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Short article

Spatial memory and explicit knowledge: An effect of instruction on representational momentum

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Freyd (1987; Finke & Freyd, 1985) suggested that representational momentum (i.e., forward displacement in memory for the location of a moving target) is impervious to error feedback (i.e., is modular or cognitively impenetrable), but studies supporting this claim might not have allowed sufficient opportunity for learning to occur. In the experiment reported here, participants were (a) naïve regarding representational momentum, (b) informed about representational momentum but not instructed to counteract it, or (c) informed about representational momentum and instructed to counteract it. All participants exhibited significant displacement. However, participants informed about representational momentum exhibited less forward displacement than did naïve participants due to a greater tendency to respond *same* to probes behind the true–same position. Possible mechanisms of compensation and the notion that displacement reflects both modular (cognitively impenetrable) and nonmodular (cognitively penetrable) components are addressed.

Keywords: Representational momentum; Displacement; Modularity; Cognitive penetrability; Naïve physics.

The world that we live in is a dynamic environment of constant change. As a consequence of the dynamic nature of the world, our representations of the environment and objects in that environment contain dynamic properties (Freyd, 1987). For example, when perceiving or remembering stimuli from our environment, we often have errors in our perception and memory that reflect a dynamic nature of representation that is based on our previous experience. Such errors often involve anticipations of a probable future state of the world, and rather than being disadvantageous, they are advantageous in that they provide accurate predictions about what is likely to be next encountered (e.g., Lashley, 1951). More generally, such anticipatory errors are likely due to previous experience with the environment and the modification of schemata via experience (Courtney, 2006; Neisser, 1976). One such anticipatory error involves distortion in memory for location in which a moving target is remembered as slightly farther along the anticipated trajectory (i.e., the representation of target location is displaced in the direction of target motion), and this is referred to as *representational momentum* (Freyd & Finke, 1984). Numerous studies have examined the

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extent to which an observer's knowledge, beliefs, or expectations regarding the target or the path of future target motion can influence this displacement (for review, see Hubbard, 2005). In this report, we examine whether providing observers with explicit knowledge of the existence of representational momentum can influence the displacement exhibited by those observers.

One type of knowledge or belief that influences displacement is concrete knowledge based on prior observation of the target. Displacement of a target expected to bounce off a barrier is in the direction of the anticipated bounce if that target vanishes at the moment it contacts the barrier (Hubbard & Bharucha, 1988). Similarly, if an observer expects a target to stop at or not go beyond a barrier, forward displacement is decreased as the target approaches that barrier (Hubbard & Motes, 2005). If observers view an oscillating visual target, forward displacement is greatly reduced if measured at the edge of an oscillatory period (Verfaillie & d'Ydewalle, 1991), and if observers hear an oscillating pitch pattern, forward displacement in auditory pitch is reversed if measured at the edge of the pattern's oscillatory period (Johnston & Jones, 2006). For both visual and auditory stimuli that exhibit changes of direction, the direction of displacement is in the direction of anticipated motion, even when the direction of anticipated motion differs from the direction of actual motion. Although it has been suggested that knowledge of this type must build up over multiple trials in which direction of motion or vanishing point is blocked (Kerzel, 2002), forward displacement can be found when direction of motion and vanishing points vary randomly across trials (e.g., Hubbard, 1990; Munger, Solberg, Horrocks, & Preston, 1999). Johnston and Jones (2006) also found evidence against Kerzel's claim regarding knowledge via randomizing stimuli within a session.

A second type of knowledge or belief that influences displacement is general or abstract knowledge about the general type of target or target motion. For example, the validity of verbal cues presented prior to target onset and that describe the (forthcoming) path of motion of the target influence displacement, and displacement is larger following presentation of a valid cue than following presentation of an invalid cue (Hubbard, 1994). Semantic information activated by general knowledge of the target type or category also influences displacement. In one example, forward displacement of an ascending target was influenced by the verbal label attached to that target, as memory for a triangular shape labelled "rocket" exhibited larger forward displacement than did memory for an identical triangular shape labelled "cathedral" (Reed & Vinson, 1996).[1] A third type of knowledge or belief that can influence representational momentum involves beliefs regarding the source of target motion. For example, if observers believe that the motion of a target resulted from an impetus imparted from another object that contacted that target, then displacement of that target is decreased relative to the displacement of a control target that was not contacted (Hubbard & Ruppel, 2002).

