ERROR FEEDBACK AND REPRESENTATIONAL MOMENTUM

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

There are inaccuracies in the judgment of the final location of a moving target. One such inaccuracy is *Representational Momentum*, in which the perceiver judges the final location of a stimulus to be further ahead in the path of the anticipated motion than that stimulus actually is. In the literature on representational momentum, experiments examining the influence of learning on representational momentum have shown mixed results; although some evidence suggests that representational momentum is impermeable to feedback information (Finke & Freyd, 1985), participants who receive information about representational momentum before an experiment exhibit less representational momentum (Courtney & Hubbard, in press). One way to clarify the difference and investigate the role of learning would be to attempt to train participants to be more accurate in their judgements of the final position of a moving target. This might be done by providing feedback to participants regarding their judgements.

Representational Momentum

When observers are asked to indicate the final position of a moving target, they tend to indicate a position slightly forward, i.e. displaced in the direction of the anticipated motion. Freyd and Finke (1984) termed this displacement *representational momentum* and attributed it to the implied momentum of the target. However, variables other than implied momentum influence the magnitude of this forward displacement (for review, Hubbard 2005), and so Hubbard (1995, 2005) suggested that the term "representational momentum" should be used only to refer to that component of forward displacement attributable to implied momentum of the target, reflecting a forward shift in the direction of the anticipated motion.

Rather than momentum per se, the displacement in the final position of the moving target reflects an anticipation of where a target will be when an immediate response from the observer could reach that target. This can be seen most clearly in instances when a person attempts to intercept a moving target. As shown in Figure 1, when an individual initially sensing a moving target in location (a) would immediately trigger a sequence of perceptual, cognitive and perhaps motor processes. These neural processes are rapid, but are not instantaneous. The object continues to move while the neural processes are occurring and hence, by the time the individual is able to reach it, the object would have travelled a further distance at location (b). If the observer is to successfully intercept the object, the response should be tailored to where that target will be at that moment when a response would reach it and not to where that target was when it was initially sensed. Thus, the tendency to extrapolate an object's motion beyond the final observed position may helps to predict the future position of that object despite an inability to maintain a constant eye contact with it (Freyd & Johnson, 1987). Representational momentum, by adjusting the representation of the target to reflect where the target would be in the very near future, bridges the gap between the initial perceived position and the subsequent action position (Hubbard, 2006).

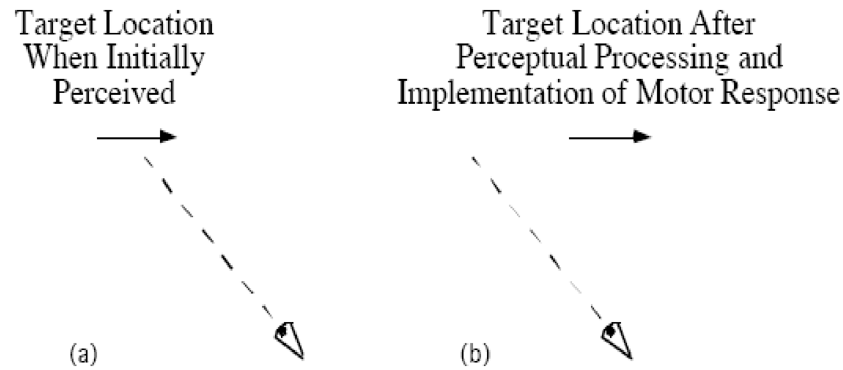

Figure 1. An illustration of the importance of displacement. In panel (a) a moving target is initially sensed, and perceptual and cognitive processes begin. During this time the target continues to move. In panel (b), the initial perceptual and cognitive processing is complete but the target is no longer at the location where it was initially perceived. In order for a response such a catching, hitting and blocking to be maximally effective, an observer must compensate for the movement of the target during the time when the perceptual process was initiated and when the processing is completed and a motor response initiated, that is, an observer must bridge the gap between perception and action. This bridging of gap might be accomplished by representational momentum and related types of displacements (Adapted from Hubbard, 2005).

Although representational momentum might help bridge the gap between perception and action, once a response has reached the target, there is no need for the representation of the target to remain displaced. Indeed, a longer lasting displacement could be maladaptive if it led to a permanent distortion of information regarding the target in memory. It might be most useful if the displacement exists only during the brief time in which there would be an immediate response, and then decreased before that distorted information could be encoded into long term storage. The findings of

Freyd and Johnson (1987) that the magnitude of representational momentum declines after a few hundred milliseconds are consistent with this idea.

There are several theories that purport to explain representational momentum (reviewed in Hubbard, in press). These range from low level perceptual mechanisms (e.g., motion afterefftects, Bertamini, 2002; occulomotor behaviour, Kerzel, 2001) to high level cognitive mechanisms (e.g., internalisation of the effects of momentum, Finke et al., 1986; second-order isomorphism, Hubbard, 2006). In explanations based on low-level mechanisms, the localization error may not result exclusively from a process operating in memory but from perceptual processes as well. In such an account, the control of eye movements and a foveal localization bias can contribute to the displacement. Other low level accounts suggest representational momentum is suggested to result from motion aftereffects and perceptual adaptation (Bertamini, 2002) or visual persistence (Kerzel, 2000). However, a recent review of empirical findings on representational momentum concluded that although low-level factors can contribute to or modulate representational momentum, they do not cause it (Hubbard, 2005).

In explanations based on high-level mechanisms, the localization error results mainly from cognitive factors (e.g., see Hubbard, 1994, 1995; Reed & Vinson, 1996). Real world experience and knowledge have an influence on representational momentum. For example, when labels such as “rocket” or a “steeple” were used to refer to stimuli which were identical in appearance and movement, memory for stimuli labelled as “rocket” exhibited larger forward displacement than did memory for stimuli labelled as “steeple”. This is consistent with the typical motions of rockets, which tend to go up, and steeples, which tend not to move at all. These effects were consistent with the real-world typical motions associated with the various stimuli presented (Reed & Vinson, 1996). Other instances of cognitive influences which can influence the direction and magnitude of memory shift are the beliefs concerning the future behavior (Hubbard, 1994; Johnston & Jones, 2006) and attributions regarding the source of the target motion (Hubbard & Favretto, 2003; Hubbard & Ruppel, 2002).

Data consistent with high-level explanations suggest that knowledge regarding the target can influence displacement. This raises the question whether representational momentum is influenced by learning? For instance, most people can cross a road without colliding into an approaching vehicle. This non-collision can reinforce such a mistaken belief that the approaching vehicle was further ahead in the direction of the anticipated motion (Gray & Thornton, 2001). Indeed, reinforcement in the form of feedback has significant effects on visual information processing (e.g., feedback can bias the categorization of perceptual stimuli, Spratling et al., 2006). On this basis, it is contended that if a reinforcing stimulus is given to an individual immediately after the completion of a perceptual act, the probability of that perceptual act occurring again in the presence of the perceptual stimulus will be altered. In this instance, the non-collision with an approaching object would be the reinforcement, which rewards the underestimation in the time to collision.

Learning

Domjan (2003) defined *learning* as an enduring change in mechanisms of behavior involving specific stimuli and/or responses that result from prior experience with those or similar stimuli and responses. One mechanism of learning is *operant* *conditioning*. This is when the relative frequency of a response increases as a result of reward or reinforcement that is contingent on the response being emitted (Colman, 2001). Following the presentation of a stimulus, if a satisfying event follows a subsequent response, it strengthens the association between the stimulus (S) and the response (R) is strengthened. On the other hand, if an annoying event follows the response, it weakens association between the stimulus (S) and response (R) is weakened. This was seen in experiments in which participants estimated the relative lengths of stripes or drew lines of given lengths while blindfolded and were told after each response whether it was right or wrong. The results indicated a considerable gain in accuracy for subjects who had received the feedback relative to control subjects who had not received feedback (Thorndike, 1927).

Discussion on feedback must also consider the source of information. Feedback for an organism can be from internal sources (e.g. interoceptive information) and from external sources (e.g. environment). In motor learning, defined as augmented feedback, knowledge of results is in addition to the sources of feedback which are naturally received in which there is a response (Salmoni, 1984). Feedback can be in the form of correct feedback, where the participant is told when he or she made a correct judgment. Also, feedback can be in the form of error feedback, in which the participant is told when he or she had made an incorrect judgment. Although the research comparing error feedback and correct feedback is limited, there is indication that knowledge of results based on error feedback in performance can be superior to that attained with correct feedback (Williams & Briggs, 1962). However, there appears to be a limitation in the study. For participants receiving error feedback, the later stages of the training session resembled the retention test. However, for participants receiving correct feedback, the later stages of the training session resembled the testing session the least. In a recent study on representational momentum, participants who received feedback during training situation and no feedback during testing were less likely to respond “same” than participants who did not receive feedback in training and testing (Ruppel, Fleming & Hubbard, in press). However, there was no difference in feedback per se.

In experiments on representational momentum, the participants typically judge if a subsequently presented probe was in a location different from that of the final location of the inducing stimulus. These responses are essentially stimulus discrimination judgments. Thus, an organism is said to exhibit stimulus discrimination if it responds differently to two or more stimuli, or rather, makes a response in the presence of a stimulus and not in the absence of that stimulus. More importantly, a participant would exhibit good stimulus discrimination when a probe in the same location as that of the final inducing stimulus is judged as “same”, and a probe in a different location from the final inducing stimulus is judged as “different”. The probe in the same location as the final inducing stimulus, and probes in a different location from the final inducing stimulus, differ in only one dimension (i.e., the horizontal location of the probes). They are identical in all other respects.

Experiments in representational momentum are typically intra-dimensional discrimination. Experiments involving intra-dimensional discrimination have sharp generalization gradients (Mazur, 1998; Switalski et al., 1966; Tomie et al., 1975). For example, Jenkins and Harrison (1962) trained pigeons to discriminate a 1000-Hz tone, which was the S+ (a discriminative stimulus for reinforcement). A 950Hz tone was the

S- (a discriminative stimulus for the absence of reinforcement). In a subsequent extinction test, these pigeons produced a very narrow generalization gradient (Figure 2). There was little response to tones of 950Hz or lower frequency, a sharp increase in response to tones in the vicinity of 1000Hz, and little response to tones above 1100Hz. These results suggest that generalization gradients are dependent on experience.

