Psychonomic Bulletin & Review
2006, 13 (1), 174-177

Computational theory and cognition in representational momentum and related types of displacement: A reply to Kerzel

TIMOTHY L. HUBBARD
Texas Christian University, Fort Worth, Texas

Kerzel's (2006) commentary on Hubbard's (2005) review of the literature on representational momentum and related types of displacement highlights differences of interpretation between Hubbard and Kerzel, but also contains mischaracterizations of Hubbard's position. In this reply to Kerzel, these differences and mischaracterizations are addressed. Issues are briefly considered that involve the following: whether displacement involves multiple processes; the Marr (1982) framework; the relationship of displacement to internalized physics, goodness of perceived motion, apparent motion, and oculomotor overshoot; generalization from flashed objects to moving objects; necessary and sufficient criteria for displacement; and whether the existence of auditory representational momentum provides evidence for a supramodal account of displacement.

Kerzel's (2006) commentary on my review (Hubbard, 2005) challenges my claim that results from Freyd and Finke (1984) and Hubbard and Bharucha (1988) converged on the idea that memory was displaced, but this challenge overlooks salient aspects of my view (e.g., differences between computational theory level and implementation level; displacement resulting from either low-level perception or high-level cognition is reflected in subsequent memory). More generally, Kerzel's commentary highlights differences of interpretation on several issues regarding data and theory between Kerzel and myself but, unfortunately, also contains mischaracterizations of my position that exaggerate the apparent differences between our views. These differences of interpretation and mischaracterizations will be briefly addressed.

Single Process Versus Multiple Processes

In his introduction ("I will present an alternative view . . . that more than a single process of extrapolation exists, and that each extrapolation process is specific to certain types of motion and responses"), Kerzel implies that I claim that only a single process of extrapolation exists (p. 166). However, I stated that

> displacements of different targets can reflect different combinations of different influences . . . at the level of specific influences and mechanisms, all displacement does not reflect the same underlying cause. (Hubbard, 2005, p. 842)

The author thanks Jon Courtney, Scott Jordan, and Greta Munger for helpful comments. Correspondence should be addressed to T. L. Hubbard, Department of Psychology, Texas Christian University, TCU Box 298920, Fort Worth, TX 76129 (e-mail: t.hubbard@tcu.edu).

I also stated that "this new taxonomy involving characteristics of the target, display, context, and observer explicitly suggests that displacement is multiply determined" (Hubbard, 2005, p. 847) My review is consistent with the notion that multiple processes contribute to displacement; indeed, a large part of the review was devoted to cataloguing the effects of numerous variables on displacement (including motion and response types). Kerzel and I agree that displacement is multiply determined and that different examples of displacement might reflect different processes; however, we disagree on the relative importance of different processes and on the appropriate level of description.

The Marr Framework

I suggested that different examples of displacement (e.g., those resulting from smooth motion or implied motion, in the direction of implied gravity) reflected a single phenomenon at the computational theory level, because those examples solved similar problems (target localization) in a similar way (displacement in the direction of anticipated motion). Kerzel (2006) suggests that different examples of displacement reflect different phenomena, because those examples arise from different mechanisms or processes. However, within Marr's (1982) framework, a single phenomenon at the computational theory level can have multiple instantiations at the implementation level, and so different examples of displacement could reflect a single phenomenon at the computational theory level and involve different mechanisms or processes at the implementation level; indeed, different types of stimuli provide different information and, so, might be expected to engage different types of mechanisms. Kerzel's commentary ignores my use of Marr's framework; however, Marr's framework is critical to my view of displacement, and ignoring it mischaracterizes my position and makes our views appear more divergent than they actually are. Kerzel's commentary focuses on an implementation level and ignores other levels, whereas my review (in Part IV) focuses on a computational theory level and acknowledges multiple levels.

