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ORIGINAL ARTICLE

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# Naïve impetus and Michotte's "tool effect": evidence from representational momentum

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**Abstract** Displacement in the remembered position of targets in displays based on Michotte's (1951/1991) tool effect paradigm was examined. Targets in tool effect displays exhibited less forward displacement than did otherwise identical targets presented in isolation; the decrease in forward displacement was not dependent upon the motion of a visible intermediary, but was dependent upon a visible intermediary contacting both the launcher and the target. The data were consistent with naïve impetus theory and the hypothesis that decreases in forward displacement of targets in tool effect displays resulted from the intermediary transferring perceived impetus of the launcher to the target and a dissipation of that impetus with subsequent target motion. Possible connections between displacement, impetus, and the perception of causality are discussed.

## Introduction

The extent to which an observer can be said to directly perceive causality has long been of interest (for review see Scholl & Tremoulet, 2000), and the view that observers can directly perceive causality has been championed most strongly by Michotte (1946/1963; see also Thinès, Costall, & Butterworth, 1991). The paradigm of many of Michotte's studies is illustrated in Fig. 1: Observers viewed a display in which a moving stimulus, the "launcher", approached and contacted a stationary stimulus, the "target". When the launcher contacted the target, the launcher's motion would cease, and the target would begin to move. If the latency between when the launcher contacted the target and when the target began to move, the direction of the target's motion relative to the previous motion of the launcher, and the ratio of the velocities of the launcher and the target were all within a narrow set of limits, then observers would typically report that contact from the launcher caused the subsequent motion of the target. Michotte claimed that this response was not a simple inference based on the proximity of the locations of the launcher and the target or on the contiguity of the movements of the launcher and the target; rather, he suggested that observers actually perceived that the launcher caused the initial movement of the target. Michotte referred to this impression of causality as the "launching effect".

Hubbard, Blessum, and Ruppel (2001) examined representational momentum for a target in a launching effect display. "Representational momentum" is the name initially given to a distortion in memory in which the remembered final position of a moving stimulus is displaced forward in the direction of target motion (Freyd & Finke, 1984; for review see Hubbard, 1995b). Initial theories of representational momentum attributed this distortion to an internalization of the laws of physical momentum (e.g., Finke, Freyd, & Shyi, 1986); however, a literal momentum metaphor was not supported by subsequent findings, and more recent theories of representational momentum attributed this distortion to spatiotemporal coherence (Freyd, 1987, 1993), shaping of the functional architecture of representation by environmentally invariant principles (Hubbard, 1995b, 1999), implicit knowledge of physical principles (Hubbard, 1998a), oculomotor overshoot coupled with a bias to mislocalize targets toward the fovea (Kerzel, 2000), or belief in naïve impetus (Kozhevnikov & Hegarty, 2001). Subsequent studies found that the distortion in memory for position was influenced by factors other than the implied momentum of the target (e.g., distribution of attention, Hayes & Freyd, 2002; retention interval, Bertamini, 1993; Freyd & Johnson, 1987; implied

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friction, Hubbard, 1995a; implied gravitational attraction and weight, Hubbard, 1997; conceptual knowledge of target identity, Reed & Vinson, 1996; Vinson & Reed, 2002; beliefs concerning future target motion, Hubbard, 1994; Verfaillie & d'Ydewalle, 1991), and so now the more neutral term "displacement" is preferred unless the distortion is attributable solely to the implied momentum of the target.

Hubbard et al. (2001) found that forward displacement of the target in a launching effect display was significantly decreased relative to forward displacement of an otherwise identical target not in a launching effect display. Numerous control conditions ruled out several possible explanations: A control condition in which the target moved in a direction orthogonal to the previous motion of the launcher ruled out an explanation based on the launcher serving as a landmark for judgments of the target, a control condition in which the display consisted of a single stimulus that decelerated from the initial fast velocity of the launcher to the subsequent slow velocity of the target ruled out an explanation based on a deceleration of a single motion event, and a control condition in which a single stimulus traveled a distance equal to the combined distances of the motions of the launcher and target ruled out an explanation based on the length of the path of target motion. The decrease in forward displacement of targets in launching effect displays was apparently due to the relationship between the motions of the launcher and the target. This is consistent with the introspections of Michotte's observers that motion of a target in a launching effect display was attributed to the launcher; changes in displacement with changes to the launching effect display offered some of the first quantitative behavioral evidence that tracked changes in the qualitative perceptual reports of Michotte's observers.

The decrease in forward displacement of targets in a launching effect display may reflect naïve theories and beliefs regarding impetus. According to naïve impetus theory, the act of setting a target in motion imparts an impetus to that target, and the strength of this impetus dissipates with time (see McCloskey, 1983; McCloskey & Kohl, 1983). The idea of "impetus" involves at least two deviations from Newtonian mechanics: any effect of friction or resistance on a target is placed "inside" that target (i.e., made an intrinsic part of the target) and not influenced by conditions or stimuli outside of the target, and the imparted impetus replaces any pre-existing influences on the target. Placing effects of friction or resistance inside a target presupposes a sensitivity to the effects of such friction or resistance; indeed, the mental representation of a target is biased in ways consistent with the effects of implied friction: forward displacement of a moving target is decreased with increases in implied friction on that target (attributed to "representational friction", see Hubbard, 1995a, 1998b). More salient for our purpose, the results of Hubbard et al. (2001) are consistent with the possibility that effects of friction inside the target diminish impetus with continued forward motion of the target. Such diminution occurs only when an initial impetus is imparted from elsewhere and cannot be replenished (e.g., as in launching); if impetus could be replenished (e.g., as in self-generated motion), then effects of friction could be overcome and impetus would not diminish.

Within the framework of naïve impetus theory, a moving target initially set into motion by contact from another object would possess only the limited amount of impetus initially imparted from that other object. That impetus would be largest at the beginning of the target's motion, and effects of friction and resistance inside the target would cause that impetus to dissipate without replacement with continued target motion. If the impetus imparted to a target is dissipated without replacement, then motion of that target would be expected to stop once the level of impetus dropped below the minimal threshold required to maintain target motion; therefore, observers would expect targets in launching effect displays to slow down and stop as impetus was dissipated. Forward displacement of a target is decreased with slower target velocities (Freyd & Finke, 1985; Hubbard & Bharucha, 1988) and when observers expect a target to stop (Finke et al., 1986), and so

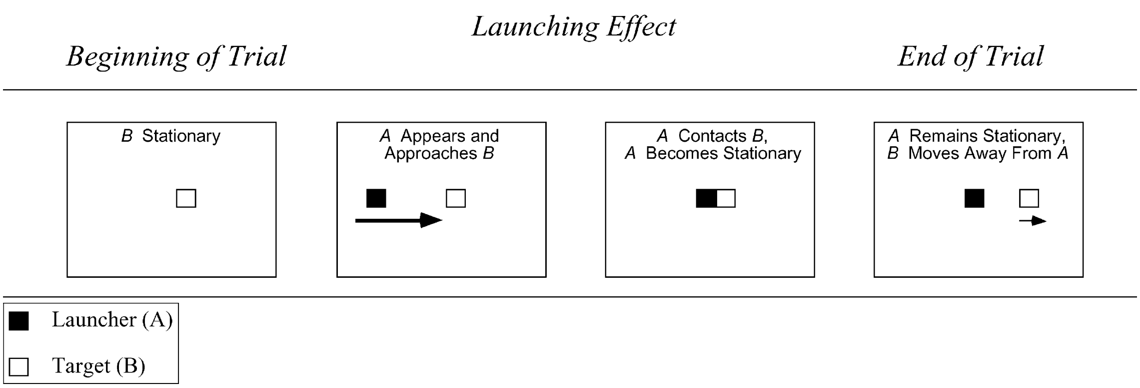



**Fig. 1** An illustration of the launching effect paradigm. A moving launcher contacts an initially stationary target. At the moment the launcher contacts the target, the launcher becomes stationary and the target begins to move. Observers often report the causal impression that the launcher "causes"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

perhaps the forward displacement of a target in a launching effect display is decreased relative to the forward displacement of an otherwise identical target not in a launching effect display because observers expect the target in a launching effect display to slow down and stop. Consistent with this, Michotte (1946/1963) reported that the launching effect was diminished when a target that initially appeared to have been launched did not stop and moved farther than might have been expected given an initial attribution of target motion to the launcher[1].

A moving target that was not initially set into motion by contact from another object, but whose motion was more autonomous or self-generated, would not necessarily possess only a limited amount of impetus that would be largest at the beginning of that target's motion or that would dissipate without replacement with continued target motion. In the absence of other information (e.g., the presence of nontarget stimuli such as a barrier that might block forward motion of the target), observers would not expect a nonlaunched target to slow and stop, because the impetus of a nonlaunched target need not necessarily dissipate without replacement (e.g., self-generated motion would continually replenish impetus). Thus, displacement of a target that is otherwise identical to a target in a launching effect display (e.g., same velocity, same direction of motion, etc.) but that is not launched would not exhibit the decrease in displacement characteristic of a launched target. More generally, if a given target motion is attributed to an impetus imparted from a launcher, then that impetus would dissipate without replacement with continued target motion, and the extent of that target motion would be limited by the magnitude of the initial impetus imparted from the launcher; if a given target motion is not attributed to an impetus imparted from a launcher (e.g., if motion is more autonomous or self-generated), then any impetus resulting from target motion need not dissipate without replacement with continued target motion, and the extent of that target motion would not be limited by the magnitude of the initial impetus.