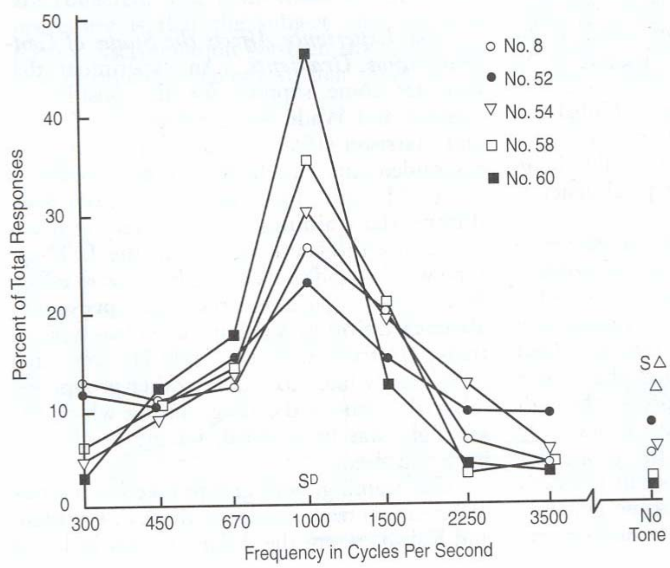

Figure 2. Intra-dimensional discrimination. Generalization gradient for the tone frequency in Jenkins and Harrison (1960) experiments after presence-absence training with a 100-Hz tone.

However, unlike the symmetry and sharp generalisation gradients for S- stimulus seen in Jenkins and Harrison (1962) study, experiments in representational momentum show an asymmetry and broad generalization gradient for probe positions ahead of the final inducing stimulus. The asymmetry in generalization gradients was also present when participants were provided feedback for their judgments (Ruppel et al., in press). Thus, participants generalize the final location of a moving target, ahead in the direction of the anticipated motion.

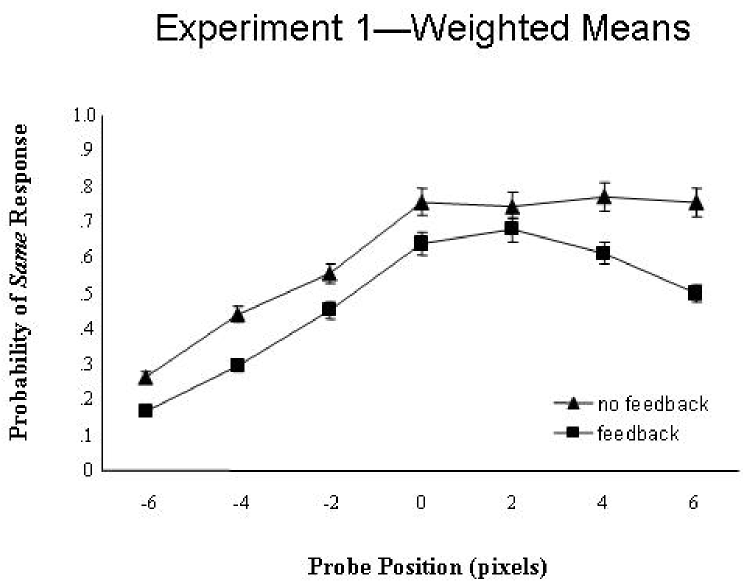

Figure 3. Generalization gradients in Representational momentum. Probability of "same" response as a function of distance of probe from the final inducing stimulus (Ruppel et al, in press).

Representational Momentum and Learning

Research examining representational momentum from a learning perspective has been limited. In an initial study, Finke and Freyd (1985) provided feedback during practice trials. In these experiments, feedback was in the form of the word "error" or "correct" shown after the participants had responded. Feedback can be viewed as a form of reinforcement to a response (Annett, 1969). Thus, a feedback of "correct" would be a "reward" and a feedback of "incorrect" would be a "punishment". Finke and

Freyd provided the feedback only during a small number of practice trials and not during experimental trials. Feedback provided during practice trials did not reduce representational momentum, and there were no differences between the displacement in the practice trials and the displacement in the experimental trials. Also, Freyd and Finke (1985) did not directly compare feedback with no-feedback conditions to truly assess the effects of feedback (Joordens, Spalek, Razmy, & Duijn, 2004).

Courtney and Hubbard (in press) found a difference in displacement between participants who were informed about representational momentum prior to the experimental trials and participants who were not informed about representational momentum prior to the experimental trials. There were three groups of participants: informed, informed plus compensate, and naïve. Prior to conducting the experiments, the "informed" group was told about the effects of representational momentum. The "informed plus compensate" group was told about the effects of representational momentum and also asked them to compensate for it. The "naïve" group was not told about representational momentum. Forward displacement in the "informed" and "compensate" groups was smaller than was forward displacement in the naïve group. However, a significant forward displacement occurred in all groups, even when the authors explicitly instructed the participants to counteract forward displacement. Thus, explicit knowledge of the existence of representational momentum can decrease, but not eliminates representational momentum.

The results of Courtney and Hubbard (in press) are consistent with results of experiments in the field of motor learning, in which the provision of knowledge about the general principles or rules that govern performance has an impact on learning. For example, Judd (1908, as cited in Chamberlin & Lee, 1993) had subjects throw darts at submerged targets. One group was provided knowledge of the principle of refraction, while a second group was not. Although no data were reported, an advantage was claimed for the group receiving light-refraction instruction, but this advantage occurred only when transferred to a target of different length. Holding (1965) concluded that knowledge of general principles is effective only if the principle affecting performance is simple and directly applicable to the skill being performed (as cited in Chamberlin & Lee, 1993). Also, reduced representational momentum in the informed plus compensate groups in Courtney and Hubbard (in press) would have established a standard of performance. This standard before action brings a reference of correctness and a matching reference with intrinsic feedback during a trial (Schmidt, 1982, as cited in Salmoni, Schmidt, & Walter, 1984). Thus, participants know what to expect before a trial.

Joordens et al. (2004) criticised the relatively uninformative nature of the feedback in the experiment by Finke and Freyd (1985), and they suggested that it would have been difficult for the participants to use any information provided by the feedback without knowing the direction of the error. To address these criticisms, Ruppel et al. (in press) conducted a series of experiments to examine the role of feedback in representational momentum. Ruppel et al. (in press) presented binary feedback ("correct", "error") during practice trials and also during larger blocks of experimental trials. Feedback did not in general reduce representational momentum, nor did the presence of more informative feedback specifying the direction of error ("error–in front of", "error–behind") during the experimental trials generally reduce representational momentum. However, representational momentum was smallest when feedback was consistently provided or consistently absent across two blocks of trials, and was larger when feedback was presented in one block of trials and absent in a second block.

The better performance (i.e., smaller displacement) in the feedback-consistent conditions is consistent with other context-dependent effects such as encoding specificity. In encoding specificity, recall of a stimulus is maximized if the cues that were present at the time of recall matched with the cues that were present at the time of learning (Santa & Lamwers, 1974). The presence or absence of feedback in both the training and testing would have created a similarity of cues in both situations. Thus, if feedback is considered as a cue which enhances learning during the training trials, its absence during the test of retention would have interfered with performance.

For procedures involving experiments on representational momentum, (Finke & Freyd, 1985; Courtney & Hubbard, in press; Ruppel et al., in press), participants have to indicate if a probe is in the "same" location as the final inducing stimulus. Probes are presented in either the same location or else a different location (few pixels ahead or behind). As seen in Figure 4, the probability of "same" response for probe positions is greater for probes ahead than for probes behind.

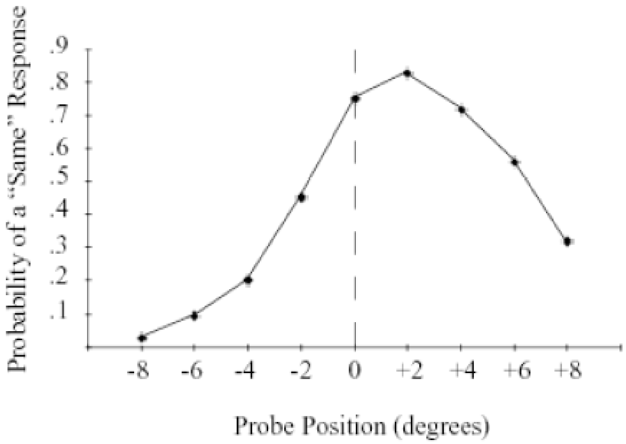

Figure 4. Representational Momentum based on probability of "same" response. Probability of "same" response as a function of probe orientation relative to the final inducing stimulus. The dashed line is the "same" orientation of the final inducing stimulus, negative probes were backward from the final inducing stimulus and positive probes were forward from the final inducing stimulus. Representational Momentum is indicated by the higher probability of "same" response for the positive probes (Adapted from Hubbard, 2005).

Indicating "same" for a probe in locations different from the final inducing stimulus is as an error in judgment. As shown in Figure 5, the responses of the participants can also be calculated as percentage correct. Thus, probe positions ahead of the same location would be judged correctly less often than probe positions behind the "true same". It is proposed that one way of correcting this error would be to provide feedback to participants for their responses. Feedback provides an opportunity to a participant to learn the error in judgement.

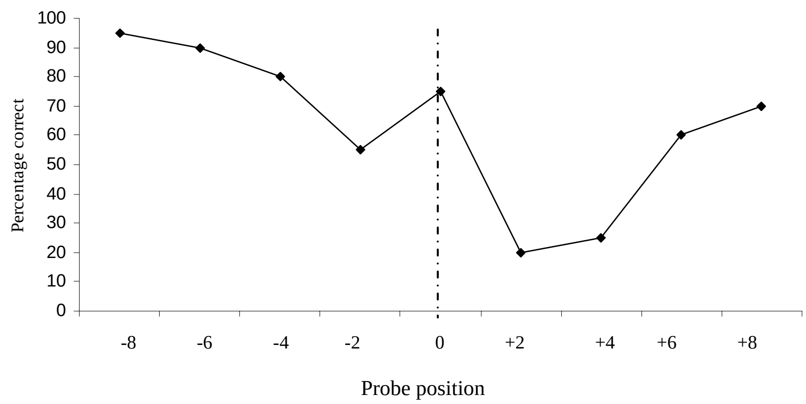

Figure 5. Representational Momentum reinterpreted as percentage correct. Percentage correct as a function of probe orientation relative to the final inducing stimulus. The dashed line is the "same" orientation of the final inducing stimulus, negative probes were backward from the final inducing stimulus and positive probes were forward from the final inducing stimulus. Representational Momentum is indicated by the lower percentage correct for the positive probes.

Overview of Experiments

The objective of the study reported here was to examine the effect of error feedback on representational momentum. In Experiment 1, participants were assigned to two conditions: feedback present vs. feedback absent. Participants in each of these conditions were assigned to six groups. These groups were based on the distance of the probe from the point of disappearance of the target and each participant viewed only one probe distance. Half the participants saw a probe ahead of the point of disappearance of the target and the remaining saw a probe behind it. Performance of the participants was examined across 10 blocks of 20 trials each. In Experiment 2, participants were presented probes at all the above distances. It is hypothesised that if representational momentum can be modified by learning, and if feedback offers sufficient information to allow learning, then it could be predicted that the responses of participants in the feedback present condition will differ from the responses of participants in the feedback absent condition. Alternatively, if representational momentum cannot be modified by learning, or if feedback does not offer sufficient information to alter learning, then it could be predicted that the responses of participants in the feedback present condition will not differ from the responses of participants in the feedback absent condition.

