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Representational Momentum and Michotte's (1946/1963) "Launching Effect" Paradigm

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In A. Michotte's (1946/1963) launching effect, a moving launcher contacts a stationary target, and then the launcher becomes stationary and the target begins to move. In this experiment, observers viewed modifications of a launching effect display, and displacement in memory for the location of targets was measured. Forward displacement of targets in launching effect displays was decreased relative to that of targets (a) that were presented in isolation and either moved at a constant fast or slow velocity or decelerated or (b) that moved in a direction orthogonal to previous motion of the launcher. Possible explanations involving a deceleration of motion or landmark attraction effects were ruled out. Displacement patterns were consistent with naive impetus theory and the hypothesis that observers believed impetus from the launcher was imparted to the target and then dissipated.

An observer's memory for the location of a moving target is usually distorted so that the target is remembered as having traveled slightly farther than it actually did. This distortion is consistent with the operation of momentum on a physical object, and so Freyd and Finke (1984) referred to this forward distortion as *representational momentum.* Subsequent studies have shown that the magnitude of this distortion is influenced by factors other than the implied momentum of the target (e.g., conceptual knowledge related to the target, Reed & Vinson, 1996; beliefs concerning future target motion, Hubbard, 1994; Verfaillie & d'Ydewalle, 1991; implied friction, Hubbard, 1995a), and so now the more neutral term *displacement* is preferred unless the distortion is attributable solely to the implied momentum of the target. The early studies on displacement usually presented targets in isolation, but more recent studies have begun to examine the effects of context on displacement. Context is relevant because physical objects exist in complex environments in which there may be interactions or other contact between objects. In the data reported here, we examined displacement of an initially stationary object that began to move when it was contacted by a previously moving object. Similar displays have been used by Michotte (1946/1963) to explore the perception of causality, and it is clear that observers believe that two such objects interact in a causal manner. How such a belief may influence displacement has not been previously examined.

The type of display Michotte (1946/1963; see also Thinès, Costall, & Butterworth, 1991) used in studies on the perception of causality is illustrated in Figure 1. Observers saw a moving stimulus, *A*, approach and contact a stationary stimulus, *B*. When *A* contacted *B*, *A*'s motion would cease, and *B* would begin to move. If *B* (a) began moving within one tenth of a second after being contacted by *A*, (b) moved in the same direction as the previous motion of *A*, and (c) moved at a slower velocity than *A*, then observers would typically report that *A* caused *B* to move. The impression was of more than a simple contiguity of the movements of *A* and *B;* Michotte's observers reported causal impressions that *A* was responsible for the initial movement of *B*. Causal impressions did not occur in the majority of cases, and this fact suggests that Michotte's observers were not simply responding to demand characteristics. Michotte referred to such causal impressions as the *launching effect.* For ease of discourse, we refer to the initially moving stimulus (i.e., Michotte's *A*) as the *launcher* and to the initially stationary stimulus that is subsequently launched (i.e., Michotte's *B*) as the *target.* We also refer to displays modeled on those Michotte reported as evoking a launching effect as *launching effect displays.*

The subjective and introspective impressions of Michotte's observers that the depicted stimuli were subject to causal principles foreshadowed the responses of observers in experiments on representational momentum and related types of displacement that occurred many years later: When shown computer-generated displays of moving or stationary targets, observers instructed to remember the final position of a target often responded as if that target were influenced by implied momentum (for review, see Hubbard, 1995b), gravitational attraction (Freyd, Pantzer, & Cheng, 1988; Hubbard, 1997), friction with another object (Hubbard, 1995a, 1998), and centripetal force (Hubbard, 1996). Such responses suggested that observers were sensitive to the physical properties implied by the displays, even though the stimuli in the displays were simple depictions that would neither have contained the same mass nor have experienced the same momentum, gravitational attraction, friction, or centripetal force as actual physical objects.

Given that the impressions of Michotte's observers and the responses of observers in displacement experiments were both consistent with the notion that observers might be sensitive to implied physical principles, one could predict that displacement of a target in a launching effect display should be consistent with physical principles. However, when observers shown displays in which two stimuli collide were asked to distinguish which stimulus