Internalized Physics

Kerzel (2006) notes in numerous places that displacement is not consistent with internalized physics, but this reiterates what has been known for years (e.g., Cooper & Munger, 1993; Freyd, 1987; Hubbard, 1995). The only reason to repeatedly raise this issue is if Kerzel thinks that my review claimed that internalized physics is the only mechanism of displacement. However, I stated that

> the empirical evidence is clear that (1) displacement does not always correspond to predictions based on physical principles and (2) variables unrelated to physical principles . . . can influence displacement. (Hubbard, 2005, p. 842)

And I stated that

> information based on a naive understanding of physical principles . . . appears to be just one of many types of information that could potentially contribute to the displacement of any given target. (Hubbard, 2005, p. 842)

Beliefs or expectations regarding physical principles do not *solely account for* displacement but can *contribute to* displacement. Kerzel suggests that effects previously attributed to internalized analogues of physical principles reflect modulation of smooth pursuit movements induced by the display. However, given his statement elsewhere that "smooth pursuit eye movements are always predictive in nature and prediction is a high-level process" (p. 168). It is possible that high-level information regarding physical principles could contribute to displacement by influencing eye movements. If eye movements modulate or mediate the effects of such information on displacement, disrupting normal eye movement behavior would disrupt the effects of that information.

Goodness of Perceived Motion

Kerzel (2006) suggests that displacement "depends solely on the goodness of the perceived motion" (p. 169) and that larger displacement occurred with faster velocities in Freyd and Finke (1985) because smaller interstimulus intervals (ISIs) with faster velocities in that study improved goodness of perceived motion. Smooth motion targets have shorter ISIs than do implied motion targets; this predicts that smooth motion should produce larger forward displacement than does implied motion.[1] However, Kerzel elsewhere suggests that "forward displacement occurs only with apparent motion" (p. 170). Apparent motion is stronger with implied motion than with smooth motion; this predicts that implied motion should result in larger forward displacement than does smooth motion. Kerzel (2003b) reported that implied motion resulted in larger forward displacement than did smooth motion, but this conflicts with his explanation of Freyd and Finke's (1985) data. Also, how can forward displacement depend solely on goodness of perceived motion if forward displacement is evoked by a single stationary frozen-action photograph? Goodness of perceived motion might be sufficient for displacement, but it is not necessary; therefore, displacement does not depend solely on goodness of perceived motion.

Flashed Objects and Moving Objects

Kerzel (2006) suggests that "although most of the studies of perception time have been concerned with the localization of flashes, the concept may easily be applied to the localization of the endpoint of a moving target" (p. 167). This generalization is not easy or appropriate. Observers judging endpoints of moving targets have information regarding the previous (and expected) trajectory, and that information clearly influences displacement. Such information does not exist for flashed objects, and so judgments of the positions of flashed objects are not informationally equivalent to judgments of the final positions of moving targets. Furthermore, generalization from flashed objects to moving objects is not consistent with Kerzel's claims that smooth pursuit eye movements (with smooth motion) or apparent motion (with implied motion) are necessary for displacement in moving targets, because such variables could not contribute to displacement of single flashed objects. Existence of the flash-lag effect (i.e., a briefly presented object aligned with a moving object is perceived to lag behind the moving object; Nijhawan, 2002) also suggests that the processing of the positions of flashed objects differs from the processing of the positions of moving targets.

Apparent Motion

Kerzel's (2006) speculations regarding links between representational momentum and apparent motion are intriguing but contain weaknesses. First, representational momentum occurs with stimuli that do not produce apparent motion (e.g., frozen-action photographs; Futterweit & Beilin, 1994). Second, apparent motion cannot account for displacement in directions other than the direction of target motion (e.g., O displacement; Hubbard & Bharucha, 1988). Third, Reed and Vinson's (1996) study manipulated typicality of motion by changing the verbal label associated with the target. Physical stimuli and motion were identical across trials; therefore, apparent motion was identical across trials and, so, could not account for differences in displacement across trials. Kerzel might argue that differences in apparent motion are a function of verbal label or that Reed and Vinson's stimuli resulted in long-range apparent motion, but such tactics require cognitive elements he seems determined to avoid. Fourth, hypothesized links between displacement and apparent motion depend on Kerzel's finding that implied motion results in larger forward displacement than does smooth motion, but other researchers have not found this pattern (e.g., Munger & Owens, 2004).