Experiment 1

Method

Participants. The participants were 132 undergraduate students who had participated for partial course credit from Texas Christian University. None of them were familiar with the hypotheses under investigation.

Apparatus. The stimuli were displayed upon and the data collected on a Macintosh microcomputer equipped with a 15 inch color monitor.

Stimuli. As shown in Figure 6, the moving target was a black square 20 pixels in width and 20 pixels in length, and the target was presented on a white background. On each trial, there were five successive presentations of the target that implied either consistent rightward or leftward motion of the target. Consistent with previous literature on representational momentum**,** these are referred to as *inducing stimuli*. Each inducing stimulus was presented for 250 milliseconds, and there was a 250 millisecond inter-stimulus interval between successive inducing stimuli. For rightward motion, the first inducing stimulus appeared approximately midway between the left side and the center of the display, and the horizontal coordinates of each successive inducing stimulus was located 40 pixels (approximately 1.66 degrees of visual angle) to the right of the previous inducing stimulus. For leftward motion, the first inducing stimulus appeared approximately midway between the right side and the center 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 location of first inducing stimulus varied across trials, and this was to prevent participants from learning a specific location for the disappearance of the final inducing stimulus. The vertical coordinate of the inducing stimuli was approximately centered along the vertical axis.

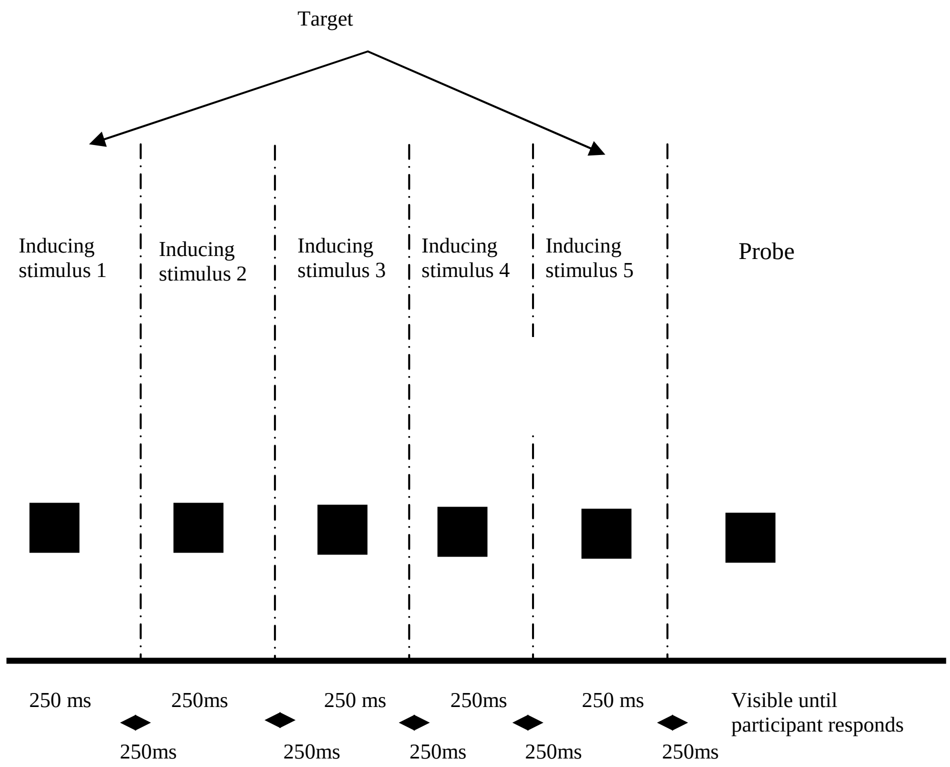

Figure 6. A schematic presentation of trial structure in Experiment 1 and 2.

A probe of the same size, shape and colour as the inducing stimuli was presented at the same vertical coordinates as the target. On half the trials, the probe was located at the same horizontal location as the final inducing stimulus and these were referred to as the “same probes”. On the other half of the trials, the probe was located at a different horizontal location from the final inducing stimulus, and these were referred to as the “different probes”. The different probes were located ± 12, ± 8 or ± 4 pixels away from the final inducing stimulus, depending on the experimental group the participants were in. Probes denoted by a minus sign were shifted away from the final inducing stimulus by the indicated number of pixels in the direction opposite to the motion of the target. Probes denoted by a plus sign were shifted away from the final inducing stimulus by the indicated number of pixels in the direction of the motion of the target.

Half of the participants received feedback for incorrect judgements. An incorrect judgement occurred when a participant indicated that a different probe was in the “same” location as the final inducing stimulus. Another type of incorrect judgment occurred when the participant indicated a same probe was in a “different” location from the final inducing stimulus. The feedback was presented as an “Error” message on the top right hand corner of the screen. This message remained until the participant initiated the next trial. There was no feedback for correct judgments. The other half of the participants did not receive feedback.

Each participant received 200 trials. There were 10 blocks of 20 trials each. In each block, there were 2 directions (leftward, rightward), 5 starting locations of inducing stimulus and 2 probes (same, different).

Design and Procedure. As shown in Table 1, participants were assigned to two experimental conditions, based on *feedback*. In one condition, participants received feedback, whereas in the other condition, participants did not receive feedback. Each condition was further divided into 6 groups. Each group was based on the *distance* of the different probe, for that group, from the final inducing stimulus. Thus, there were a total of 12 cells. Within each cell, participants were presented two kinds of *probes*. The first kind was the same probe and the second kind was the different probe.

Table 1

Assignment of participants to different experimental conditions

Feedback present					
Distance of probes (pixels) presented to participants in different groups					
-12 / 0 *n=11*	- 8 / 0 *n=11*	- 4 / 0 *n=11*	+ 4 / 0 *n=11*	+ 8 / 0 *n=11*	+ 12 / 0 *n=11*
Feedback absent					
Distance of probes (pixels) presented to participants in different groups					
- 12 / 0 *n=11*	- 8 / 0 *n=11*	- 4 / 0 *n=11*	+ 4 / 0 *n=11*	+ 8 / 0 *n=11*	+ 12 / 0 *n=11*

The probes were presented for targets that moved from the left to right and for the right to left *direction*. Each participant went through a *block* of 20 trials. The order of presentation of probes within a block was randomized. Participants went through 10 blocks of 20 trials each. The design of the experiment is shown in Table 2. The table illustrates the between and within subjects variables. Table 2 specifically illustrates the experimental condition of a participant in the - 12 / 0 distance, group, in the feedback present condition, in the first block of trials.

Table 2

Design of Experiment 1

<table>
<tr><td colspan="5"></td><td colspan="13">Within subjects variables</td></tr>
<tr><td rowspan="19">Between subjects variables</td><td rowspan="19">Feedback</td><td rowspan="12">Present</td><td rowspan="19">Distance</td><td rowspan="6">-12 / 0</td><td colspan="13">Block</td></tr>
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</table>

*Names of the variables are in italics.

* The table elaborates the variables for participants in the -12 / 0 distance group, during the first block of trials, in the feedback present condition. Similar elaboration can be assumed for participants in the remaining conditions, groups and blocks.

A participant first went though a practice session consisting of 10 trials that were randomly drawn from the experimental trials for that participant's group. Participants initiated each trial by pressing a designated key. The inducing stimuli were presented, and the retention interval between the disappearance of the final inducing stimulus and the subsequent appearance of the probe was 250 milliseconds. Participants were to indicate whether the probe was in the "same" (S) or in a "different" (D) location from the final inducing stimulus, by pressing keys marked as *S* and *D*, respectively.

The dependent variables in this experiment were (a) the consolidated probability of each probe position being chosen as "same", (b) consolidated percentage correct for each probe position, and (c) percentage correct for each probe position according to the corresponding block. (Interested reader may contact the author for further information on the computer programs used to implement the stimuli and collect responses).

Results

Participants judged if the probes were in the "same" location as the final inducing stimulus or in a "different" location than the final inducing stimulus. These responses were analyzed in three different ways. Firstly, the responses were analyzed as consolidated probability of "same" response. Consistent with previous representational momentum literature, responses that judged probes to be in the "same" location as the final inducing stimulus, were summed up and divided by the number of times the probe appeared at a specific location in the experiment. The weighted mean provided an estimate of the displacement. Secondly, the responses were analyzed as consolidated percentage correct. The responses that correctly identified the probes to be in the "same" or "different" location were summed up, and then divided by the number of times the probe appeared at a specific location in the experiment, and then multiplied by 100. Thirdly, the responses were analyzed as percentage correct according to the corresponding block. The responses that correctly identified the probes to be in the "same" or "different" location within a specific block were summed, and then divided by the number of times the probe appeared at a specific location in the block, and multiplied by 100. There were a total of 10 blocks comprising of 20 trials each.

Consolidated Probability of "Same" Response. The consolidated probability of "same" response was analyzed using 2 (Feedback: present, absent) X 6 (Distance: - 12 / 0, - 8 / 0, - 4 / 0, + 4 / 0, + 8 / 0, + 12 / 0) X 2 (Probe: same, different) X 2 (Direction: left to right, right to left). Feedback and Distance were the between subjects variables and the Probe and Direction were the within subjects variables. Figure 7 shows the probability of "same" response for each probe, presented at varying distances from the final inducing stimulus.

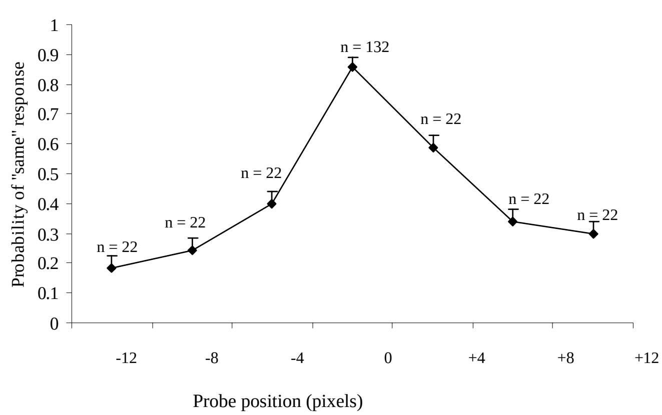


Figure 7. Probability of "same" response according to distance of probe (pixels) from final inducing stimulus, collapsed across feedback conditions.

There was no significant effect of Feedback, $F(1, 120) = .39$, $p = .54$. There was a significant main effect of Probe, $F(1,120) = 439.99$, $p < .01$. Participants were more likely to indicate “same” for a same probe (*M* = .86, *SEM* = .01) and less likely to indicate “same” for a different (-12, -8, -4, +4, +8 and +12 pixels away) probe (*M* = .34, *SEM* = .02).