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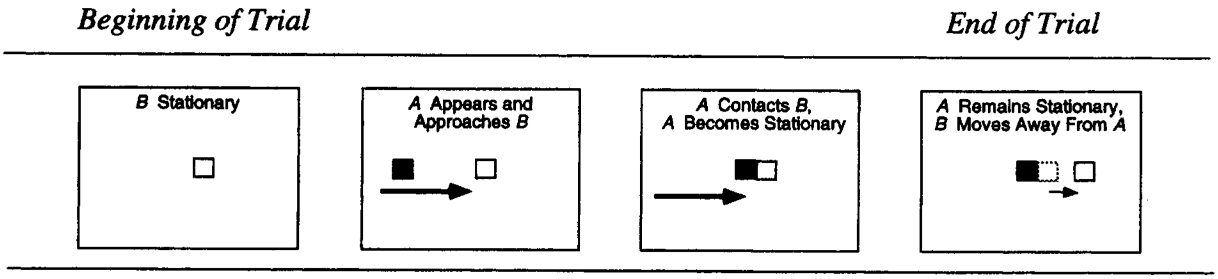

Figure 1. An illustration of the launching effect. A moving object, *A*, contacts an initially stationary object, *B*. At the moment *A* contacts *B*, *A* becomes motionless and *B* begins to move. Observers often report the causal impression that *A* "causes" *B* to move. The text within the figure is included for clarity; in the actual experimental trials, no text was presented.

is the more massive (e.g., Todd & Warren, 1982), they seemed to rely on heuristics (e.g., slower objects or objects that ricochet a smaller distance are more massive) rather than on a veridical understanding of momentum conservation (Gilden & Proffitt, 1989; see also Gilden, 1991). If observers' judgments of the relative mass of an object involved in a collision are based on heuristics regarding the velocity of the object or the distance traveled by that object after it ricochets, then it is possible that other aspects of a collision are understood heuristically and that observers would not have direct perception of causality or exhibit sensitivity to the implied physical principles. McCloskey (1983) proposed a naive impetus theory in which the act of setting an object into motion involves imparting an "impetus" to that object, and on the basis of this notion, one could hypothesize that observers might attribute motion of the target in a launching effect display to an impetus imparted to the target from the launcher. Given that impetus does not correspond to a valid physical principle, researchers could then predict that displacement of a target in a launching effect display would not be consistent with physical principles.

A naive impetus hypothesis would suggest that observers interpret the launcher as giving the target a push and that this initial push is responsible for any subsequent motion of the target. Once the target is no longer in contact with the launcher, the target does not receive any additional impetus, and the impetus from the initial contact dissipates (cf. McCloskey, 1983). Indeed, in everyday experience an initially stationary object that receives a single push sufficient to overcome any initial resistance will begin to move, but unless additional energy to sustain motion is available, that object will eventually stop because of friction (or other resistance) as the initial energy of the push is dissipated. Analogously, observers may expect a target in a launching effect display to similarly stop after the impetus from the launcher is dissipated. Given that forward displacement of a target is decreased when observers expect that target to stop (Finke, Freyd, & Shyi, 1986), forward displacement in memory for a target in a launching effect display should be decreased relative to the forward displacement of a target that is not in a launching effect display but that moves at the same velocity and in the same direction as a target in a launching effect display. Such a role of impetus in the launching effect paradigm is consistent with previous speculation regarding the role of impetus in naive physics (e.g., the impetus imparted to a ball moving through a curved tube is gradually dissipated after the ball exits the tube and results in the ball following a curvilinear course after exiting the tube; McCloskey, 1983; McCloskey & Kohl, 1983; but see Cooke & Breedin, 1994).

The naive impetus hypothesis predicts a decrease in displacement in memory for targets in a launching effect display, but there are at least two other alternative explanations for such a hypothesized decrease that would need to be ruled out before we could have confidence in a naive impetus explanation. One alternative is that such a decrease might result because of differences in the relative velocities of the launcher and the target. The change from the fast velocity of the launcher to the slow velocity of the target might be interpreted as a deceleration of a single motion, rather than as two discrete motions with constant (albeit different) velocities. Given that displacement is decreased when a target decelerates, displacement of the target would be decreased if a launching effect display were interpreted as a single motion that decelerated rather than as two motions with constant velocities. A second alternative is that observers may use the launcher as a landmark in memory for the target. Memory for the location of a previously perceived target is displaced toward a landmark (Bryant & Subbiah, 1994; Hubbard & Ruppel, 2000), and a combination of this landmark attraction effect with representational momentum results in larger forward displacement for targets that move toward a stationary landmark and smaller forward displacement for targets that move away from a stationary landmark (see Hubbard & Ruppel, 1999). In a launching effect display, the target typically moves away from the final location of a launcher, so if observers used the stationary launcher as a landmark, forward displacement of the target would be decreased.

