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A possible role of naïve impetus in Michotte's "launching effect": Evidence from representational momentum

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In Michotte's (1946/1963) launching effect paradigm, a moving launcher contacts a stationary target, and then the launcher becomes stationary and the target begins to move. In the experiments reported here, observers were presented with modifications of a launching effect display, and displacement in memory for targets was measured. Faster launcher velocities resulted in larger displacements for moving targets, and the effect of launcher velocity was larger with faster target velocities. Launcher velocity did not influence displacement of targets that remained stationary after contact. Increases in the distance travelled by moving targets after contact from the launcher resulted in smaller displacements. Displacement appeared to result from an expectation that impetus would be imparted from the launcher rather than from contact between the launcher and the target. Displacement patterns were consistent with naïve impetus theory and with the hypothesis that observers believed impetus from the launcher was imparted to the target and dissipated with subsequent target motion.

The extent to which one action or event can be said to cause another action or event has long been a topic of interest in psychology and in philosophy (e.g., see Hewstone, 1989; Schustack, 1988; Sperber, Premack, & Premack, 1995). One of the most basic types of causality involves whether the movement or action of one physical object directly leads to or is responsible for the movement or action of a second physical object; this type of causality is referred to as *mechanical causality*. Recent research on the perception of mechanical causality has focused on whether observers are sensitive to dynamic or kinematic influences implicit in physical systems (e.g., Gilden, 1991; Kaiser, Proffitt, Whelan, & Hecht, 1992; Michaels & de Vries, 1998). The results of some

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studies suggest observers may be sensitive to or directly perceive effects of causal dynamics (e.g., Bingham, 1987; Runeson & Frykholm, 1983; Valenti & Costall, 1997). However, the results of other studies suggest observers may appeal to heuristics instead of directly perceiving causal dynamics (e.g., Gilden & Proffitt, 1989; Proffitt & Gilden, 1989), and these latter findings are more consistent with post-Humean notions that causality must be inferred from contiguity and with findings in so-called naïve physics (Catrambone, Jones, Jonides, & Seifert, 1995; Cooke & Breedin, 1994).

In a series of landmark studies on the perception of mechanical causality, Michotte (1946/1963; see also Thinès, Costall, & Butterworth, 1991) demonstrated that observers made causal attributions when they viewed various types of interacting stimuli. Figure 1 illustrates the standard paradigm of these studies: Observers were presented with a display in which a moving stimulus, *A*, approached and contacted a stationary stimulus, *B*. When *A* contacted *B*, *A*'s motion would cease, and after some interval of time, *B* would begin to move in the same direction in which *A* had previously moved. If the relative motions of *A* and *B* were adjusted appropriately, observers did not see the motions of *A* and *B* as disconnected events that happened to occur contiguously; rather, observers reported that *A* caused *B* to move. Michotte referred to this impression of causality as the *launching effect*, and he suggested that it reflected a direct perception (rather than an inference) that *A* caused *B* to move. For simplicity, we will refer to the initially moving stimulus (i.e., Michotte's "*A*") as the *launcher*, and to the initially stationary stimulus which is subsequently launched (i.e., Michotte's "*B*") as the *target*. We will also refer to displays similar to those which Michotte reported to produce a launching effect as *launching effect displays*.

Michotte's research on the perception of causality is relevant to contemporary research on the perception of dynamics (cf., Kaiser, 1998) and on the extent to which mental representation may be considered a dynamic process (cf., Freyd, 1987). These topics were explicitly linked when memory for the location of a target in a launching effect display was examined by Hubbard, Blessum, and Ruppel (2001) in a representational momentum paradigm. *Representational momentum* is the name initially given to a distortion of memory in which the remembered position of a recently perceived moving target is

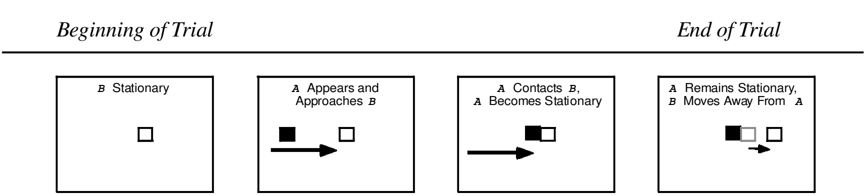

Figure 1. An illustration of the launching effect. A moving object, *A*, contacts an initially stationary object, *B*. At the moment *A* contacts *B*, *A* becomes motionless and *B* begins to move. Observers often report the causal impression that *A* "causes" *B* to move. Adapted from Michotte (1946/1963).

displaced forward in the direction of the anticipated future motion of that target (e.g., Freyd & Finke, 1984; for review, see Hubbard, 1995b). Hubbard et al. showed observers computer-animated displays similar to the launching effect displays of Michotte, and after the target had travelled a short distance, the launcher and the target simultaneously vanished. Observers then indicated where the target had vanished, and the displacement between the actual vanishing point of the target and the judged vanishing point of the target was measured. The forward displacement of a target in a launching effect display was decreased relative to the forward displacement of (a) an otherwise identical moving target presented in the absence of a launcher, (b) a single target that initially moved at the fast velocity of the launcher and then decelerated to the slow velocity of the target, and (c) a target that moved in a direction orthogonal to the previous motion of the launcher.

Hubbard et al. (2001) suggested the decrease in displacement of a target in a launching effect display resulted from observers perceiving or believing that an "impetus" from the launcher was imparted to the target. According to naïve impetus theory, the act of setting an object in motion imparts an impetus to the object, and the strength of this impetus dissipates with time (McCloskey, 1983). If motion of the target in a launching effect display was attributed to an impetus imparted from the launcher to the target, then this initial impetus would be expected to dissipate with subsequent target motion, and once the impetus had dissipated, the target would be expected to stop. The displacement of a target is decreased when observers expect that target to stop (e.g., Finke, Freyd, & Shyi, 1986), and so displacement of the target in a launching effect display is decreased. Furthermore, impetus imparted from the launcher should operate only in the direction of the previous motion of the launcher, and this is consistent with Hubbard et al.'s finding that displacement of a target that moved in a direction orthogonal to the previous motion of the launcher (a) was larger than displacement of a target that moved in the same direction as the previous motion of the launcher, and (b) did not differ from displacement of an otherwise identical moving target presented in the absence of a launcher. Evidence consistent with naïve impetus theory was also observed when the final location of the launcher and the initial location of the target were spatially separated; a decrease in displacement of the target did not occur unless a visible intermediary object bridged the gap between the launcher and the target (and hence provided a conduit for impetus; see Hubbard & Favretto, 2002).