There was a significant main effect of Distance, $F(5,120) = 3.11$, $p < .05$. As shown in Table 3, participants in the- 12 / 0 distance groups were less likely to indicate that the probes were in the “same” location (*M* = .56, *SEM* = .02) than were participants in the + 4 / 0 distance groups, who were more likely to indicate that the probes were in the “same” location (*M* = .68, *SEM* = .02).

Table 3

Probability of “Same” Response for Probes for different Distance groups

	Distance of probe positions from the final inducing stimulus (pixels)					
	- 12 / 0	- 8 / 0	- 4 / 0	+ 4 / 0	+ 8 / 0	+ 12 / 0
Mean	.56[a]	.57 [a]	.60[ab]	.68[b]	.61 [ab]	.60 [ab]
SEM	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)

A Tukey B post-hoc test indicated that participants in the +4 / 0 distance groups were more likely to respond “same” to probes than were participants in the -8 / 0, -12 / 0 distance groups. On a one-sample *t*-test for participants in the +4 / 0 distance groups, the probability of “same” response for the different probe (*M* = .59, *SD* = .05) did not differ from chance, $t(21) = 1.63$, $p = .12$ (2 tailed significance). In contrast, on a one-sample *t*-test for participants in the -4 / 0 distance groups, the probability of “same” response for a different probe (*M* = .40, *SD* = .17) was not due to chance, *t*(21) = -2.86, *p* < .01 (2 tailed significance).

There was a significant two-way Probe X Distance interaction, *F*(5,120) = 10.96, *p* < .01. As shown in Table 4, when the different probes were presented, participants in the -12 / 0 distance groups were less likely to indicate “same” (*M* = .19, *SEM* = .04) for the different probe than were participants in the +4 / 0 distance groups (*M* = .59, *SEM* = .04). There was a significant difference in the probability of “same” response between the two scores, *F*(1, 42) = 15.41, *p* < .01. In contrast, there was an insignificant trend for the same probes, participants in the +12 / 0 distance groups were more likely to indicate “same” (*M* = .93, *SEM* = .03) than were participants in the +4 / 0 distance groups (*M* = .77, *SEM* = .03), *F*(1, 42) = 36.68, *p* < .01.

Table 4

Probability of "Same" Response for Probes at Same or Different Locations, for different Distance groups

	Probe	
Group Distance	Same	Different
- 12 / 0	.93 (.03)	.18 (.04)
- 8 / 0	.89 (.03)	.24 (.04)
- 4 / 0	.81 (.03)	.40 (.04)
+ 4 / 0	.77 (.03)	.59 (.04)
+ 8 / 0	.87 (.03)	.34 (.04)
+ 12 / 0	.90 (.03)	.30 (.04)
- 12 / 0	.93 (.03)	.18 (.04)

There was a significant two-way Direction X Distance interaction, F (5,120) = 5.13, $p < .05$. As shown in Table 5, participants in the -4 / 0 distance groups were more likely to indicate "same" for probes of targets that moved from right to left (M = .65, *SEM* = .03) than for probes of targets that moved from left to right (*M* = .55, *SEM* = .03). There was a significant difference between the probability of "same" response between the two scores, $F(1, 21) = 15.92$, $p < .05$. In contrast, there was an insignificant trend for participants in the +4 / 0 distance groups to be likely to indicate "same" for probes of targets that moved from left to right (*M* = .69, *SEM* = .03) than for probes of targets that moved from right to left (*M* = .65, *SEM* = .03), $F(1, 21) = 2.16$, $p = .16$.

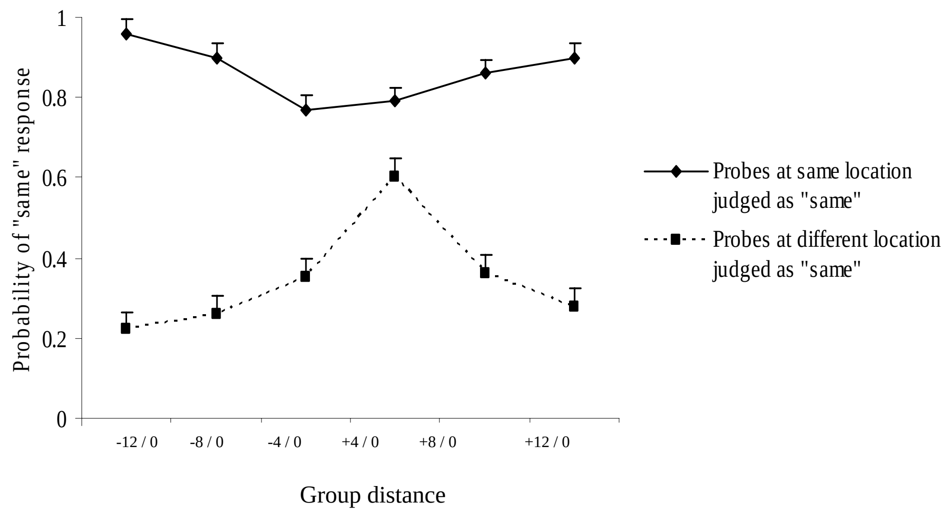
Table 5

Probability of "Same" Response for Probes, according to group Distance, for targets moving from a Left to Right vs. Right to Left Direction

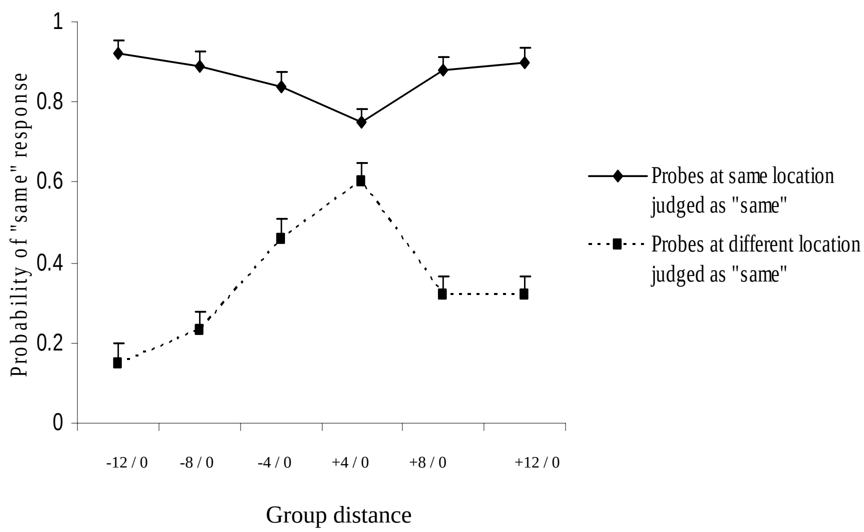
	Direction	
Groups distance	Left to Right	Right to Left
- 12 / 0	.58 (.03)	.54 (.03)
- 8 / 0	.57 (.03)	.56 (.03)
- 4 / 0	.55 (.03)	.65 (.03)
+ 4 / 0	.69 (.03)	.65 (.03)
+ 8 / 0	.61 (.03)	.60 (.03)
+ 12 / 0	.60 (.03)	.61 (.03)

There was a significant Direction X Probe X Distance interaction, $F(5,120) = 2.62$, $p < .01$ (see Figure 8). When same probes were presented, participants in the -4 / 0 distance groups were more likely to indicate "same" when the target moved from right to left ($M = .84$, $SEM = .03$) than when the target moved from left to right ($M =$

.77, *SEM* = .03). The difference between these scores approached significance, *F*(1, 21) = 4.49, *p* = .05. In contrast, there was an insignificant trend for participants in the +4 / 0 distance groups to be less likely to indicate “same” when the target moved from right to left (*M* = .75, *SEM* = .03) than when the target moved from left to right (*M* = .78, *SEM* = .03), F(1, 21) = 2.65, *p* = .12. When different probes were presented, participants in the -4 / 0 distance groups were more likely to indicate “same” when the target moved from right to left (*M* = .46, *SEM* = .05) than when the target moved from left to right (*M* = .34, *SEM* = .05). The difference between the two scores was significantly different, F(1, 21) = 6.75, *p* < .05. In contrast, there was an insignificant trend for participants in the +4 / 0 distance groups to be less likely to indicate “same” when the target moved from right to left (*M* = .58, *SEM* = .05) than when the target moved from left to right (*M* = .60, *SEM* = .05), *F*(1, 21) = .58, *p* < .45.



(a): Probability of “same” for target moving from the left to right direction.



(b) Probability of “same” response for target moving from the right to left direction.

Figure 8. Probability of “same” response for target moving in opposite directions, collapsed across feedback conditions.

A new variable referred to as “Sign” was calculated. The probability of “same” responses of participants in the -12 / 0, -8 / 0, -4 / 0 groups were collapsed into a negative group (i.e. different probes behind the final inducing stimulus). The probability of “same” responses of participants in the +12 / 0, +8 / 0, +4 / 0 was collapsed into a positive group (i.e. different probes ahead of the final inducing stimulus). There was a main effect of Sign (positive vs. negative), $F(1,128) = 6.84$, $p < .05$, such that participants in the positive group ($M = .63$, $SEM = .01$) were more likely to indicate “same” for probes than were participants in the negative group ($M = .58$, $SEM = .01$).

There was a significant Probe X Sign interaction, $F(1, 128) = .89$, $p < .01$. Participants in the positive group ($M = .41$, $SEM = .03$) were more likely to indicate “same” for different probes than were participants in the negative group ($M = .28$, $SEM = .03$). The difference between these scores was significant, $F(1, 130) = 11.26$, $p < .01$. On the other hand, there was an insignificant trend for participants in the positive group ($M = .85$, $SEM = .02$) to be less likely to indicate “same” for same probes than were participants in the negative group ($M = .88$, $SEM = .02$), $F(1, 130) = 1.29$, $p = .26$.

Consolidated Percentage Correct. The percentage correct scores were analyzed using 2 (Feedback: present, absent) X 6 (Distance: - 12 / 0, - 8 / 0, - 4 / 0, + 4 / 0, + 8 / 0, + 12 / 0) X 2 (Probe: same, different) X 2 (Direction: left to right, right to left). The Feedback and Distance were the between subjects variables and Probe and Direction were the within subjects variables. Figure 9 shows the scores of percentage correct responses for each probe position. Participants in the groups that were presented different probes behind the final inducing stimulus were more accurate in indicating "different" to probes behind the final inducing stimulus. In contrast, participants in the groups that were presented different probes and ahead of the final inducing stimulus were less accurate in indicating "different" to probes ahead of the final inducing stimulus.