Impetus that was imparted from a launcher to a target would be imparted immediately upon contact with the target and only in the direction of that launcher's previous motion. Therefore, motion of the target that began only after some delay between when the launcher contacted the target and when the target began to move, or motion of the target in some direction other than the direction of the previous motion of the launcher, should not be attributable to impetus imparted from the launcher. These "limitations" on the imparting of impetus from the launcher, in conjunction with the idea that an imparting of impetus from the launcher leads observers to expect a launched target to slow and stop, explain the decrease in displacement for launching effect trials relative to target only trials and are also consistent with (a) Hubbard et al.'s (2001) finding that displacement of a target that moved in a direction orthogonal to the previous motion of the launcher was not decreased, and (b) Michotte's (1946/1963) report that the launching effect decreased if a target moved in a direction that differed from the direction of the previous motion of the launcher or if the delay between when the launcher contacted the target and when the target began to move was larger than one-tenth of a second. Overall, ideas from naïve impetus theory appear to provide a link connecting the introspective reports of Michotte's observers with the behavioral displacements in remembered position of Hubbard et al.'s observers.

If forward displacement of a target in a launching effect display is related to the amount of remaining (i.e., undissipated) impetus, and the impetus imparted to a target is dissipated without replacement during target motion, then an impetus account would predict that forward displacement of a launched target should decrease with increases in the distance traveled by that target (at least as long as target motion is within the radius of action of the launcher). Also, a faster launcher would presumably impart more impetus to a target upon contact than would a slower launcher, and so an impetus account would predict launched targets contacted by faster launchers should exhibit larger forward displacement than would launched targets contacted by slower launchers. Consistent with these predictions, Hubbard and Ruppel (2002) found that (a) launched targets which traveled a longer distance exhibited smaller forward displacement than did launched targets which traveled a shorter distance, and (b) launched targets contacted by faster launchers exhibited larger forward displacement than did launched targets contacted by slower launchers, even when target velocity and the distance traveled by the target were held constant. However, if a target remained stationary after contact from the launcher, then launcher velocity did not influence displacement of that target, and this is consistent with the idea that impetus imparted from a moving object will not influence the position of a target if the amount of impetus imparted is below the threshold needed to overcome any friction or resistance on that target.

In Hubbard and Ruppel's (2002) studies, the launcher always contacted the target. A more rigorous test of the impetus hypothesis could be made if the final location of the launcher and the initial location of the target were spatially separated. If an intermediary stimulus bridged the gap between the final location of the launcher and the initial location of the target, then impetus from the launcher would be conveyed to the target through that

[1]Michotte referred to the area within which motion of the target was attributed to the launcher, and beyond which motion of the target was not attributed to the launcher, as the launcher's "radius of action." Typically, if an object moves beyond the launcher's radius of action, motion of that object is perceived to be "triggered" rather than "launched" by the launcher. In both launching and triggering the initial motion is initiated by the launcher, but in launching all of the subsequent movement of the target is still attributed to the initial influence of the launcher, whereas in triggering the target moves more of its own accord even though contact from the launcher is a necessary antecedent to target motion (Michotte, 1946/1963).

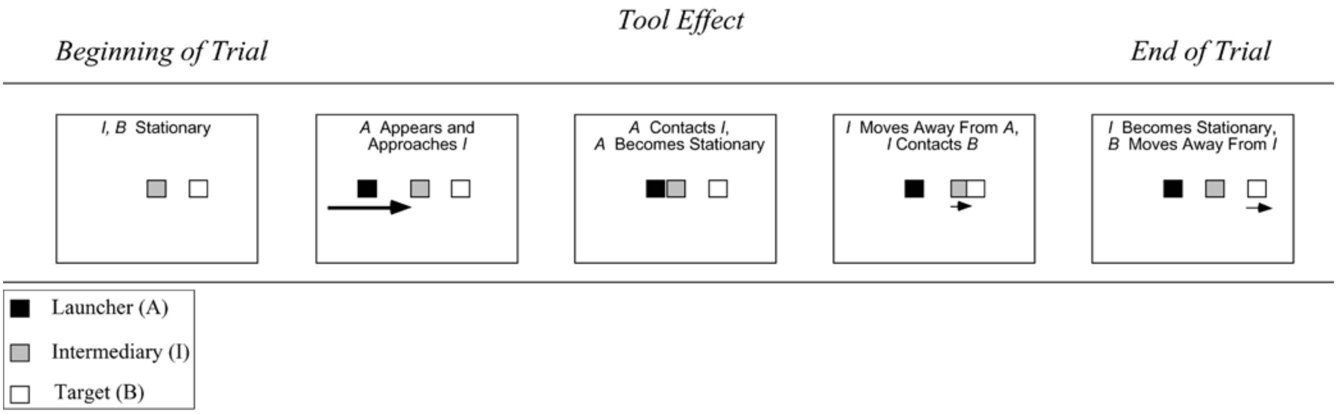



**Fig. 2** An illustration of the tool effect paradigm. A moving launcher contacts a stationary intermediary. At the moment the launcher contacts the intermediary, the launcher becomes stationary and the intermediary begins to move. The intermediary then contacts the stationary target. At the moment the intermediary contacts the target, the intermediary becomes stationary and the target begins to move. Observers often report the causal impressions that the launcher "causes" the target to move and that the intermediary did not have a causal role in the motion of the target

intermediary (and displacement of the target would decrease), whereas if an intermediary stimulus did not bridge the gap between the final location of the launcher and the initial location of the target, then impetus from the launcher would not be conveyed to the target (and displacement of the target would not decrease). Michotte (1951/1991) presented observers with just such a display in which an intermediary stimulus bridged the gap between the final location of the launcher and the initial location of the target: as shown in Fig. 2, the launcher would contact a stationary intermediary stimulus, the launcher would cease moving and the intermediary stimulus would move away from the launcher, the intermediary would contact a stationary target, the intermediary would cease moving and the target would move away from the intermediary. Michotte's observers reported a single action in which the launcher was the sole active or causal agent. The movement of the intermediary was not perceived as spontaneous or autonomous, and observers did not perceive that the intermediary launched the target through the intermediary's own power; rather, observers perceived that the intermediary functioned as a conduit for the influence of the launcher. Michotte referred to this impression as a "tool effect".

The phenomenology of the tool effect suggests that an intermediary stimulus located between the final location of the launcher and the initial location of the target can convey the influence of the launcher to the target, and the plausibility of an impetus-based explanation of the tool effect was tested in the following experiments. In all experiments, observers were presented with computer-generated stimuli based on variations of Michotte's tool effect paradigm, and displacement in memory for the final location of the target was measured. Experiment 1 presented tool effect trials in which the distance traveled by the intermediary varied. Experiments 2 and 3 were similar to Experiment 1, except that the intermediary was not visible, and so there was a gap between the final location of the launcher and the initial location of the target. In Experiment 2, the delay between when the launcher stopped moving and when the target began moving matched that in Experiment 1, whereas in Experiment 3, the target began to move immediately upon the cessation of the motion of the launcher. Experiment 4 presented a stationary intermediary which varied in length and which was already in contact with the target before the launcher contacted the intermediary. Experiment 5 presented a stationary intermediary that contacted either the launcher or the target, but not both the launcher and the target. In all experiments, the launcher, target, and intermediary (if present) vanished simultaneously, and observers indicated the vanishing point of the target.

## Experiment 1

In this experiment, observers were presented with displays modeled on Michotte's tool effect paradigm, and the length of the path of the intermediary varied across trials. Additionally, observers were presented with target only control trials in which only the moving target portion of a tool effect trial was displayed. If the intermediary can serve as a conduit to convey the impetus of the launcher to the target, then displacement of the target in a tool effect display should be less than displacement of the target in a target only trial. Alternatively, if the intermediary cannot serve as a conduit to convey impetus from the launcher to the target, then displacement of the target in a tool effect display should not differ from displacement of the target in a target only trial. If the intermediary is perceived as separate from the launcher and does not function as a tool or extension of the launcher, then impetus would decrease with increases in the length of the path of the intermediary, and forward displacement of the target should decrease with increases in the length of the path of the intermediary. Alternatively, Michotte's observers reported that the intermediary was perceived to be an extension of the launcher, and so if the intermediary was not perceived as separate from the launcher, then forward displacement of the target should not be influenced by the length of the path of the intermediary.

## Method

### Participants

The observers in all experiments were undergraduates at Texas Christian University who participated in return for partial course credit. Seventeen observers participated in Experiment 1.

### Apparatus

The stimuli were generated by and responses collected upon an Apple Macintosh IIsi microcomputer connected to an Apple RGB color monitor. The monitor was approximately 60 cm from the observer, and this distance could be adjusted slightly to provide observers with maximum comfort and confidence in their responses.

### Stimuli

The launcher, intermediary, and target stimuli were square shapes 20 pixels (approximately 0.83 degrees) in width and were presented on a white background. The launcher and intermediary were filled black squares; the target was a black outline square (with white interior), and the outline was one pixel in width. The background of the stimulus display was 640×460 pixels (approximately 26.67×19.17 degrees). There were five types of trials: 30, 60, 90, 120, and target only. The 30, 60, 90, and 120 trials were tool effect trials in which the distance traveled by the intermediary corresponded to 30, 60, 90, and 120 pixels (approximately 1.25, 2.50, 3.75, 5.00 degrees), respectively. In these tool effect trials, the launcher emerged from one edge of the display and traveled in a straight line toward the opposite edge of the display; thus, motion was either left-to-right (LR), right-to-left (RL), top-to-bottom (TB), or bottom-to-top (BT). The combined launcher + intermediary distance remained constant across tool effect trials; given the finite extent of the display, increases in the length of the path traveled by the intermediary resulted in decreases in the length of the path traveled by the launcher. The launcher crossed 300, 270, 240, or 210 pixels (approximately 12.50, 11.25, 10.00, 8.75 degrees) before contacting the intermediary, and when the launcher contacted the intermediary, forward motion of the launcher immediately ceased. The intermediary began moving and crossed 30, 60, 90, or 120 pixels before contacting the target. When the intermediary contacted the target, forward motion of the intermediary immediately ceased, and the target began moving. On each trial, the direction of motion of the intermediary and of the target were the same as the direction of motion of the launcher. The path of motion for horizontally moving launchers, intermediaries, and targets was approximately centered along the vertical midline of the display, and the path of motion for vertically moving launchers, intermediaries, and targets was approximately centered along the horizontal midline of the display. Target only trials were the same as tool effect trials, except that neither the launcher nor the intermediary were presented. Michotte reported that once a target moved beyond a launcher's radius of action the causal impression of launching was greatly diminished, and in the absence of explicit displacement data on this issue, a relatively short distance for target motion was used; based on Hubbard et al. (2001), a 30 pixel (approximately 1.25 degrees) distance should provide enough motion for representational momentum to be evoked but still be within the potential radius of action of a launcher, and so in all trials, the target vanished after traveling 30 pixels. The launcher and the intermediary traveled at a relatively fast velocity, and the target traveled at a relatively slow velocity. The fast velocity was produced by shifting the launcher or intermediary three pixels between successive presentations, and the slow velocity was produced by shifting the target one pixel between successive presentations; the fast and slow velocities were approximately equal to 15 degrees per second and 5 degrees per second, respectively. The launcher, intermediary, and target were not deformed as a result of contact. A fixation point was not used, nor were observers' heads or viewing restrained in any way; observers viewed the display binocularly and were free to track the target. Each observer received 120 trials [5 trial types (target only, 30, 60, 90, 120 pixels) × 4 directions (LR, RL, TB, BT) × 6 replications] in a different random order.

