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An effect of contrast and luminance on visual representational momentum for location

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Abstract. Effects of the contrast of target luminance and background luminance, and of the absolute level of target luminance, on representational momentum for the remembered final location of a previously viewed moving target were examined. Targets were high in contrast or luminance, decreasing in contrast or luminance, increasing in contrast or luminance, or low in contrast or luminance; the background was black or white. Representational momentum for target location was larger if targets were high or increasing in contrast or luminance and smaller if targets were low or decreasing in contrast or luminance. Representational momentum for target location was larger if targets were presented on a white background than on a black background. Implications for theories of localization and for theories of representational momentum are discussed.

Keywords: representational momentum, contrast, luminance, spatial cognition, displacement

1 Introduction

The judged final location of a moving target is often displaced (ie mislocalized) in the direction of target motion, and this displacement has been referred to as *representational momentum* (eg Freyd & Finke, 1984). The effects of numerous variables and stimulus features on representational momentum for location have been investigated in detail (for review, see Hubbard, 2005, in press), but two variables that have not been systematically investigated are contrast of the target to the background and the overall luminance of the target. Given that targets with less contrast or lower luminance might not be detected as easily, processing of such targets might require more attention. Given that increases in attention decrease representational momentum for location (Hayes & Freyd, 2002; Hubbard, Kumar, & Carp, 2009), such targets might be predicted to exhibit decreased representational momentum. Alternatively, targets with less contrast or lower luminance might result in weaker motion signals; given that weaker motion signals have been suggested to result in larger forward displacement (Maus & Nijhawan, 2009), such targets might be predicted to exhibit increased representation momentum. Accordingly, the study reported here presented a target that increased, decreased, or maintained constant luminance on a white or black background, and forward displacement for final location of the target was measured.

In the first reported study on luminance and representational momentum, Brehaut and Tipper (1996) presented a stationary target that increased or decreased in luminance, and participants judged whether a subsequently presented probe was lighter or darker than the final target luminance. Memory for final target luminance was displaced backward (in the direction opposite to representational momentum), and the magnitude of backward displacement increased with increases in the length of the retention interval (up to nearly 800 ms). Brehaut and Tipper also presented a target that changed in orientation and in luminance; if participants judged final target orientation, forward displacement of remembered location (consistent with representational momentum) occurred, whereas if participants judged final target luminance, backward displacement of remembered luminance (inconsistent with representational momentum) occurred. Thus, whether representational momentum occurred was a function of which stimulus dimension participants attended. More broadly, Brehaut and Tipper suggested that representational momentum occurred for only dimensions of change that were strongly correlated with motion in the world (cf Finke, Freyd, & Shyi, 1986; Freyd, 1987), and because changes in luminance of an object are not strongly correlated with motion (ie with changes in position), memory for target luminance did not exhibit forward displacement.

Favretto (2002) presented a stationary target that increased or decreased in luminance during each trial, and luminance of the background surrounding the target varied across trials. Consistent with Brehaut and Tipper (1996), Favretto found that memory for final target luminance was displaced backward; furthermore, the magnitude of backward displacement increased if targets on a darker background increased in luminance or if targets on a lighter background decreased in luminance (ie displacement of remembered luminance increased with increases in contrast). There appeared to be at least two components to the displacement Favretto observed: a bias in the direction opposite target luminance change, and a bias toward the luminance of the background. If these biases operated in the same direction, displacement increased, whereas if these biases operated in opposite directions, displacement decreased. The effect of background luminance on memory for target luminance is similar to the effect of background orientation on memory for target orientation, as remembered final target orientation is also biased in the direction of background orientation (ie representational momentum of a rotating target increased if the orientation of a surrounding square frame was rotated forward from the final target orientation and decreased if the orientation of a surrounding square frame was rotated backward from the final target orientation; Hubbard, 1993).

Maus and Nijhawan (2006) measured displacement of the remembered location of a white dot (a) at a constant luminance that traveled a short distance and abruptly vanished or (b) that decreased in luminance as it traveled a longer distance. Targets were presented on a dark background. Participants could detect the target at a lower luminance if the target traveled a longer trajectory. Maus and Nijhawan suggested that a longer trajectory allowed development of an internal model based on previous motion of the target, and that this internal model resulted in forward displacement.[(1)] Maus and Nijhawan (2009) presented two simultaneously moving targets in modified flash–lag effect displays (in a flash–lag effect display, a briefly presented stationary object aligned with a moving target is perceived to lag behind that moving target; for review, see Hubbard, 2014), and if one of the targets abruptly vanished, memory for the vanishing point location was not displaced or exhibited a small

