Canadian Journal of Experimental Psychology
2009, Vol. 63, No. 1, 49–58

1196-1961/09/$12.00 DOI: 10.1037/a0013980

Representational Momentum Is Not (Totally) Impervious to Error Feedback

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The influence of feedback on representational momentum for the final location of a moving target was examined in 3 experiments. The presence of binary feedback (*correct*, *error*) during practise trials or during larger blocks of experimental trials did not reduce representational momentum, nor did the presence of more informative feedback specifying the direction of error (*error—in front of*, *error—behind*) during larger blocks of experimental trials reduce representational momentum. Effects on representational momentum of whether feedback was consistently provided were inconsistent. Even though feedback did not reduce representational momentum per se, feedback did influence the probability of a *same* response for different probe positions. Implications of the data for R. A. Finke and J. J. Freyd's (1985; J. J. Freyd, 1987) claim that representational momentum is impervious to error feedback, and possible roles of perceptual learning in representational momentum, are discussed.

Keywords: representational momentum, error feedback, displacement

When observers are asked to indicate the final position of a moving target, they tend to indicate a position that is slightly forward, that is, displaced in the direction of anticipated motion. This displacement is referred to as *representational momentum* (Freyd & Finke, 1984). A number of variables influence the amount of displacement observed for the remembered final position of the moving target (for review, see Hubbard, 2005), and this displacement is often cognitively penetrable to (i.e., influenced by) knowledge, expectations, and beliefs regarding the future trajectory or behaviour of the target (e.g., Hubbard, 1994; Hubbard & Bharucha, 1988; Hubbard & Ruppel, 2002; Johnston & Jones, 2006; Verfaillie & d'Ydewalle, 1991). Given the cognitive penetrability of representational momentum to an observer's knowledge, expectations, and beliefs regarding the future trajectory of the target, it could be hypothesised that other types of information might also influence representational momentum. One type of information that might influence an observer's representational momentum involves information provided by feedback regarding an observer's performance on a localisation task in which representational momentum is typically exhibited. Surprisingly, whether providing observers with extensive error feedback (e.g., informing observers whether their judgements were correct, in front of, or behind the actual target location over a large number of trials) influences displacement has not yet been examined in the literature on representational momentum.

Although a few researchers (e.g., Munger & Minchew, 2002; Spering, Kerzel, Braun, Hawken, & Gegenfurtner, 2005) provided feedback during practise trials to train their participants and to ensure that participants were performing the experimental task correctly, none of those researchers examined what effect, if any, that feedback had on participants' subsequent representational momentum. In the only published study explicitly examining the effects of error feedback on representational momentum in the literature to date, Finke and Freyd (1985) provided feedback during practise trials in the form of a message stating *correct* or *error* after participants responded, but no feedback was provided to the participants during experimental trials. There was no significant difference in the magnitude of forward displacement in practise trials and the magnitude of forward displacement in experimental trials, nor was there a difference in the magnitude of forward displacement observed across experimental trials. Based on these results, Finke and Freyd concluded that feedback did not have any effect on the amount of representational momentum observed (see also Freyd, 1987). This claim has surprisingly not been challenged until recently (e.g., in Courtney & Hubbard, in press; Joordens, Spalek, Razmy, & van Duijn, 2004), despite the relative weakness of the underlying empirical evidence.

As noted by Joordens et al. (2004), the lack of an effect of feedback in Finke and Freyd (1985) might have been due to feedback being relatively uninformative, as it did not indicate the direction of the error, but only indicated that an error had occurred. Without knowing the direction of the error, it would have been

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We thank Margaret Munger and Thomas Spalek for helpful comments on a version of this article.

Portions of these data were presented at the 19th Annual Meeting of the Association for Psychological Science in Washington, DC, May 2006, and the 46th Annual Meeting of the Psychonomic Society in Toronto, Ontario, Canada, November 2005.

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more difficult for observers to use any information provided by feedback to improve their performance (i.e., to decrease displacement). Joordens et al. also pointed out that participants in Finke and Freyd's study received only a small number of practise trials, and they suggested that effects of feedback might be obtained if observers received feedback for a larger number of trials. Courtney and Hubbard (in press) found that specific feedback regarding judgement of a specific target might not be required, but that possession of a general knowledge of representational momentum could reduce forward displacement. Prior to the experiment, observers in Courtney and Hubbard were assigned to either a naïve, informed, or compensate group. Observers in the naïve group were simply told that the experiment involved spatial memory; observers in the informed group were told about the existence of representational momentum but were not explicitly instructed to compensate for the effect; and observers in the compensate group were told about the existence of representational momentum and explicitly told to try to compensate for the effect. All groups exhibited significant forward displacement, but the naïve group exhibited larger forward displacement than did the informed and compensate groups, and the magnitude of forward displacement in each of the latter two groups did not differ.

Given the general penetrability of displacement to knowledge, expectations, and beliefs regarding the probable future behaviour of that target, coupled with a consideration of the limited amount of uninformative feedback in Finke and Freyd (1985) and the effects of knowledge of representational momentum on displacement in Courtney and Hubbard (in press), it could be predicted that a larger amount of feedback or a more informative type of feedback might influence representational momentum. Accordingly, the experiments reported here contained a detailed examination of the possible effect of feedback on forward displacement. Experiment 1 was a partial replication and extension of Finke and Freyd (1985) in which forward displacement on subsequent experimental trials for observers receiving feedback (*correct*, *error*) during practise trials was compared with forward displacement on subsequent experimental trials for observers not receiving feedback during practise trials. Experiment 2 examined the effect of providing such feedback over a larger number of trials, and forward displacement during blocks of trials in which feedback was provided was compared with forward displacement during blocks of trials in which feedback was not provided. Experiment 3 was similar to Experiment 2, but provides more informative feedback; on trials in which observers made an error, they were told whether they indicated a location in front of the actual final location of the target or behind the actual final location of the target.