### Procedure

Observers were first given 10 practice trials at the beginning of the session, and practice trials were drawn randomly from experimental trials. Observers initiated each trial by pressing a designated key. In tool effect trials, a stationary intermediary and a stationary target immediately appeared, and the launcher then immediately emerged from either the left, right, top, or bottom edge of the display and moved toward the intermediary. When the launcher contacted the intermediary, the launcher became stationary and the intermediary immediately began to move. The intermediary moved toward the target, and when the intermediary contacted the target, the intermediary became stationary and the target immediately began to move. The launcher, intermediary, and the target simultaneously vanished shortly thereafter. In target only trials, a moving target immediately appeared, and then vanished shortly thereafter. For all trial types, the cursor (in the form of a plus sign) appeared near the center of the display after the target (and the launcher and intermediary, if present) vanished, and observers were instructed 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 in order to record the display coordinates of the cursor. Observers then initiated the next trial.

## Results

The differences between the true vanishing point and the judged vanishing point of the target were calculated along the axis of motion of the target. Consistent with previous reports, these differences were referred to as "M displacement"[2]. Positively signed M displacement indicated the judged vanishing point was beyond the true vanishing point (i.e., left of a RL target, right of a LR target, below a TB target, above a BT target), and negatively signed M displacement indicated the judged vanishing point was behind the true vanishing point (i.e., right of a RL target, left of a LR target, above a TB target, below a BT target).

M displacements were analyzed in a 5 (trial type) × 4 (direction) repeated measures ANOVA. As shown in Fig. 3, trial type significantly influenced M displacement, $F(4, 64) = 4.85$, $MSE = 15.13$, $P < .002$, and a post-hoc Newman-Keuls test ($P < .05$) of all pairwise

[2]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.

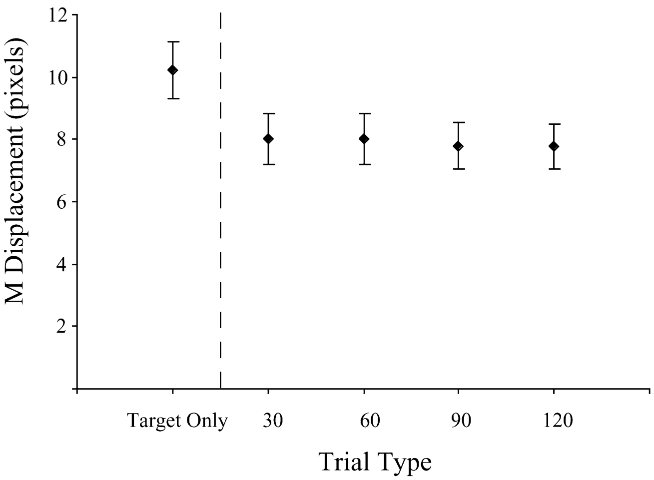



**Fig. 3** M displacement as a function of trial type in Experiment 1. Error bars reflect the standard error. In all experiments the "Target Only" trials are control trials in which neither an intermediary nor a launcher is visible. The 30, 60, 90, and 120 trials are tool effect trials in which a launcher, intermediary, and target are visible (see Fig. 2), and the numerical designation reflects the distance (in pixels) traveled by the intermediary

comparisons of target only ($M$ = 10.24), 30 pixel ($M$ = 8.01), 60 pixel ($M$ = 8.04), 90 pixel ($M$ = 7.80), and 120 pixel ($M$ = 7.76) trials revealed that M displacement was (a) larger in target only trials than in each of the tool effect trials, and (b) not influenced by the length of the path of the intermediary. Direction also significantly influenced M displacement, $F(3, 48) = 5.72$, MSE = 69.89, $P < .003$, and a post-hoc Newman-Keuls test ($P < .05$) of all pairwise comparisons of LR ($M$ = 11.01), RL ($M$ = 9.01), TB ($M$ = 7.53), and BT ($M$ = 5.53) trials revealed M displacement was larger in LR trials than in TB trials and BT trials. The Trial type × Direction interaction was not significant, $F(12, 192) = 1.41$, MSE = 13.22, $P > .15$.

The average M displacements for target only, 30, 60, 90, and 120 pixel trials were tested against a mean of zero. With a Bonferroni correction ($P < .05/5$), M displacement was significantly greater than zero in target only, $t(67) = 10.05$, $P < .0001$, 30 pixel, $t(67) = 9.79$, $P < .0001$, 60 pixel, $t(67) = 9.70$, $P < .0001$, 90 pixel, $t(67) = 10.31$, $P < .001$, and 120 pixel, $t(67) = 10.61$, $P < .0001$, trials. Thus, there was a significant forward M displacement in all trial types, and so the decrease in M displacement in tool effect trials did not result from memory for targets in tool effect trials failing to exhibit forward M displacement.

## Discussion

M displacement of targets in tool effect trials was less than M displacement of targets in target only trials. This pattern is consistent with the hypothesis that motion of the target in tool effect trials was represented as resulting from an impetus imparted from the launcher through the intermediary to the target. Given reports of Michotte's observers that in tool effect displays and in launching effect displays motion of the target is ultimately attributed to the launcher, this pattern is also consistent with previous findings that M displacement of a target in a launching effect display is decreased relative to M displacement of an otherwise identical target not in a launching effect display. The length of the path of the intermediary in tool effect displays did not influence M displacement of the target, and this suggests that any impetus imparted from the launcher to the intermediary did not dissipate during motion of the intermediary. The lack of an effect of the length of the path of the intermediary is consistent with reports of Michotte's observers regarding the phenomenology of the tool effect, and so in functioning as a tool, the intermediary conveys the impetus from the launcher without any significant dissipation resulting from the distance traveled by the intermediary.

One alternative explanation for the decreased M displacement of the target in tool effect trials relative to target only trials is that observers interpreted tool effect displays as comprised of two consecutive launching effects (i.e., the launcher launches the intermediary, and the intermediary launches the target), but such an explanation is not consistent with the reports of Michotte's observers. More critically, if the intermediary had been launched, then the impetus available to be imparted upon contact with the target would have decreased with increases in the distance traveled by the intermediary. Intermediaries that traveled a longer distance would have less available impetus remaining to impart to the target, and so targets contacted by intermediaries that traveled a longer distance should have exhibited less forward M displacement than did targets contacted by intermediaries that traveled a shorter distance. Therefore, the lack of an effect of the distance traveled by the intermediary on the displacement of the target does not support the hypothesis that the intermediary was perceived as a separate launched object. Additionally, perception of a launching effect is increased when the previous velocity of the launcher is greater than the subsequent velocity of the target (Michotte, 1946/1963), but in Experiment 1, the previous velocity of the launcher and the subsequent velocity of the intermediary were the same. By using the same velocity for the launcher and for the intermediary, the possibility that the intermediary would be perceived as launched by the launcher would have been decreased and the possibility that the intermediary would be perceived as a tool or extension of the launcher would have been increased.

A second alternative explanation for the decreased M displacement of the target in tool effect trials relative to target only trials is that observers used the intermediary and/or launcher as a landmark. Memory for a target is biased toward a landmark (the "landmark attraction effect", see Bryant & Subbiah, 1994); when landmark attraction and representational momentum operate in the same direction (i.e., when the target approaches the landmark), they sum and forward displacement of the target is relatively large, whereas when landmark attraction and representational momentum operate in opposite directions (i.e., when the target moves away from the landmark), they partially cancel and forward displacement of the target is relatively small (see Hubbard & Ruppel, 1999). Given that targets in tool effect trials moved away from the intermediary and launcher, perhaps the decreased M displacement of targets in tool effect trials was due to a landmark attraction effect from the launcher and/or the intermediary partially canceling representational momentum of the target and thus decreasing the overall forward displacement of the target. However, Hubbard et al. (2001) rejected a landmark account of the decreased displacement of targets in launching effect trials because the launcher should have been equally effective as a landmark when the target moved in a direction orthogonal to the previous motion of the launcher as when the target moved in the same direction as the previous motion of the launcher, yet displacement was not decreased in an orthogonal motion condition. This renders it less likely a landmark explanation could account for differences in M displacement between tool effect trials and target only trials in Experiment 1.

Overall, the displacement pattern is consistent with introspections of Michotte's observers that an intermediary in a tool effect display functioned as an extension of the launcher and conveyed the influence of the launcher to the target. Given that one of the criticisms of Michotte's work is that his studies relied almost exclusively on introspections of trained and practiced observers, the finding that displacement patterns of naïve observers provide behavioral evidence convergent with the introspections of Michotte's observers is an important contribution to the literature on the perception of causality. Even so, it is not yet clear which aspect of the intermediary is most critical for the conveyance of the launcher's impetus to the target. Is it merely the presence of the intermediary in the gap between the final location of the launcher and the initial location of the target, or is motion of the intermediary from the final location of the launcher to the initial location of the target necessary? Does the intermediary need to contact both the launcher and the target? Is the intermediary even necessary, or could "launching-at-a-distance" occur in which an intermediary is not present and the launcher does not contact the target, but memory for the target still exhibits a decrease in displacement typical of a tool effect or a launching effect? The following experiments address these issues in greater detail, and the role of the intermediary and the possible influence of implied impetus are examined.