[(1)] Although Maus and Nijhawan (2006) did not explicitly mention representational momentum, it should be noted that representational momentum involves a similar forward displacement of a moving target, and Maus and Nijhawan's proposed model shares many features of representational momentum. For example, Maus and Nijhawan stated "motion in the model cannot be stopped instantaneously" (page 4380), which is nearly identical to prior characterizations of representational momentum (eg Finke et al., 1986, page 176, stated "mental extrapolations, like moving objects, cannot be instantly halted. Instead, they continue for some time … mental extrapolations are likewise more difficult to stop as the implied velocity of the inducing displays increases"). Also, Maus and Nijhawan's notion that abrupt disappearance of a target triggers a process to compensate for forward displacement has previously been discussed in the representational momentum literature (eg "cognitive resistance" in Finke et al., 1986; "compensation" in Joordens, Spalek, Razmy, & van Duijn, 2004). Relatedly, Maus and Nijhawan (2009) discuss a velocity effect in their data as an apparently new finding (eg "our results show a forward displacement of the perceived position of the moving object. The forward displacement scales with the speed of motion", page 613, "which reveals a roughly linear relationship between speed and amount of forward displacement", page 615), but such an effect is well established in the representational momentum literature (Hubbard, 1995, 2005).

backward displacement, but memory for the location of the other target at the time the first target vanished was displaced forward. Maus and Nijhawan (2009) claimed that a weaker motion signal or stronger offset transient signal should result in less forward displacement, and this predicts a smaller displacement for low or decreasing-contrast targets; curiously, this appears opposite to the larger forward displacement for decreasing-contrast targets reported in Maus and Nijhawan (2006).

Stimuli in Maus and Nijhawan (2006) were limited to relatively light targets (that in some conditions decreased in luminance during a trial) presented on a dark background, and so it is not clear whether their results reflect the decrease in contrast between the target and the background or the absolute luminance of the target. If the former, then targets that increased in contrast to the background should result in decreased forward displacement, but if the latter, then targets that increased in luminance on a light background should result in increased forward displacement. In order to evaluate whether relative contrast or absolute luminance of the target influences displacement, and to determine which of these variables contributed to the results of Maus and Nijhawan, it is necessary to examine effects of changes in contrast using dark backgrounds and light backgrounds as well as targets that increase in luminance and targets that decrease in luminance. If effects of contrast and luminance consistent with Maus and Nijhawan's claims are found with a wider range of contrast and luminance values, then their suggestions regarding abrupt vanishing of targets and the role of transients in target localization would be supported. Alternatively, if effects of contrast and luminance inconsistent with Maus and Nijhawan's claims are found, then their suggestions would not be supported.

In the experiment reported here, participants viewed a horizontally moving target on a white or black background. The contrast of the target to the background was high, decreasing from high to low, increasing from low to high, or low. A probe at the same luminance and contrast as the final target luminance and contrast was presented, and participants indicated whether the probe was at the location where the target vanished or at a different location. The location of the probe relative to the final target location varied across trials, and this allowed estimation of any potential displacement between the judged vanishing location and the actual vanishing location. Whether Maus and Nijhawan's (2006, 2009) findings regarding displacement of a moving target are limited to targets that decrease in luminance on a dark background or are more applicable to a wider range of luminance and contrast values is examined. Maus and Nijhawan (2006, 2009) suggested that a strong transient signal occurred with an abrupt offset, and that this transient signal retroactively attenuated forward displacement generated by the internal model (cf postdiction in Brenner & Smeets, 2000; Eagleman & Sejnowski, 2000). Although all targets in the current experiment vanished abruptly, high-contrast or increasing-contrast targets could result in relatively stronger transient signals than would low-contrast or decreasing-contrast targets, and so Maus and Nijhawan's suggestion predicts that high-contrast or increasing-contrast targets should exhibit smaller forward displacement than do low-contrast or decreasing-contrast targets.

2 Method

2.1 *Participants*

The participants were thirty undergraduates from the University of South Carolina, Upstate, who participated for partial course credit and were naive to the hypotheses, and all participants had normal or corrected-to-normal vision. Fifteen participants (one male, fourteen females; 18–24 years of age) viewed targets presented on a white background, and fifteen participants (two males, thirteen females; 18–24 years of age) viewed targets presented on a black background.

2.2 *Apparatus*

The stimuli were displayed upon, and the data were collected with, a Gateway desktop computer connected to 17-inch color monitor (Dell Ultra Sharp 1708 FP) with a refresh rate of 60 Hz and a resolution of 1024 × 768 pixels.[2] Participants' head and eye movements were not constrained, and the average viewing distance was approximately 60 cm.