In our experiment we examined displacement of a target in a launching effect display. All observers were presented with launching effect displays in which the launcher's velocity was faster than that of the target's, and with displays in which only the moving target component of a launching effect display was presented. Additionally, a number of control trials were presented. In a distance–velocity condition, the target traveled a distance that equaled the combined distance traveled by both the launcher and the target in launching effect displays, and the target's motion could be relatively fast or slow. This condition controlled for the possibility that differences in displacement might be due to differences in the distance traveled by the target or to differences in the final velocity of the target. In a deceleration–acceleration condition, the target traveled a distance that equaled the combined distance traveled by both the launcher and the target in launching effect displays, and the velocity of the target matched that of a launcher in launching effect displays for the initial portion of the path and that of a target in launching effect displays for the final portion of the path. The target could also be initially stationary and then begin to move after a delay approximately equal to the duration of the motion of a launcher in launching effect displays. This condition controlled for the possibility that the difference in displacement might be due to changes in the velocity of the target. In a landmark condition, the target moved in a direction orthogonal to the direction of the previous motion of the launcher. This condition controlled for the possibility that the subsequently stationary launcher might be used as a landmark for judgments of the final location of the target.

Method

Participants

The observers were 48 undergraduates at Texas Christian University, who participated in return for partial course credit. Fifteen observers participated in the distance–velocity condition, 17 observers participated in the deceleration–acceleration condition, and 16 observers participated in the landmark condition.

Apparatus

The stimuli were generated by and responses collected on an Apple Macintosh IIsi microcomputer connected to an Apple RGB color monitor.

Stimuli

General. Both the launcher and the target stimuli were square shapes 20 pixels (approximately 0.83°) in width, and both were presented on a white background. The launcher was a filled black square; the target was a black outline square (with white interior), and the outline was 1 pixel in width. The background of the stimulus display was 640 pixels in width and 460 pixels in height. Launching effect (LE) trials and target only (TO) trials were presented in all three conditions. In LE trials, the launcher emerged from the left, right, top, or bottom edge of the screen and traveled in a straight line across the screen. The path of motion for ascending and descending launchers was approximately centered along the horizontal midline of the display, and the path of motion for leftward and rightward launchers was approximately centered along the vertical midline of the display. The launcher crossed slightly more than half of the distance across the screen before contacting the target, and when the launcher contacted the target, forward motion of the launcher immediately ceased. The target was stationary until the launcher contacted it, but immediately after contact with the launcher, the target began to move in the same direction as the previous motion of the launcher. Neither the launcher nor the target exhibited deformation as a result of contact. The velocity of the launcher was controlled by shifting the launcher 3 pixels between successive presentations, and the velocity of the target was controlled by shifting the target 1 pixel between successive presentations (thus, the ratio between the velocity of the launcher and the velocity of the target was 3:1, near the optimum ratio reported by Michotte, 1946/1963), and these shifts resulted in approximate velocities of 15°/s and 5°/s. Michotte reported that the impression of launching diminished if the target traveled beyond a launcher's limited "radius of action," and so in order to more closely parallel the displays in which Michotte found the strongest launching effect, the target vanished after traveling only 30 pixels. In TO trials, neither the launcher nor the stationary portion of the target was presented, and a moving target appeared in one of the locations initially occupied by stationary targets in launching effect trials.

Distance–velocity condition. Observers in the distance–velocity condition were also presented with slow total (ST) trials and fast total (FT) trials, and the structure of these trials is illustrated in Figure 2. In ST and FT trials, a single target stimulus identical to the target in LE trials (i.e., a black outline square with a white interior) traversed a distance equal to that of the combined paths of the launcher and the target in launching effect trials. The target emerged from the left, right, top, or bottom edge of the screen, traveled in a straight line across the screen, and vanished at the same coordinates as did targets in LE trials. In ST trials, target velocity was controlled by shifting the target 1 pixel between successive presentations (thus matching the velocity of a target in launching effect trials); in FT trials, target velocity was controlled by shifting the target 3 pixels between successive presentations (thus matching the velocity of a launcher in launching effect trials). Each observer received 128 trials (4 trial types [LE, TO, ST, FT] × 4 directions [rightward, leftward, ascending, descending] × 8 replications) in a different random order.