## Experiment 2

In the tool effect trials in Experiment 1, observers viewed a clearly visible intermediary that moved from the final location of the launcher to the initial location of the target. Given that the intermediary is hypothesized to be a conduit or linkage through which the launcher imparts impetus to the target, whether or not this linkage is visible should influence whether or not observers attribute motion of the target to impetus imparted from the launcher. More specifically, if a linkage is visible, then motion of the target would be attributed to impetus imparted from the launcher, and M displacement of the target should be less than M displacement of a target in a target only trial; however, if a linkage is not visible, then motion of the target would not be attributed to impetus from the launcher, and M displacement of the target should not differ from M displacement of a target in a target only trial. Thus, a decrease in M displacement from that observed in tool effect trials if the intermediary is not visible would be evidence against the impetus hypothesis. Accordingly, in Experiment 2 tool effect displays similar to those shown in Experiment 1 were presented, but the intermediary was not visible. The temporal interval between when the launcher stopped moving and when the target began to move was a function of the spatial separation between the final location of the launcher and the initial location of the target, and the temporal intervals in Experiment 2 matched the temporal intervals in Experiment 1. Additionally, target only trials were presented.

### Method

#### *Participants*

The observers were 14 undergraduates drawn from the same participant pool used in Experiment 1. None of the observers had participated in the previous experiment.

#### *Apparatus*

The apparatus was the same as in Experiment 1.

#### *Stimuli*

The stimuli are illustrated in Fig. 4, and were the same as in Experiment 1, with the following exception: In trials in which a launcher and an intermediary were presented, the intermediary was a filled square drawn in the same color as the display background. By drawing the intermediary in the same color as the display background, the intermediary was rendered invisible, but the temporal interval between when the launcher stopped moving (i.e., when the launcher contacted the intermediary) and when the target began moving (i.e., when the intermediary contacted the target) was preserved. Each observer received 120 trials [5 trial types (target only, 30, 60, 90, 120 pixels) $\times$ 4 directions (LR, RL, TB, BT) $\times$ 6 replications] in a different random order.

#### *Procedure*

The procedure was the same as in Experiment 1, except that the intermediary was not visible.

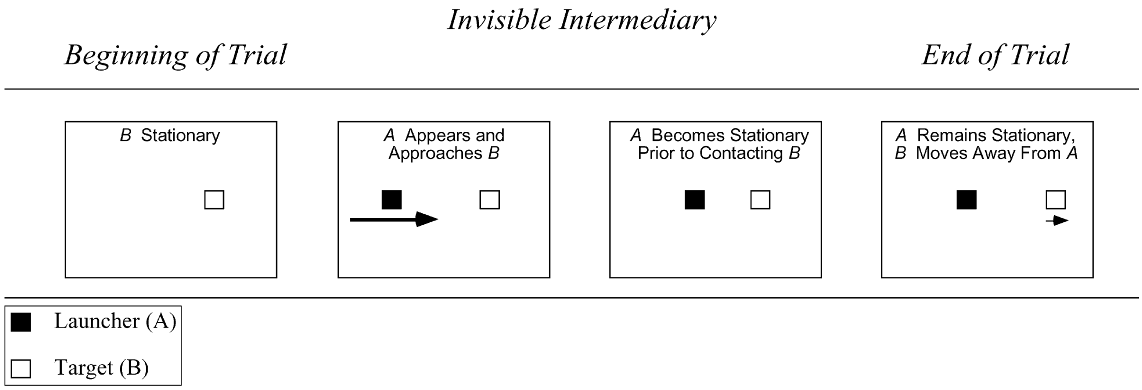



**Fig. 4** An illustration of invisible intermediary trials in Experiments 2 and 3. A moving launcher approaches a stationary target, but the launcher becomes stationary prior to contacting the target. The target begins to move, and target motion begins after an interval equal to that which an intermediary would have taken in crossing the gap between the final location of the launcher and the initial location of the target (Experiment 2) or immediately (Experiment 3)

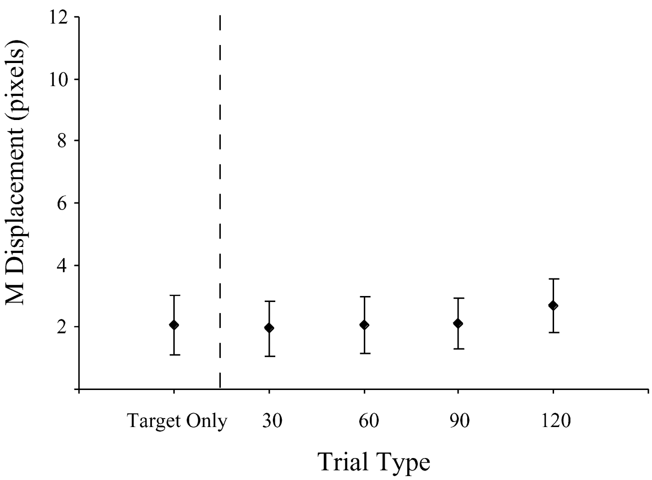



**Fig. 5** M displacement as a function of trial type in Experiment 2. Error bars reflect the standard error. The 30, 60, 90, and 120 trials are invisible intermediary trials in which only a launcher and target are visible (see Fig. 4), and the numerical designation reflects the distance (in pixels) between the final location of the launcher and the initial location of the target (i.e., the distance traveled by the invisible intermediary)

## Results

The M displacements were calculated as in Experiment 1, and were analyzed in a 5 (trial type) × 4 (direction) repeated measures ANOVA. As shown in Fig. 5, trial type did not significantly influence M displacement, $F(4, 52) = 0.31$, MSE = 16.10, $P > .85$. Direction significantly influenced M displacement, $F(3, 39) = 11.79$, MSE = 61.10, $P < .001$, and a post-hoc Newman-Keuls test ($P < .05$) of all pairwise comparisons of LR ($M = 5.24$), RL ($M = 3.89$), TB ($M = 1.71$), and BT ($M = -2.11$) trials were significant except for the LR versus RL comparison and the RL versus TB comparison. The Trial type × Direction interaction was not significant, $F(12, 156) = 0.88$, MSE = 10.62, $P > .56$.

The average M displacements for target only, 30, 60, 90, and 120 pixel trials were tested against a mean of zero. With a Bonferroni correction ($P < .05/5$), M displacement was marginally greater than zero in target only, $t(55) = 2.16$, $P = .018$, 30 pixel, $t(55) = 2.22$, $P = .015$, and 60 pixel, $t(55) = 2.29$, $P = .013$, trials, and significantly greater than zero in 90 pixel, $t(55) = 2.62$, $P < .006$, and 120 pixel, $t(55) = 10.61$, $P < .002$, trials. Without any type of correction for multiple $t$ tests, the M displacements in all five trial types were all significant; even with an extremely conservative Bonferroni correction those $t$ tests that did not quite reach significance were no more than .008 above the level required for significance. Even though the magnitude of M displacement appears decreased from that in Experiment 1, forward M displacement of targets in Experiment 2 did occur.

## Discussion

M displacement of targets in invisible intermediary trials did not differ from M displacement of targets in target only trials. This suggests M displacement of the target in invisible intermediary trials was not influenced by the launcher; more specifically, motion of the target in invisible intermediary trials was not influenced by impetus from the launcher. The differences in M displacement patterns of Experiments 1 and 2 were due to whether the intermediary was visible; when the intermediary was visible (Experiment 1), differences in M displacement between tool effect trials and target only trials were observed, whereas when the intermediary was not visible (Experiment 2), differences in M displacement between invisible intermediary trials and target only trials were not observed. Overall, this pattern is consistent with the impetus hypothesis. Also, the data of Experiment 2 do not support the hypothesis that the decrease in M displacement in tool effect trials in Experiment 1 resulted solely from the spatial configuration of the launcher and the target, because the spatial configuration of launchers and targets in Experiment 2 was the same as the spatial configuration of launchers and targets in Experiment 1. Similarly, the data of Experiment 2 do not support the hypothesis that the decrease in M displacement of the target in tool effect trials relative to target only trials in Experiment 1 resulted from landmark attraction effects from the launcher.

Comparison of Figs. 3 and 5 suggests that M displacement in Experiment 2, including M displacement in target only trials, is less than M displacement in Experiment 1. Perhaps the presence of a visible intermediary in Experiment 1 made the differences between target only trials and tool effect trials more salient in Experiment 1 than the differences between target only trials and invisible intermediary trials in Experiment 2, and this increased salience increased M displacement in target only trials in Experiment 1 relative to M displacement in target only trials in Experiment 2. Alternatively, given that a launching effect or tool effect did not occur in Experiment 2, it may be possible that other effects contributed to the weaker general displacement of the target in Experiment 2. For example, the overall decreased displacement in Experiment 2 may reflect a landmark attraction effect toward the launcher that would have been overshadowed by a tool effect (or would not have occurred) in Experiment 1. Although a landmark attraction effect cannot account for decreases due to the launching effect, in the absence of a launching effect it would not be surprising to see effects of a landmark on displacement of a target. However, it is not clear how such a landmark effect might have carried over to target only trials in Experiment 2, unless the presence of a launcher on 80% of the trials primed observers to look behind the target even on target only trials.