2.3 *Stimuli*

The target was a square 20 pixels (approximately 0.83 deg) in width and in height and was presented on a black (0.68 cd m^{-2}) or white (181.50 cd m^{-2}) background. As shown in figure 1, there were five successive presentations of the target that implied consistent rightward motion or consistent leftward motion, and these are referred to as *inducing stimuli*. Each inducing stimulus was presented for 250 ms, and there was a 250 ms interstimulus interval between inducing stimuli (during which the display was blank); this resulted in an approximate target velocity of 3.32 deg s^{-1}. The vertical coordinates of the inducing stimuli were approximately centered along the vertical axis of the display. 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 were located 40 pixels (approximately 1.66 deg) 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.

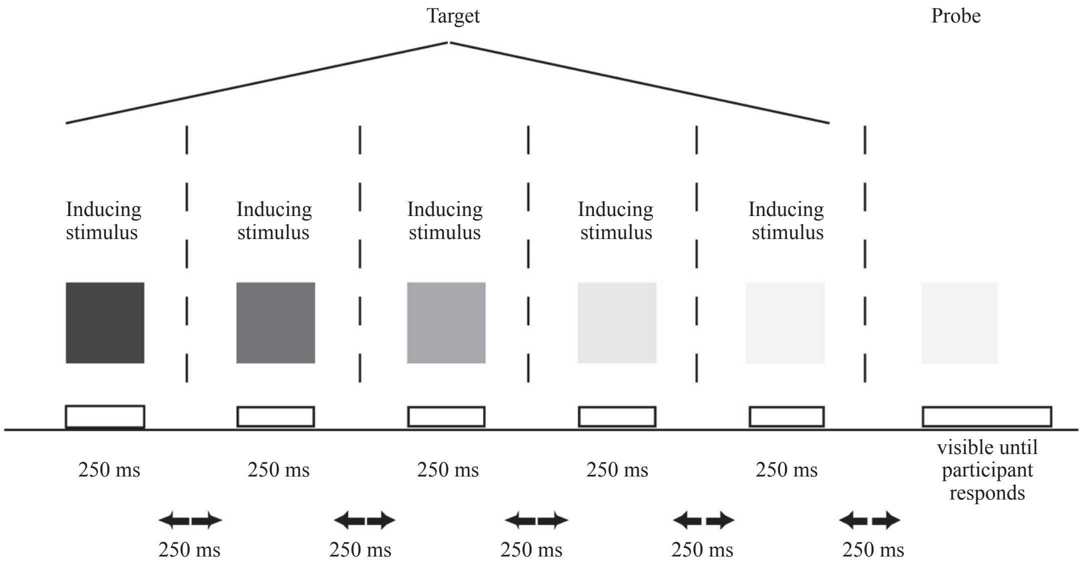

Figure 1. The structure of a trial. A sequence of five inducing stimuli which composed the target were presented. Each inducing stimulus was presented for 250 ms, and there was a 250 ms between successive inducing stimuli and between the final inducing stimulus and the probe. The example here demonstrates the decreasing-contrast condition.

[2] LCD monitors such as the one used in the experiment reported here can exhibit slightly different latencies in changing from black to white than in changing from white to black (or, more generally, in changing between different hue or brightness levels), and such differences might influence onset or offset times of inducing stimuli (for discussion, see Elze & Tanner, 2012). Accordingly, target onset and offset times were independently confirmed, and no systematic bias toward earlier or later times as a function of condition was found. We thank an anonymous reviewer for bringing this issue to our attention.

There were four different types of targets, and these varied in the contrast between the target and the background: high, decreasing, increasing, and low. Luminance values for each inducing stimulus, for each target type, are listed in table 1. In high-contrast targets, all of the inducing stimuli exhibited the same high contrast to the background (if the background was white, the target was dark gray; if the background was black, the target was light gray). In decreasing-contrast targets, the first inducing stimulus exhibited high contrast to the background, and subsequent inducing stimuli exhibited successively decreasing contrast to the background (if the background was white, the target began as dark gray and ended as light gray; if the background was black, the target began as light gray and ended as dark gray). In increasing-contrast targets, the first inducing stimulus exhibited low contrast to the background, and subsequent inducing stimuli exhibited successively increasing contrast to the background (if the background was white, the target began as light gray and ended as dark gray; if the background was black, the target began as dark gray and ended as light gray). In low-contrast targets, all of the inducing stimuli exhibited the same low contrast to the background (if the background was white, the target was light gray; if the background was black, the target was dark gray). In order to minimize potential across-trial disruptions from adaptation to a different background, visual persistence, or visual aftereffects (eg the much larger surface area of the background than of the target might make it more difficult to detect a dark target on a light background if participants had just viewed a light target on a dark background in the previous trial), background was treated as a between-subjects variable.

Table 1. Luminance values of stimuli.