Deceleration–acceleration condition. Observers in the deceleration–acceleration condition were also presented with deceleration (DE) trials and acceleration (AC) trials, and the structure of these trials is illustrated in Figure 2. In DE trials, a single target stimulus identical to the launcher in LE trials (i.e., a filled black square) emerged from the left, right, top, or bottom edge of the screen and traveled in a straight line across the screen. When the target reached the position corresponding to where the initially stationary target in a LE trial would have been located, it changed into a black outline square (identical to a target in LE trials). Kelly and Freyd (1987) demonstrated that representational momentum was reduced if target identity was not maintained across a trial; changing the target from a solid to an outline square at the moment of deceleration also guarded against the possibility that a decrease in displacement in LE trials might result merely from a change in identity (i.e., from a solid figure to an outline figure) between the launcher and the target. The velocity of the target during the initial portion of its motion (as a filled black square) matched the velocity of the launcher in LE trials, and the velocity of the target during the final portion of its motion (as a black outline square) matched the velocity of the target in LE trials. The target vanished after traveling 30 pixels beyond the point at which its velocity and appearance changed, and this distance matched that traveled by a target in LE trials. In AC trials, a stationary target (black outline square; identical to a target in LE trials) was drawn on the screen at the coordinates corresponding to the initial location of the target in LE trials. After a duration approximately equal to that required for motion of the launcher in LE trials, the target began to move, and the velocity of the target matched that of the target in LE trials. The target vanished after traveling 30 pixels, and this distance matched that traveled by the target in LE trials. Each observer received 128 trials (4 trial types [LE, TO, DE, AC] × 4 directions [rightward, leftward, ascending, descending] × 8 replications) in a different random order.

Landmark condition. Observers in the landmark condition were also presented with orthogonal (OR) trials, and the structure of these trials is illustrated in Figure 2. The OR trials were the same as LE trials, except that in OR trials the target moved in a direction orthogonal to the previous motion of the launcher (e.g., if target direction was toward the right, the previous motion of the launcher was upward or downward). Given that there were two directions of launcher motion that were orthogonal to each direction of target motion, there were twice as many OR trials for each direction of target motion as there were LE trials or TO trials. Each observer received 128 trials (3 trial types [LE, TO, OR] × 4 directions [rightward, leftward, ascending, descending] × 8 replications) in a different random order.[1]

Procedure

General. Observers were first given 10 practice trials at the beginning of the session, and the practice trials were drawn randomly from the experimental trials. Observers initiated each trial by pressing a designated key. In LE trials, a stationary target immediately appeared. There was a 1-s

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[1] The initial specification might not appear to result in 128 trials, but it should be borne in mind that there were two orthogonal trials for every LE and TO trial. If the stimulus specification is listed as 4 trial types (LE, TO, OR, OR) × 4 directions (rightward, leftward, ascending, descending) × 8 replications, the total of 128 may be seen more clearly.

pause, and then the launcher emerged from the left, right, top, or bottom edge of the screen and moved toward the target. When the launcher contacted the target, the launcher became stationary and the target began to move in the same direction as the previous motion of the launcher. The launcher and the target simultaneously vanished after approximately 250 ms. In TO trials, the moving target appeared 1 s after the observer pressed the designated key to begin the trials, and then the target vanished after having traveled a distance equal to that traveled by the target in LE trials. For all trial types, the cursor (in the form of a plus sign) appeared near the center of the screen after the target vanished, and observers were instructed