The data of Experiment 2 suggest that for any influence of the launcher on M displacement of the target to be observed when the launcher does not contact the target, a visible intermediary or tool is necessary. When the intermediary was not visible, there was no evidence that any causal influence of the launcher was represented as passing through the spatial coordinates that a visible intermediary would have passed through; M displacement in invisible intermediary trials did not differ from M displacement in target only trials. Michotte (1946/1963) reported that the introduction of a spatial gap between the final location of the launcher and the initial location of the target usually destroyed the perception of a causal relationship between the movement of the launcher and the movement of the target[3]. The invisible intermediary trials introduced a spatial gap between the final location of the launcher and the initial location of the target, and the lack of any apparent influence of the launcher on the displacement of the target, as well as the lack of any effect of the distance traveled by the invisible intermediary (i.e., a lack of effect of the length of the spatial gap between the final location of the launcher and the initial location of the target), are consistent with Michotte's idea that the tool conveyed the force of the launcher to the target, and also consistent with the effects of a spatial gap on the perception of causality. As in Experiment 1, displacement once again offered a quantitative behavioral measure consistent with the introspective reports of Michotte's observers.

[3]Michotte did find that under limited circumstances a "launching-at-a-distance" could occur, but in such cases, larger spatial gaps between the initial location of the launcher and the initial location of the target required faster launcher velocities. The velocity used in Experiment 2 was well beneath that which might have been capable of producing launching-at-a-distance, given the sizes of the spatial gaps in Experiment 2, and so the stimuli in Experiment 2 were typical of those Michotte had shown would not result in a launching-at-a-distance.

## Experiment 3

The temporal intervals in Experiment 2 between when the launcher stopped moving and when the target began moving were the same as the corresponding temporal intervals in Experiment 1. Presumably, impetus imparted from the launcher would have "moved" at the same velocity as the previous motion of the launcher; given that the intermediary in Experiment 1 moved at the same velocity as the launcher, the preservation of the temporal intervals from Experiment 1 between when the launcher stopped moving and when the target began moving should have maximized the probability that in Experiment 2 any impetus imparted from the launcher would have passed through the spatial gap between the final location of the launcher and the initial location of the target and reached the target at the precise moment at which the target began to move. However, it is possible that in the absence of a visible moving intermediary, observers might have interpreted the apparent pause between when the launcher stopped moving and when the target began moving as an opportunity for dissipation of the launcher's impetus; such an interpretation would have weakened any possible influence of the launcher on the target. Accordingly, in Experiment 3 invisible intermediary trials similar to those in Experiment 2 were presented, but motion of the target began immediately upon the cessation of motion of the launcher, and so an opportunity for dissipation of the launcher's impetus prior to motion of the target did not occur. In addition, target only trials were presented.

### Method

#### *Participants*

The observers were 14 undergraduates drawn from the same participant pool used in Experiment 1. 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 2. Each observer received 120 trials [5 trial types (target only, 30, 60, 90, 120 pixels) × 4

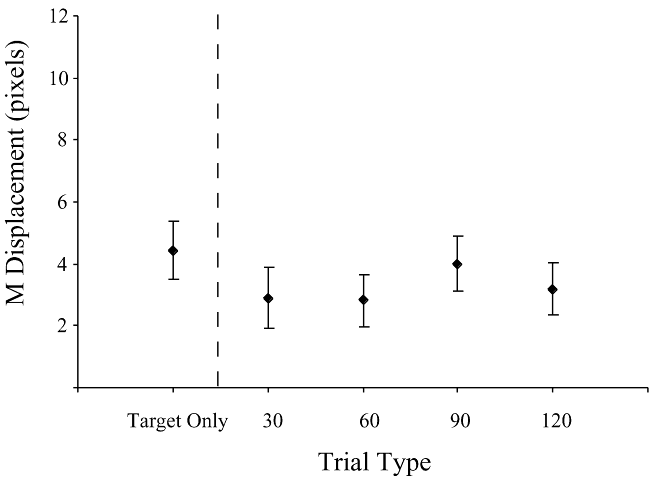



**Fig. 6** M displacement as a function of trial type in Experiment 3. Error bars reflect the standard error. The 30, 60, 90, and 120 trials are invisible intermediary trials in which only a launcher and target are visible (see Fig. 4), and the numerical designation reflects the distance (in pixels) between the final location of the launcher and the initial location of the target (i.e., the distance traveled by the invisible intermediary)

directions (LR, RL, TB, BT) × 6 replications] in a different random order.

*Procedure*

The procedure was the same as in Experiment 2, with the following exception: in the 30, 60, 90, and 120 pixel trials, the target began to move immediately upon the cessation of the movement of the launcher.

## Results

The M displacements were calculated as in Experiment 1, and were analyzed in a 5 (trial type) × 4 (direction) repeated measures ANOVA. As shown in Fig. 6, trial type did not significantly influence M displacement, $F(4, 52) = 1.17$, MSE = 24.43, $P > .32$. Direction significantly influenced M displacement, $F(3, 39) = 4.83$, MSE = 119.22, $P < .01$, and a post-hoc Newman-Keuls test ($P < .05$) of all pairwise comparisons of LR ($M = 6.32$), RL ($M = 4.87$), TB ($M = 2.99$), and BT ($M = -0.32$) trials revealed that M displacement in BT trials was smaller than in LR, RL, and TB trials, and that M displacement in TB trials was smaller than in LR trials. The Trial type × Direction interaction was not significant, $F(12, 156) = 0.56$, MSE = 16.08, $P > .86$.

The average M displacements for target only, 30, 60, 90, and 120 pixel trials were tested against a mean of zero. With a Bonferroni correction ($P < .05/5$), M displacement was significantly greater than zero in target only, $t(55) = 4.73$, $P < .001$, 30 pixel, $t(55) = 2.96$, $P < .005$, 60 pixel, $t(55) = 3.33$, $P < .002$, 90 pixel, $t(55) = 3.99$, $P < .001$, and 120 pixel, $t(55) = 3.75$, $P < .001$, trials. A significant forward M displacement was observed in all trial types.

## Discussion

As in Experiment 2, M displacement of targets in invisible intermediary trials did not differ from M displacement of targets in target only trials. The results of Experiment 3 suggest the nonsignificant difference in Experiment 2 between M displacement in invisible intermediary trials and M displacement in target only trials did not result from a dissipation of impetus during the delay between when the launcher stopped moving and when the target began moving; in Experiment 3 there was no obvious delay between when the launcher stopped moving and when the target began moving, and thus there was no time during which such dissipation could have occurred. In more positive terms, the results of Experiments 2 and 3 offer quantitative empirical evidence that suggests an imparting of the impetus of the launcher to the target when the final location of the launcher and the initial location of the target are spatially separated requires a visible linkage between the launcher and the target. As in Experiment 2, the spatial configuration of the launcher and target in Experiment 3 was not sufficient to produce a decrease in M displacement consistent with that observed in tool effect trials in Experiment 1. Also, the magnitudes of M displacement in Experiment 3 appear similar to those of Experiment 2 and less than those of Experiment 1; in general, overall M displacement was decreased when the intermediary was not visible, although differences in M displacement between target only and intermediary trials reached significance only when the intermediary was visible.

The M displacement patterns in Experiments 2 and 3 differ from the M displacement patterns in tool effect displays in Experiment 1 and in launching effect displays in Hubbard et al. (2001), and these differences provide useful empirical validation of the phenomenological reports of Michotte's observers. In general, when Michotte's data suggest the launcher is perceived as the cause of the motion of the target, then M displacement of the target is decreased, whereas when Michotte's data suggest the launcher is not perceived as the cause of the motion of the target, then M displacement of the target is not decreased. Observers did not appear to spontaneously extrapolate any potential causal influences across the spatial gap between the final location of the launcher and the initial location of the target in Experiments 2 and 3. This suggests that effects of impetus (or perhaps momentum) must be attached to a specific object, and is also somewhat reminiscent of the inability of observers to mentally rotate an empty frame of reference that did not contain a specific stimulus (e.g., in Cooper & Shepard, 1973); both in tool effect displays and in studies of mental rotation, observers required a concrete stimulus (i.e., a visible intermediary, a specific letter or numeral) and were not able to mentally manipulate or extrapolate through an "empty space." The notion that mechanisms underlying representational momentum may be similar to mechanisms underlying imagery has been previously suggested (e.g., Hubbard, 2002; Kelly & Freyd, 1987; Munger &

Minchew, 2002; Munger, Solberg, & Horrocks, 1999), and differences between the M displacement pattern from Experiment 1 and the M displacement pattern from Experiments 2 and 3 are consistent with such a similarity.

## Experiment 4

In Experiments 2 and 3, the intermediary was not visible, and no differences in M displacement were observed between invisible intermediary trials and target only trials. This pattern suggests that the decrease in M displacement of the target in tool effect trials observed in Experiment 1 requires that an intermediary be visible to observers. However, it is not yet clear whether it is the motion of a visible intermediary, or the visible contact between the launcher and the intermediary and then between the intermediary and the target, that is the most critical factor in the decrease of M displacement of the target in tool effect trials. One way to examine this is to present a visible stationary intermediary that is contacted by the launcher and that is also in contact with the target. If motion of the intermediary contributes to the decrease in M displacement in tool effect trials, then presentation of a stationary intermediary that contacts both the launcher and the target should not result in a decrease in M displacement. Alternatively, if contact of the intermediary with both the launcher and the target contributes to the decrease in M displacement in tool effect trials, then presentation of a stationary intermediary that contacts both the launcher and the target should result in a decrease in M displacement. Accordingly, in Experiment 4 a visible stationary intermediary was presented, and one end of the intermediary was in contact with the stationary target. The launcher contacted the opposite end of the intermediary, and the target immediately began to move away from the intermediary. Target only trials were also presented.

### Method

#### Participants

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

#### Apparatus

The apparatus was the same as in Experiment 1.

#### Stimuli

The stimuli are illustrated in Fig. 7, and were the same as in Experiment 1, with the following exceptions: In trials in which a launcher and an intermediary were presented, the intermediary was stationary and filled the entire gap between the final location of the launcher and the initial location of the target. Thus, for LR and RL motion, the intermediary was the same height but a larger width than the launcher and the target, and for TB and BT motion, the intermediary was the same width but a larger height than the launcher and the target. Each observer received 120 trials [5 trial types (target only, 30, 60, 90, 120 pixels) × 4 directions (LR, RL, TB, BT) × 6 replications] in a different random order.