	Inducing stimulus/cd m^{-2}				
	1	2	3	4	5
High					
white background	2.87	2.87	2.87	2.87	2.87
black background	144.60	144.60	144.60	144.60	144.60
Decreasing					
white background	2.87	16.51	46.86	90.63	144.80
black background	144.60	88.58	44.44	14.89	1.43
Increasing					
white background	144.80	90.63	46.86	16.51	2.87
black background	1.43	14.89	44.44	88.58	144.60
Low					
white background	144.80	144.80	144.80	144.80	144.80
black background	1.43	1.43	1.43	1.43	1.43

The probe was a square the same size and luminance as the final inducing stimulus. The probe was located at the same vertical coordinates as the inducing stimuli and at one of seven positions relative to the horizontal coordinates of the final inducing stimulus: –9, –6, –3, 0, +3, +6, +9 pixels. Probe positions denoted by a minus sign indicated the probe was backward (shifted in the direction opposite to target motion) by the indicated number of pixels, and probe positions denoted by a plus sign indicated the probe was forward (shifted in the direction of target motion) by the indicated number of pixels; the zero probe position was in the same location as the actual final location of the target. Each participant received 280 trials [4 contrasts (high, decreasing, increasing, low) × 2 directions (rightward, leftward) × 7 probes (–9, –6, –3, 0, +3, +6, +9) × 5 replications] in a different random order.

2.4 *Procedure*

Room lights were left on during the experiment, and the ambient room illumination level was approximately 347 lux. Participants were first given a practice session consisting of 10 practice trials that were randomly drawn from the experimental trials. Participants pressed a designated key to begin each trial. There was a 1000 ms pause, and then the inducing stimuli were presented. After the final inducing stimulus vanished, there was a retention interval of 250 ms before the probe was presented. After the probe was presented, participants pressed a key marked 'S' or a key marked 'D' (the 'M' and 'C' keys, respectively, of a standard keyboard) to indicate if the location of the probe was the same as or different from the final location of the target. Participants then initiated the next trial.

3 Results

The average probability of a *same* response for each probe position for each contrast and background condition is shown in figure 2. Consistent with previous studies of displacement for the final location of a previously viewed target (eg Hayes & Freyd, 2002; Hubbard et al., 2009; Munger, Solberg, Horrocks, & Preston, 1999), estimates of direction and magnitude of displacement were determined by calculating a weighted mean [the products of the distance of each probe from the actual final location (in pixels) and the proportion of *same* responses to that probe were summed, and this sum was then divided by the sum of the proportions of *same* responses] for each participant for each contrast and background condition. The sign of a weighted mean indicated the direction of displacement (ie a minus sign indicated displacement in the direction opposite to target motion; a plus sign indicated displacement in the direction of target motion), and the absolute value of a weighted mean indicated the magnitude of displacement. The average weighted mean for each contrast and background condition is shown in figure 3. If the weighted mean in a given condition was significantly larger than zero, then forward displacement (ie representational momentum) occurred in that condition. Similarly, if the weighted mean in a given condition was significantly smaller than zero, then backward displacement occurred in that condition.

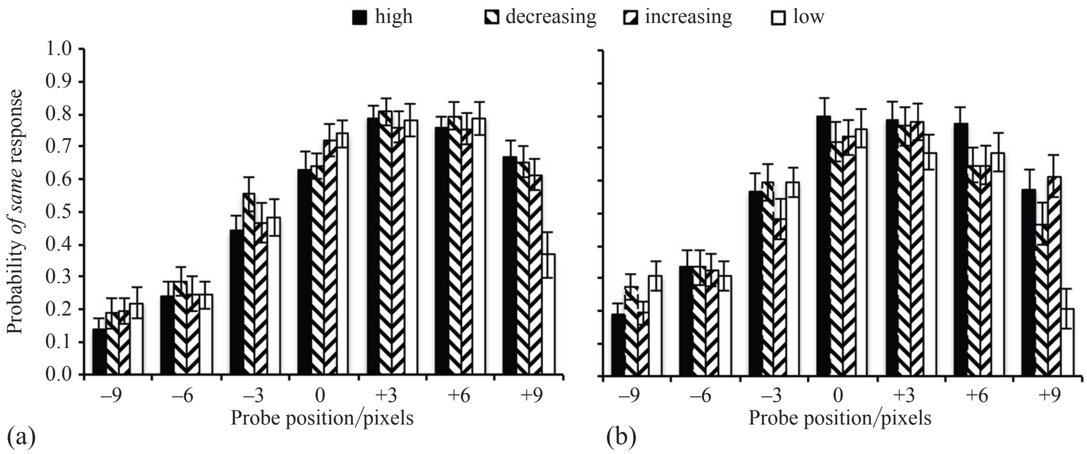

Figure 2. Probability of a *same* response as a function of probe position: (a) illustrates responses if the target was presented on the white background and (b) illustrates responses if the target was presented on a black background. Data for high-contrast conditions are indicated by black columns. Data for decreasing-contrast conditions are indicated by columns containing downward-sloping diagonals, and data for increasing conditions are indicated by columns containing upward-sloping diagonals. Data for low-contrast conditions are indicated by white columns. Error bars reflect standard errors.