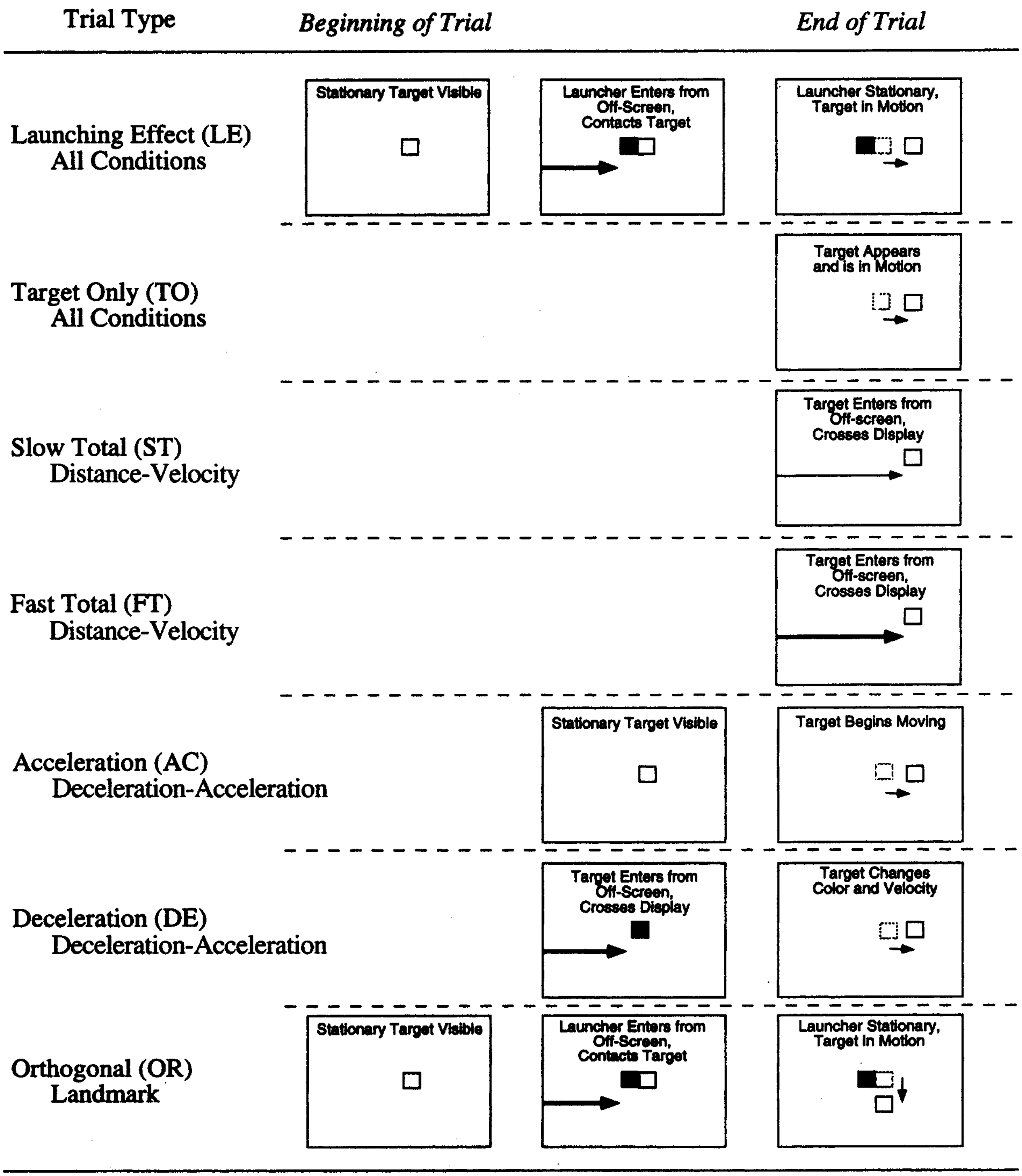

Figure 2. The structure of the experimental trials. The target is indicated by the black outline square, and the launcher is indicated by the filled black square. After the target has moved, the beginning position of the target is indicated by the dotted outline. Arrows indicate the velocity and extent of motion; thicker arrows represent faster velocities, and longer arrows indicate a greater extent of motion. The text within the figure is included for clarity; in the actual experimental trials, no text was presented.

to position the center of the cursor over where the center of the target had been when the target vanished. The cursor was positioned by the movement of a computer mouse, and after positioning the mouse, observers clicked a button on the mouse to record the screen coordinates of the cursor. Observers then initiated the next trial.

Distance–velocity condition. In ST trials and FT trials, there was a 1-s pause after observers pressed the designated key to begin the trials, and then a black outline target stimulus emerged from the left, right, top, or bottom edge of the screen. The target then moved in a straight line across the screen at a constant velocity equal to either the launcher's fast velocity or the target's slow velocity in LE trials, and it vanished after covering a distance equal to the sum of the distances traveled by a launcher and by a target in LE trials.

Deceleration–acceleration condition. In DE trials, there was a 1-s pause after observers pressed the designated key to begin the trials, and then a solid filled target stimulus emerged from the left, right, top, or bottom edge of the screen. The target moved at the fast velocity in a straight line across the screen. When the target reached the coordinates corresponding to the location of the target in LE trials, the target changed into a black outline square and began moving at the slow velocity. After the target changed velocity and appearance, it traveled a distance equal to that of the targets in LE trials before it vanished. In AC trials, a stationary black outline target stimulus immediately appeared after observers pressed the designated key to begin the trials, and the target was located at the same coordinates as the stationary target in LE trials. There was a 1-s pause, and then the target began to move at the slow velocity. In DE trials and AC trials, the target vanished after having traveled a distance equal to that traveled by the target in LE trials.

Landmark condition. The procedure for OR trials was the same as that used in LE trials, except the target moved in a direction orthogonal to the previous motion of the launcher.

Results

The differences between the true vanishing point and the judged vanishing point of the target (in pixels) were calculated along the axis of motion of the target. Consistent with previous reports, these differences along the axis of target motion were referred to as *M displacement.* Positively signed M displacements indicated the judged vanishing point was beyond the true vanishing point (i.e., left of a leftward moving target, right of a rightward moving target, below a descending target, above an ascending target), and negatively signed M displacements indicated the judged vanishing point was behind the true vanishing point (i.e., right of a leftward moving target, left of a rightward moving target, above a descending target, below an ascending target). M displacement values are listed in Table 1, and the alpha level required for significance in all analyses was set at $p < .05$.