Experiment 1

In this experiment, a moving target exhibited leftward or rightward implied motion. After the target disappeared, a probe stimulus was presented. The probe was the same size, shape, and colour as the target; probe position varied across trials, and the probe was located slightly behind the final location of the target, at the final location of the target, or slightly beyond the final location of the target. Observers judged whether the probe was in the same location as where the moving target vanished or in a different location. Half of the observers were provided with feedback during the practise trials; feedback was in the form of the word *correct* or the word *error* printed in the display after those observers indicated their judgement of *same* or *different*. The other half of the observers were not provided with feedback during the practise trials. If Finke and Freyd (1985) were correct that feedback during practise trials does not influence representational momentum in subsequent experimental trials, then there should be no difference in forward displacement in subsequent experimental trials between observers who receive feedback during practise trials and observers who do not receive feedback during practise trials.

Method

Participants. The observers were 40 undergraduate students from a small liberal arts college who participated for partial experimental credit. Of the 40 observers, 20 observers were provided with feedback during the practise trials, and 20 observers were not provided with feedback during the practise trials.

Apparatus. The stimuli were displayed on and the data collected on a Gateway desktop computer equipped with a 15-in. colour monitor.

Stimuli. The moving target was a filled black square 20 pixels (approximately 0.83° of visual angle) in width, and was presented on a white background. On each trial, there were five successive presentations of the target that implied consistent rightward motion of the target or consistent leftward motion of the target, and consistent with previous representational momentum literature, these are referred to as *inducing stimuli*. Each inducing stimulus was presented for 250 ms, and there was a 250-ms interstimulus interval between successive inducing stimuli. For 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° 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 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 centered along the vertical axis. The probe was the same size, shape, and colour as the inducing stimuli. The probe was presented at the same vertical coordinates as the target, and was located at one of seven horizontal positions relative to the final location of the target: −6, −4, −2, 0, +2, +4, or + 6 pixels. Probe positions denoted by a minus sign indicated that the probe was backward (i.e., shifted in the direction opposite to motion of the target) from the final location of the target by the indicated number of pixels, and probe positions denoted by a plus sign indicated that the probe was forward (i.e., shifted in the direction of motion of the target) from the final location of the target by the indicated number of pixels; the zero probe position was the same as the final location of the target. Each participant received 112 trials (2 directions [leftward, rightward] × 7 probe positions [−6, −4, −2, 0, +2, +4, +6] × 8 replications) in a different random order.

Procedure. Observers were first given a practise session consisting of 20 practise trials that were randomly drawn from the experimental trials. Observers 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 ms. After the probe appeared, 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 final location of the target. On practise trials for those participants who received feedback, after entering their judgement, feedback in the form of the word *correct* or the word *error* was printed in the upper left quadrant of the display and remained visible until observers pressed a designated key to initiate the next trial. On practise trials for those participants who did not receive feedback, after entering their judgement, the display remained blank until observers pressed a designated key to initiate the next trial.

Results

The proportions of *same* responses for each probe position for each condition are shown in Figure 1. Consistent with previous studies in the displacement literature (e.g., Freyd & Jones, 1994; Hubbard, 1993; Munger, Solberg, Horrocks, & Preston, 1999), we determined estimates of the direction and magnitude of displacement on remembered location by calculating the arithmetic weighted mean (i.e., the sum of the products of the proportion of *same* responses and the distance of the probe from the final location of the moving target, in pixels, divided by the sum of the proportions of *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 observers displaced the final position of the target forward (in the direction of motion), and a negative weighted mean suggested observers 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 the displacement. The weighted means on experimental trials when feedback was present during practise trials, $t(19) = 4.253$, $p < .001$, and when feedback was absent during practise trials, $t(19) = 6.534$, $p < .001$, were significantly larger than zero (Bonferroni correction of .05/2 = .025), indicating that representational momentum occurred in both groups.

The weighted means were analysed using a 2 (Direction: leftward, rightward) × 2 (Feedback: present during practise trials, absent during practise trials) analysis of variance (ANOVA) in which direction was a within-subject variable and feedback was a between-subjects variable. Forward displacement on experimental trials when feedback was present during practise trials ($M = 0.99$, $SEM = 0.165$) did not differ from forward displacement on experimental trials when feedback was absent during practise trials ($M = 1.139$, $SEM = 0.165$), $F < 1$, $p = .525$, nor was the Feedback × Direction interaction significant, $F < 1$, $p = .753$. A significant effect of direction was found, $F(1, 38) = 7.648$, $p = .009$, with larger forward displacement with rightward motion ($M = 1.327$, $SEM = 0.167$) than with leftward motion ($M = 0.802$, $SEM = 0.131$).