Even though an observer's consciously available information in the form of explicit knowledge, beliefs, or expectations regarding a target or target motion might influence displacement of that target, it is not the case that such explicit knowledge, beliefs, or expectations regarding a target always influence displacement of that target. Freyd and Jones (1994) presented observers with displays involving a ball passing through and exiting a spiral tube. Upon exiting the tube, the ball could follow a straight, curved, or spiral trajectory, and displacement for targets on each type of trajectory was measured. Observers also completed a questionnaire that assessed explicit knowledge about relevant physical principles and what the correct path of the ball upon exiting the spiral tube should be. Although the majority of observers indicated that the ball should travel a straight path (i.e., the majority of observers had correct explicit

[1] According to Amorim et al. (2000), semantic knowledge might also induce different cognitive sets (e.g., body imagery vs. pictorial imagery).

physical knowledge), displacement was largest along the spiral path. Kozhevnikov and Hegarty (2001) presented relatively small or relatively large ascending targets. Consideration of the correct physical principles suggests that larger objects should ascend faster, and although expert physicists indicated this on a subsequent questionnaire that assessed explicit physical knowledge, both expert physicists and physics novices produced larger displacement for smaller targets.

Given the dissociation between explicit knowledge of physical principles and displacement in Freyd and Jones (1994) and in Kozhevnikov and Hegarty (2001), the question of whether explicit knowledge of the existence of representational momentum would influence displacement is especially interesting. Surprisingly, this issue has received little investigation. In the only published study that examined effects of observers' knowledge of representational momentum on displacement, Finke and Freyd (1985) provided feedback ("correct" or "error") on practice trials, and they reported (a) no differences in displacement between practice trials (with feedback) and experimental trials (without feedback) and (b) no change in the magnitude of displacement across experimental trials. This pattern led Freyd (1987) to claim that representational momentum was impervious to error feedback (and cognitively impenetrable). However, feedback in Finke and Freyd's study was quite limited, and Joordens, Spalek, Razmy, and van Duijn (2004) speculated that the amount and specificity of feedback in Finke and Freyd's study were insufficient to allow explicit learning. The goal of the current study was to examine whether providing observers with explicit knowledge of the existence of representational momentum could influence displacement.

Method

There were three groups of observers. The first group (uninformed condition) was told that the experiment was about memory. The second group (informed condition) was told that the experiment was about memory and was also informed about the existence of representational momentum. The third group (counteract condition) was told that the experiment was about memory, was informed about the existence of representational momentum, and was also instructed to compensate for representational momentum in their responses. If forward displacement can be influenced by explicit knowledge about representational momentum, then observers who are informed about representational momentum should exhibit smaller forward displacement than do observers who are not informed about representational momentum. If forward displacement is not influenced by explicit knowledge about representational momentum, and the magnitude of forward displacement is thus not influenced by group, then Freyd's (1987) claim that representational momentum is impervious to error feedback would be supported.

Participants

The observers were 47 undergraduates from Texas Christian University who participated for partial course credit and were naive to the hypotheses. Observers were randomly assigned to the uninformed ($n = 16$), informed ($n = 16$), or counteract ($n = 15$) group.

Apparatus

The stimuli were displayed and the data collected on an Apple iMac desktop computer equipped with a 15-inch colour monitor and with True Basic Silver software (Kurtz, 1999).