In the following experiments, observers were presented with variations of Michotte's launching effect display. In Experiment 1, the relative velocities of the launcher and the target were varied, and this allowed an examination of the effect of the velocity (impetus) of the launcher on the displacement of the target. In Experiment 2, the target remained stationary throughout the duration of each trial, and this allowed for a separation of the effects of the impetus of the launcher and the effects of the representational momentum of the target. In Experiment 3, the distance travelled by the target was varied, and this allowed an examination of whether impetus dissipated with increases in the distance travelled by the target. In Experiments 1, 2, and 3, the launcher exhibited continuous smooth motion (i.e., the launcher moved in a straight line and at a constant velocity). In Experiment 4, the launcher exhibited a more periodic motion (i.e., the leading edge of the launcher expanded, and then the trailing edge of the launcher contracted, thus producing a "caterpillar-like" motion), and this allowed a separation of the moment the launcher contacted the target and the moment the launcher would have imparted impetus to the target. In all experiments, the launcher and the target vanished simultaneously, and then observers indicated the remembered vanishing point of the target.

EXPERIMENT 1

If the decrease in displacement of the target in a launching effect display is due to observers' perception or belief that the launcher imparts an impetus to the target, then the magnitude of displacement of the target in a launching effect display should be influenced by the velocity of the launcher. Previous studies have shown that memory for targets moving at a faster velocity (in the absence of other context) exhibits larger forward displacement (e.g., Freyd & Finke, 1985; Hubbard & Bharucha, 1988), and so presumably a launcher moving at a faster velocity would have more impetus to impart to the target. If memory for the target is influenced by the impetus of the launcher, then it could be predicted that the forward displacement of targets preceded by fast launchers should be larger than the forward displacement of targets preceded by slow launchers, regardless of the velocity of the target. Alternatively, if memory for the target is not influenced by the impetus of the launcher, then it could be predicted that targets moving at a fast velocity should exhibit larger forward displacement than would targets moving at a slow velocity, regardless of the velocity of the launcher. Accordingly, observers were presented with displays based on the launching effect described by Michotte, and the relative velocities of the launcher and the target varied across trials.

Method

Participants. The observers in all experiments were undergraduates at Texas Christian University who participated in return for extra credit in an introductory psychology course. Fifteen observers participated in Experiment 1.

Apparatus. The stimuli were generated by and the responses were collected upon an Apple Macintosh IIsi microcomputer connected to an Apple RGB colour monitor.

Stimuli. Both the launcher and the target were square shapes 20 pixels (approximately 0.83°) in width and were presented on a white background. In order to make the launcher and the target more easily distinguishable, the launcher was a filled black square and the target was a black outline square with a white interior (the outline was one pixel thick). The background of the stimulus display was 640 pixels in width and 460 pixels in height. The launcher emerged from either the left, right, bottom, or top edge of the display and travelled across the display. When the launcher contacted the left, right, bottom, or top of the target, the target moved rightward, leftward, upward, or downward, respectively. The path of motion for upward or downward launchers and targets was approximately centred along the horizontal axis of the display, and the path of motion for leftward or rightward launchers and targets was approximately centred along the vertical axis of the display. The launcher crossed slightly more than halfway across the display 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. Neither the launcher nor the target exhibited any deformation as a result of contact. On one-quarter of the trials, the launcher travelled at a fast velocity and the target travelled at a slow velocity; these trials corresponded to those Michotte reported as most likely to produce a launching effect. On one-quarter of the trials, both the launcher and the target travelled at a slow velocity. On one-quarter of the trials, the launcher travelled at a slow velocity and the target travelled at a fast velocity. On one-quarter of the trials, both the launcher and the target travelled at a fast velocity. The slow velocity was achieved by shifting the launcher or the target 1 pixel between successive presentations, and the fast velocity was achieved by shifting the launcher or the target 3 pixels between successive presentations; these shifts resulted in velocities of approximately 5°/s and 15°/s, respectively. In all trials, both the launcher and the target simultaneously vanished after the target travelled a distance of 30 pixels (approximately 250 ms for slow targets and 83 ms for fast targets). Each observer received 128 trials (2 launcher velocities [slow, fast] × 2 target velocities [slow, fast] × 4 directions [rightward, leftward, upward, downward] × 8 replications) in a different random order.

Procedure. 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. A stationary target immediately appeared. There was a 1 s pause, and then the launcher emerged from either the left, right, top, or bottom edge of the display and moved toward the target. When the launcher contacted the target, the launcher immediately became stationary and the target immediately began to move. The launcher and the target simultaneously vanished shortly thereafter. The cursor (in the form of a plus sign) appeared near the centre of the display after the target vanished, and observers were instructed to position the centre of the cursor over where the centre 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 in order to record the display coordinates of the cursor. Observers then initiated the next trial.

Results

The difference between the true vanishing point and the judged vanishing point of the target (in pixels) was calculated along the axis of motion. Consistent with previous reports, this difference was referred to as *M displacement*.[1] Positively signed M displacement indicated the judged vanishing point was beyond the true vanishing point (i.e., left of a leftward moving target), and negatively signed M displacement indicated the judged vanishing point was behind the true vanishing point (i.e., right of a leftward moving target).