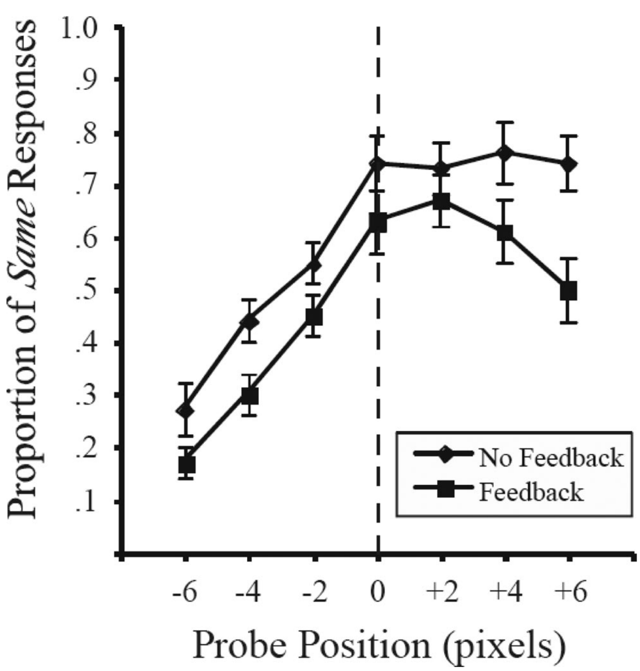

Figure 1. The proportion of *same* responses as a function of probe position in Experiment 1. The data for observers who received feedback during the practise trials are shown by filled squares, and the data for observers who did not receive feedback during the practise trials are shown by filled diamonds. Error bars depict the standard error of the mean.

Discussion

Whether observers received feedback in the practise trials did not appear to influence forward displacement on the subsequent experimental trials, and this is consistent with Finke and Freyd (1985). As Finke and Freyd suggested (see also Freyd, 1987), such findings might indicate that representational momentum is impenetrable to feedback, that is, the magnitude of forward displacement is not influenced by the observer's knowledge of his or her performance. However, given numerous other ways in which an observer's knowledge can influence displacement (for review, see Hubbard, 2005), such a conclusion would be surprising. As an alternative, it is possible that the amount of feedback given in the practise trials was simply insufficient for learning (and thus for any potential resultant modulation of representational momentum by learning) to occur, and that effects of feedback might have been found if feedback were given over a larger number of trials. Also, displacement was larger for rightward motion than for leftward motion. Although differences in forward displacement between rightward motion and leftward motion are not consistently reported in the representational momentum literature, when such differences do occur, forward displacement is usually larger for rightward motion (e.g., Halpern & Kelly, 1993).

Even though feedback did not influence the magnitude of forward displacement, inspection of Figure 1 suggests that the presence of feedback during the practise trials might have reduced the proportion of *same* responses during the experimental trials. Given that there were seven probe positions, six of which should have led to a *different* response and one of which should have led to a *same* response, the presentation of feedback on even the limited number of practise trials would have informed observers that a *different* response would have been correct on more trials than would a *same* response (i.e., the probability of a correct *same* response was relatively low). However, observers who did not receive feedback might have assumed that half of the responses should be *same* and half should be *different*. It is interesting that observers who received feedback during the practise trials apparently learned about the low probability of correct *same* responses in a relatively small number (20) of trials. Overall, then, the presence of feedback during practise trials did not influence the shape of the distribution of *same* responses (i.e., did not influence the weighted mean estimate of forward displacement) for the subsequent experimental trials, but there was a consistent trend for the presence of feedback to decrease the amplitude of the distribution of *same* responses (i.e., to influence the probability of a *same* response) for the subsequent experimental trials.

Experiment 2

The lack of any significant effect of feedback during practise trials on forward displacement in subsequent experimental trials in Experiment 1 might have reflected the limited amount of feedback that was provided during a limited number of practise trials. If observers were provided with more feedback, perhaps effects of feedback on subsequent forward displacement would be observed. However, it is not clear whether any changes due to feedback on a specific set of stimuli within a given block of trials would necessarily generalise to a different set of stimuli or a different block of trials. Accordingly, Experiment 2 presented the same target stimulus as Experiment 1, but some observers received feedback on a much larger number of trials. Each observer received two blocks of trials. Half of the observers received two blocks in which the presence or absence of feedback was consistent across blocks (i.e., feedback was given in both blocks or in neither block), and half of the observers received two blocks in which the presence or absence of feedback was inconsistent across blocks (i.e., feedback was given in one block and not given in the other block). In feedback blocks, observers received *correct* or *error* feedback regarding their response after every trial. In nonfeedback blocks, observers did not receive any feedback regarding their response. Munger and Owens (2004) reported that the magnitude of representational momentum remains consistent across blocks of trials; therefore, any change in forward displacement across blocks in Experiment 2 should be due to the presence or absence of feedback.

Method

Participants. The observers were 90 undergraduate students from the same participant pool used in Experiment 1, and none of the observers had participated in that earlier experiment. Two observers were excluded because of incomplete data. Of the 88 remaining observers, each was randomly assigned to one of four groups: a feedback/feedback (f/f) group that received feedback in both blocks ($n = 22$), a nonfeedback/nonfeedback (nf/nf) group that received feedback in neither block ($n = 22$), a feedback/nonfeedback (f/nf) group that received feedback in the first block and no feedback in the second block ($n = 22$), and a nonfeedback/feedback (nf/f) group that received no feedback in the first block and received feedback in the second block ($n = 22$).

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

Stimuli. The stimuli were the same as in Experiment 1 with the following exceptions: Each observer participated in two blocks of experimental trials, and each block was composed of 70 trials (2 directions [leftward, rightward] $\times$ 7 probe positions [-6, -4, -2, 0, $+2$, $+4$, $+6$] $\times$ 5 replications) presented in a different random order. Which pair of blocks a given observer received was dependent on the feedback group to which that observer was assigned: f/f, nf/nf, nf/f, f/nf.