Stimuli

The moving targets and probes were filled black squares 20 pixels (approximately 0.83 degrees of visual angle) in width and were presented on a white background. In order to minimize any potential contributions of smooth pursuit eye movements to any potential displacement, implied target motion was used. On each trial, there were five successive presentations of the target that implied either consistent rightward or consistent leftward motion of the target, and, consistent with the previous literature, these are referred to as *inducing stimuli*. Each inducing stimulus was presented for 250 ms, and there was a 250-ms interstimulus interval (ISI) between successive inducing stimuli. In trials with rightward motion, the first inducing stimulus appeared approximately midway between the left side and the centre of the display, and the horizontal coordinates of each successive inducing stimulus were located 40 pixels (approximately 1.66 degrees of visual angle) to the right of the previous inducing stimulus. In trials with leftward motion, the first inducing stimulus appeared approximately midway between the right side and the centre of the display, and the horizontal coordinates of each successive inducing stimulus were located 40 pixels to the left of the previous inducing stimulus. The vertical coordinates of the inducing stimuli were approximately centred along the vertical axis. The probe appeared at one of seven horizontal positions relative to the previous location of the final inducing stimulus: −9, −6, −3, 0, +3, +6, or +9 pixels. Positions denoted by a minus sign indicated the probe was backward (i.e., shifted in the direction opposite to motion of the moving target) from the previous location of the final inducing stimulus by the indicated number of pixels, and positions denoted by a plus sign indicated the probe was forward (i.e., shifted in the direction of motion of the moving target) from the previous location of the final inducing stimulus by the indicated number of pixels; the zero position was the same as the previous location of the final inducing stimulus. Each observer received 84 trials—7 (probes: −9, −6, −3, 0, +3, +6, +9) × 2 (directions: leftward, rightward) × 6 (replications)—in a different random order.

Procedure

In the uninformed group, observers were told only that they were participating in a memory experiment. In the informed group, observers were told that they were participating in a memory experiment, and representational momentum was introduced and defined as follows:

> We are studying an effect known as representational momentum. In this effect, when a square moves across a computer screen and then disappears, people remember the position of the square being further along the path of motion than it actually was when it disappeared.

In the counteract group, observers were given the same definition of representational momentum and were also given the added following instruction:

> We would like for you to try and counteract this effect.

Participants were not given instruction regarding how they should counteract the effect as strategy taking was not a motivation for the current study. In both informed and counteract groups, observers were asked whether they had previously heard of representational momentum and also if they understood what representational momentum was following the description. All participants confirmed that they understood the description of representational momentum. Two observers previously familiar with the representational momentum effect were given an alternative activity for course credit.

Before beginning the experimental trials, observers were given a practice session consisting of eight trials randomly drawn from the experimental trials. Observers initiated each trial by pressing a designated key. The inducing stimuli were presented, and after a 250-ms retention interval, the probe was presented. The retention interval between the disappearance of the final inducing stimulus and the appearance of the probe was 250 ms. After the probe appeared, it remained visible until observers pressed a key marked *S* or a key marked *D* to indicate whether the location of the probe was the same as or different from the previous location of the final inducing stimulus. Observers then initiated the next trial.

Results

The probability of a *same* response as a function of probe position is shown in Figure 1. If observers responded accurately, there would be 0% *same* responses for −9, −6, −3, +3, +6, and +9 probe positions and 100% *same* responses for the 0 probe position. Consistent with previous literature, weighted mean estimates of displacement (i.e., the sum of the products of the proportion of *same* responses and the distance of the probe from the location of the final inducing stimulus,

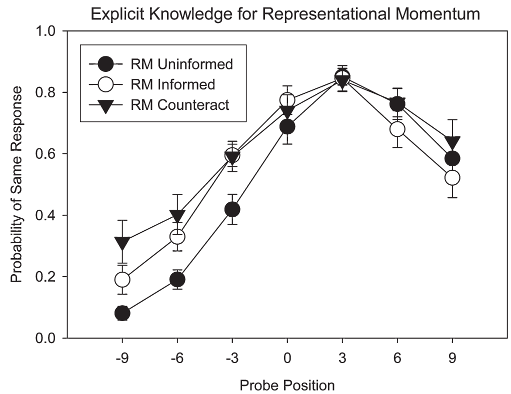

Figure 1. *Probability of* same *response in pixels plotted as a function of probe position for each instruction group. Error bars are standard errors of the mean.*

in pixels, divided by the sum of the proportions of *same* responses) were calculated for each observer. The sign of the weighted mean indicates the direction of displacement (i.e., a minus sign indicates displacement in the direction opposite to the motion of the moving target, and a plus sign indicates displacement in the direction of motion of the moving target), and the absolute value of the weighted mean indicates the magnitude of displacement (i.e., larger absolute values indicate larger magnitudes of displacement).