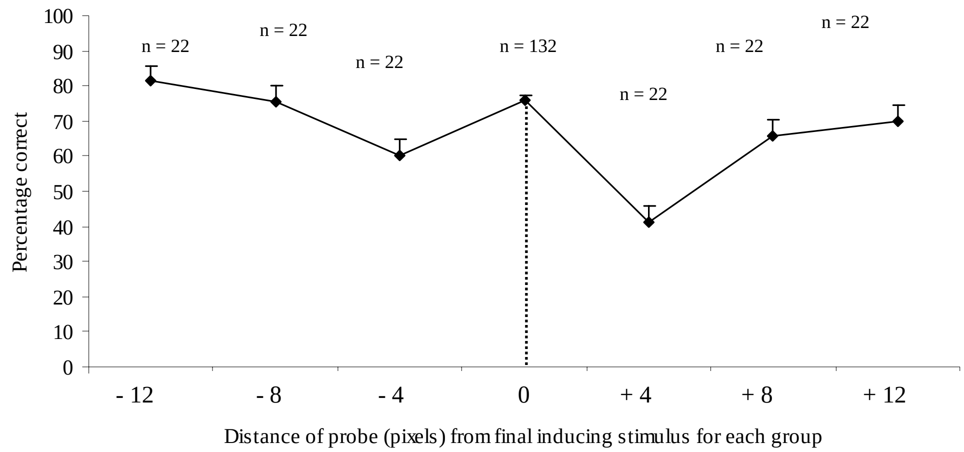


Figure 9. Percentage correct according to distance of probe (pixels) from final inducing stimulus, collapsed across feedback conditions.

There was no main effect of Feedback, $F(1,120) = .79$, $p = .38$. There was a significant main effect of Probe position, $F(1,120) = 108.70$, $p < .01$. Participants were more accurate in correctly indicating "same" for a probe that was at the same location (0 pixels away) as the final inducing stimulus ($M = 86.11$, $SEM = 1.31$) than in correctly identifying a probe that was not in the same location (- 12, - 8, - 4, + 4, + 8, + 12 pixels away) as the final inducing stimulus ($M = 65.75$, $SEM = 1.80$).

There was a significant main effect of Distance, $F(5,120) = 10.93$, $p < .05$. As shown in Table 6, participants in - 12 / 0 distance groups were highly accurate ($M = 87.93$, $SEM = 3.03$) in correctly indicating if the probe was in the "same" or "different" location as the final inducing stimulus, whereas participants in + 4 / 0 distance groups were less accurate in correctly indicating if the probe was in a “same” or “different” location (*M* = 59.36, *SEM* = 3.03).

Table 6

Percentage Correct for different Distance groups.

	Distance of probe positions from the final inducing stimulus (pixels)					
	- 12 / 0	- 8 / 0	- 4 / 0	+ 4 / 0	+ 8 / 0	+ 12 / 0
Mean	87.39[a]	82.39 [ab]	70.34[bc]	59.11[c]	76.52 [ab]	79.84 [ab]
SEM	(3.03)	(3.03)	(3.03)	(3.03)	(3.03)	(3.03)

A Tukey B post hoc test indicated that participants in the - 4 / 0 distance groups were not significantly more accurate in correctly indicating if the probe was in the “same” or “different” location from the final inducing stimulus than were participants in + 4 / 0 distance groups. However, on a one-sample *t*-test the percentage correct scores for the different probe for participants in the + 4 / 0 distance groups did not differ from chance, $t(21) = -1.63$, $p = .12$ (2 tailed significance). On the other hand, the percentage correct scores for the different probe of participants in the - 4 / 0 distance group was greater than chance, $t(21) = 2.86$, $p = .009$ (2 tailed significance).

There was a significant two-way Probe X Distance interaction, $F(5,120) = 3.11$, $p < .05$. As shown in Table 7, participants in - 12 / 0 distance groups were highly accurate in indicating that the different probe as “different” (*M* = 81.45, *SEM* = 4.41) and were even more accurate in indicating that the same probe as “same” (*M* = 93.32, *SEM* = 3.22). The percentage correct scores for participants in the -12 /0 distance group, were significantly different for the same probe and different probe, $F(1, 20) = 11.46$, $p < .05$. However, the participants in + 4 / 0 distance groups were least accurate in indicating the different probe as "different" ($M = 41.27$, $SEM = 4.41$), but were relatively more accurate in indicating the same probe as "same" ($M = 76.96$, $SEM = 3.22$). The percentage correct scores for participants in the + 4 / 0 distance group, were significantly different for the same probe and different probe $F(1, 20) = 30.00$, $p < .01$.

Table 7

Percentage Correct in Discriminating the Probes' Positions as "Same" or "Different", at for different Distance groups

Group Distance	Probe Position	
	Same	Different
- 12 / 0	93.32 (3.22)	81.45 (4.41)
- 8 / 0	89.14 (3.22)	75.64 (4.41)
- 4 / 0	80.50 (3.22)	60.18 (4.41)
+ 4 / 0	76.96 (3.22)	41.23 (4.41)
+ 8 / 0	87.18 (3.22)	65.86 (4.41)
+ 12 / 0	89.59 (3.22)	70.09 (4.41)

There was a significant two-way Direction X Distance interaction, $F(5,120) = 2.62$, $p < .05$. As shown in Table 8, there was an insignificant trend for participants in the - 4 / 0 groups to be more accurate in indicating probes to be in the “same” or “different” location for targets that moved from the left to right ($M = 71.91$, $SEM = 3.12$) than for targets that moved right to left ($M = 68.77$, $SEM = 3.18$), $F(1, 20) = 3.05$, $p = .1$. In contrast, there was a marginally significant trend for participants in the + 8 / 0 distance groups to be more accurate in indicating probes to be in the “same” or “different” location for targets that moved in the right to left ($M = 78.23$, $SEM = 3.18$), than for targets, that moved from left to right ($M = 74.82$, $SEM = 3.12$), $F(1, 20) = 3.90$, $p = .06$.

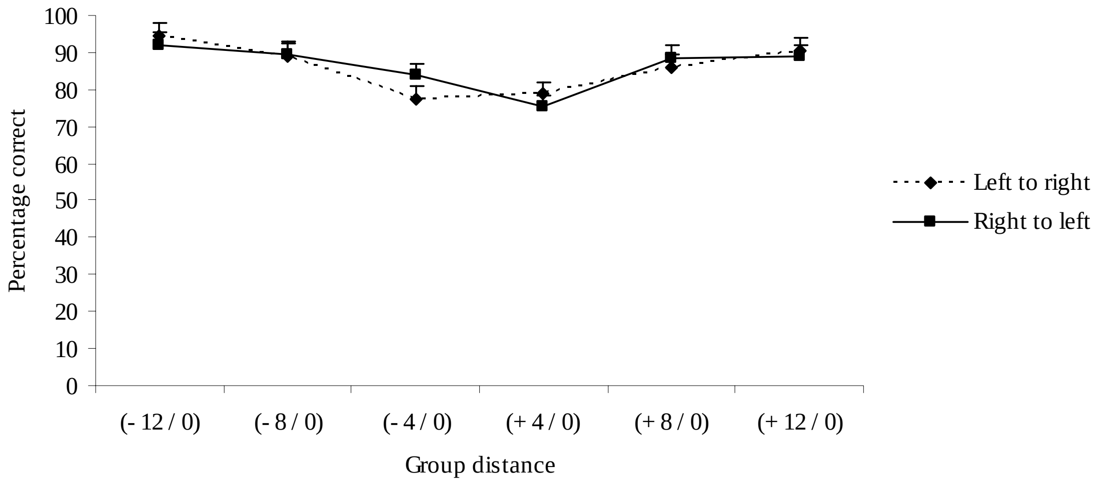
Table 8

Percentage Correct in Discriminating the Probes at Different Distances from the Final Inducing Stimulus, for Targets moving from a Left to Right vs. Right to Left Direction

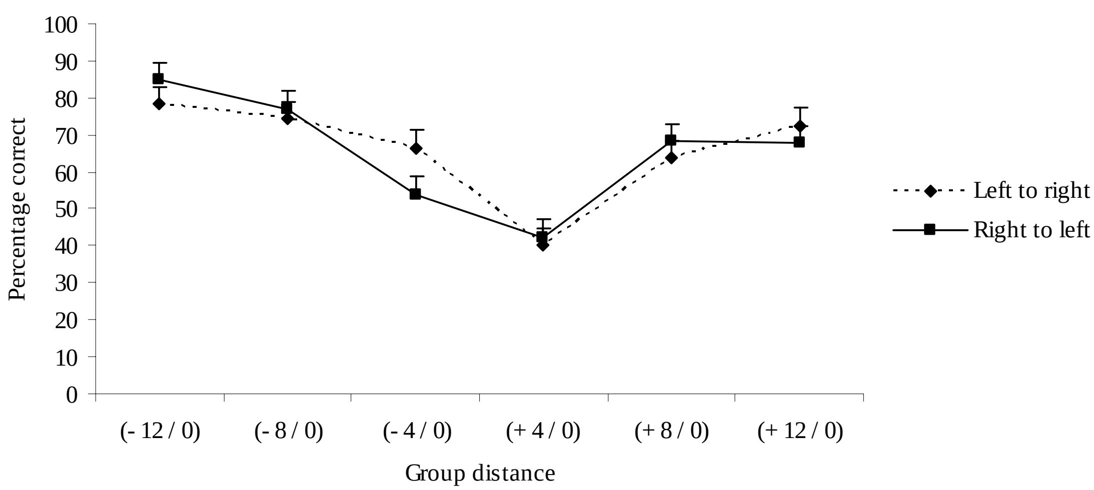
Distance from final inducing stimulus (pixels)	Direction: Left to Right	Direction: Right to Left
- 12 / 0	86.32 (3.12)	88.46 (3.18)
- 8 / 0	81.64 (3.12)	83.14 (3.18)
- 4 / 0	71.91 (3.12)	68.77 (3.18)
+ 4 / 0	59.50 (3.12)	58.73 (3.18)
+ 8 / 0	74.82 (3.12)	78.23 (3.18)
+ 12 / 0	81.46 (3.12)	78.23 (3.18)

NOTE: The values in parenthesis reflect the standard error of the mean.

There was a significant Direction X Probe X Distance interaction, $F(5,120) = 5.132$, $p < .01$ (see Figure. 10). When the same probe was presented, participants in the - 4 / 0 distance groups were more accurate for leftward target motion (*M* = 83.73, *SEM* = 3.37) than rightward target motion (*M* = 77.27, *SEM* = 3.41). The difference in the two scores approached significance, $F(1, 21) = 4.49$, $p = .05$. In contrast, when the same probe was presented, there was a non - significant trend for participants in the + 4 / 0 distance groups to be more accurate for rightward target motion (*M* = 78.23, *SEM* = 3.41) than for leftward target motion (*M* = 75.18, *SEM* = 3.37), $F(1, 21) = 2.65$, $p = .12$. When the different probe was presented, participants in the - 4 / 0 distance groups were more accurate for rightward target motion (*M* = 66.54, *SEM* = 4.65) than for leftward target motion (*M* = 53.82, *SEM* = 4.78). The difference in the two scores was significant, $F(1,21) = 6.75$, $p < .05$. When the different probe was presented, there was a non – significant trend for participants in the + 4 / 0 distance groups to be more accurate for a leftward target motion (*M* = 42.27, *SEM* = 4.78) than for a rightward target motion (*M* = 40.27, *SEM* = 4.65), $F(1, 21) = .58$, $p = .45$.