Procedure. The observers were first given 20 practise trials randomly selected from the experimental trials. The results of Experiment 1 suggested that feedback given during practise would not influence forward displacement on subsequent experimental trials; however, to ensure that observers in the nf/nf and nf/f groups were as naïve as possible during the first block, and that all observers received the same type of practise trials, we provided no feedback to observers during practise trials. The presentation of the target and probe was the same as in Experiment 1. In feedback block trials, the observer received feedback regarding the accuracy of his or her response in the form of the word *correct* or the word *error* printed in the display after the observer indicated whether the probe was in the same or different position as the final inducing stimulus. In nonfeedback block trials, the observer did not receive feedback regarding the accuracy of his or her response. Observers were then prompted to press a designated key to initiate the next trial. Each observer received two blocks of trials, and there was a brief break between blocks.

Results

The proportions of *same* responses for each probe position for each feedback group are shown in Figure 2, and weighted means were calculated as in Experiment 1. The weighted means in the f/f group, $t(21) = 4.076$, $p < .001$, nf/nf group, $t(21) = 9.716$, $p < .001$, f/nf group, $t(21) = 4.241$, $p < .001$, and nf/f group, $t(21) = 8.435$, $p < .001$, were all significantly larger than zero (Bonferroni correction of $.05/4 = .013$), indicating that representational momentum occurred in all groups.

Weighted means were analysed with a 2 (Direction: leftward, rightward) $\times$ 2 (Block: first, second) $\times$ 4 (Feedback Group: f/f, nf/nf, f/nf, nf/f) ANOVA with direction and block as within-subject variables and feedback group as a between-subjects variable. As shown in panel A of Figure 3, neither block, $F < 1$, $p = .957$, nor feedback group, $F(1, 84) = 1.334$, $p = .269$, reached significance. The Block $\times$ Feedback Group interaction was significant, $F(3, 84) = 2.874$, $p = .041$; observers in the nf/nf group exhibited smaller forward displacement in the second block ($M = 0.888$, $SEM = 0.127$) than in the first block ($M = 1.381$, $SEM = 0.135$), $t(21) = 4.241$, $p < .001$, but no difference in forward displacement was found between the first block and the second block for the f/nf group, $t(21) = -1.016$, $p = .321$, the nf/f group, $t(21) = -1.39$, $p = .179$, or the f/f group, $t(21) = 0.796$, $p = .435$. Consistent with Experiment 1, there was also a significant effect of direction, $F(1, 84) = 6.592$, $p = .012$, with rightward motion ($M = 1.197$, $SEM = 0.106$) resulting in larger forward displacement than did leftward motion ($M = 0.943$, $SEM = 0.114$). No other main effects or interactions were significant.

An additional analysis was conducted in which the four feedback groups were collapsed into two conditions: a consistent condition in which feedback was either present in both blocks or absent in both blocks (i.e., the f/f and nf/nf groups), and an inconsistent condition in which feedback was present in one block and absent in the other block (i.e., the f/nf and nf/f groups). A 2 (Block: first, second) $\times$ 2 (Condition: consistent, inconsistent)

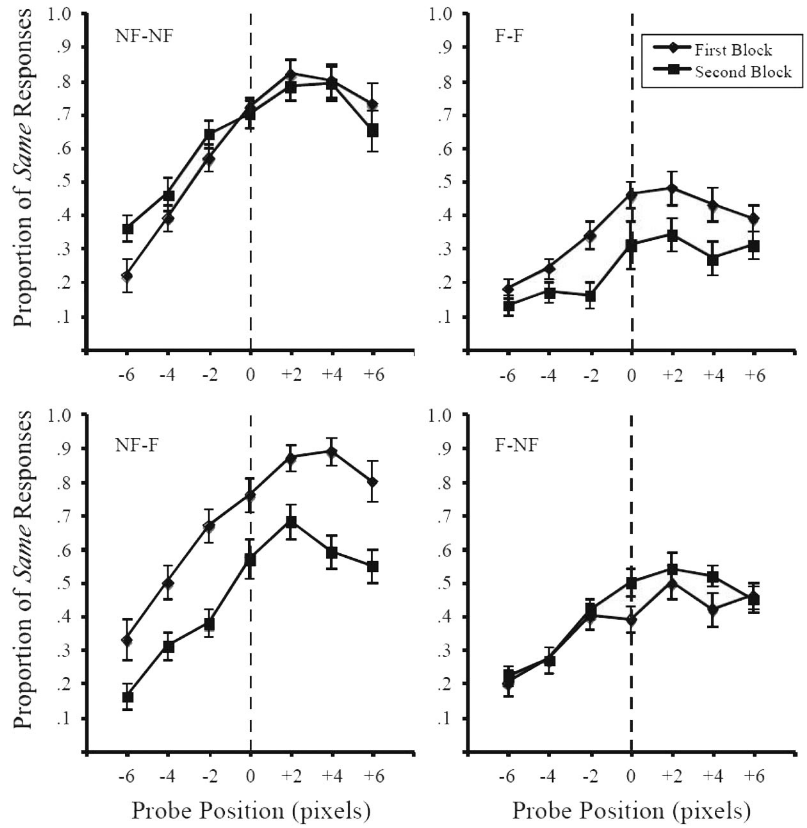

Figure 2. The proportion of *same* responses as a function of probe position in Experiment 2. The panel in the upper left shows the data for observers in the nonfeedback/nonfeedback group, and the panel in the upper right shows the data for observers in the feedback/feedback group. The panel in the lower left shows the data for observers in the nonfeedback/feedback group, and the panel in the lower right shows the data for observers in the feedback/nonfeedback group. In all panels, data from the first block are shown by filled diamonds, and data from the second block are shown by filled squares. Error bars depict the standard error of the mean.