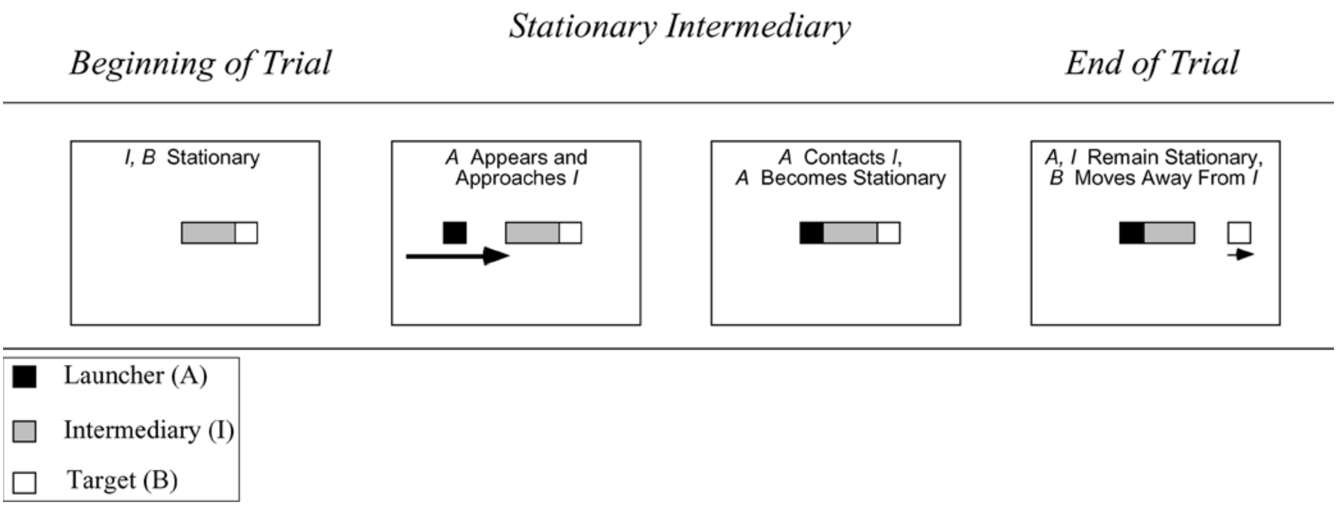
#### Procedure

The procedure was the same as in Experiment 1, with the following exceptions: the target began to move immediately after the launcher contacted the intermediary, and the intermediary was stationary throughout the duration of a trial.

### Results

The M displacements were calculated as in Experiment 1, and were analyzed in a 5 (trial type) × 4 (direction) repeated measures ANOVA. As shown in Fig. 8, trial type significantly influenced M displacement, $F(4, 60) = 4.39$, $MSE = 25.74$, $P < .005$, and a post-hoc Newman-Keuls test ($P < .05$) of all pairwise comparisons of target only

**Fig. 7** An illustration of stationary intermediary trials in Experiment 4. A moving launcher contacts a stationary intermediary. At the moment the launcher contacts the intermediary, the launcher becomes stationary. The intermediary remains stationary, and the target immediately moves away from the intermediary



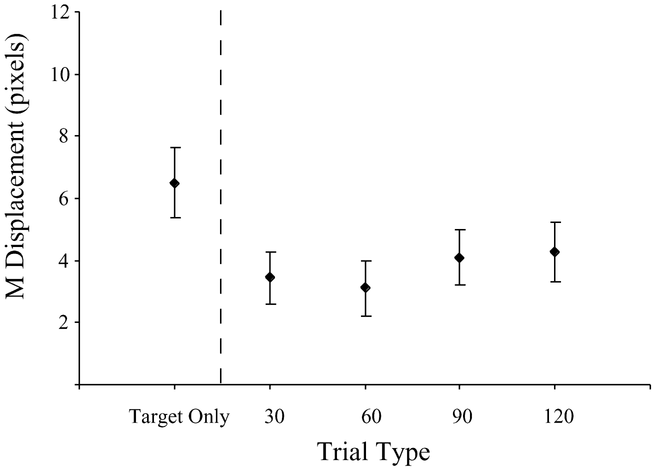



**Fig. 8** M displacement as a function of trial type in Experiment 4. Error bars reflect the standard error. The 30, 60, 90, and 120 trials are stationary intermediary trials in which a launcher and a stationary intermediary are visible (see Fig. 7), and the numerical designation reflects the length (in pixels) of the stationary intermediary

($M = 6.50$), 30 pixel ($M = 3.44$), 60 pixel ($M = 3.10$), 90 pixel ($M = 4.09$), and 120 pixel ($M = 4.27$) trials revealed M displacement was (a) larger in target only trials than in each of the stationary intermediary trials, and (b) not influenced by the length of the intermediary. Direction influenced M displacement, $F(3, 45) = 4.86$, MSE = 134.13, $P < .01$, and a post-hoc Newman-Keuls test ($P < .05$) of all pairwise comparisons revealed M displacement was larger in LR ($M = 5.52$), RL ($M = 6.65$), and TB ($M = 4.79$) trials than in BT ($M = 0.15$) trials. The Trial type × Direction interaction was not significant, $F(12, 180) = 1.54$, MSE = 13.65, $P > .11$.

The average M displacements for target only, 30, 60, 90, and 120 pixel trials were tested against a mean of zero. With a Bonferroni correction ($P < .05/5$), M displacement was significantly greater than zero in target only, $t(63) = 5.77$, $P < .0001$, 30 pixel, $t(63) = 4.13$, $P < .0001$, 60 pixel, $t(63) = 3.44$, $P < .001$, 90 pixel, $t(63) = 4.58$, $P < .0001$, and 120 pixel, $t(63) = 4.56$, $P < .0001$, trials. There was a significant forward M displacement in all trial types, and so the decrease in M displacement in stationary intermediary trials did not result from memory for targets in stationary intermediary trials failing to exhibit forward M displacement.

### Discussion

M displacement of targets in stationary intermediary trials was less than M displacement of targets in target only trials. The results of Experiment 4 suggest that contact of the intermediary with both the launcher and the target, rather than motion of the intermediary from the final location of the launcher to the initial location of the target, was responsible for the decrease in M displacement of targets in tool effect trials in Experiment 1. The results of Experiment 4 are also consistent with the more general hypothesis that the decrease in M displacement of targets in tool effect trials results from the impetus of the launcher being imparted to the target through the intermediary, because a stationary intermediary in contact with both the launcher and the target could serve as a conduit or medium for impetus just as effectively as could an intermediary initially contacted by the launcher and that subsequently contacted the target. In Experiment 4, the intermediary clearly conveyed the influence of the launcher to the target even though the intermediary itself did not move, and so motion per se is not a requirement for a stimulus to function as a tool or for a tool to be perceived as an extension of the launcher. However, inspection of Figs. 3 and 8 suggests that M displacement in stationary intermediary trials in Experiment 4 is slightly smaller than M displacement in tool effect trials in Experiment 1, and so perhaps a stationary intermediary is not quite as good a conductor of impetus as is a moving intermediary.

Although the decrease in M displacement of targets in tool effect trials in Experiment 1 and in stationary intermediary trials in Experiment 4 is consistent with the hypothesis that the intermediary conveyed the impetus of the launcher to the target, it might also initially appear consistent with the possibility that the intermediary functioned as a launcher and conveyed its own impetus to the target. In the discussion of Experiment 1 it was noted that such an interpretation was inconsistent with the reports of Michotte's observers; in Experiment 4 the possibility that the intermediary functioned as a launcher is less tenable because the stationary intermediary in Experiment 4 would not have had any impetus of its own to impart, and so it could not have functioned as a launcher per se. Furthermore, the stationary intermediary in Experiment 4 was in extended contact with the target prior to motion of the target, and so it is not clear how impetus could have either originated spontaneously within the intermediary at the moment target motion began or originated earlier and been "delayed" until the target began to move. Although Michotte (1946/1963) documented a type of "launching-by-expulsion" in which a launcher could be in contact with the target for an extended period of time prior to launching, in launching-by-expulsion the launcher typically entrained or transported the target for some distance prior to launching (and so the launcher was in motion and had impetus), whereas in Experiment 4 the intermediary was not in motion prior to launching (and so the intermediary did not have impetus). Thus, the results of Experiment 4 are more consistent with the hypothesis that the launcher was responsible for the motion of the target and do not support the hypothesis that the intermediary functioned as a launcher.

## Experiment 5

The results of Experiment 4 suggested that contact of the intermediary with the launcher and with the target, rather than motion of the intermediary from the final location of the launcher to the initial location of the target, is responsible for the decrease in M displacement of the target in tool effect trials. If this is correct, then a decrease in M displacement of the target in stationary intermediary trials relative to target only trials should not occur if the intermediary is stationary but does not contact both the launcher and the target. Accordingly, Experiment 5 presented the same launchers and targets as Experiment 4, but the stationary intermediary did not fill the entire gap between the final location of the launcher and the initial location of the target. In launcher-intermediary trials, one side of a stationary intermediary was contacted by the launcher, and there was a gap between the intermediary and the initial location of the target. In intermediary-target trials, one side of a stationary intermediary was in contact with the target, and there was a gap between the final location of the launcher and the intermediary. If contact both between the launcher and the intermediary and between the intermediary and the target is necessary for the decrease in M displacement to occur, then M displacement of the target in launcher-intermediary trials and in intermediary-target trials should not be decreased. Target only trials were also presented.

## Method

### Participants

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

### Apparatus

The apparatus was the same as in Experiment 1.