(a): Percentage correct responses for same probe for target moving in opposite directions .



(b): Percentage correct responses for same probe for target moving in opposite directions

Figure 10. Percentage correct responses for targets moving in opposite directions, collapsed across feedback conditions.

Here as well, a new variable referred to as “Sign” was calculated. The percentage correct scores of participants in the -12 / 0, -8 / 0, -4 / 0 groups were collapsed into a negative group (i.e. different probes behind the final inducing stimulus). The percentage correct scores of participants in the +12 / 0, +8 / 0, +4 / 0 was collapsed into a positive group (i.e. different probes ahead of the final inducing stimulus).There was a main effect of Sign (positive vs. negative), $F(1,128) = 8.60$, $p < .05$. Participants in the negative group were more accurate (*M* = 80.04, *SEM* = 1.98) in indicating whether the probe was in a “same” or “different” location than were participants in the positive group (*M* = 71.83, *SEM* = 1.98).

There was a significant Probe X Sign interaction, $F(1, 128) = .89$, $p = .01$. When the same probe was presented, there was a non - significant trend participants in the positive group (*M* = 84.58, *SEM* = 1.93) to be less accurate than were participants in the negative group (*M* = 87.65, *SEM* = 1.93) $F(1, 130) = 1.29$, $p = .26$. However, when a different probe was presented, participants in the negative group were more accurate (*M* = 72.42, *SEM* = 1.93) than were participants in the positive group (*M* = 59.08, *SEM* = 2.83), $F(1,130) = 11.26$, $p < .01$.

Percentage Correct According to the Corresponding Block. The percentage correct scores of the participants were collected across 10 blocks of 20 trials each. This data was analyzed in a 10 (Block: 1-10) X 2 (Probe: same, different) X 2 (Direction: left to right, right to left) X 6 (Distance: - 12 / 0, - 8 / 0, - 4 / 0, + 4 / 0, + 8 / 0, + 12 / 0) X 2 (Feedback: present, absent). Feedback and Distance were between subjects variables and Block, Direction and Probe were within subjects variables.

There was a main effect of Block, $F(9, 1080) = 3.36$, $p < .01$. Participants were less accurate ($M = 72.69$, $SEM = 1.64$) in the first block of trials than in the last block of trials ($M = 77.96$, $SEM = 1.38$). The difference between the first block of trials and the second block of trials was significant. There was no Block X Feedback interaction, $F(9, 1080) = .45$, $p = .91$ (see Figure 11). There was no Block X Feedback X Distance interaction, $F(45, 1080) = 1.05$, $p = .38$.

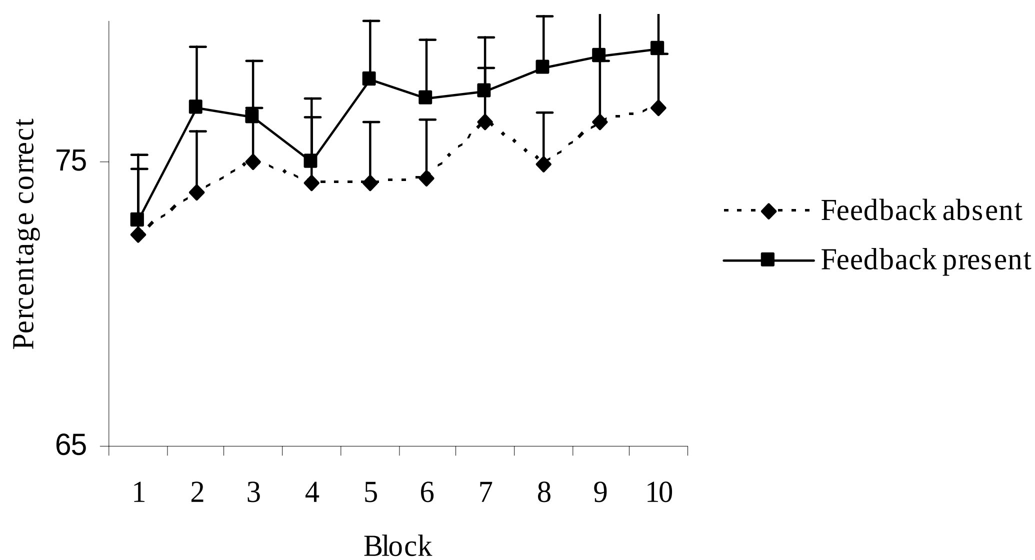


Figure 11. Effect of Feedback According to the Corresponding Block

There was a significant Probe X Block X Distance interaction, $F(45, 1080) = 1.44$, $p < .05$. Participants in the + 8 / 0 distance groups had the most improvement in percentage correct scores across the 10 blocks of trials in correctly indicating "different" for the different probe. In contrast, participants in the - 12 / 0 distance groups had the least improvement in percentage correct scores across the 10 blocks of trials in correctly indicating “same” for the same probe. Participants in the - 12 / 0 distance groups had a 10 point difference in percentage correct scores for correctly indicating “same” or “different” in the first block of trials. Participants in this group exhibited a marginally significant trend to be more accurate in indicating “same” for the same probe (M = 90.91, SEM = 4.23) than in indicating “different” for a different probe (M = 80.00, SEM = 5.77) in the first block of trials. The difference between these scores approached significance, $F(1, 21) = 4.44$, $p = .05$. This 10 point percentage correct difference was maintained in the last block of trials. These participants remained more accurate in indicating “same” for the same probe (M = 93.18, SEM = 3.84) than in indicating “different” for a different a probe (M = 83.18, SEM = 5.02) in the last block of trials. This difference was significant in the last block of trials, $F(1, 21) = 8.56$, $p < .01$. In contrast, for the + 8 / 0 distance groups, the difference in percentage points between the same and different probe positions reduced from the first to the last block of trials. In the first block of trials there was a 28 point difference in percentage correct scores. Participants were more accurate in correctly indicating “same” (M = 83.64, SEM = 4.23) than in indicating “different” (M = 55.91, SEM = 5.77) in the first block of trials. The difference in scores was significant, $F(1, 21) = 24.69$, $p < .01$. This difference was reduced in the last block of trials. The difference in percentage correct for correctly indicating “same” or “different” was reduced to 15 points. Participants were more accurate in correctly indicating “same” (M = 90.00, SEM = 3.84) than in indicating “different” (M = 75.91, SEM = 5.02). However, the difference in scores was significant, $F(1, 21) = 8.39$, $p < .05$.

There was a significant Distance X Direction X Block interaction, $F(45,1080) = 1.92$, $p < .01$. As shown in Figure 12, participants in the - 8 / 0 distance groups were more accurate in correctly indicating “same” or “different” for a target in leftward motion ($M = 89.54$, $SEM = 4.21$) than in rightward motion ($M = 78.18$, $SEM = 4.00$), in the ninth block of trials. The difference between the two scores was significant, $F(1, 21) = 14.01$, $p < .01$. In contrast, participants in the + 4 / 0 distance groups were more accurate in correctly indicating “same” or “different” for a target in rightward motion ($M = 65.91$, $SEM = 4.00$), than for a target in leftward motion ($M = 56.82$, $SEM = 4.21$), in the ninth block of trials. The difference between the two scores was significant, $F(1, 21) = 7.99$, $p < .05$.

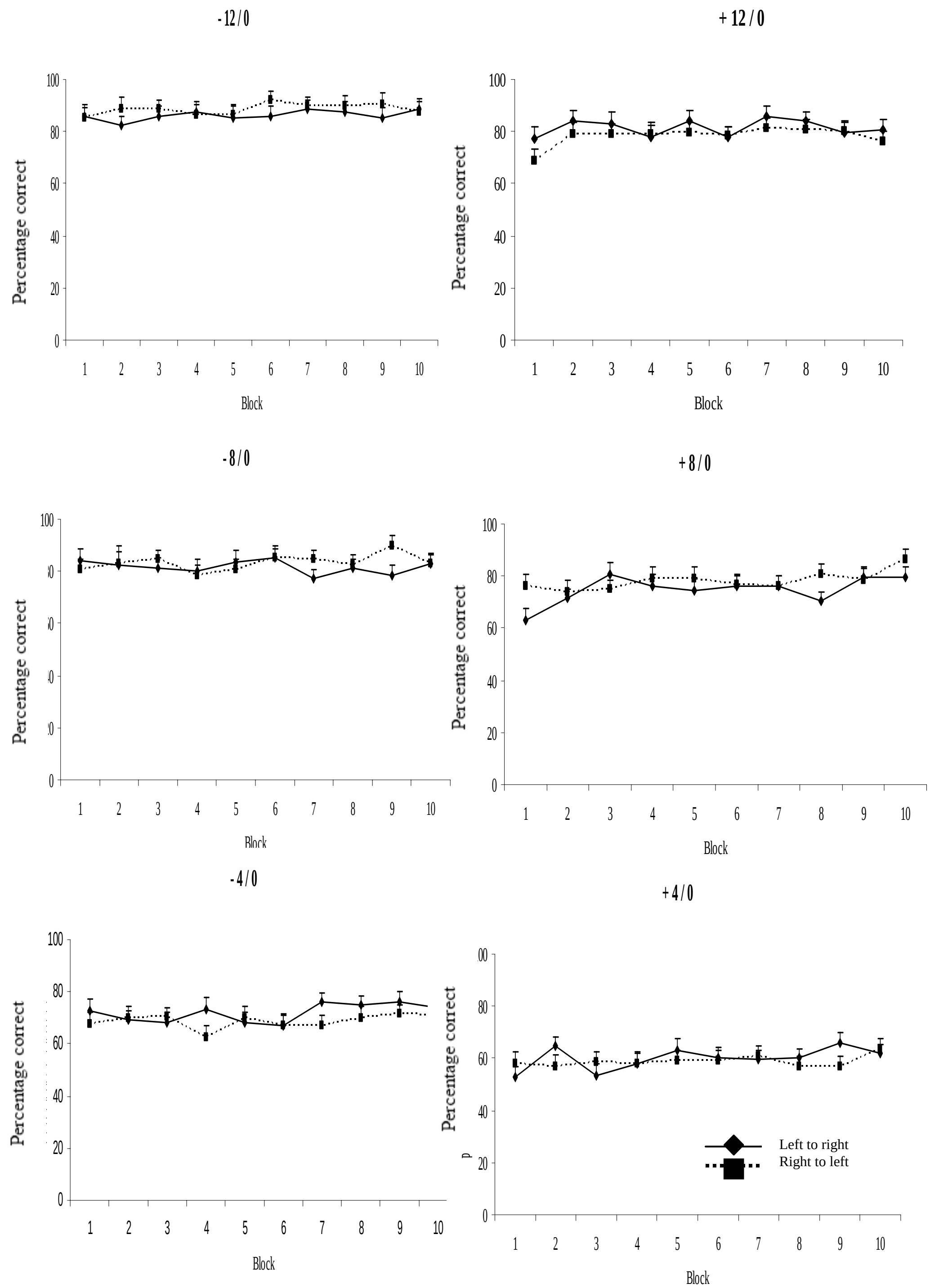


Figure 12. Percentage correct for targets moving from the left to right vs. right to left, according to the corresponding block, for different group distances.