The M displacement scores were analysed in a 2 (launcher velocity) × 2 (target velocity) × 4 (direction) repeated measures analysis of variance (ANOVA), and are listed in Table 1. Launcher velocity influenced M displacement of the target, $F(1, 14) = 5.23$, $MSe = 27.49$, $p < .04$, with slow ($M = 3.33$) launchers resulting in less M displacement of the target than did fast ($M = 4.88$) launchers. Launcher velocity also interacted with target velocity, $F(1, 14) = 7.36$, $MSe = 8.33$, $p < .02$. As shown in Table 1, M displacement of the target was larger

TABLE 1
M displacement (in pixels) in Experiment 1

	Direction of launcher motion			
	Rightward	*Leftward*	*Upward*	*Downward*
Slow launchers				
Slow targets	7.15	5.78	–0.40	2.89
Fast targets	6.45	5.42	–1.82	0.40
Fast launchers				
Slow targets	8.13	6.99	0.26	2.99
Fast targets	8.91	9.50	–0.37	2.64

The sign of the displacement indicates the direction of displacement such that positive values indicate displacements beyond the target (i.e., right of a rightward target, left of a leftward target, above an upward target, below a downward target) and negative values indicate displacements behind the target (i.e., left of a rightward target, right of a leftward target, below an upward target, above a downward target).

[1]Displacement may be measured along different axes (e.g., previous studies distinguished between displacement along the axis of motion, *M displacement*, and displacement along the axis orthogonal to motion, *O displacement*), and the "M" specifies displacement along the axis of motion. Even though no other displacements are of interest in the current study, the "M" qualifier is retained in order to be consistent with previous practice.

when the launcher moved at the fast velocity, and the increase in displacement with the fast launcher velocity was larger when target velocity was fast than when target velocity was slow. Direction influenced M displacement, $F(3, 42) = 10.52$, $MSe = 84.11$, $p < .001$, and interacted with target velocity, $F(3, 42) = 2.90$, $MSe = 7.66$, $p < .05$. As in previous reports (e.g., Hubbard, 1990), horizontal motion of the target led to larger M displacement than did vertical motion. There was also a slight decrease in M displacement with increases in target velocity for vertical motion. No other main effects or interactions approached significance.

Discussion

The velocity of the launcher influenced M displacement of the target, such that targets preceded by fast launchers exhibited larger M displacement than did targets preceded by slow launchers. This is consistent with the hypothesis that motion of the target was attributed to impetus imparted from the launcher, because fast launchers would be expected to impart more impetus to the target than would slow launchers, and more impetus would be expected to result in a faster target velocity and a larger M displacement. The main effect of target velocity on M displacement was not significant, and this is also consistent with the hypothesis that motion of the target was attributed to impetus imparted from the launcher. Previous studies reported robust effects of target velocity on the forward displacement of targets presented in the absence of nontarget stimuli or other context (e.g., Finke et al., 1986, Freyd & Finke, 1985; Hubbard, 1990; Hubbard & Bharucha, 1988), and so the lack of an effect of target velocity on the displacement of the target in Experiment 1 is presumably due to the additional context provided by the launcher. Such a modulation of the overall displacement of the target as a function of context is consistent with previous findings (e.g., Hubbard, 1993; Hubbard & Ruppel, 1999).

The interaction of launcher velocity and target velocity was highly significant, such that increases in target velocity led to increases in M displacement when launchers moved at a fast velocity and decreases in M displacement when launchers moved at a slow velocity. The smallest M displacement occurred in the condition least consistent with the conservation of physical momentum (i.e., slow launcher, fast target), and given that displacement has been hypothesized to reflect experience with stimuli in the physical environment (Hubbard, 1995b, 1999), it may be that displays less typical of everyday experience and less consistent with the conservation of physical momentum were less likely to evoke representational momentum. Such a conclusion would be consistent with the decreases in representational momentum that occur when target motion is not in a consistent direction (Freyd & Finke, 1984) or when a constant target identity is not maintained (Kelly & Freyd, 1987). Such an account would also be consistent with the decrease in M displacement with increases in target velocity that occurred with vertical motion in Experiment 1, because observers may have had more experience with collisions similar to those of the launching effect for stimuli that moved horizontally than for stimuli that moved vertically. Overall, the data are consistent with the hypothesis that the forward displacement of the target reflected impetus imparted from the launcher.

EXPERIMENT 2

In Experiment 1, it was not possible to fully isolate the effects of impetus imparted from the launcher from the effects of representational momentum of the target. One way to isolate the component of target displacement unique to impetus imparted from the launcher would be to have targets remain stationary after being contacted by the launcher (as such targets would possess zero representational momentum). If impetus imparted from the launcher influences displacement of a stationary target, memory for that target should be displaced away from the launcher and in the direction of the previous motion of the launcher (e.g., a launcher moving toward the right would contact the left side of a target, and memory for that target should be displaced toward the right). Given that impetus is imparted immediately upon contact, a greater effect of impetus on displacement of the target might be expected if the launcher and the target vanished immediately upon contact; if observers saw the target remain stationary after being contacted by the launcher, that might suggest impetus of the launcher did not influence the target. Accordingly, observers were shown trials in which a moving launcher contacted a target that remained stationary, and the temporal interval between when the launcher contacted the target and when the launcher and target simultaneously vanished varied across trials. Also, if displacement of a stationary target is influenced by impetus from the launcher, then stationary targets should be displaced more in the direction of launcher motion if contacted by a fast launcher than if contacted by a slow launcher.

Method

Participants. The observers were 15 undergraduates from the same participant pool used in Experiment 1, and none of the observers had participated in the previous experiment.

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

Stimuli. The launchers and targets were the same as in Experiment 1, with the following exceptions: Targets remained stationary for the duration of each trial. Also, the delay between when the launcher contacted the target and when the launcher and target simultaneously vanished was either immediate or after an additional 125, 250, 375, 500, 625, or 750 ms had elapsed. Each observer received 168 trials (7 delays [immediate, 125, 250, 325, 500, 625, 750 ms] × 4 directions [rightward, leftward, upward, downward] × 2 launcher velocities [slow, fast] × 3 replications) in a different random order.