Oculomotor Overshoot

Kerzel (2006) claims that "the size of the oculomotor overshoot and the mislocalization of the endpoint are closely coupled" for smooth motion targets (p. 167). Although oculomotor overshoot and displacement might be coupled in the special case of tracking a smoothly moving visual target, oculomotor overshoot and displacement are uncoupled in other cases (e.g., with implied motion or frozen-action photographs). Indeed, the three-factor approach Kerzel proposes explicitly suggests that oculomotor overshoot and displacement are not necessarily coupled. If displacement is not necessarily coupled with oculomotor overshoot more generally, oculomotor overshoot might mediate or modulate forward displacement with smooth motion targets, and a third variable (e.g., high-level expectation) would be the ultimate cause of displacement with smooth motion targets. Indeed, "displacement = constant delay ∗ velocity" does not account for important aspects of forward displacement with smooth motion targets (e.g., differences between launched and unlaunched targets [Hubbard, Blessum, & Ruppel, 2001], effects of verbal cue validity [Hubbard, 1994]) unless a third variable, such as high-level expectation, influences eye movements.

Kerzel (2006) admits that "high-level factors such as expectations about the future trajectory of the target may influence smooth pursuit eye movements" (p. 167) and "smooth pursuit eye movements are always predictive in nature and prediction is a high-level process" (p. 168). If high-level factors are responsible for smooth pursuit eye movements that lead to displacement (smooth motion) and for displacement when smooth pursuit eye movements do not occur (implied motion), high-level factors are responsible for displacement in each case (and more generally). Why, then, claim that displacement with smooth motion is due to smooth pursuit eye movements and that displacement with implied motion is due to high-level factors (see also Kerzel, 2003a)? Why not acknowledge that high-level factors are causal of displacement more generally? Even if high-level factors are ultimately causal, oculomotor factors can still contribute to displacement. Along these lines, Kerzel mischaracterizes my position as suggesting that displacement occurs only after veridical perception; however, my approach allows top-down effects on perceptual representation in which high-level factors influence predictions that Kerzel admits influence smooth pursuit eye movements.

Kerzel (2006) claims that "any factor that will reduce eye velocity will also reduce displacement" (p. 167). Although consistent with smooth motion, this statement is too broad and implies that eye velocity in scanning frozen-action photographs or viewing implied motion is related to displacement. Kerzel also claims that "the possibility cannot be ruled out that the target is subjectively perceived beyond the physical disappearance point, due to visible persistence of the target" (p. 167). However, visual persistence of moving targets lasts approximately 60 msec after targets have vanished (Kerzel, 2000), whereas forward displacement typically increases during the first few hundred milliseconds after targets have vanished. If forward displacement is due to visual persistence, it should not continue to increase after visual persistence has faded. Visual persistence cannot account for displacement in frozen-action photographs or in a direction other than the direction of motion. In general, I am not convinced that it is appropriate to hypothesize multiple, highly specific accounts on the basis of different oculomotor factors to account for limited subsets of data (1) in the absence of acknowledgment of broader similarities in displacement across stimulus types, (2) without a common computational level theory, or (3) when cognitive explanations are more parsimonious.