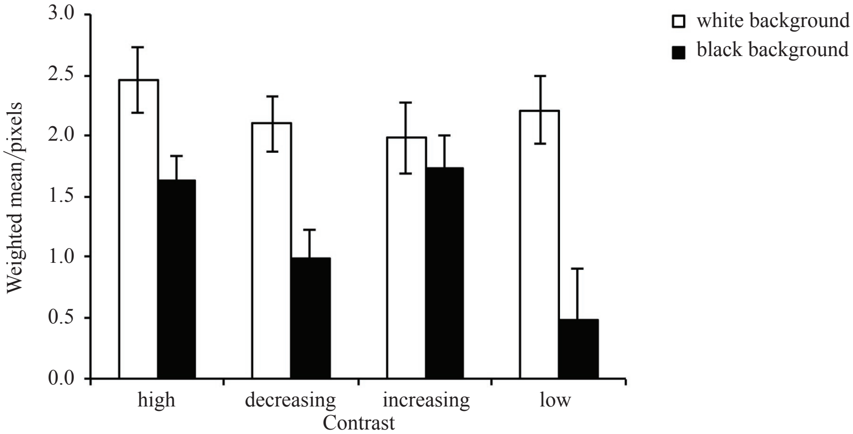

Figure 3. Weighted means as a function of contrast. Data for targets presented on a white background are indicated by white columns, and data for target presented on a black column are indicated by black columns. Error bars reflect standard errors.

3.1 *Weighted means versus zero*

Weighted means for each of the contrast conditions were compared with zero, and the α value required for significance was adjusted by a Bonferroni correction (four comparisons: $0.05/4 = 0.0125$ required for significance). If contrast was high ($M = 2.04$, $SE = 0.14$), weighted means were significantly larger than zero ($t_{29} = 9.18$, $p < 0.0001$). If contrast was decreasing ($M = 1.55$, $SE = 0.14$), weighted means were significantly larger than zero ($t_{29} = 7.05$, $p < 0.0001$). If contrast was increasing ($M = 1.89$, $SE = 0.14$), weighted means were significantly larger than zero ($t_{29} = 8.08$, $p < 0.0001$). If contrast was low ($M = 1.35$, $SE = 0.14$), weighted means were significantly larger than zero ($t_{29} = 3.92$, $p < 0.0005$). As suggested by the greater probabilities of *same* responses to positive probes than to negative probes shown in figure 2, representational momentum occurred in all conditions.

3.2 *Contrast of target luminance and background luminance*

Weighted means were analyzed in a 4 (contrast) × 2 (direction) × 2 (background) ANOVA in which contrast and direction were within-subjects variables and background was a between-subjects variable. Contrast was significant ($F_{3,84} = 5.38$, $MSE = 1.12$, $p < 0.003$), and all pairwise comparisons of high-contrast ($M = 2.04$, $SE = 0.14$), decreasing-contrast ($M = 1.55$, $SE = 0.14$), increasing-contrast ($M = 1.89$, $SE = 0.14$), and low-contrast ($M = 1.35$, $SE = 0.14$) targets were significant except for the high-contrast and increasing-contrast comparison and the low-contrast and decreasing-contrast comparison. Background was significant ($F_{1,28} = 5.16$, $MSE = 10.82$, $p < 0.04$), and interacted with contrast ($F_{3,84} = 5.39$, $MSE = 1.12$, $p < 0.002$) such that displacement was larger if the background was white ($M = 2.18$, $SE = 0.13$) than if the background was black ($M = 1.22$, $SE = 0.15$). As shown in figure 3, low-contrast or decreasing-contrast targets exhibited smaller displacement than did high-contrast or increasing-contrast targets on a black background, but low-contrast or decreasing-contrast targets exhibited similar displacement to high-contrast or increasing-contrast targets on a white background. No other main effects or interactions were significant.