ANOVA was conducted with block as a within-subject variable and condition as a between-subjects variable. Neither block, $F < 1$, $p = .679$, nor condition, $F < 1$, $p = .418$, reached significance. A significant Block × Condition interaction occurred, $F(1, 88) = 9.296$, $p = .003$; observers in the consistent condition exhibited smaller forward displacement in the second block ($M = 0.709$, $SEM = 0.168$) than in the first block ($M = 1.129$, $SEM = 0.154$), $t(45) = 2.848$, $p = .007$, whereas observers in the inconsistent condition exhibited a trend for larger forward displacement in the second block ($M = 1.238$, $SEM = 0.171$) than in the first block ($M = 0.919$, $SEM = 0.158$), $t(43) = -1.644$, $p = .107$.

Discussion

Forward displacement was not directly influenced by whether observers received no feedback, one block of feedback, or two blocks of feedback. This initially appears consistent with Finke and Freyd's (1985) suggestion that representational momentum is impervious to feedback. However, examination of Figure 2 suggests the proportion of *same* responses was generally lower in the feedback blocks than in the nonfeedback blocks, and this was similar to the slightly lower proportion of *same* responses on experimental trials when observers received feedback during practise trials in Experiment 1. As in Experiment 1, the presentation of feedback in Experiment 2 could have informed observers that a response of *different* would be correct on more trials than would a response of *same*; however, observers who did not receive any feedback in Experiment 2 (or observers who only later received feedback) might have initially assumed that half of the responses should be *same* and half should be *different*. The notion that feedback reduces the overall probability of *same* responses but does not influence the weighted mean estimates of forward displacement is consistent with the differences between nf/f and f/nf groups: In the nf/f group, feedback was not given until the second block, and there was a large difference between the blocks, whereas in the f/nf group, feedback was given during the first block, and the information regarding the relative number of *same* responses and *different* responses carried over into the second block.

When feedback was consistently provided (or not provided) across blocks, observers exhibited smaller forward displacement in the second block than in the first block. One possible explanation is that in consistent conditions, implicit perceptual learning of the

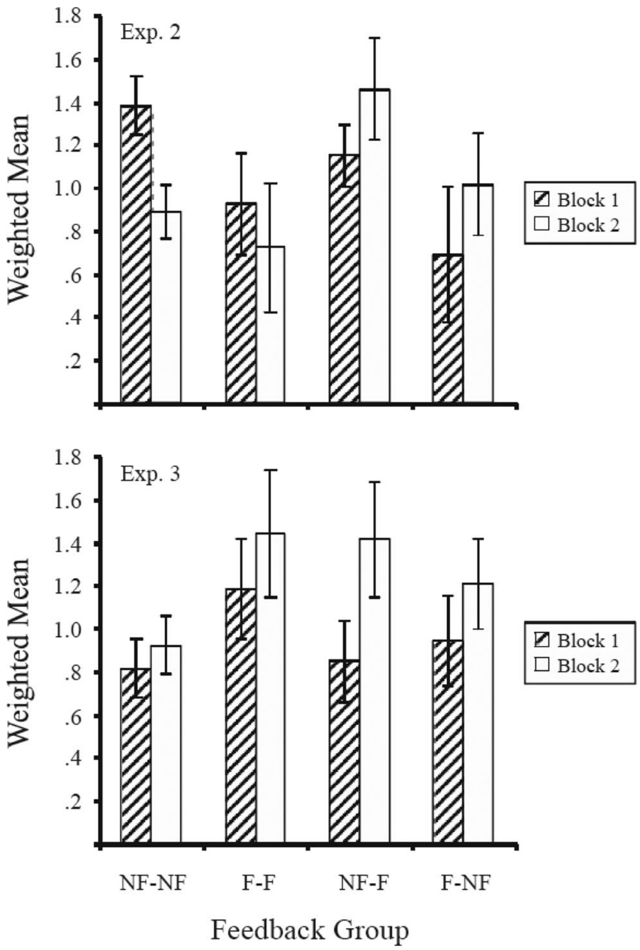

Figure 3. Weighted mean estimates of displacement in Experiments 2 (upper panel) and 3 (lower panel). The weighted means for the first block of trials are shown by the striped columns, and the weighted means for the second block of trials are shown by the white columns. Error bars depict the standard error of the mean.

target occurred over repeated target presentations. Repetitive exposure to experimental stimuli in perceptual tasks such as shape classification (Munsinger, 1965), line drawing to match block size (Baker & Young, 1960), and drawing a 4-in. line with eyes closed (Seashore & Bavelas, 1941) often improves performance on those tasks even when explicit feedback is not provided. Similarly, observers who repeatedly view stimuli evoking the Müller-Lyer illusion (Coren & Porac, 1984) or Ponzo illusion (Predebon, 1990) exhibit a decreased magnitude of illusion simply through increased exposure. Improvements in performance with increasing exposure in these cases have been attributed to perceptual learning; thus, decreases in displacement with increasing exposure to a consistent trial structure (i.e., in the consistent conditions) might result from similar perceptual learning. A change in trial structure from the presence of feedback to the absence of feedback, or from the absence of feedback to the presence of feedback, might have disrupted such perceptual learning. However, the existence of perceptual learning potentially decreasing forward displacement across blocks does not initially seem consistent with Munger and Owens' (2004) finding that representational momentum did not decrease across blocks.