Distance–Velocity Condition

The M displacement scores were analyzed in a 4 (trial type) × 4 (direction) repeated measures analysis of variance (ANOVA). Trial type significantly influenced M displacement, $F(3, 42) = 7.77$, $MSE = 160.37$, and a post hoc Newman–Keuls test indicated that all pairwise comparisons between LE ($M = 4.20$), TO ($M = 11.15$), ST ($M = 11.28$), and FT ($M = 15.15$) trials were significant except for the TO versus ST comparison. The displacements in the TO trials, ST trials, and FT trials are very similar to those in previous studies on representational momentum, and so the presence of LE trials did not disrupt representational momentum in non-LE trials. The decreased M displacement in LE trials relative to TO trials (4.20 vs. 11.15) is consistent with the predictions of the naive impetus hypothesis; observers may have expected the target to stop once the initial impetus had dissipated, and given that displacement is decreased when observers expect a target to stop, displacement was reduced in LE trials relative to TO trials. The decreased M displacement in LE trials relative to ST trials (4.20 vs. 11.28) suggests that differences in the final velocity of the target did not cause the decrease in displacement in LE trials, as targets in LE trials and ST trials had the same final

Table 1
M (Motion) Displacements (in Pixels)

	Direction					
Trial type	R	L	Hor.	Asc.	Des.	Ver.
Distance–velocity						
LE	7.92	8.70	8.31	1.09	−0.91	0.09
TO	16.71	17.13	16.92	1.83	8.93	5.38
ST	14.98	16.20	15.59	6.54	7.39	6.96
FT	21.20	21.92	21.56	11.10	6.37	8.73
Deceleration–acceleration						
LE	13.92	11.99	12.95	2.91	6.73	4.82
TO	15.41	17.44	16.42	4.83	10.08	7.45
AC	14.62	14.00	14.31	2.98	10.78	6.88
DE	14.76	15.49	15.12	4.32	7.44	5.88
Landmark						
LE	3.70	4.15	3.97	−2.78	0.81	−0.99
TO	5.71	9.09	7.40	0.76	1.07	0.91
OR	7.38	6.44	6.91	0.76	2.60	1.68

Note. The sign of the displacement indicates the direction of displacement so that positive values indicate displacements beyond the target (i.e., right of a rightward target, left of a leftward target, above an ascending target, below a descending target) and negative values indicate displacements behind the target (i.e., left of a rightward target, right of a leftward target, below an ascending target, above a descending target). R = rightward, L = leftward, Hor. = average horizontal, Asc. = ascending, Des. = descending, Ver. = average vertical, LE = launching effect, TO = target only, ST = slow total, FT = fast total, AC = acceleration, DE = deceleration, OR = orthogonal.

velocity. The larger M displacement for FT trials relative to ST trials and TO trials (15.14 vs. 11.28, 11.15) and the lack of difference in M displacement between ST trials and TO trials were consistent with previous findings that faster velocities lead to larger forward displacements when targets are presented in the absence of other stimuli. The distance of target movement in LE trials and TO trials was the same, so the decrease in M displacement in LE trials relative to TO trials (4.20 vs. 11.15) suggests that differences in the total distance of movement did not cause the decrease in LE trials; this notion is also supported by the lack of difference in M displacement between ST trials and TO trials. Direction influenced M displacement, $F(3, 42) = 19.43$, $MSE = 109.61$, and interacted with trial type, $F(9, 126) = 2.03$, $MSE = 44.21$. Horizontal motion resulted in larger magnitudes of M displacement, and the effects of trial type were larger for horizontal motion. The larger M displacement for horizontal motion is consistent with the typical effect of direction in studies of displacement (e.g., Hubbard, 1990).