3.3 *Absolute level of target luminance*

Responses were recoded to allow examination of any potential effect of the absolute level of target luminance on displacement, regardless of target contrast to the background. Weighted means were analyzed in a 4 (target luminance) × 2 (direction) × 2 (background) ANOVA in which target luminance and direction were within-subjects variables and background was a between-subjects variable. Target luminance was marginally significant ($F_{3,84} = 2.24$, MSE = 1.22, $p < 0.09$). Paralleling the analysis for effects of contrast, a planned comparison of the average of high-luminance ($M = 1.74$, SE = 0.25) and increasing-luminance ($M = 1.96$, SE = 0.18) targets (which had the same final high luminance) with the average of low-luminance ($M = 1.65$, SE = 0.21) and decreasing-luminance ($M = 1.47$, SE = 0.19) targets (which had the same final low luminance) was significant ($F_1 = 5.02$, $p < 0.03$). Thus, displacement was larger if the final luminance of the target was higher than if the final luminance of the target was lower, and if luminance was changing, there was a trend for differences in displacement to be amplified. Target luminance also interacted with background ($F_{3,84} = 5.47$, MSE = 1.22, $p < 0.002$), such that low-luminance or decreasing-luminance targets exhibited smaller displacement than high-luminance or increasing-luminance targets on a black background, but low-luminance or decreasing-luminance targets exhibited similar displacement to high-luminance or increasing-luminance targets on a white background. No other main effects or interactions were significant.

4 Discussion

Forward displacement of remembered final location of a moving target increased with larger contrast between the target and the background and with higher target luminance. More specifically, displacements for (a) high-contrast and increasing-contrast targets did not differ, (b) low-contrast and decreasing-contrast targets did not differ, but (c) high-contrast and increasing-contrast targets were larger than for low-contrast and decreasing-contrast targets. Similarly, displacements for (a) high-luminance and increasing-luminance targets did not differ, (b) low-luminance and decreasing-luminance targets did not differ, but (c) high-luminance and increasing-luminance targets were larger than for low-luminance and decreasing-luminance targets. Thus, displacement of remembered final locations was influenced more by final contrast or final target luminance than by initial contrast or initial target luminance (eg high-contrast targets and increasing-contrast targets had different initial luminances, but did not differ in displacement) or average contrast or average target luminance (eg increasing-contrast targets and decreasing-contrast targets had the same average luminance, but displacements for increasing-contrast targets were larger than displacements for decreasing-contrast targets). The importance of final contrast and final target luminance is reminiscent of the importance of final velocity (cf Actis-Grosso, Bastianelli, & Stucchi, 2008; Finke et al., 1986), and suggests that displacement is influenced primarily by the end state of the target.

Maus and Nijhawan (2009) stated "stronger transients, that is, bigger changes in luminance, led to more accurate localization of the moving [target]" (page 620). Although this statement might describe the findings from their experiments, it does not describe the findings of the current experiment in which a broader range of target luminance and contrast values were presented. The results of the current experiment demonstrated that the magnitude of displacement was related to the final contrast of the target with the background. Increasing-contrast targets exhibited a much greater change in luminance than did high-contrast targets, and yet forward displacement for these two types of targets did not differ. Similarly, decreasing-contrast targets exhibited a much greater change in luminance than did low-contrast targets, and yet forward displacement for these two types of target did not differ. Even if the 'changes in luminance' to which Maus and Nijhawan refer are limited to differences between the final contrast of the target and the background, larger displacement for high-contrast targets and for increasing-contrast targets in the current experiment is not consistent with Maus and Nijhawan's claims. Furthermore, numerous papers in representational momentum literature reported forward displacement for high-contrast targets that abruptly vanished (and thus presumably had a strong offset transient), and this suggests that the presence of a strong offset transient does not necessarily (or usually) lead to more accurate localization (ie to reduced forward displacement).[3]

The data in the current experiment are consistent with Maus and Nijhawan's (2009) suggestion that weaker motion signals lead to less forward displacement, but are inconsistent with the larger forward displacement for targets that exhibited decreasing contrast to a dark background reported in Maus and Nijhawan (2006). Why did the current experiment find smaller forward displacement with decreases in contrast, but Maus and Nijhawan (2006) found larger forward displacement with decreases in contrast? One possible explanation involves differences in methodology between the current experiment and Maus and Nijhawan. There are several such differences, and the most obvious difference is that the current experiment presented implied motion, whereas Maus and Nijhawan presented smooth continuous motion.[4] Implied motion was used in the current experiment because forward displacement