Experiment 3

The type of feedback given in Finke and Freyd (1985) and in Experiments 1 and 2 was relatively uninformative in that feedback of *error* did not inform the observer whether a different probe that elicited a *same* response was in front of or behind the actual target location (nor did feedback of *error* inform the observer whether a same probe that elicited a *different* response was at the actual location). Without knowing the direction of the error, it might be more difficult to use such feedback to improve performance. Thus, the general lack of an effect of feedback in Experiments 1 and 2 might reflect the relatively uninformative nature of the feedback rather than any cognitive impenetrability of representational momentum to feedback per se. Accordingly, in Experiment 3, a more informative type of feedback was provided: When observers responded incorrectly, feedback specified whether the probe had actually been in front of, behind, or at the same location as the target. The same f/f, nf/nf, f/nf, nf/f groups used in Experiment 2 were used in Experiment 3.

Method

Participants. The observers were 92 undergraduate students from the same participant pool used in Experiment 1, and none of the observers had participated in the previous experiments. One observer was excluded from the analysis because of incomplete data. Of the 91 remaining observers, each was randomly assigned to one of four groups: an f/f group ($n = 22$), an nf/nf group ($n = 23$), an f/nf group ($n = 25$), and an nf/f group ($n = 21$).

Apparatus. The apparatus was the same as in Experiments 1 and 2.

Stimuli. The stimuli were the same as in Experiment 2.

Procedure. The procedure used was similar to that of Experiment 2 with the following exceptions: For error responses, there were three types of feedback, *error—in front of*, *error—behind*, *error—it was in the correct position*. For correct responses, there was only one type of feedback, *correct*.

Results

The proportions of *same* responses for each probe position for each condition are shown in Figure 4, and weighted means were calculated as in Experiment 1. The weighted means in the f/f group, $t(21) = 5.65$, $p < .001$, nf/nf group, $t(22) = 6.842$, $p < .001$, f/nf group, $t(24) = 6.146$, $p < .001$, and nf/f group, $t(20) = 5.568$, $p < .001$, were all significantly larger than zero (Bonferroni correction of $.05/4 = .013$), indicating that representational momentum occurred in all groups.

Weighted means were analysed with a 2 (Direction: leftward, rightward) $\times$ 2 (Block: first, second) $\times$ 4 (Feedback Group: f/f, f/nf, nf/f, nf/nf) ANOVA, with direction and block as within-subject variables and feedback group as a between-subjects variable. Consistent with Experiment 2, feedback group did not reach significance, $F < 1$, $p = .548$. Unlike in Experiment 2, block was significant, $F(1, 87) = 6.954$, $p = .01$, with larger forward displacement in the second block ($M = 1.263$, $SEM = 0.126$) than in

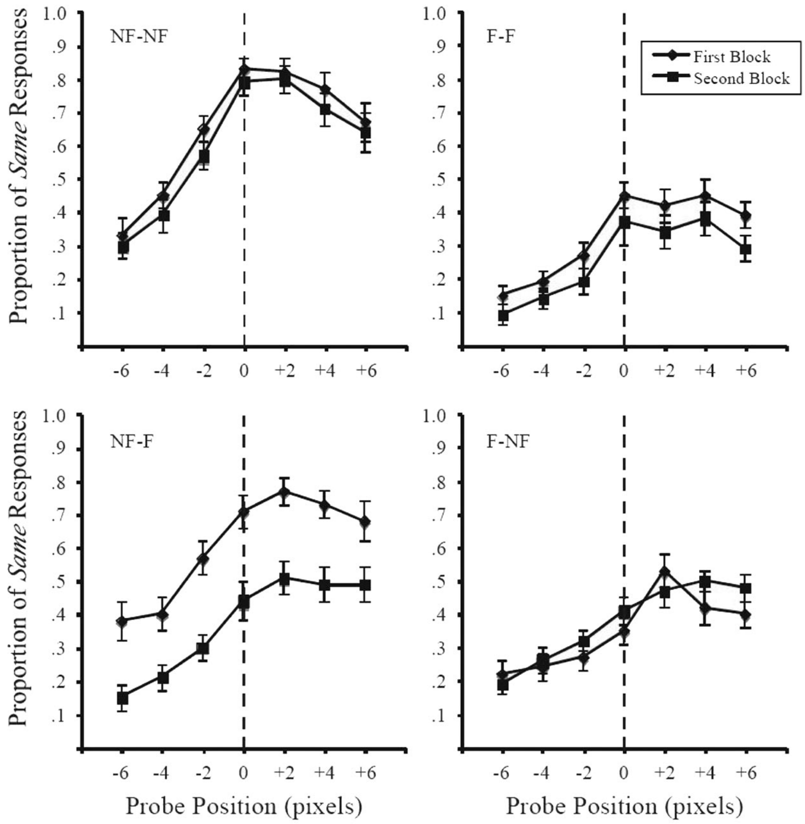

Figure 4. The proportion of *same* responses as a function of probe position in Experiment 3. The panel in the upper left shows the data for observers in the nonfeedback/nonfeedback group, and the panel in the upper right shows the data for observers in the feedback/feedback group. The panel in the lower left shows the data for observers in the nonfeedback/feedback group, and the panel in the lower right shows the data for observers in the feedback/nonfeedback group. In all panels, data from the first block are shown by filled diamonds, and data from the second block are shown by filled squares. Error bars depict the standard error of the mean.