A *t* test comparing the weighted means of each group to zero indicated that a significant forward displacement occurred in the uninformed ($M = 2.65$), $t(15) = 9.84$, $p < .001$, informed ($M = 1.53$), $t(15) = 5.09$, $p < .001$, and counteract ($M = 1.46$), $t(14) = 3.65$, $p < .01$, groups. Thus, all groups exhibited significant representational momentum. A one-way analysis of variance (ANOVA) conducted on group (via weighted means) was significant, $F(2, 44) = 4.31$, $p < .02$, and Tukey's HSD ($p < .05$) revealed that a larger magnitude of displacement was found in the uninformed group than in the informed and counteract groups, and there was no difference evident between informed and counteract groups. As shown in Figure 1, the differences in displacement between the uninformed group and the informed and counteract groups arises from an increased likelihood of observers in the informed group or the counteract group to respond *same* to probes behind the true–same position.

Discussion

Providing observers with explicit information regarding the existence of representational momentum decreased forward displacement, and this result suggests that displacement can be influenced by explicit knowledge regarding representational momentum. This finding appears inconsistent with Freyd's (1987; Finke & Freyd, 1985) claim that representational momentum is impervious to error feedback, but consistent with Joordens et al.'s (2004) suggestion that the feedback condition in Finke and Freyd (1985) was insufficient for explicit learning to have occurred. However, providing observers with explicit information regarding the existence of representational momentum did not entirely eliminate representational momentum, as all groups of observers exhibited significant forward displacement. A significant forward displacement occurred even when participants were explicitly instructed to counteract forward displacement. Thus, explicit knowledge of the existence of representational momentum can decrease, but not eliminate, representational momentum.

Whether the decrease in forward displacement shown by observers informed about representational momentum reflected a deliberate strategy or an automatic process is not clear. One hypothesis is that knowledge of representational momentum created a response bias such that observers deliberately responded *same* to probes that appeared to be earlier in the motion sequence relative to final target location. This pattern is consistent with the larger probability of a *same* response for negative probes by observers in the informed and counteract groups. A second hypothesis is that observers informed about representational momentum attended more selectively to the target's location, and this increased attention reduced displacement (cf. Hayes & Freyd, 2002). A third hypothesis is that explicit information regarding representational momentum increased the strength or saliency of cognitive resistance (cf. Finke, Freyd, & Shyi, 1986) or some other compensation mechanism (cf. Joordens et al., 2004) that operates in the direction opposite to representational momentum. Investigation of the precise mechanism(s) of this decrease in displacement awaits further research.

Differences in displacement in the uninformed group from displacement in the informed and counteract groups, in conjunction with the presence of forward displacement in all groups, suggests that two different mechanisms contribute to displacement. One mechanism is modular (i.e., cognitively impenetrable) and not influenced by expectations, knowledge, or beliefs, and the other mechanism is nonmodular (i.e., cognitively penetrable) and influenced by knowledge, beliefs, and expectations regarding the target; the resultant displacement reflects a combination of these mechanisms. Such a two-process theory is consistent with Hubbard's (2006) suggestion that displacement reflects two levels: an automatic extrapolation consistent with physical principles, which provides a default displacement in the absence of other information, and a more cognitive component that modifies that default on the basis of additional knowledge, beliefs, or expectations. A similar two-process approach was suggested by Finke and Freyd (1989) in their analogy involving displacement and a moving train: Displacement (i.e., motion along a track) had to occur, but the direction of displacement could be influenced by other information (e.g., switching tracks).

Observers given explicit knowledge of representational momentum exhibited less forward displacement than did naive observers; however, explicit knowledge of representational momentum did not eliminate forward displacement. This pattern suggests that displacement is composed of both cognitively penetrable (perhaps top-down or high-level) and cognitively impenetrable (perhaps bottom-up or low-level) components. The data reported here are consistent with Hubbard's (2005) conclusions that (a) both modular and nonmodular processes might contribute to displacement, and (b) displacement reflects at least some high-level processes. Regardless of the mechanism that leads to decreased displacement in observers informed about representational momentum, the finding that explicit knowledge of representational momentum influences displacement challenges the long accepted belief that representational momentum is impervious to such effects. Future studies of representational momentum should explicitly consider instructional set, as well as other sources of expectations regarding the target, as potential contributors to a mechanism for displacement.

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