Deceleration–Acceleration Condition

The M displacement scores were analyzed in a 4 (trial type) × 4 (direction) repeated measures ANOVA. Trial type had a significant effect on M displacement, $F(3, 48) = 3.86$, $MSE = 27.47$. We examined planned comparisons between LE trials and TO trials, LE trials and DE trials, and LE trials and AC trials. M displacement in LE trials ($M = 8.89$) was significantly less than M displacement in TO trials ($M = 11.94$), $F(1, 16) = 9.92$, $MSE = 31.93$, and DE trials ($M = 10.50$), $F(1, 16) = 5.54$, $MSE = 16.02$, and it was marginally less ($p < .07$) than M displacement in AC trials ($M = 10.59$), $F(1, 16) = 3.74$, $MSE = 26.41$. The decrease in M displacement in LE trials relative to TO trials (8.89 vs. 11.94) replicates the pattern observed in the distance–velocity condition and is consistent with the naive impetus hypothesis. The decrease in M displacement in LE trials relative to DE trials (8.89 vs. 10.50) suggests the decrease in LE trials relative to TO trials was not due to an apparent deceleration from the relatively fast velocity of the launcher to the relatively slow velocity of the target. Similarly, the marginally significant decrease in M displacement in LE trials relative to AC trials (8.89 vs. 10.59) suggests the decrease in LE trials relative to TO trials was not due to an increase in the velocity of an initially stationary target. Indeed, had the logic of the velocity change alternative hypothesis been correct, we would have expected M displacement in AC trials to be significantly larger than M displacement in TO trials, because the target in AC trials would have been perceived as accelerating. The displacements for DE trials, AC trials, and TO trials are all similar, and this would be expected, given that targets in those trials were all presented in the absence of other nontarget context and all had the same final velocity. Direction influenced M displacement, $F(3, 48) = 14.97$, $MSE = 126.83$, and a post hoc Newman–Keuls test indicated that all pairwise comparisons between rightward ($M = 14.68$), leftward ($M = 14.73$), descending ($M = 8.76$), and ascending ($M = 3.76$) motion were significant except for the rightward versus leftward comparison. The Trial Type × Direction interaction did not approach significance.

Landmark Condition

The M displacement scores were analyzed in a 3 (trial type) × 4 (direction) repeated measures ANOVA. Trial type significantly influenced M displacement, $F(2, 30) = 5.71$, $MSE = 27.99$. We examined planned comparisons between LE trials and TO trials, LE trials and OR trials, and TO trials and OR trials. M displacement in LE trials ($M = 1.49$) was significantly less than M displacement in TO trials ($M = 4.16$), $F(1, 15) = 7.51$, $MSE = 30.28$, and significantly less than M displacement in OR trials ($M = 4.30$), $F(1, 15) = 21.63$, $MSE = 11.62$. M displacement in TO trials did not differ from M displacement in OR trials, $F(1, 15) = 0.01$, $MSE = 11.62$. Overall, M displacement was decreased in LE trials relative to TO trials and OR trials (1.49 vs. 4.16, 4.30), and this is consistent with the naive impetus hypothesis and with data from the distance–velocity and deceleration–acceleration conditions. The decrease in M displacement in LE trials relative to OR trials (1.49 vs. 4.30) and the lack of difference in M displacement between TO trials and OR trials (4.16 vs. 4.30) are not consistent with the hypothesis that the decrease in M displacement in LE trials resulted from the observers' use of the launcher as a landmark. Given that targets in LE trials and OR trials vanished at equal distances from the launcher, landmark attraction effects would presumably have been equal. However, impetus would have been imparted only in the direction of the previous motion of the launcher, and so M displacement of the target would have been influenced by impetus only when the direction of target motion was in the same direction as the previous motion of the launcher; therefore, impetus would have influenced M displacement of the target in LE trials but not in OR trials. Additionally, the increase in M displacement in OR trials relative to LE trials (4.30 vs. 1.49) is consistent with the decrease in the strength of the launching effect when the target moved in a direction different from the previous direction of the launcher (Michotte, 1946/1963) and supports the general notion that M displacement is decreased in displays in which Michotte found the launching effect to be strongest. Direction influenced M displacement, $F(3, 45) = 7.68$, $MSE = 69.13$, and a post hoc Newman–Keuls test indicated that rightward ($M = 5.63$) and leftward ($M = 6.56$) motion resulted in larger M displacement than did descending ($M = 1.49$) and ascending ($M = -0.42$) motion. The direction effects are consistent with those in the distance–velocity and the deceleration–acceleration conditions. The Trial Type × Direction interaction did not approach significance.

Discussion

When an initially stationary target began to move after being contacted by a previously moving stimulus, the forward displacement in memory for the final location of that target was decreased relative to the forward displacement in memory for the final location of a target that moved in the same direction and at the same velocity but was not contacted by a moving nontarget stimulus prior to target motion. In other words, forward displacement was decreased for targets in displays similar to those Michotte (1946/1963) found to produce causal impressions of launching. This decrease was not due to differences in the total extent of motion, because M displacement in LE trials was decreased relative to control trials in which the total length of motion of a single stimulus was equal to that of the target (TO trials) or was equal to the combined lengths of the motions of the launcher and the target (ST trials). This decrease was not due to a perceived change in the velocity of a single motion, because M displacement in LE trials was decreased relative to control trials in which a single stimulus decelerated from the initial velocity of the launcher to the subsequent velocity of the target (DE trials) or in which a stationary target began moving without any contact from a launcher (AC trials). This decrease was not due to observers' use of the launcher as a landmark, because M displacement in LE trials was decreased relative to control trials in which targets moved the same distance from the stationary position of the launcher but in a direction orthogonal to the previous motion of the launcher (OR trials).