Necessary and Sufficient Criteria

Kerzel's (2006) discussion of necessary and sufficient criteria for displacement ignores previous findings that implied motion does not evoke smooth pursuit eye movements and that frozen-action photographs do not evoke smooth pursuit eye movements or apparent motion. When all the data on displacement are considered, Kerzel's argument that the causal chain should be restricted to necessary and sufficient factors actually leads to the conclusion that smooth pursuit eye movements and apparent motion are not necessary for forward displacement more generally. However, the existent data are consistent with the notion that oculomotor overshoot might be sufficient for forward displacement. Also, an appeal to high-level processes does not necessarily lead to infinite regress, despite Kerzel's claim to the contrary. Indeed, Kerzel's admissions that "high-level factors such as expectations about the future trajectory of the target may influence smooth pursuit eye movements" (p. 167) and "smooth pursuit eye movements are always predictive in nature and prediction is a high-level process" (p. 168), noted earlier, suggest that high-level factors are necessary parts of the causal chain.

Auditory Representational Momentum

Kerzel (2006) claims that "a supramodal process should produce the same error patterns in different modalities" (p. 171), but this is incorrect. A supramodal process receives input from and sends output to modality-specific processes; to the extent to which information in modality-specific processes might differ, input to and output from a supramodal process might differ (e.g., location information within the auditory system is less likely to involve oculomotor information, whereas location information within the visual system is more likely to involve oculomotor information). Therefore, if location information was processed at a higher level or if top-down information influenced perceptual representation, modality-specific information from one modality would not necessarily influence displacement in a second modality (e.g., oculomotor information could influence visual displacement but would not influence auditory displacement).[2] Kerzel dismisses the importance of auditory representational momentum for his hypotheses because he does not accept that high-level information and top-down influences might be ultimately causal. However, there is ample evidence for high-level information and top-down influences in displacement.

Paradigm and Purpose

Kerzel (2006) claims that I present "two basic paradigms that have been used to investigate the localization of the final position of a moving target" (p. 166). He refers to the paradigms of Freyd and Finke (1984) and Hubbard and Bharucha (1988) introduced in Part I of my review, but in Part II, I went beyond those paradigms and discussed four methods of stimulus presentation and three types of response measure. Kerzel's commentary is based on information discussed in Part I and on his own data on response types, but Part IV of my review suggested that a theory of displacement should consider all the data from all the paradigms. However, even if consideration is limited to information in Part I, the commentary fails in its stated purpose of challenging my claim that "results from these studies converged on the idea that memory for the final position of a moving target was displaced forward in the direction of target motion," because Kerzel (1) did not provide arguments for or demonstrations of why Marr's (1982) framework is inappropriate or why different types of displacement should not be considered a single phenomenon at the level of computational theory and (2) did not consider the necessary breadth of the data. Also, my claim is consistent with displacement originating in perception or in memory, because either origin would be reflected in subsequent memory.

Final Thoughts

Several themes have emerged in this reply. First, my approach focuses primarily on a computational theory level, whereas Kerzel's commentary focuses on an implementation level. Both levels are important, but confusions occur if differences between levels are ignored. Second, and related to the first theme, I focus on broader high-level explanations encompassing wider ranges of data, whereas Kerzel focuses on narrower low-level mechanisms specific to different types of stimuli and responses. Third, and related to the second theme, I question the usefulness of developing multiple and incompatible explanations (e.g., oculomotor overshoot, apparent motion, visual persistence) that disregard a computational theory of displacement, whereas Kerzel prefers such approaches. From my perspective, Kerzel's explanations of displacement for different types of stimuli ignore data on displacement inconsistent with those explanations; from his perspective, explanations of displacement for a given type of stimulus can ignore data on displacement in other stimuli, because different mechanisms are involved for different stimuli.

Disagreements between Kerzel and myself involve primarily theory and interpretation (e.g., the breadth of the data relevant for a given account of displacement, what my position actually is), although we disagree on some methodological issues (e.g., Kerzel questions the usefulness of data for which eye movements were uncontrolled; I question the ecological validity of observers fixating away from a target whose location they know they will have to remember). Despite these disagreements, our positions are not as incompatible as Kerzel implies; my approach is compatible with different examples of displacement implemented in different structures or processes and with displacement occurring in perceptual representation (via top-down influences). I view different types of displacement as different examples of the same phenomenon and Marr's (1982) notions as providing unifying principles that place different types and mechanisms of displacement in a common framework. Even so, when all the variables that influence displacement are considered, it is clear that a complete account of displacement must have a cognitive component.

