have been proposed. One early theory suggested observers had internalized the physical principle of momentum (Finke et al., 1986); much as a moving physical object cannot stop immediately upon application of a resisting force (e.g., a moving automobile does not immediately stop upon application of the brake) because of its momentum, so too the mental representation of a moving physical object cannot stop immediately because of analogous momentum. More recent research has pointed out limitations of such a literal momentum metaphor (e.g., Cooper & Munger, 1993), and explanatory accounts involving spatiotemporal coherence (Freyd, 1987, 1992, 1993), expectations regarding future behaviour of the target (Hubbard, 1994), weighted patterns of spreading activation in spatial representation (Hubbard, 1995b), conceptual knowledge of the typical behaviour of the target (Reed & Vinson, 1996), implicit knowledge of physical principles (Hubbard, 1998a), properties of image schemata (Gibbs & Berg, in press), and eye movements (Kerzel, 2000) have been proposed. Despite much recent progress, however, many questions concerning the nature of representational momentum remain unanswered.

In September 2000, a small workshop on representational momentum was hosted by the Max Planck Institute for Biological Cybernetics in Tübingen, Germany. The main goals of that meeting were to (1) showcase a range of current studies on representational momentum, (2) explore how representational momentum might be related to other phenomena, and (3) explore possible new research directions by considering more general issues regarding how the brain processes dynamic objects and dynamic events. The idea for this Special Issue evolved from the Tübingen workshop, and both the content and the organization of the papers described next reflect this connection.

The first four papers present new empirical studies on factors that influence representational momentum. Hayes and Freyd explore the impact of attention by presenting multiple stimuli or by introducing a secondary, non-visual task. They demonstrate that decreases in attention allocated to a specific target resulted in increases in the forward displacement of that target. Nagai, Kazai, and Yagi examine how representational momentum is influenced by implied gravitational attraction. By using both upright and prone observers, effects of body axes and environmental axes were separated. Forward displacement was enhanced when targets moved in the direction of implied gravitational attraction, and the orientation of the environmental axes was more influential than was the orientation of the body axes. Vinson and Reed consider "object-specific" effects on representational momentum. They demonstrate that representational momentum is influenced by a complex interaction between the physical appearance of the object (e.g., whether the object is pointed) and the conceptual context in which the object is placed. Finally in this group, Kerzel asks whether expectations concerning the direction of motion and/or the point of disappearance play an important role in representational momentum tasks. He reports that increasing the level of uncertainty about object behaviour can reduce or even eliminate representational momentum.

The next seven papers forge links between representational momentum and other phenomenon related to the processing of dynamic objects. Senior, Ward, and David describe a study that uses Transcranial Magnetic Stimulation (TMS) to identify the neural substrates involved in representational momentum. Their data provide converging evidence that V5/MT structures are involved in the cognitive representation of motion and in representational momentum. Next, Intraub considers how boundary extension (the tendency for the remembered spatial expanse of a scene to be extended beyond the boundaries of the view; Intraub, Bender, & Mangels, 1992), may be related to representational momentum. She provides an excellent review of the relevant literatures, and reaches the conclusion that representational momentum and boundary extension may both reflect anticipatory projections of the immediate future.

Müsseler, Stork, and Kerzel present the first direct attempt to measure three well known forms of localization error—representational momentum, the flash-lag effect (unpredictable events such as a brief flash are perceived to lag behind continuously visible or predictable events; Nijhawan, 1994), and the Fröhlich effect (the onset of fast moving objects are mislocalized forward in the direction of motion; Fröhlich, 1923; Müsseler & Aschersleben, 1998)—within the same experimental task. They also discuss a model of localization that might provide a framework for unifying these effects. In a similar vein, Whitney and Cavanagh examined the effect of motion of a non-target context on both representational momentum and on the Fröhlich effect. They found that both effects were influenced by the direction and velocity of surrounding motion, and suggest that both static and moving targets are affected by motion signals integrated over larger areas of space, possibly via a common mechanism.

Hubbard and Ruppel examine the connection between representational momentum and the launching effect (a moving stimulus is perceived to cause the subsequent motion of a previously stationary object with which it collides; Michotte, 1946/1963). Representational momentum was reduced for "launched" targets, and they suggest this pattern is consistent with a naïve impetus theory of causality and propose a reconciliation of naïve impetus theory and dynamics. Munger and Minchew examine the relationship between deliberate prediction of a subsequent position and representational momentum for memory of the final position. Larger backward displacement in a prediction task and larger forward displacement in a representational momentum task were found for rotation about the line-of-sight and for faster velocities. They suggest that displacement reflects the amount of information the observer is attempting to maintain in the representation of the event. Finally in this group, Bertamini explores the explanatory power of two notions, adaptation and internalization, as they relate to representational momentum.

The final three papers in this Special Issue deal with broader notions of dynamics and dynamic events. Verfaillie and Daems, exploring long-term priming of biological motion sequences, presented observers with animations of moving human figures, and observers judged whether a subsequently presented static test posture showed a possible or impossible body configuration. Consistent with representational momentum, these decisions were speeded if the posture was preceded by a motion sequence that would have resulted in the test posture had the motion sequence continued. In the next paper, Wallis uses dynamic sequences of human faces to examine whether temporal association influences the formation of long-term representations. During learning, observers were shown sets of faces, each presented so that they appeared to belong to a single rotating head. In a subsequent matching task, the ability to correctly identify two faces as "different" was impaired when those faces belonged to the same set, and thus had appeared in close temporal succession. This suggests that temporal association can play an important role in the representation and/or organization of objects in memory. Finally, Kourtzi and Nakayama also explore the nature of object representations. Using an immediate priming paradigm they found that matching responses to novel object views could be facilitated across image changes, but not temporal delays, when the target objects were preceded by a dynamic prime. Static priming occurred over temporal delays but not image changes. These results suggest distinct representational mechanisms for static and dynamic objects, and are consistent with findings of different brain loci for the processing of static versus dynamic targets.

Overall, the 14 papers included in this Special Issue present a number of exciting new findings and raise a number of important new questions that will continue to fuel research in this area. We believe that representational momentum addresses fundamental issues in mental representation. As such, it can also serve as a useful tool with which to further develop our understanding of dynamic objects and events. It is our hope that the following papers will help to bring both the basic phenomenon of representational momentum and the more general issue of dynamic representations to the attention of a much broader audience within the field of visual cognition.

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