[3] Other elements of Maus and Nijhawan's (2006) account are inconsistent with research on representational momentum. Maus and Nijhawan stated "when a moving object unpredictably stops, it does not appear to overshoot its final position" (page 4375), and while this might describe their findings, it is inaccurate as a general statement. Although some early studies in the representational momentum literature presented targets that stopped at a predictable location, the majority of subsequent studies presented targets that vanished (a) at one of a small number of previously determined vanishing points (and so the specific vanishing point on a given trial could not be known in advance by the participant) or (b) at a random location. Robust representational momentum usually occurred in both these latter conditions (ie if the target unpredictably vanished). Maus and Nijhawan (2006) stated "when a moving object abruptly changes direction, then the perceived position at which the object reverses is not displaced forward (Whitney & Murakami, 1998)" (page 4376). However, displacement of a target that vanishes at the moment of an anticipated change in direction is forward, but it is forward in the direction of new or anticipated motion rather than forward in the direction of previous motion [eg if participants view a target that repeatedly bounces off the inner walls of a larger surrounding stimulus before vanishing, and that target vanishes at the moment of collision, displacement is in the direction of motion anticipated to occur after the bounce (ie forward) rather than in the direction of motion at the moment of collision; Hubbard & Bharucha, 1988; see also Johnston & Jones, 2006, and Verfaillie & d'Ydewalle, 1991, for related examples]. In this latter case, no retinal transient is necessary to account for the lack of displacement in the direction of physical motion; rather, participants' expectations of subsequent target behavior (ie an internal model) involving motion in the new direction are sufficient. Along these lines, the "offset lag" suggested by Maus and Nijhawan (2009) might simply reflect the decay of representational momentum for the vanished (part of the) stimulus and a continuing extrapolation for the (part of the) stimulus that remained visible. No active inhibitory process (based on a transient signal) needs to be postulated or invoked.

[4] A related potential explanation for the larger forward displacement in the current experiment than in Maus and Nijhawan, but that can be rejected, is that use of inducing stimuli and implied motion targets in the current experiment resulted in participants' responses indicating an explicit guess regarding the next location of the target rather than indicating the remembered final location of the target. Data were collected from an additional group of thirty participants who viewed the same stimuli as in the experiment reported here (fifteen viewed stimuli on a white background; fifteen viewed stimuli on a black background), but who predicted the location at which a sixth inducing stimulus would have been presented had the target sequence continued. Probe locations were clustered around the location at which a sixth inducing stimulus would have been presented [unlike in the experiment reported here in which probes were clustered around the location of the final (fifth) inducing stimulus]. Predicted location did not exhibit forward displacement; indeed, judgments exhibited a trend for backward displacement from the location at which a sixth inducing stimulus would have been presented (see also Munger & Minchew, 2002). Neither contrast nor luminance influenced displacement, although the trend toward backward displacement was stronger for targets presented on a white background. Thus, forward displacement in the experiment reported here did not result from participants explicitly attempting to predict a subsequent location of the target.

with implied motion is not influenced by oculomotor behavior (Kerzel, 2003a), whereas forward displacement is greatly reduced or eliminated if participants fixate away from a smoothly moving target (de sá Teixeira, Hecht, & Oliveira, 2013; Kerzel, 2000). Indeed, Maus and Nijhawan's (2006, 2009) findings of forward displacement with fixation away from a smoothly moving target are quite surprising. Also, Maus and Nijhawan (2006) presented a circular trajectory, whereas Maus and Nijhawan (2009) and the current experiment presented horizontal motion.

A second possible explanation for the differences between the findings of the current experiment and the findings of Maus and Nijhawan (2006) is that Maus and Nijhawan used inadequate comparison conditions. Maus and Nijhawan compared their decreasing-contrast target condition with conditions in which the target was presented at different luminances and traveled different distances. Thus, differences in displacement could be due to several potential variables such as trajectory length, target luminance, or contrast. More appropriate comparison conditions would match trajectory length of targets that decreased or increased in luminance or in contrast to the trajectory lengths of targets with a constant high or low contrast, and that is what was presented in the current experiment. Relatedly, in Maus and Nijhawan (2009), stimuli other than the target were presented in the display, and these could have served as landmarks that biased displacement (cf Hubbard & Ruppel, 1999); indeed, in some conditions, the nonvanishing stimulus was aligned with the vanished target, and it is possible that perception of the nonvanishing stimulus influenced displacement of the vanished target. Interestingly, if Maus and Nijhawan (2009) interrupted target motion by briefly decreasing contrast of a target, they found that forward displacement decreased, and this is consistent with the results presented here.

One potential explanation for the differences between the findings of the current study and the findings of Maus and Nijhawan (2006, 2009) that can be rejected is that the current experiment used a representational momentum methodology, whereas Maus and Nijhawan's experiments used a modified flash–lag effect methodology. Representational momentum is usually considered to involve primarily memory (ie an 'offline' judgment of where a previously viewed target vanished), whereas the flash–lag effect is usually considered to involve primarily perception (ie an 'online' judgment of whether two currently perceived stimuli are aligned). However, participants in Maus and Nijhawan (2006, 2009) did not respond until after the target vanished, and so it could be argued that participants' responses involved (offline) memory for a previously perceived target rather than (online) perception. Indeed, indicating the position of a previously perceived target after that target has vanished is characteristic of experiments examining representational momentum, and so any explanation of the differences between the findings of the current experiment and the findings of Maus and Nijhawan cannot be based primarily on differences between representational momentum methodologies (ie querying memory) and flash–lag effect methodologies (ie querying perception), because Maus and Nijhawan used methodologies consistent with those used to study representational momentum.