Procedure. The procedure was the same as that used in Experiment 1, with the following exceptions: The target did not begin moving after being contacted by the launcher, and the time between when the launcher contacted the target and when the launcher and the target simultaneously vanished was varied across trials.

Results

Given that targets were not in motion, the term *M displacement* was not appropriate. Hubbard and Ruppel (2000) referred to the displacement of a stationary target toward or away from a stationary landmark as *T displacement*, and so that term was used here to refer to the displacement of stationary targets. The T displacement scores were determined by calculating the differences between the true vanishing point and the judged vanishing point along the axis connecting the centre of the launcher and the centre of the target. Positively signed T displacement indicated the judged vanishing point was displaced away from the launcher, and negatively signed T displacement indicated the judged vanishing point was displaced toward the launcher; this sign convention ensured that the T displacements from Experiment 2 were comparable with the M displacements from Experiment 1.[2]

The T displacement scores were analysed in a 2 (launcher velocity) × 7 (delay) × 4 (direction) repeated measures ANOVA, and are listed in Table 2. Direction influenced displacement, $F(3, 42) = 3.66$, $MSe = 164.66$, $p < .02$; a post hoc Newman-Keuls test ($p < .05$) of all pairwise comparisons of rightward ($M = 1.30$), leftward ($M = -1.43$), downward ($M = 0.55$), and upward ($M = -2.34$) motion revealed that only rightward trials and upward trials were significantly different. No other main effects or interactions approached significance.

Discussion

Memory for a stationary target was not displaced in the direction of the previous motion of the launcher (i.e., away from the launcher). When the launcher

[2]In order to prevent a potential confusion, it should be noted that the use of positive and negative displacement in Experiment 2 is opposite to that used by Hubbard and Ruppel (2000) in which positive T displacements indicated displacements towards the landmark. As noted, the convention of positive and negative displacement in Experiment 2 is, however, the same as that used for M displacement in Experiment 1.

TABLE 2
T displacement (in pixels) in Experiment 2

	Direction of launcher motion			
	Rightward	*Leftward*	*Upward*	*Downward*
Slow launchers				
immediate	2.09	–2.42	–3.11	–0.88
125 ms	2.52	–2.95	–2.69	–0.30
250 ms	2.48	–1.02	–4.02	–0.55
375 ms	–0.02	–0.55	–2.64	0.94
500 ms	–0.04	–1.22	–2.53	1.95
625 ms	2.50	–1.19	–1.88	0.41
750 ms	1.70	–2.35	–1.48	1.01
Fast launchers				
immediate	1.72	0.18	–0.75	0.81
125 ms	0.21	–0.62	–2.49	0.54
250 ms	0.92	–1.89	–3.18	–0.32
375 ms	–0.06	–0.08	–2.89	–0.68
500 ms	2.32	–2.51	–0.75	0.19
625 ms	0.41	–1.60	–0.88	2.48
750 ms	1.50	–1.84	–3.42	2.12

The sign of the displacement indicates the direction of displacement such that positive values indicate displacements away from the launcher and negative values indicate displacements toward the launcher.

moved either rightward or leftward, a trend toward a slight rightward displacement of the target was observed. When the launcher moved downward, a minimal T displacement was observed, but when the launcher moved upward, a larger downward T displacement was observed. Although the difference between upward and downward motion of the launcher did not reach significance, the trend is consistent with a combination of a landmark attraction effect and representational gravity.[3] The small rightward displacement of the target with leftward or rightward launchers and the small downward displacement of

[3]Previous research has found that a target is typically remembered as being slightly closer to a landmark than that target actually was, and this has been referred to as a *landmark attraction effect* (e.g., Bryant & Subbiah, 1994). Hubbard and Ruppel (2000) suggested the landmark attraction effect and representational gravity were combined in the determination of the ultimate displacement of a stationary target: When landmark attraction and representational gravity were in the same direction (i.e., when the target was above the landmark), they summed and displacement downward was larger, whereas when landmark attraction and representational gravity were in the opposite directions (i.e., when the target was below the landmark), they partially cancelled and downward displacement was smaller (or, if landmark attraction was greater than representational gravity, displacement was upward). Although Hubbard et al. (2001) rejected a landmark explanation for the decrease in displacement of a target in a launching effect display, the targets in Experiment 2 were not launched, and so it is not surprising that an effect of landmark attraction might have occurred.

the target with upward or downward launchers are consistent with the rightward and downward displacements of stationary targets presented in isolation in Hubbard and Ruppel (2000), and this suggests that any impetus imparted from the launcher does not influence the displacement of a stationary target. The delay between when the launcher contacted the target and when the launcher and the target vanished did not influence the displacement of the target, and this also suggests that any impetus imparted from the launcher does not influence the displacement of a stationary target.

Launcher velocity did not influence the magnitude of target displacement in Experiment 2, but this result initially seems inconsistent with the finding that faster launcher velocities led to larger magnitudes of target displacement in Experiment 1. However, there was also a significant interaction of launcher velocity and target velocity in Experiment 1; the effect of launcher velocity on the displacement of the target was stronger with the fast target velocity and weaker with the slow target velocity. Given that stationary targets in Experiment 2 had a velocity of zero, the lack of an effect of launcher velocity in Experiment 2 is consistent with the weaker effect of launcher velocity on targets with a slow velocity in Experiment 1. The interaction of launcher velocity and target velocity on displacement of moving targets in Experiment 1, coupled with the absence of an effect of launcher velocity on displacement of stationary targets in Experiment 2, suggests that motion of the target is necessary in order for effects of impetus imparted from the launcher to the target on memory for the target to be observed. In other words, impetus imparted from the launcher does not influence the remembered location of the target *per se*; rather, impetus imparted from the launcher only modulates displacement of the target if the target actually moves.