REFERENCES

Cooper, L. A., & Munger, M. P. (1993). Extrapolating and remembering positions along cognitive trajectories: Uses and limitations of analogies to physical motion. In N. Eilan, R. McCarthy, & B. Brewer (Eds.), *Spatial representation: Problems in philosophy and psychology* (pp. 112-131). Cambridge, MA: Blackwell.

Freyd, J. J. (1987). Dynamic mental representations. *Psychological Review*, **94**, 427-438.

Freyd, J. J., & Finke, R. A. (1984). Representational momentum. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **10**, 126-132.

Freyd, J. J., & Finke, R. A. (1985). A velocity effect for representational momentum. *Bulletin of the Psychonomic Society*, **23**, 443-446.

Futterweit, L. R., & Beilin, H. (1994). Recognition memory for movement in photographs: A developmental study. *Journal of Experimental Child Psychology*, **57**, 163-179.

Hubbard, T. L. (1994). Judged displacement: A modular process? *American Journal of Psychology*, **107**, 359-373.

Hubbard, T. L. (1995). Environmental invariants in the representation of motion: Implied dynamics and representational momentum, gravity, friction, and centripetal force. *Psychonomic Bulletin & Review*, **2**, 322-338.

Hubbard, T. L. (2005). Representational momentum and related displacements in spatial memory: A review of the findings. *Psychonomic Bulletin & Review*, **12**, 822-851.

Hubbard, T. L., & Bharucha, J. J. (1988). Judged displacement in apparent vertical and horizontal motion. *Perception & Psychophysics*, **44**, 211-221.

Hubbard, T. L., Blessum, J. A., & Ruppel, S. E. (2001). Representational momentum and Michotte's (1946/1963) "launching effect" paradigm. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **27**, 294-301.

Kerzel, D. (2000). Eye movements and visible persistence explain the mislocalization of the final position of a moving target. *Vision Research*, **40**, 3703-3715.

Kerzel, D. (2003a). Centripetal force draws the eyes, not memory of the target, toward the center. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **29**, 458-466.

Kerzel, D. (2003b). Mental extrapolation of target position is strongest with weak motion signals and motor responses. *Vision Research*, **43**, 2623-2635.

Kerzel, D. (2006). Why eye movements and perceptual factors have to be controlled in studies on "representational momentum." *Psychonomic Bulletin & Review*, **13**, 166-173.

Marr, D. (1982). *Vision*. New York: Freeman.

Munger, M. P., & Owens, T. R. (2004). Representational momentum and the flash-lag effect. *Visual Cognition*, **11**, 81-103.

Nijhawan, R. (2002). Neural delays, visual motion and flash-lag effect. *Trends in Cognitive Sciences*, **6**, 387-393.

Reed, C. L., & Vinson, N. G. (1996). Conceptual effects on representational momentum. *Journal of Experimental Psychology: Human Perception & Performance*, **22**, 839-850.

NOTES

1. Kerzel (2003b) examined effects of motion type by varying the stimulus onset asynchrony (SOA) between presentations of a target; he suggested that with brief SOAs (e.g., $<$30 msec), smooth motion occurred, and with longer SOAs (e.g., $>$500 msec), implied motion occurred. Given this, an extension of his claims regarding ISI (SOA minus target duration) to include smooth motion seems reasonable.

2. A supramodal displacement mechanism might use input from sensory structures when such information is normally available (e.g., eye movement information when a smoothly moving visual target is tracked), and when such input information is disrupted, displacement would be disrupted. Given this, it is not surprising that forward displacement is disrupted when observers are prevented from tracking smoothly moving visual targets.

(Manuscript received November 18, 2005;
revision accepted for publication January 30, 2006.)