If processing of targets with low contrast or with low luminance is hypothesized to require more attention than does processing of targets with high contrast or with high luminance, then the results of the current experiment are consistent with previous findings that increases in the allocation of attention to the target (or to the final target location) decrease the magnitude of forward displacement (Hayes & Freyd, 2002; Hubbard et al., 2009). Increases in contrast or in target luminance might also lead to facilitated processing of the target (analogously, brighter flashed objects lead to a smaller flash–lag effect, which has been attributed to a facilitated processing of the flashed object; Öğmen, Patel, Bedell, & Camuz, 2004; Purushothaman, Patel, Bedell, & Öğmen, 1998). However, if forward displacement is viewed as a way to compensate for delays due to neural processing times (eg Hubbard, 2005; Nijhawan, 2008), then such a facilitated processing should lead to a smaller forward displacement (as less compensation would be needed, because the target would have traveled a shorter distance during neural processing). Alternatively, a facilitated processing of the target might increase activation and strength of the target representation, which would lead to increased spreading activation (and hence larger forward displacement) from the representation of the target in the anticipated direction of target motion (cf Hubbard, 1995, 2008).

Inspection of the data suggests forward displacement was larger for increasing-luminance targets than for decreasing-luminance targets, and this effect was confirmed ($p < 0.02$) by a posteriori least squared comparison. However, this finding is inconsistent with experiment 3a in Brehaut and Tipper (1996), in which luminance changes did not influence displacement in remembered orientation. There are several potential explanations for this inconsistency. First, Brehaut and Tipper presented rotational motion, but the current experiment presented horizontal motion. The correlation of luminance change and motion might be stronger for linear motion (which can lead to larger changes in depth or distance) than for rotary motion. Second, the number of participants that judged location in the current experiment was much larger than the number of participants that judged orientation in Brehaut and Tipper. Third, a larger range of motion was presented in the current experiment (five inducing stimuli) than in Brehaut and Tipper (three inducing stimuli). Representational momentum is quite robust, but if modulating effects of a target luminance change on representational momentum for target location are relatively weak or subtle, then Brehaut and Tipper's methodology might not have been sensitive enough to observe the luminance effect on memory for location. Regardless, the current experiment revealed that differences in contrast of the target and the background and in target luminance can influence memory for target location.

An unexpected finding was the larger effect of contrast that occurred if the target was presented on a white background than if the target was presented on a black background. Perhaps additional luminance from the white background provided additional activation or energy beyond that available from the black background, and this extra energy increased displacement (eg increasing the activation of the target representation, and thus increasing spreading activation in the anticipated direction of motion) or overshadowed the effects of contrast resulting from black backgrounds. Consistent with this, low-luminance or decreasing-luminance targets exhibited less displacement than did high-luminance or increasing-luminance targets if presented on a black background, but low-luminance or decreasing-luminance targets exhibited displacement similar to that of high-luminance and increasing-luminance targets if presented on a white background. The combination of low energy from the background and from the target for low-luminance and decreasing-luminance targets on a black background resulted in a relatively lower level of activation, and hence a relatively smaller displacement for that condition. Thus, target luminance, background luminance, and contrast of target luminance and background luminance all influence forward displacement in judged location of a target.

Increases in the contrast between target luminance and background luminance, as well as increases in the absolute target luminance, led to larger forward displacement in memory for final location of a horizontally moving target. The data are not consistent with suggestions that (a) target luminance does not influence displacement of target location (Brehaut & Tipper, 1996), (b) forward displacement is larger for low-contrast or low-luminance (ie fading) targets (Maus & Nijhawan, 2006), and (c) stronger offset transients lead to decreased forward displacement (Maus & Nijhawan, 2009). The data are consistent with suggestions that (a) increases in allocation of attention to the target can decrease forward displacement (Hayes & Freyd, 2002; Hubbard et al., 2009) and (b) weaker motion signals result in smaller forward displacement (Maus & Nijhawan, 2009; cf Kerzel, 2003b). An effect of background luminance on displacement of target location (ie larger displacement if targets were presented on a white background than on a black background) suggests luminance energy from the background influences representation of the target and extrapolation of target location. Displacement for location is increased by increases in target luminance, background luminance, and contrast between target luminance and background luminance, and this is consistent with effects of other object-specific information (eg Nagai & Yagi, 2001; Reed & Vinson, 1996) and context (eg Hubbard, 1993; Hubbard & Ruppel, 1999) on representational momentum.

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