### Stimuli

The stimuli are illustrated in Fig. 9, and were the same as in Experiment 4, with the following exceptions: The intermediary was always 20 pixels in width and 20 pixels in height (i.e., the intermediary was the same size as launchers and targets in previous

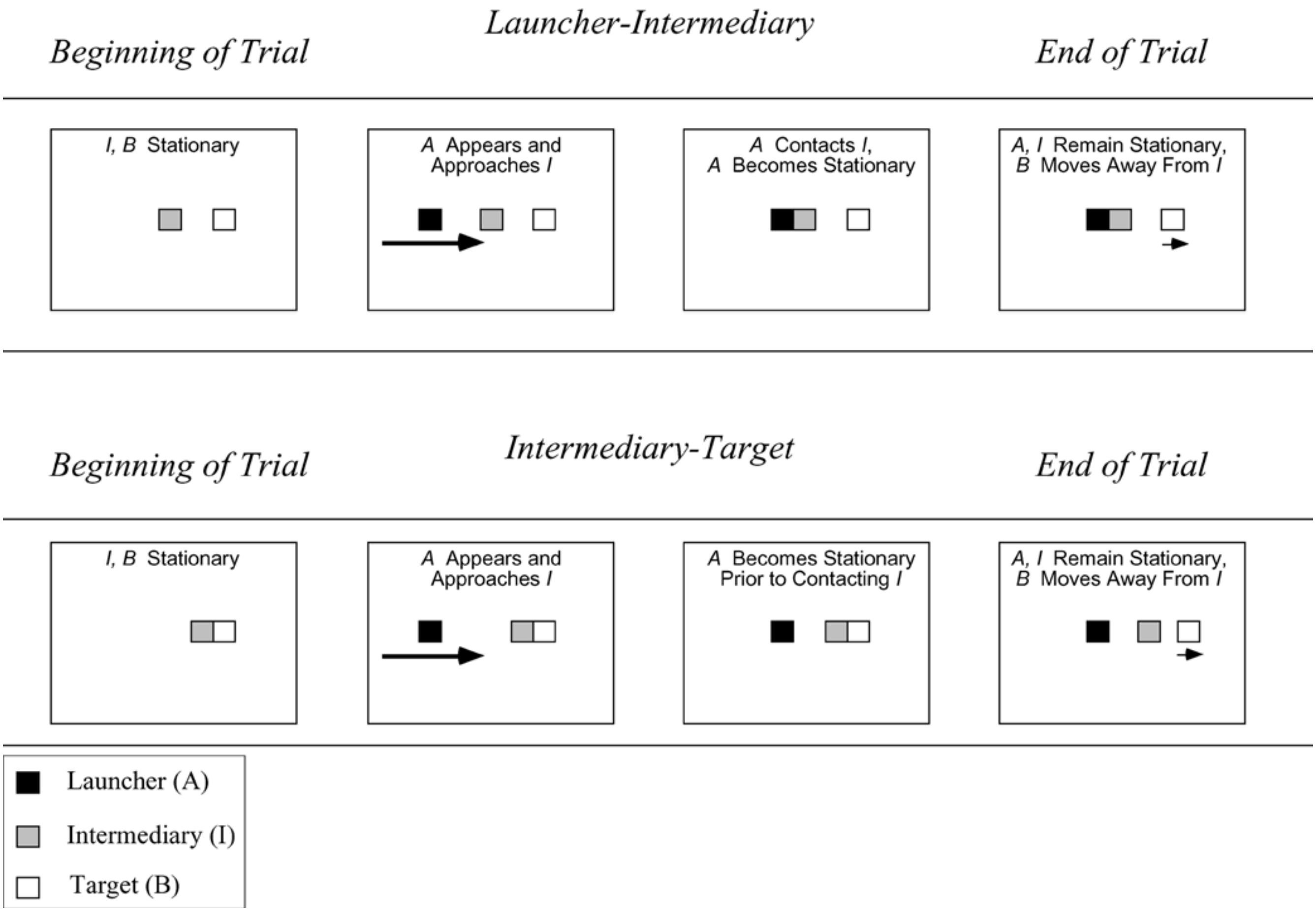



**Fig. 9** An illustration of launcher-intermediary (*top panel*) trials and intermediary-target (*bottom panel*) trials in Experiment 5. In launcher-intermediary trials, a moving launcher contacts a stationary intermediary, and the launcher becomes stationary. The intermediary remains stationary, and the target immediately begins to move. There is no contact between the intermediary and the target. In intermediary-target trials, a moving launcher approaches the intermediary, but the launcher becomes stationary prior to contacting the intermediary. When the launcher becomes stationary, the target immediately moves away from the intermediary. There is no contact between the launcher and the intermediary

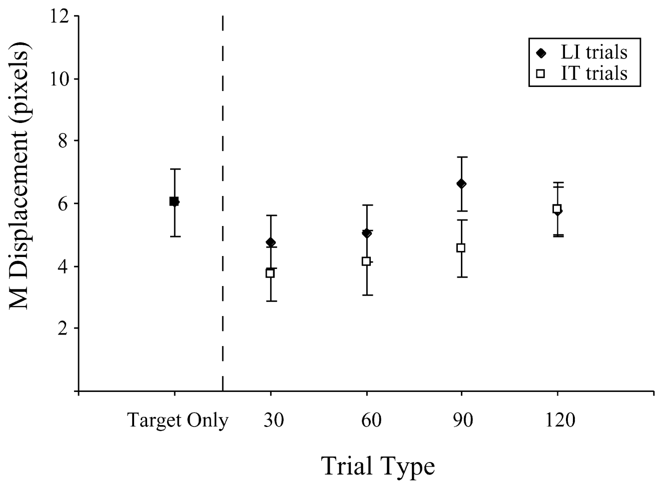



**Fig. 10** M displacement as a function of trial type in Experiment 5. Data from the launcher-intermediary trials are plotted using *filled diamonds*, and data from the intermediary-target trials are plotted using *open squares*. Error bars reflect the standard error. The 30, 60, 90, and 120 trials are launcher-intermediary trials or intermediary-target trials in which a stationary intermediary (always 20 pixels in length) is adjacent to either the final location of the launcher or the initial location of the target (see Fig. 9), and the numerical designation reflects the distance (in pixels) between the final location of the launcher and the initial location of the target

experiments, and was the same size as the visible intermediary in Experiment 1). The intermediary was always located between the final location of the launcher and the initial location of the target, and was presented either adjacent to the location in which the launcher stopped (launcher-intermediary trials, denoted as "LI" preceded by the pixel separation between the final location of the launcher and the initial location of the target) or adjacent to the initial location of the target (intermediary-target trials, denoted as "IT" preceded by the pixel separation between the final location of the launcher and the initial location of the target). Each observer received 144 trials [9 trial types (target only, 30LI, 60LI, 90LI, 120LI, 30IT, 60IT, 90IT, 120IT) × 4 directions (LR, RL, TB, BT) × 4 replications] in a different random order.

### Procedure

The procedure was the same as in Experiment 4, with the following exceptions: In IT trials, the launcher stopped moving before contacting the intermediary, and in LI trials, the target was never in contact with the intermediary. As in Experiments 3 and 4, the target began to move as soon as the launcher stopped moving.

## Results

The M displacements were calculated as in Experiment 1, and were analyzed in a 9 (trial type) × 4 (direction) repeated measures ANOVA. As shown in Fig. 10, trial type significantly influenced M displacement, $F(8, 120) = 2.18$, MSE = 26.87, $P < .05$. M displacement in target only trials did not differ from the average M displacement when an intermediary was present, $F(1, 15) = 0.70$, MSE = 76.88, $P > .41$. M displacement in target only trials did not differ from M displacement in LI trials, $F(1, 15) = .44$, MSE = 11.91, $P > .50$, but was larger than M displacement in IT trials, $F(1, 15) = 4.10$, MSE = 110.26, $P < .05$. M displacement in LI trials was larger than M displacement in IT trials, $F(1, 15) = 4.64$, MSE = 124.25, $P < .05$. Direction influenced M displacement, $F(3, 45) = 8.71$, MSE = 109.24, $P < .001$, and a post-hoc Newman-Keuls test ($P < .05$) of all pairwise comparisons revealed M displacement in LR ($M = 8.59$) trials was larger than in RL ($M = 5.22$), TB ($M = 4.45$) and BT ($M = 2.41$) trials. The Trial type × Direction interaction was not significant, $F(24, 360) = 1.07$, MSE = 18.53, $P > .37$.

The average M displacements for target only, LI30, LI60, LI90, LI120, IT30, IT60, IT90, and IT120 trials were tested against a mean of zero. With a Bonferroni correction ($P < .05/9$), M displacement was significantly greater than zero in target only, $t(63) = 5.65$, $P < .0001$, LI30, $t(63) = 5.74$, $P < .0001$, LI60, $t(63) = 5.50$, $P < .0001$, LI90, $t(63) = 7.61$, $P < .0001$, LI120, $t(63) = 7.13$, $P < .0001$, IT30, $t(63) = 4.39$, $P < .0001$, IT60, $t(63) = 4.01$, $P < .0002$, IT90, $t(63) = 4.90$, $P < .0001$, and IT120, $t(63) = 7.14$, $P < .0001$, trials. There was a significant forward M displacement in all trial types, and so the decrease in M displacement in IT trials did not result from memory for targets in IT trials failing to exhibit forward M displacement.

## Discussion

M displacement of the target in target only trials did not differ from the average M displacement of the target in trials in which an intermediary was present but did not contact both the launcher and the target. This pattern is consistent with the hypothesis that contact both between the launcher and the intermediary and between the intermediary and the target is necessary for the decreased M displacement attributable to a tool effect to occur. This pattern is not consistent with the general possibility of launching-at-a-distance or with the hypothesis that the effect of the intermediary in Experiments 1 and 4 resulted from contact of the intermediary with only the launcher or with only the target. Rather, this pattern is more consistent with the hypothesis that the decrease in M displacement of targets in tool effect trials requires the intermediary to be a visible bridge between the final location of the launcher and the initial location of the target. Such a bridge or contact may be in the form of a stationary stimulus that offers simultaneous contact between the launcher and the target (as in Experiment 4) or in the form of a moving stimulus that offers sequential contact between the launcher and the target (as in Experiment 1).