Why would impetus imparted from the launcher influence displacement of the target only if the target moved? A stationary physical target will usually remain stationary unless some physical launcher operates upon the target with a force sufficient to overcome any resistance (e.g., friction) on that target. As long as the force imparted from a launcher does not exceed the threshold force necessary to overcome any resistance on a target, then the target will not move, and it does not matter whether that force is relatively strong or relatively weak. In Experiment 2, impetus imparted from the launcher was not sufficient to overcome resistance on the target (i.e., the target did not move), and so there was no effect of launcher velocity on the displacement of stationary targets. In Experiment 1, impetus imparted from the launcher was sufficient to overcome resistance on the target (i.e., the target did move), and so there was an effect of launcher velocity on the displacement of moving targets. Thus, in both Experiments 1 and 2, displacement of the target reflected the amount of impetus imparted from the launcher that exceeded the threshold necessary to overcome resistance to movement. Furthermore, when the impetus did exceed the threshold necessary to overcome resistance to movement, displacement was in the direction of impetus, whereas when impetus did not exceed the threshold necessary to overcome resistance to movement, displacement was more typical of that of an otherwise identical stationary target presented in the absence of a launcher.

EXPERIMENT 3

Naïve impetus theory suggests that the impetus imparted to a target begins to dissipate immediately after the launcher contacts the target, and that the impetus continues to dissipate as the target moves away from the launcher. After the target has travelled a sufficient distance, the impetus should be completely dissipated, and the target would be expected to stop. Therefore, if motion of the target is attributed to the impetus imparted from the launcher, then the forward displacement of the target should reflect the current level of remaining impetus, and so the forward displacement of the target should decrease as the distance travelled by the target increases. However, if no launcher (and hence no impetus to be imparted) is presented, the forward displacement of the target does not decrease as the distance travelled by the target increases (e.g., in Hubbard et al., 2001, M displacement of an isolated target that travelled a distance equal to that traveled by the target in a launching effect display did not differ from the M displacement of a target that travelled a distance equal to that travelled by both the launcher and the target in a launching effect display). Therefore, if the forward displacement of a target in a launching effect display is not related to the amount of remaining impetus, then we would expect that the forward displacement of the target would not change as the target moved away from the launcher. Accordingly, observers were shown launching effect displays in which the distance travelled by a target varied across trials.

Method

Participants. The observers were 14 undergraduates from the same participant pool used in Experiment 1, and none of the observers had participated in the previous experiments.

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

Stimuli. The launchers and targets were the same as in Experiment 1, with the following exceptions: Launchers always moved at the fast velocity (a shift of 3 pixels between successive presentations), and targets always moved at the slow velocity (a shift of 1 pixel between successive presentations). Also, the distance the target travelled before the launcher and target simultaneously vanished was either 10, 30, 50, or 70 pixels (the 30 pixel distance was same as that used in Experiment 1). Each observer received 64 trials (4 distances [10, 30, 50, 70 pixels] × 4 directions [rightward, leftward, upward, downward] × 4 replications) in a different random order.

Procedure. The procedure was the same as that used in Experiment 1.

Results

M displacements were calculated as in Experiment 1, and are listed in Table 3. The M displacement scores were analysed in a 4 (distance) × 4 (direction) repeated measures ANOVA. Distance influenced M displacement of the target, $F(3, 39) = 5.23$, $MSe = 44.67$, $p < .001$, and a post hoc Newman-Keuls test ($p < .05$) of all pairwise comparisons revealed that the 10 pixel ($M = 8.91$) trials resulted in larger M displacement than the 50 ($M = 4.30$) and 70 ($M = 2.40$) pixel trials, and that the 30 pixel ($M = 6.60$) trials resulted in larger M displacement than the 70 pixel trials. Direction influenced M displacement of the target, $F(3, 39) = 7.04$, $MSe = 88.77$, $p < .001$, and a post hoc Newman-Keuls test ($p < .05$) of all pairwise comparisons revealed that upward motion ($M = 0.59$) resulted in less M displacement than downward ($M = 6.59$), rightward ($M = 7.65$), or leftward ($M = 7.37$) motion. The Distance × Direction interaction did not approach significance.

Discussion

M displacement decreased as the target moved further from the launcher, and this is consistent with predictions based on naïve impetus theory. The motion of the target away from the launcher reflected the effect of impetus imparted from the launcher, and as the impetus dissipated, the magnitude of M displacement

TABLE 3
M displacement (in pixels) in Experiment 3

	Direction of launcher motion			
	Rightward	*Leftward*	*Upward*	*Downward*
Target distance (pixels)				
10	12.78	9.01	4.49	8.85
30	8.13	9.08	0.95	8.23
50	7.87	5.62	−1.17	4.88
70	1.82	5.77	−2.42	4.41

The sign of the displacement indicates the direction of displacement such that positive values indicate displacements beyond the target (i.e., right of a rightward target, left of a leftward target, above an upward target, below a downward target) and negative values indicate displacements behind the target (i.e., left of a rightward target, right of a leftward target, below an upward target, above a downward target).

of the target decreased. Experience with physical objects in the everyday environment suggests that if a stationary physical object is launched into motion because of the force from a moving object that collides with that stationary object, then the motion of that launched object would then gradually decelerate because of friction between that object and (a) the surface that the object is moving across or (b) the medium that the object is moving through. Even though targets in Experiment 3 did not actually decelerate as they moved away from the launcher, the M displacement patterns suggest that observers represented the targets as decelerating, and this highlights just how robust are the effects of implied impetus on displacement.[4] An explanation for the M displacement pattern in Experiment 3 that is based on an impetus imparted from the launcher is consistent with previous findings that the forward displacement of targets presented in isolation is not influenced by the distance travelled by the target, because the motion of targets presented in isolation would not be represented as resulting from any type of external impetus that would be expected to dissipate.