There was a trend towards a significant Feedback X Sign X Direction X Probe interaction, $F(1, 128) = .08$, $p = .08$. Participants in the Feedback present condition who were in the negative groups (- 4 / 0, - 8 / 0, - 12 / 0), and were presented the same probe, for targets in a right to left motion were more accurate in their judgments (*M* = 90.18, *SEM* = 2.83) than were participants in the feedback absent condition, who were in the positive sub–groups (+ 4 / 0, + 8 / 0, + 12 / 0) and were presented different probes, for targets in a left to right motion (*M* = 57.39, *SEM* = 4.09). In contrast, participants in the Feedback present condition, who were in the positive groups (+ 4 / 0, + 8 / 0, + 12 / 0) and were presented the different probes for targets in a left to right motion were less accurate (*M* = 60.85, *SEM* = 4.09) than participants in the Feedback absent condition who were in the negative groups (- 4 / 0, - 8 / 0, - 12 / 0) and were presented the same probe, for targets in a right to left motion (*M* = 86.76, *SEM* = 2.83).

Discussion

The objective of the study was to test whether feedback could influence representational momentum. Contrary to expectations, participants in the feedback present condition were not more accurate in their judgments than participants in the feedback absent condition. Participants in the feedback present condition were as likely to indicate “same” for same probes and “different” for different probes as participants in the feedback absent condition. Thus, the presence of feedback did not reduce forward displacement. Moreover, feedback did not significantly interact with any other variable. The main effects and interaction effects of the other variables is consistent with the literature in representational momentum.

Participants were to discriminate if the location of the probe differed from the final inducing stimulus along the horizontal axis. The nature of the task presented to them was one of intra–dimensional discrimination. When collapsed across all group distances and feedback conditions, participants were on average able to discriminate correctly the final location of the moving target from other locations in which the probe was presented. Thus, participants were in general less likely to indicate "same" for probes in a different location from the final inducing stimulus, but were more likely to indicate "same" for probes at the same location as the final inducing stimulus. This would suggest that the distances of the probes, located at a different position from the final inducing stimulus, were above the just noticeable difference. Just noticeable difference is the minimum amount by which stimulus intensity must be changed in order to produce a noticeable variation in sensory experience (http://www.usd.edu/psyc301/WebersLaw.htm).

There was a significant effect of Distance, participants in groups that were presented the different probe furthest away from and behind the final inducing stimulus were most accurate in correctly indicating if the probes were in the "same" or "different" location. In contrast, participants in groups where the different probe was presented closest to and ahead of the final inducing stimulus were least accurate in indicating if the probes were in the "same" or "different". Stated differently, participants in groups that were presented the different probe furthest away and behind the final inducing stimulus were least likely to indicate "same" for the probes, whereas participants in groups that were presented the different probe ahead of and closest to the final inducing stimulus, were most likely to indicate "same". These results are in agreement with existing literature. When probes are presented ahead of and close to the final inducing stimulus, participants displace the location of the final inducing stimulus, in the direction of the anticipated motion (Freyd & Finke, 1984; Hubbard, 2005).

In order to prevent participants from fixating on a particular final location as well as to avoid potential monotony, both final location and the direction of target motion were varied. As previously mentioned, participants in the - 4 / 0 distance groups had a less challenging task, whereas participants in the + 8 / 0 distance groups had a more challenging task. Thus, viewing a target in rightward motion along with a more challenging task produced the higher errors. Whereas, viewing a target in leftward motion along with a less challenging task produced fewer errors.

Because the participants were primarily native English language speakers, who were accustomed to reading from left to right, greatest errors for participants in the + 4 / 0 distance groups for the left to right direction was expected. Higher displacement for left to right motion has been previously documented (Halpern & Kelly, 1993). Halpern and Kelly (1993) proposed that reading habits can influence directionality in motion perception, and they further speculated that a group of monolingual Arabic or Farsi readers would show a tendency towards a rightward bias. Similar influence of reading habits on aesthetic preference was also noted. Another explanation for the bias towards the right can be attributable to learning derived from traffic rules that specify driving on the right side of the road or right-handedness. Although handedness was the best predictor of participants' directional preference, participants from the United States were statistically more likely to turn right in a T maze task than were participants from United Kingdom (Scharine & McBeath, 2002). Thus, it may be suggested that the greatest displacement or least percentage correct for the + 8 / 0 distance groups, for the left to right direction, might reflect an interaction of the task and cultural factors.

The Direction X Probe X Distance interaction can be understood from the preceding passages. When the same probe was presented, the effect of direction was marginally significant for the – 4 / 0 distance group, but not significant for the + 4 / 0 distance group. In contrast, when a different probe was presented, the effect of direction was significant for the – 4 / 0 distance group, but not significant for the + 4 / 0 distance group. A greater forward displacement is noted for the left to right than right to left motion (Halpern & Kelly, 1993). However, Hubbard and Bharucha (1988) did not find consistent differences between displacement for leftward motion and displacement for rightward motion. Participants in the - 4 / 0 distance group had a less challenging task than did participants in the + 4 / 0 distance groups. Thus, when a target moved leftwards and a probe was presented in a location that was against the direction of the anticipated motion it was easily be identified as “different”. However, these effects are not seen when a probe was presented in the direction of the anticipated motion. Thus, the effect of direction for the – 4 / 0 distance group, is consistent with the findings of Halpern and Kelly (1993) and the lack for effect of direction in the + 4 / 0 distance group are consistent with the findings of Hubbard and Bharucha (1988).

The results were re-analyzed as a function of positive or negative sign. Participants in the negative group were more accurate than were participants in the positive group. More specifically, participants in the positive groups were more likely to indicate “same” for the probes ahead of the final inducing stimulus, whereas participants in the negative groups were more likely to indicate “same” for the probes in the same location as the final inducing stimulus. Thus, the probes behind the location of the final inducing stimulus were better identified as “different” than were the probes ahead of the location of the final inducing stimulus. The above findings are consistent with typical findings in representational momentum literature, in which displacement of the final location of the inducing stimulus in the direction of anticipated motion is observed (Freyd & Finke, 1984).

When responses were analyzed as a function of block, participants were more accurate in the first block of trials than in the last block of trials. In other words, participants were more likely to indicate “same” for probes in the first block of trials and less likely to indicate “same” for probes in the last block of trials. The improvement in performance is gradual over the blocks of trials. The absence of a Feedback X Block interaction is indicative of the ineffectiveness of the error feedback in improving performance. The improvement in performance of all groups across all blocks of trials is consistent with the possibility of perceptual learning. Applying Gibson’s (1953) notion of perceptual learning, it could be suggested that over the course of several blocks participants learnt to discriminate the location of the final inducing stimulus from other locations in which the probes were presented. Thus, the performance improved across blocks, not because of the formation of new associations or learning of new responses, but rather because participants had learnt to perceive things in a different way (Pick, 1992). The findings parallel those previously reported, in which the improvement in percentage correct scores in perceptual learning shows a very gradual and continuous rise with no marked acceleration (Gibson, 1953).

The Probe X Block X Distance interaction is indicative of greater differentiation in perceptual learning, which is consistent with existing literature (Gibson, 1953). It is plausible that forward displacement of the location of final inducing stimulus, which appeared robust, may be susceptible to change. This is especially pertinent, as the positive groups had a lower percentage correct than did the negative groups. Stated differently, participants in the positive groups were more likely to indicate "same" for the probes. In contrast, participants in the negative groups were less likely to indicate "same" for the probes. However, there was greater improvement in percentage correct for the different probe in the + 8 / 0 distance groups, relative to same probe in the - 12 / 0 distance groups. This is indicative of a greater differentiation between the same and different probe positions in the + 8 / 0 distance groups, as participants progressed from block one to block 10. Also, the post–hoc tests indicate that the percentage correct scores for the + 8 / 0 distance groups were different from the scores of the + 4 / 0 distance groups. Thus, the forward displacement noted in the + 4 / 0 distance group might not be as strong as in the + 8 / 0 distance groups.

The Distance X Direction X Block interaction is more difficult to explain. The higher percentage correct scores for the right to left than for the left to right direction, in the - 8 / 0 distance groups, is in agreement with the existing literature (Halpern & Kelly, 1993). However, the opposite in the + 4 / 0 distance groups cannot be explained by the existing literature.

As mentioned earlier, the percentage correct scores or probability of "same" response scores for participants in the feedback present group did not differ from participants in the feedback absent group. These findings are in agreement with previous findings, which indicate that representational momentum cannot be eliminated by feedback (see also Finke & Freyd, 1985; Ruppel et al., in press). Although Finke and Freyd (1985) only presented findings in the practice trials and not in the experimental trials, it is hypothesised that these were insufficient for learning. In Ruppel et al. (in press), a reduction in representational momentum was found in the groups in which feedback was consistently absent or present across blocks. Forward displacement was observed in groups where feedback was present in the first block and absent in the second, or absent in the first and present in the second block. Similarly, Courtney and Hubbard (in press) found that participants who received information about representational momentum before an experiment exhibited less displacement than did participants who did not receive any information about representational momentum. It might be that representational momentum can have two components, one which is influenced by learning and the other which is not influenced by learning. Such a hypothesis is consistent with the suggestions in Hubbard (2006) and Finke and Freyd (1989) that representational momentum is composed of both modular and non-modular components.

The trend towards significance, in the Feedback X Sign X Direction X Probe interaction, is also evidence in support of the theory of representational momentum. The highest percentage correct was noted when feedback was provided to the participants in the negative group for trials where the target that moved from right to left and the same probe was presented. Even without feedback, each of the remaining factors, namely the negative sign, the same location, and the right to left direction, contributed to high percentage correct scores. Thus, feedback had an elevating effect on the percentage correct scores. Participants were more likely to indicate “same” for probes in this condition. In contrast, the lowest percentage correct scores were noted when feedback was not provided to participants in the positive group, in trials where the target moving from left to right and the different probes were presented. Without taking feedback into account, the positive sign, different locations and left to right direction, contribute to the low percentage correct scores. Thus, participants in this condition were highly likely to indicate “same” for the probes. Thus, error feedback did not eliminate forward displacement. Instead it made participants more accurate, in instances, where forward displacement was not observed.