There was a clear representational momentum effect in the TO trials in each condition; the remembered location was displaced forward in the direction of target motion. The inclusion of LE trials did not eliminate forward displacement, although the addition of a launcher to the display did modulate forward displacement of a target when the direction of motion of that target was along a continuation of the previous motion of the launcher. Furthermore, several of the findings are consistent with previous reports in the representational momentum literature. First, the generally larger displacements for horizontal motion than for vertical motion and the generally larger displacements for descending motion than for ascending motion are consistent with previously reported effects of target direction on displacement (e.g., Hubbard, 1990). Second, the larger displacements in FT trials than in ST trials are consistent with previously reported effects of target velocity on displacement (e.g., Freyd & Finke, 1985; Hubbard & Bharucha, 1988). Third, the influence of the launcher on displacement of targets in an LE display was consistent with previously reported effects of nontarget context on displacement of the target (e.g., Hubbard, 1993, 1995a; Hubbard & Ruppel, 1999) and with suggestions that the ultimate displacement of a target reflects a combination of multiple influences (e.g., Hubbard, 1995b).

One finding that might initially seem puzzling is the difference in the magnitude of displacement in LE trials and in TO trials in the different conditions: Inspection of Table 1 reveals that M displacement in LE trials and TO trials is larger in the distance–velocity and deceleration–acceleration conditions than in the landmark condition. These differences must presumably arise because of differences in the other types of trials in each condition. In the distance–velocity and deceleration–acceleration conditions, the motion of the target was always in the same direction as the previous motion of the launcher, whereas in the landmark condition, the motion of the target was in the same direction as the previous motion of the launcher on only one third of the trials in which a launcher was presented (one fourth of the total trials). Thus, there may have been stronger priming of the path of target motion in the distance–velocity and deceleration–acceleration conditions than in the landmark condition. It is possible the increased levels of M displacement in the distance–velocity and deceleration–acceleration conditions resulted from this stronger priming. Similarly, the presence of a significant Trial Type × Direction interaction in the distance–velocity condition and the absence of a significant Trial Type × Direction interaction in the deceleration–acceleration and the landmark conditions may reflect an enhancement of the normal direction effect in the FT trials because of a greater potential priming by the faster velocity.

The M displacement of a target was clearly influenced by the behavior of the launcher relative to that target; if the target was perceptually independent of the launcher, there would have been no difference in displacement between LE trials and other types of trials in which the final velocity of the target matched that in LE trials. This influence of the launcher is consistent with reports of Michotte's (1946/1963) observers that the initial motion of a launched target was attributed to the launcher, and it is also consistent with the hypothesis that the decrease in displacement of the target in launching effect displays results from the launcher imparting an "impetus," which provides an initial push to the target. McCloskey's (1983) naive impetus theory suggests that once the initial impetus is dissipated, observers expect the target to stop. Given that representational momentum is decreased when observers expect a target to stop, forward displacement of a target in a launching effect display is therefore decreased. The motion of a target in a non-LE trial would not be attributed to the launcher (i.e., target motion would be perceived as more autonomous or self-generated) and so would not be dependent on impetus from a launcher; observers would not expect such a target to stop, and so M displacement of a target in a non-LE trial is not decreased. Furthermore, impetus would be imparted only in the direction of previous launcher motion, and so motion of the target in a direction orthogonal to the previous motion of the target could not be attributed to impetus; therefore, M displacement was not decreased when the direction of target motion was orthogonal to the previous direction of motion of the launcher.

The decrease in the forward displacement of targets in a launching effect display is not consistent with the hypotheses that observers are sensitive to the implied dynamics or that observers possess an accurate implicit knowledge of physical principles. However, the decrease in the forward displacement of targets in a launching effect display is consistent with the hypothesis that observers appeal to the heuristic that the launcher imparts an impetus or influence to the target that will gradually dissipate. Such a heuristic is consistent with previous research on naive physics (e.g., McCloskey, 1983), with the perception of collisions (e.g., Gilden & Proffitt, 1989), and with the introspections of Michotte's (1946/1963) observers that the launcher was responsible for the initial motion of the target and that motion of a launched target seemed less autonomous. Also, the influence of a launcher on the displacement of a target is consistent with previous findings that nontarget context can influence displacement in memory for the target. Representational momentum and the launching effect may both reflect the expectations of observers regarding the influence of other stimuli on a target and the future behavior of that target. Further clarification of these issues should increase our understanding of how the representation of stimuli is related to implied physical principles and the cognition of causality.

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