The decrease in M displacement with increases in the distance travelled by the target make it tempting to speculate that if a target in a launching effect display travelled far enough, then M displacement would decrease to zero or even become negative. However, Michotte's observers reported that targets were no longer perceived as "launched" if those targets moved beyond a certain threshold distance from the launcher. Such a threshold distance defined the launcher's "radius of action", and once targets moved beyond the launcher's radius of action, the continued motion of those targets was no longer attributed to the impetus imparted from the launcher. Instead, motion of targets beyond the launcher's radius of action was perceived as "triggered" rather than "caused" by the launcher. A "triggered" motion would not be sustained by the impetus imparted from the launcher (as that impetus would dissipate), but would rather be sustained by some other (perhaps autonomous) source. Forward displacement of a target that moved beyond a launcher's radius of action might be based more upon that target's (internally generated motion and) momentum than upon any residual of impetus imparted by the launcher. The vanishing points in Experiment 3 were all relatively close to the launcher, and so were probably all within the launcher's radius of action; therefore, decreases in M displacement were observed with increases in target distance. If M displacement for vanishing points beyond the radius of action were measured, then it could be predicted that such decreases would not be observed; this possibility is under further investigation.

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[4] An analogous argument that decreases in the forward displacement of targets that experience more implied friction (even though velocity remains constant) reflects the robustness of representational friction was made in Hubbard (1995a, b).

EXPERIMENT 4

In Experiments 1, 2, and 3, the motion of the launcher appeared smooth and continuous. The impetus of the launcher would have been imparted at the moment of contact, and so it was not possible to fully isolate effects of the moment-of-contact from effects of the imparting-of-impetus. One way to dissociate moment-of-contact and imparting-of-impetus would be to present a launcher that moved in a periodic manner. For example, a launcher could approach and contact the target, but the observer would expect the launcher to stop at the moment of contact and then attempt to resume motion only after some interval of time had elapsed. If the target moved at the precise moment the launcher would be expected to resume motion, then effects of impetus should be observed. If observers are able to anticipate effects of impetus even after a launcher has been in contact with a target, that would provide evidence that impetus imparted from the launcher, rather than contact from the launcher *per se*, is related to the decrease in displacement of a target in a launching effect display. Accordingly, observers were shown trials in which the launcher exhibited a caterpillar-like motion. This involved alternating motion of the leading and the trailing edges of the launcher, and allowed the leading edge of the launcher to be in contact with the target for a brief time before the leading edge of the launcher would be expected to push forward again and impart impetus to the target. Observers were also shown launching effect trials and control trials in which only the moving-target portion of the launching effect display was presented.

Method

Participants. The observers were 16 undergraduates drawn from the same participant pool used in Experiment 1, and none of the observers had participated in the previous experiments.

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

Stimuli. The stimuli were the same as in Experiment 1, with the following exceptions: In launching effect trials, the launcher always shifted 3 pixels between successive presentations and the target always shifted 1 pixel between successive presentations. In target only trials, only the moving-target portion of the launching effect trial was shown. The structure of caterpillar trials is illustrated in Figure 2. In caterpillar trials, the launcher first appeared as a square, and the edge closest to the target was located 180 pixels from the nearest edge of the target. The leading edge of the launcher immediately began to move toward the target, and the leading edge moved forward a distance of 60 pixels. This yielded a rectangle that expanded toward the target, and at the height of its

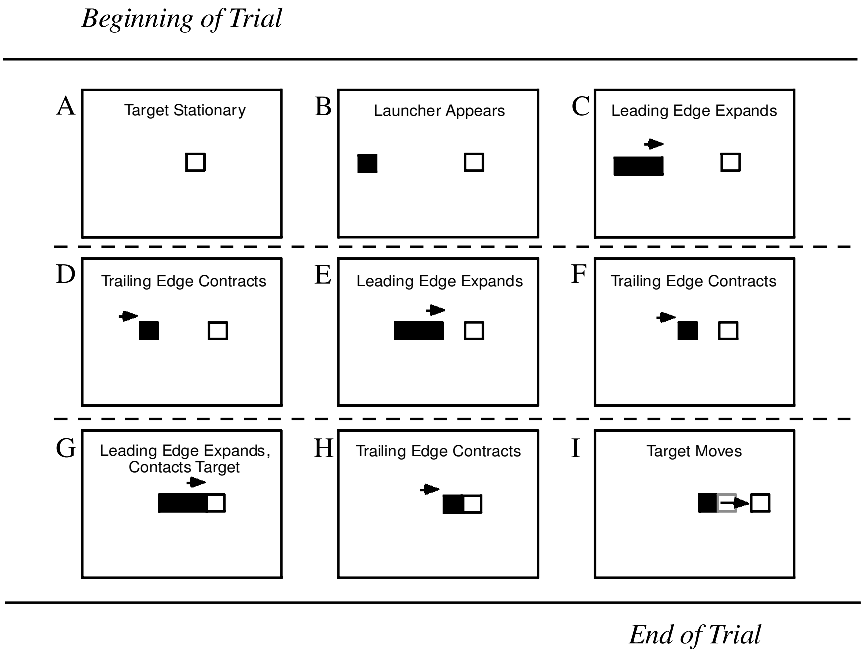

Figure 2. An illustration of the caterpillar trials in Experiment 4. In A, the target initially appears. In B, the launcher appears. In C, the leading edge of the launcher expands forward. In D, the trailing edge of the launcher contracts. In E, the leading edge of the launcher expands forward. In F, the trailing edge of the launcher contracts. In G, the leading edge of the launcher expands forward. In H, the trailing edge of the launcher contracts. In I, the target moves away from the launcher.

expansion, the rectangle was four times longer along its axis of motion than along its orthogonal axis. The leading edge then became stationary. The trailing edge of the launcher then began to move toward the target, and the trailing edge moved forward a distance of 60 pixels. This yielded a rectangle that contracted, and at the maximum contraction, the launcher was again a square shape. The trailing edge then became stationary, and the leading edge began to expand toward the target. The cycle of expansion and contraction occurred three times, and on the final expansion, the leading edge of the launcher contacted the target when the launcher reached its limit of expansion. The cycle of expansion and contraction created a remarkably "organic" motion; indeed, observers spontaneously referred to this type of launcher as a "caterpillar" or an "inchworm". Each observer received 120 trials (3 trial types [target only, launching effect, caterpillar] × 4 direction [rightward, leftward, upward, downward] × 10 replications) in a different random order.