Experiment 2

In addition to the presence or absence of error feedback, there are also two critical differences between the methodology of Experiment 1 and the methodologies of previous experiments on representational momentum. Firstly, Experiment 1 treated distance of the different probe as between subjects variable rather than as a within subjects variable. As a consequence, it was not possible to calculate a measure of displacement for a given participant. Secondly, and as a consequence of the first difference, Experiment 1 presented the same probe on one-half of the trials received by a given participant, whereas previous experiments typically present the same probe on one-seventh or one-ninth of the trials. Although the data in Figure 7 and the analysis of the sign variable suggest forward displacement occurred with the probe positions used in Experiment 1, it would be useful to demonstrate a forward displacement if the same probe positions used in Experiment 1 were also varied within subjects, with equal probability. Accordingly, Experiment 2 presented probes at the same positions as Experiment 1, except that probe position was varied within subjects and each probe position was equally likely. Lastly, as error feedback did not produce any difference between the feedback present and absent groups, no feedback was presented to participants in Experiment 2.

Method

Participants. The participants were 14 undergraduate students who had participated for partial course credit from Texas Christian University. None of them were familiar with the hypotheses under investigation..

Apparatus. The apparatus was the same as used in Experiment 1.

Stimuli. The stimulus was the same as used in Experiment 1. However, probes in all locations [- 12, - 8, - 4, 0, + 4, + 8, + 12] used in Experiment 1 were presented to each participant (one probe per trial). Each participant received 168 trials. There were 2 directions [leftward, rightward], 3 locations of inducing stimulus separated by 10 pixels, 7 probe locations [- 12, - 8, - 4, 0, + 4, + 8, + 12”] and 4 replications of each type of trial. All trials were presented in random order.

Procedure. The procedure was the same as in Experiment 1, with the following exceptions: None of the participants received feedback in the experiment. In Experiment 1, each participant was presented probes at different distances from the final inducing stimulus (i.e. probe position of the different probe was a ‘between subjects’ variable). In Experiment 2, each participant was presented probes at - 12, - 8, - 4, 0, + 4, + 8, + 12 pixels away from the final inducing stimulus (i.e. probe position of the different probe was a ‘within subjects’ variable).

The dependent variable of the experiment was the consolidated probability of each probe position being chosen as “same”. (Interested reader may contact the author for further information on the computer programs used to implement the stimuli and collect responses).

Results

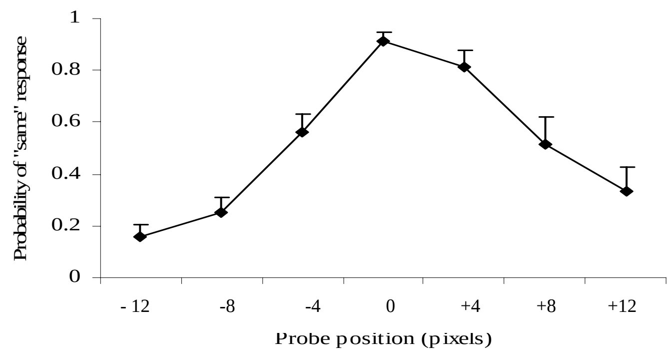
Consistent with previous studies in the representational momentum literature (Hayes & Freyd, 2002; Hubbard 1993; Munger, Solberg, & Horrocks, 1999) estimates of direction and magnitude of displacement were determined by calculating the arithmetic weighted mean (i.e. the sum of the products of the proportion of “same” response and the distance of the probe from the final location of the moving target, in pixels, divided by the sum of the proportions of the “same” responses) for each observer. The sign of the weighted mean indicated the direction of displacement for each probe position: a positive weighted mean suggested participants displaced the final position of the target forward (in the direction of motion), and a negative weighted mean suggested that participants displaced the final position of the target backward (in the direction opposite to motion). The absolute value of the weighted mean indicated the magnitude of displacement.

The weighted means were analyzed using a one sample *t*-test. The weighted mean (M = 1.27, SEM = .44) was larger than zero, and thus indicated that the participants displaced the location of the final inducing stimulus in the direction of the anticipated motion, $t(13) = 2.86$, $p < .05$..

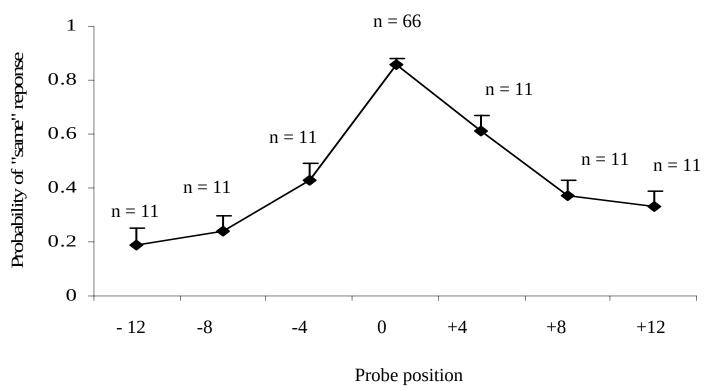
Discussion

When probe positions were varied within subjects, a strong forward displacement was observed. The results of Experiment 2 demonstrate that participants displaced the location of the final inducing stimulus in the direction of the anticipated motion. As shown in Figure 13, the data from the within subjects design is very similar to the between subjects data from Experiment 1. This demonstrates the robustness of representational momentum, across between and within subjects methodologies, and suggests the results of Experiment 1 were not due to inconsistency of a between subjects methodology to representational momentum.

Experiment 1 presented the same probe on one-half of the trials received by a given participant, whereas previous experiments on representational momentum typically present the same probe on one-seventh or one-ninth of the trials. This also demonstrates the robustness of representational momentum. Regardless of the ratio of same probes presented to participants, a forward displacement would be noted in both instances. The results of Experiment 1 were not due to the relative proportion of same and different probes.



(a): Probability of “same” response when each participant was presented probes in for all locations in separate trials, in Experiment 2.



(b): Probability of “same” response for participants in the feedback absent condition for different distance groups, in Experiment 1.

Figure 13. Probability of “same” response in Experiments 1 and 2.

General Discussion

Contrary to the hypothesis, error feedback did not reduce or eliminate representational momentum. In Finke and Freyd (1985) and in Experiments 1 and 2 in Ruppel et al. (in press), “error” and “correct” feedback was presented. Experiment 1 only provided error feedback. The results of Finke and Freyd (1985) and Ruppel et al. (in press) have been replicated, where feedback did not eliminate forward displacement. These results support the speculation by Joordens et al. (2004) that the relatively uninformative nature of feedback would not have reduced the forward displacement. However, in Experiment 3 in Ruppel et al. (in press) more informative feedback in the form of “error-in front” or “error- behind” was presented. This form of feedback also did not eliminate forward displacement. This suggests that regardless of the amount of feedback presented to the participants, forward displacement cannot be eliminated.

It is possible that the large number of trials might have been fatiguing for the participants. Although there are no studies that systematically examine the extent of forward displacement as a function of the number of trials the participants were exposed to, this factor is a possible area for future investigation. The fatigue effect is noted in visual perception experiments, where the percentage of correct responses decreased with fatigue. Such decreases are especially noted in cases of increasing complexity, where participants found it difficult to sustain attention (Soetens, Hueting, & Wauters, 1992). To the extent that attention demands controlled processing, fatigued participants tended to shift towards a more automatic processing. Hayes and Freyd (2002) suggested that attention was required in order to stop forward displacement underlying representational momentum. Thus, an increase in automatic processing could lead to an increased representational momentum, which could have contracted any effect of feedback or learning. Fatigue might have also lowered the performance for most participants, and so it is plausible that any effect of error feedback, which would have differentiated the performance of the feedback presence and absence groups, would have been neutralized by the large number of trials presented in the experiment.

It is plausible that a smaller number of trials (140), distributed across two blocks, reduced the forward displacement in Ruppel et al. (in press). Also, an even small number of trials (84) in Courtney and Hubbard (in press) could have produced a reduced displacement in the informed or informed plus compensate groups. Distributed practise is more effective than massed practice (Lewis 1908, as cited in Gibson, 1953). For instance, continued exposure to the Müller-Lyer stimulus results in a decrease in the magnitude of the illusion (Judd, 1902). However, when participants studied the Müller-Lyer illusion in condition of distributed practice, there was an accelerated decrease of the illusion, in comparison to participants who studied it in conditions of massed practice. In a meta – analysis by Lee and Genovese (as cited in Chamberlin & Lee, 1999), distributed practice resulted in elevated performance as indicated by the levels of performance in the end of the practice period. Thus, if the experiment was done in separate blocks of trials, with fewer trials in each block, the plausible fatigue effects might not have occurred.

Also, participants began the experiment with 10 practice trials, randomly chosen from the experiment. Data from these trials were not recorded. Thus, when participants began the experiment, they had already learnt the stimulus material. More importantly, in the feedback present condition in Experiment 1, the initial error feedback might have made changes, which were not recorded.

In conclusion, the failure of feedback to influence forward displacement point towards the partially modular component of representational momentum. The limitation of cognitive penetrability in representational momentum is indicative of an adaptive function in this error in judgment. The tendency to extrapolate an object's motion beyond the final observed position may help us to predict the future position of that object despite our inability to maintain a constant eye contact with it (Freyd & Johnson, 1987). The observer, by adjusting the representation of the target to reflect where the target would be in the very near future, bridges the gap between the initial perceived position and the subsequent action position (Hubbard, 2005).The adaptive significance of this error in judgment is seen in time–to–collision experiments (Gray & Thornton, 2000). The systematic forward displacement of an approaching object is seen in the underestimation of the time to collide. The error in underestimation allows people to avoid collision with an approaching object. Were such displacement easily eliminated, survival of organisms might be more difficult. Thus even though expectations regarding future target behaviour or biases in spatial memory can modify the direction and magnitude of displacement, such information cannot eliminate displacement, even when given in the form of explicit feedback.

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ABSTRACT

ERROR FEEDBACK AND REPRESENTATIONAL MOMENTUM

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The objective of this study was to find out whether error feedback can affect Representational Momentum (RM). Participants viewed a target that exhibited leftward or rightward implied motion. A probe then appeared, either at the *same* location where the target had disappeared, or at a *different* location. In Experiment 1, participants in feedback absent and feedback present conditions, were assigned to six groups each, on the basis of the location of the *different* probe from the point of disappearance of the target. In Experiment 2, participants were shown the probes at different distances, in separate trials.

The findings support the hypothesis that RM reflects a partially modular or cognitively impenetrable process, as error feedback did not reduce RM. Greater displacement for rightwards motion of the target may indicate that reading habits can influence directionality in motion perception, as proposed earlier. Participants in Experiments 1 and 2 were more likely to indicate “same” for probes presented ahead than behind the final inducing stimulus.