the first block ($M = 0.93$, $SEM = 0.101$). As shown in panel B of Figure 3, observers in the nf/f group exhibited larger forward displacement in the second block ($M = 1.416$, $SEM = 0.267$) than in the first block ($M = 0.848$, $SEM = 0.189$), but no difference in forward displacement was found between the first block and the second block for the f/nf group, $t(24) = -1.309$, $p = .203$, the nf/nf group, $t(22) = -1.091$, $p = .287$, or f/f group, $t(24) = -1.014$, $p = .322$.

The Direction × Block × Feedback Group interaction was significant, $F(3, 87) = 2.724$, $p = .049$, with observers in the nf/nf group exhibiting larger forward displacement in the first block ($M = 1.11$, $SEM = 0.243$) than in the second block ($M = 0.966$, $SEM = 0.315$), but only with rightward motion. With leftward motion, the effect was reversed, as observers exhibited larger forward displacement in the second block ($M = 0.909$, $SEM = 0.263$) than in the first block ($M = 0.55$, $SEM = 0.224$). Consistent with Experiments 1 and 2, there was also a significant effect of direction, $F(1, 87) = 3.739$, $p = .056$, with rightward motion ($M = 1.198$, $SEM = 0.115$) resulting in larger forward displacement than did leftward motion ($M = 0.995$, $SEM = 0.103$). No other main effects or interactions were significant.

As in Experiment 2, a second analysis was conducted in which the four feedback groups were collapsed into two conditions: a consistent condition in which feedback was either present in both blocks or absent in both blocks, and an inconsistent condition in which feedback was present in one block and absent in the other block. A 2 (Block: first, second) × 2 (Condition: consistent, inconsistent) ANOVA was conducted with block as a within-subject variable and condition as a between-subjects variable. Neither condition, $F < 1$, $p = .861$, nor the Condition × Block interaction, $F < 1$, $p = .381$, was significant. Block was significant, $F(1, 89) = 7.94$, $p = .006$, with larger forward displacement in the second block ($M = 1.24$, $SEM = 0.12$) than in the first block ($M = 0.93$, $SEM = 0.10$).

Discussion

As in Experiment 2, forward displacement was not directly influenced by whether observers received no feedback, one block of feedback, or two blocks of feedback. We had hypothesised that forward displacement should have decreased more with more informative feedback in Experiment 3 than with less informative feedback in Experiment 2; however, even with the additional information provided by the more specific forms of error feedback in Experiment 3, there was no main effect of feedback group on forward displacement. Thus, the lack of a main effect of feedback on forward displacement in Experiments 1 and 2 was not due to the use of relatively less informative feedback in those experiments. Unlike in Experiment 2, in Experiment 3 the second block exhibited larger forward displacement than did the first block (regardless of feedback group), and forward displacement in the consistent and inconsistent conditions did not differ. Why might consistency with more informative feedback in Experiment 3 not improve performance across blocks, but consistency with less informative feedback in Experiment 2 improve performance across blocks? One possibility is that the more informative feedback in Experiment 3 triggered deeper or more complete processing (or a different processing mode) in which effects of feedback were less susceptible to changes in trial structure in the inconsistent conditions than were observed in Experiment 2.

General Discussion

When observers were provided with explicit feedback regarding their judgements of the final location of a target undergoing implied motion, that feedback did not appear to influence the magnitude of representational momentum for that target. This apparent lack of a main effect of feedback on forward displacement occurred when feedback was given during practise trials in Experiment 1, throughout two blocks of experimental trials in Experiments 2 and 3, and when feedback specified the direction of an observer's error in Experiment 3. The lack of a main effect of feedback on forward displacement appears consistent with Finke and Freyd's (1985; Freyd, 1987) claims that representational momentum is impervious to error feedback. However, forward displacement decreased when the presence or absence of feedback was consistent across blocks in Experiment 2, and a trend was observed for forward displacement to be smallest in the nf/nf groups in both Experiments 2 and 3. Thus, feedback might influence representational momentum, but in a more subtle way than simply providing explicit information that observers can use to decrease forward displacement per se.

Even though extensive feedback did not influence the shift of the distribution of *same* responses (i.e., did not influence forward displacement), inspection of Figures 1, 2, and 4 suggests that feedback did influence the amplitudes of the distributions of *same* responses (i.e., did influence the proportion of *same* responses). Such an influence of feedback was found even in Experiment 1, in which feedback was provided in only a small number of practise trials. The effect of feedback on the proportion of *same* responses is especially noticeable in the nf/f groups in Experiments 2 and 3; as in those groups, a relatively higher proportion of *same* responses with no feedback in the first block was followed by a lower proportion of *same* responses with feedback in the second block. In the nf/nf groups and f/f groups, there was no such drop in the proportion of *same* responses from the first block to the second block; in the f/nf groups, the learning from the first block regarding the proportion of correct *same* or *different* responses carried over into the second block even though there was no feedback in the second block.