Procedure. The procedure for launching effect trials was the same as that used in Experiment 1. The procedure for target only trials and caterpillar trials was the same as that used in launching effect trials, with the following exceptions: In target only trials, a moving target appeared 1 s after the observer pressed the designated key to begin the trials, and then the target vanished after having travelled a distance equal to that travelled by the target in launching effect trials. In caterpillar trials, a stationary target appeared when the observer pressed the designated key to begin the trials; 1 s later, a square launcher appeared. The trailing edge of the launcher (i.e., the edge more distant from the target) remained stationary while the leading edge of the launcher (i.e., the edge closest to the target) moved toward the target. The leading edge of the launcher then stopped and remained stationary while the trailing edge of the launcher moved toward the target. The motion of the trailing edge stopped when the launcher reached its original size and square shape, and the trailing edge then remained stationary while the leading edge moved toward the target. This cycle of expansion and contraction occurred a total of three times, and on the final cycle, the limit of expansion of the leading edge of the launcher resulted in the leading edge of the launcher contacting the nearest edge of the target. The target remained stationary during the movement of the trailing edge of the launcher, but as soon as the final contraction ended, the target began to move in the same direction as the previous motion of the launcher. Thus, motion of the target occurred when the launcher would have been anticipated to begin the next expansion. Once the target began to move, the launcher did not exhibit any further motion (i.e., there were no further changes in the shape of the launcher or in the spatial coordinates of the leading edge or trailing edge of the launcher).

Results

M displacements were calculated as in Experiment 1, and are listed in Table 4. The M displacement scores were analysed in a 3 (trial type) × 4 (direction) repeated measures ANOVA. Trial type significantly influenced M displacement, $F(2, 34) = 3.53$, $MSe = 51.75$, $p < .05$, and a post hoc Newman-Keuls test ($p < .05$) of all pairwise comparisons indicated that target only ($M = 7.49$) trials resulted in greater M displacement than did launching effect ($M = 4.90$) and caterpillar ($M = 4.59$) trials. Additionally, direction influenced M displacement, $F(3, 51) = 9.08$, $MSe = 73.02$, $p < .001$, and a post hoc Newman-Keuls test ($p < .05$) of all pairwise comparisons indicated that upward motion ($M = 1.34$) resulted in significantly less M displacement than did rightward ($M = 9.03$), leftward ($M = 7.91$), or downward ($M = 4.35$) motion. The Trial Type × Direction interaction did not approach significance.

Discussion

M displacement in caterpillar trials did not differ from M displacement in launching effect trials, and M displacement in caterpillar trials and in launching

TABLE 4
M displacement (in pixels) in Experiment 4

	Direction of launcher motion			
	Rightward	*Leftward*	*Upward*	*Downward*
Launching effect	8.60	6.85	0.70	3.46
Caterpillar	8.49	4.96	0.91	3.98
Target only	10.01	11.91	2.41	5.62

The sign of the displacement indicates the direction of displacement such that positive values indicate displacements beyond the target (i.e., right of a rightward target, left of a leftward target, above an upward target, below a downward target) and negative values indicate displacements behind the target (i.e., left of a rightward target, right of a leftward target, below an upward target, above a downward target).

effect trials was less than M displacement in target only trials. In conjunction with the results from Experiments 1 and 3, this pattern is consistent with the hypothesis that the decrease in M displacement for the target in a launching effect display resulted from observers' perception or belief that an impetus was imparted from the launcher to the target at the moment of the next expected launcher motion (immediately for launchers that exhibited continuous motion as in Experiments 1 and 3, and after a brief delay for launchers that exhibited periodic motion as in Experiment 4); if target motion began at the moment that impetus was imparted, then that motion might be represented as decelerating as the impetus dissipated, and forward displacement of the target would be decreased. Although it might be argued that contact of the launcher and target *per se*, rather than an imparting of impetus, might be the critical component that leads to the decrease in forward displacement of targets in a launching effect display, such an alternative is not consistent with the lack of a decrease in the forward displacement of targets when those targets are contacted by the launcher but move in a direction orthogonal to the direction of the implied impetus of the launcher (Hubbard et al., 2001).

The results of Experiment 4 also shed light on a pattern noted by Michotte: If a target began to move at the moment the leading edge of a caterpillar launcher contacted the target and the leading edge of that caterpillar launcher immediately became stationary, observers did not report a launching effect. However, if a target began to move at the moment the leading edge of a caterpillar launcher contacted the target and the leading edge of that caterpillar launcher also continued to move (e.g., as would occur if the launcher encountered the target midway through an expansion of the leading edge), then a launching effect could be obtained. The salient difference between these two conditions involves whether the launcher would be expected to impart impetus to the target at the moment the target would begin to move; in the former case, impetus would not be imparted to the target, whereas in the latter case, impetus would be imparted to the target. This difference, coupled with the data from Experiment 4, is very suggestive. It may be that a launching effect depends upon a perception or belief that motion of the target is caused by an impetus imparted from the launcher; when such an attribution is plausible (i.e., the onset of target motion corresponds with when impetus would be imparted), a launching effect occurs, whereas when such an attribution is not plausible (i.e., the onset of target motion does not correspond with when impetus would be imparted), a launching effect does not occur.

GENERAL DISCUSSION

The experiments reported here examined the hypothesis that the decrease in displacement previously observed for targets presented in a launching effect display was due to the perception or belief that the launcher imparted impetus to the target. Naïve impetus theory suggests that the act of setting an object in motion imparts an "impetus" to that object, and that this impetus dissipates with time. Michotte's observers had reported that motion of a target in a launching effect display was attributed to contact from the launcher, and so it was possible that the forward displacement of a target in a launching effect display would be influenced by an impetus imparted from the launcher to the target. A subsequent dissipation of the impetus imparted from the launcher to the target in a launching effect display suggests that a launched target may be represented as slowing or stopping. Given that the forward displacement of a target is generally decreased when observers expect that target to slow or stop, the forward displacement of a target in a launching effect display should be decreased relative to the forward displacement of an otherwise identical target presented in the absence of a launcher. The displacement data in the current experiments were all consistent with the naïve impetus hypothesis.

The main effect of launcher velocity in Experiment 1, coupled with the absence of a main effect of target velocity, is consistent with the attribution of target motion (and the subsequent displacement in memory for the target) to an impetus imparted from the launcher. Furthermore, the interaction of launcher velocity and target velocity in Experiment 1, coupled with the lack of an effect of launcher velocity in Experiment 2, is also consistent with an impetus account: If the impetus imparted to a stationary target by the collision of a moving launcher with that stationary target is less than the amount of resistance (e.g., friction) on that target, we would not expect that target to move. As long as the total impetus imparted to the stationary target is below the threshold required to overcome resistance on that target, then the velocity of the target should not influence the remembered location of that target. If, however, the impetus imparted to a stationary target by the collision of a moving launcher with that stationary target is greater than the amount of resistance on that target, then contact from the launcher would result in motion of the target, and any impetus beyond that needed to overcome resistance on the target would contribute to the subsequent motion of the target. As long as the total impetus imparted to a stationary target is above the threshold required to overcome resistance on that target, then a target launched by a faster launcher would be represented as moving at a faster velocity and would exhibit a larger forward displacement than would a target launched by a slower launcher.

The influence of the distance travelled by the target in Experiment 3 was consistent with the hypothesis that forward displacement reflects the level of any remaining impetus. More specifically, naïve impetus theory asserts that impetus imparted from the launcher to the target begins to dissipate immediately upon contact, and so an increase in the distance travelled by a target should result in a greater dissipation of impetus and therefore less forward displacement for that target. The vanishing points of targets in Experiments 1, 3, and 4 were all presumably within the radius of action of the launcher, and so targets vanished before dissipation of the impetus had been completed. It could be predicted that targets which moved beyond the radius of action of the launcher would not exhibit a decrease in forward displacement with increases in the distance travelled, because any continued motion of targets beyond the radius of action would not be represented as resulting from any residual impetus from the launcher. More generally, the results suggest that in at least some cases there might be a relationship between impetus and the magnitude of forward displacement of the target, and this would be consistent with the recent hypothesis that many findings previously attributable to representational momentum might actually involve a "representational impetus" (see Kozhevnikov & Hegarty, in press). Such a representational impetus would be consistent with previous observations that M displacement does not conform to the principle of physical momentum (e.g., the lack of a mass effect in Cooper & Munger, 1993).

The magnitude of the forward displacement of the target in a launching effect display was related to when impetus would have been imparted by the launcher. In Experiment 4, the caterpillar launcher exhibited a type of periodic motion, and a target preceded by a caterpillar launcher began to move at precisely the moment when the next forward motion of the leading edge of the launcher would have been expected. It is at that moment that impetus would have been expected to be imparted from the launcher to the target, and so if motion of the target is attributed to such impetus, then the M displacement of a target preceded by a caterpillar launcher should be equal to the M displacement of a target in a standard launching effect display and smaller than the M displacement of an otherwise identical target presented in the absence of a launcher. Indeed, just this pattern was observed in Experiment 4. Such a pattern, and the hypothesis that the decrease in M displacement in caterpillar trials was due to the imparting of impetus and not to just contact between the launcher and the target, are consistent with Hubbard et al.'s (2001) finding that M displacement for targets that were contacted by a launcher but that moved in a direction orthogonal to the previous motion of that launcher was not decreased. A further test of this idea would be to examine M displacement for a target that moved immediately after contact with a caterpillar launcher that was at the limit of the expansion of its leading edge, and such studies are currently being conducted.

The naïve impetus hypothesis suggests that motion of the target results from the launcher imparting impetus to the target, and this is consistent with the introspection of Michotte's observers that the initial motion of a launched target is attributable to the launcher. Indeed, the displacement data in Experiments 1, 3, and 4 and in Hubbard et al. (2001) seem to track both the introspections of Michotte's observers regarding whether the launcher was responsible for the subsequent motion of the target and predictions based on naïve impetus theory. However, the claim that the displacement data support the impetus theory might initially seem to contradict Michotte's claim that observers perceive causality directly. After all, the notion of "impetus" does not correspond to a valid physical principle, and it does not initially seem reasonable to consider a perception of causality as involving factors that are not valid physical principles. However, if we consider "impetus" to reflect information regarding the phenomenological consequences of physical principles relevant to a collision (e.g., most objects knocked into motion as a result of a collision experience friction, and this friction leads to a deceleration and eventual cessation of motion), then we could speculate that "impetus" as such might involve elements of momentum and friction. If so, then an attribution of impetus might contribute to the launching effect, and the apparent perception of causality would involve representation of phenomenological consequences of physical principles rather than representation of idealized physical principles *per se*.

The findings reported here complement and extend previous research on displacement in the remembered location of targets in a launching effect display reported by Hubbard et al. (2001; also Hubbard & Favretto, 2002). Given that many interactions with objects in the world involve one object acting on a second object, such studies form the cornerstone of a clearer understanding of naïve physics and of the cognition of causality. It may be that the apparent perception of causality actually involves the attribution of a naïve impetus: Observers may perceive or represent the phenomenological consequences of the collision between the launcher and the target. This view is consistent with recent proposals regarding displacement and phenomenology (e.g., see Hubbard, 1999) and may help in bridging the literatures on displacement and on naïve physics. The focus on impetus is also consistent with findings that when observers make judgements of such dynamical systems they focus on just one dimension of the system (Proffitt & Gilden, 1989) and may appeal to heuristics (e.g., slower moving targets are heavier; see Gilden, 1991); in the current data, such heuristics might include the imparting and dissipation of impetus and that greater launcher velocity leads to greater impetus. At a narrow level, the data highlight the possible role of a naïve expectation of impetus in the representation of colliding stimuli. At a broad level, the data underscore the general effects of context and expectation on displacement in spatial representation.

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