It should be noted that forward displacement occurred in all feedback groups and conditions; therefore, even if feedback can influence responding (e.g., influence the probability of a *same* response), it cannot eliminate forward displacement. This is consistent with Courtney and Hubbard's (in press) finding that knowledge of representational momentum did not eliminate forward displacement, and is also consistent with Finke and Freyd's (1989) and Hubbard's (2005, 2006) suggestion that displacement consists of both modular (i.e., cognitively penetrable, influenced by feedback or other information) and nonmodular (i.e., cognitively impenetrable, not influenced by feedback or other information) components. The only other example of information to which displacement is apparently impenetrable involves explicit knowledge of physical principles (see Freyd & Jones, 1994; Kozhevnikov & Hegarty, 2001). It is interesting that both data regarding (the lack of) effects of explicit knowledge of physical principles on displacement and data regarding (the lack of) effects of explicit feedback on displacement reported here involve knowledge regarding an *objectively correct answer*, whereas most other examples of cognitively penetrable information merely involve an *expectation*. Of course, any expectations could potentially involve beliefs regarding objectively correct (or believed to be correct) behaviour, and although the difference between *objectively correct* and merely *expected* is suggestive, it is not yet clear why the mental representation of the target is penetrable to only certain types of information.

The smaller displacement in the consistent conditions than in the inconsistent conditions in Experiment 2 and the trend for a smaller displacement in the nf/nf group in both Experiments 2 and 3 are not the types of effects generally associated with feedback. Feedback would normally be expected to increase the accuracy or precision of performance (i.e., decrease displacement), and more informative feedback would be expected to lead to greater increases in accuracy or precision. Why would always giving feedback or never giving feedback in both blocks in Experiment 2 result in smaller average forward displacement than would giving feedback in only one of the two blocks? Furthermore, why would this effect disappear with more informative feedback in Experiment 3? It might be that the change in trial structure (i.e., the presence or absence of feedback) between blocks in the inconsistent conditions in Experiment 2 interfered with transfer of relatively weaker learning from the first block to the second block, and so the second block was treated as a different or new stimulus. Given the more specific information in Experiment 3, learning would not have been as weak, and so might have been more resistant to disruption in trial structure. The possibility that learning can be so easily disrupted is consistent with the possibility that improvement is actually due to implicit perceptual learning because perceptual learning would (at least initially) be expected to be closely tied to a specific stimulus.

Given the trend toward smaller forward displacement in the nf/nf groups, the presence of feedback could be argued to increase displacement. Why might feedback increase displacement? One possibility is that the presence of feedback increased processing demands on observers. Given that increases in processing demands might decrease the amount of attention devoted solely to the target, coupled with Hayes and Freyd's (2002) finding that forward displacement increased under divided attention, feedback might have increased forward displacement by diverting attention away from the target. A second possibility is that feedback might emphasise how the observers responded rather than emphasise the target per se. Wulf and Prinz (2001) argued that actions are learned more efficiently when the focus is on the target and not on the sequence of motor actions (i.e., on the response of the learner); if feedback focused relatively more attention on the response of the observer than on the target, then feedback could have disrupted perceptual learning of target location. A third possibility is that presentation of explicit feedback might interfere with such normal implicit perceptual learning mechanisms (e.g., similar to the interference of explicit strategies to discover grammar with implicit learning in Reber, 1993), and so any perceptual learning of target location over repeated trials would not occur.

The claim that representational momentum is impervious to feedback initially suggested that feedback regarding any discrepancy between the actual final location of the target and remembered final location of the target should not influence representational momentum. Although feedback did not influence representational momentum in the obvious way of decreasing forward displacement, the experiments reported here suggest feedback did influence the probability of a *same* response to different probe positions. Feedback also had the seemingly paradoxical effect of producing larger forward displacement in some conditions (e.g., the nf/nf groups in Experiments 2 and 3 exhibited the smallest displacement). In addition, in Experiment 2, forward displacement decreased when feedback was always given or never given as compared to when feedback was given in one block and not in the other block. The reason for these surprising effects of feedback is not yet clear, but might involve an increase in information to be processed, a focus on the response rather than the target, and a possible interference of explicit feedback with implicit perceptual learning. Although the current study clearly established that representational momentum is not totally impervious to error feedback, and thus offers an important constraint on future theories of representational momentum, elucidation of the precise ways in which error feedback can affect representational momentum remains for future research.

Résumé

L'influence de la rétroaction sur le momentum représentationnel de la localisation finale d'une cible en mouvement a été examinée dans trois expériences. La présence d'une rétroaction binaire (« correct », « erreur ») durant les essais de pratique ou durant des blocs expérimentaux plus longs n'a pas réduit le momentum représentationnel, tout comme la présence d'une rétroaction plus informative, spécifiant la direction des erreurs (« erreur - devant », « erreur - derrière ») durant des blocs d'essais expérimentaux plus longs. Les effects d'une présentation consistante ou non de la rétroaction sur le momentum représentationnel ont été inconsistants. Même si la rétroaction n'a pas réduit le momentum représentationnel en tant que tel, la rétroaction a influé sur la probabilité d'émettre une *même* réponse pour des cibles situées à des positions différentes. Les implications de ces observations par rapport à l'affirmation de Finke et Freyd (1985; Freyd, 1987) selon laquelle le momentum représentationnel serait insensible à la rétroaction des erreurs ainsi que les rôles possibles de l'apprentissage perceptuel dans le momentum représentationnel sont discutés.

Mots-clés : momentum représentationnel, rétroaction de l'erreur, déplacement

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Received November 19, 2007
Accepted May 8, 2008 ■