M displacement of the target was smaller in IT trials than in LI trials or in target only trials. One possible explanation is that targets in IT trials were more likely to be perceived as launched than were targets in LI trials or target only trials, but the stationary intermediary in IT trials would not have had any impetus of its own to impart, nor is it clear why impetus might have "jumped the gap" in IT trials but not in LI trials. A second possible explanation is that the stationary intermediary functioned as a landmark, and so forward M displacement was decreased more for targets closer to the landmark (IT trials) than for targets further from the landmark (LI trials) or in the absence of a landmark (target only trials). However, such a landmark explanation might predict that displacement in LI trials would be less than displacement in target only trials, and so is not consistent with previous studies suggesting that landmark effects increase with increases in distance (e.g., Hubbard & Ruppel, 2000; Nelson & Chaiklin, 1980). A third possible explanation is that observers were more likely to fixate the target in LI trials and in target only trials and more likely to fixate the intermediary in IT trials. Given that targets may be mislocalized toward the fovea (Müsseler, van der Heijden, Mahmud, Deubel, & Ertsey, 1999; Skavenski, 1990), an increased fixation on the intermediary during IT trials could result in a smaller forward M displacement. However, observers were aware that they would be asked to indicate the location in which the target vanished, and so it is not clear why fixating a location or stimulus other than the target would be an adaptive strategy or why observers would choose to fixate on the intermediary in IT trials rather than tracking the target.

A fourth possible explanation for the smaller M displacement of the target in IT trials than in LI trials or in target only trials, and an explanation that may be more consistent with the ideas of impetus discussed here, is that targets in IT trials were initially perceived as "attached" in some way to the intermediary. Within a naïve impetus framework, this attachment might be perceived as offering an initial or extra resistance to motion that would have to be overcome before the target could begin moving. Motion of the target in a IT trial required an initial breaking of this attachment, and the energy for breaking the attachment would be subtracted from that which produced target motion. This would leave less energy available for target motion, and so targets in IT trials might be perceived as traveling more slowly or as encountering more resistance. Targets in LI trials or in target only trials did not have to overcome the resistance of an initial attachment to the intermediary, and so might be perceived as traveling more rapidly or as encountering less resistance. Given that either a slower velocity or an increased resistance may decrease the magnitude of forward displacement, M displacement of targets in IT trials was decreased relative to M displacement of targets in LI trials or in target only trials. Such an explanation is consistent with the implication in naïve physics noted earlier that impetus is inside a target, and is also consistent with the more general hypothesis that decreases in displacement attributable to imparting of impetus from the launcher require contact of the launcher and the target (either directly or through an intermediary).

It might be argued that the displacement pattern in Experiment 5 is not strictly consistent with the impetus hypothesis because M displacement in IT trials was less than M displacement in target only trials even though in IT trials the intermediary did not contact both the launcher and the target. Along these lines, it might be hypothesized that contact between the intermediary and the target is all that is necessary for the reduction in M displacement characteristic of a tool effect or launching effect to occur. However, such a hypothesis is not consistent with the lack of any decrease in M displacement in orthogonal trials in Hubbard et al. (2001); in such orthogonal trials, the intermediary contacted the target, but no decrease in M displacement relative to target only trials was observed. If the decrease in M displacement in IT trials in Experiment 5 is attributable to impetus from the launcher, it is not clear why impetus might apparently jump the gap in IT trials but not in LI trials. The difference between LI trials and IT trials was the location of the intermediary relative to the initial position of the target; as noted above, perhaps the lack of an attachment of the intermediary to the target in LI trials and in target only trials and the presence of an attachment of the intermediary to the target in IT trials may account for the pattern of displacement in Experiment 5. If so, then the decrease in IT trials would not reflect a tool effect per se, but would reflect resistance to breaking the initial attachment between the intermediary and the target.

## General discussion

The data are consistent with the hypothesis that a visible intermediary influences displacement in memory for the location of a target in a tool effect display. In Experiment 1, targets in tool effect trials exhibited less M displacement than did targets in target only trials. Although the length of the path of the intermediary in tool effect displays varied across trials, there were no differences in M displacement of the target as a function of the length of the path of the intermediary. In Experiments 2 and 3, the intermediary was not visible, and M displacement of targets in invisible intermediary trials did not differ from M displacement of targets in target only trials. In Experiments 4 and 5, the intermediary was visible but was stationary; when the intermediary contacted both the launcher and the target, M displacement of targets in stationary intermediary trials was less than M displacement of targets in target only trials, but when the intermediary contacted only the launcher, M displacement did not differ from M displacement of targets in target only trials. In general, when a visible intermediary bridged the gap between the final location of the launcher and the initial location of the target (Experiments 1 and 4), then displacement of the target was decreased, whereas when an intermediary was not visible (Experiments 2 and 3) or was visible but did not contact the target (Experiment 5), then displacement of the target was not decreased.

Several alternative hypotheses for the decrease in M displacement of targets in tool effect trials may be ruled out. First, the decrease in M displacement was not due to the launcher or to the intermediary functioning as a landmark for judgments of the target, because a landmark-based explanation is not consistent with the larger M displacement in launcher-intermediary trials than in intermediary-target trials in Experiment 5 or with the increased M displacement in orthogonal trials in Hubbard et al. (2001). Second, the decrease in M displacement was not due to the spatial configuration of the launcher and the target. The spatial configuration of the launcher and the target was the same across all of the experiments, but only in Experiments 1 and 4 was a consistent decrease in M displacement attributable to a tool effect observed[4]. Third, the latency between when the launcher stopped moving and when the target began moving was not responsible for the decrease in M displacement. The latencies were the same in Experiments 1 and 2, but only in Experiment 1 was a decrease in M displacement observed; furthermore, the latencies differed in Experiments 2 and 3, but no decrease in M displacement was observed. Fourth, the motion of a visible intermediary was not responsible for the decrease in M displacement, because a decrease in M displacement was found with a stationary intermediary in Experiment 4. Fifth, the decrease in M displacement was not due to the intermediary functioning as a launcher, because a decrease in M displacement was also observed when the intermediary was stationary and would not possess any impetus of its own. Sixth, the mere presence of an intermediary in the gap between the launcher and the target was not responsible for the decrease in M displacement, because a decrease in M displacement was not found when a visible intermediary contacted only the launcher in Experiment 5.

One alternative hypothesis which should be addressed in greater detail involves a possible role of eye movements. When observers fixate a location slightly below the path of a horizontally moving target, forward displacement for that target is decreased, whereas when observers track a horizontally moving target, a robust forward M displacement for that target is exhibited (Kerzel, 2000). It has been suggested that when observers track a target undergoing smooth motion, their eyes may overshoot the final location of the target, and so forward M displacement for the target would result from this oculomotor overshoot coupled with a bias to mislocalize targets toward the fovea (Kerzel, 2000; also Kerzel, Jordan, & Müsseler, 2001). In the present experiments, a reduction in forward M displacement of targets occurred when an intermediary was visible adjacent to the initial location of the target, but M displacement of the target was not decreased when an intermediary was not visible (or was relatively further from the initial position of the target). Thus, perhaps the decrease in M displacement in Experiments 1 and 4 when a visible intermediary connected the launcher and the target, as well as the decrease in M displacement in IT trials in Experiment 5, resulted from observers fixating the intermediary (or any other point behind the target) rather than tracking the target. However, as noted earlier, it is not clear why such a strategy would be adopted; observers knew their memory for the target would be measured on every trial, and so in the absence of instructions to the contrary, observers should presumably have tracked the target.

The fixation hypothesis is reminiscent of the possibility discussed in Experiment 1 that the intermediary acted as a landmark for judgments of the target; in both the fixation hypothesis and the landmark hypothesis memory for the target is biased (in part) toward a location behind the target. However, a landmark explanation was rejected in Experiment 1 because such an explanation could not also account for differences between M displacement in launching effect trials and M displacement in orthogonal trials in Hubbard et al. (2001); similarly, it is not clear how fixation on the launcher (or the target) could account for differences in displacement in launching effect trials and orthogonal trials in Hubbard et al. One strategy to save the fixation hypothesis might be to argue that orthogonal trials involve a change in the direction of motion between the previous motion of the launcher and the subsequent motion of the target, and so perhaps that change in the direction of motion (which does not occur in a launching effect or in a tool effect) might decrease the efficiency of the initial tracking of the target, thus allowing a greater M displacement. However, Kerzel (2000) has shown that not allowing observers to track smoothly moving targets (such as those in Hubbard et al., and in the current experiments) decreases forward M displacement; thus, any difficulties in tracking a target in orthogonal trials should have resulted in less forward M displacement rather than more M forward displacement.

The effect of direction was consistent across experiments, with significantly larger M displacement exhibited by targets moving from left to right (Experiments 1, 2, and 5) and significantly smaller M displacement exhibited by ascending targets (Experiments 3 and 4); even when differences between directions did not quite reach significance, the general ordering of M displacement magnitudes as a function of direction was consistent across experiments and conformed with previous findings in the representational momentum literature (e.g., Halpern & Kelly, 1993; Hubbard, 1990). Although the difference between top-to-bottom and bottom-to-top motion may be accounted for by the asymmetry in the

[4]A related notion is that the presence of multiple stimuli would decrease displacement for each stimulus. However, Finke and Freyd (1985; Finke, et al., 1986) found representational momentum in displays consisting of three independently moving targets, and so the presence of multiple stimuli per se does not necessarily decrease displacement. However, a comparison of the displacement of a single target in a such multiple target display, in which the targets do not interact with each other, to the displacement of an otherwise identical targets presented in isolation has not been reported in the literature. This remains an area for future research.

direction of implied gravitational attraction (attributed to "representational gravity", see Hubbard, 1997), reasons for the difference between left-to-right and right-to-left motion are not as clear, although one possibility may relate to hemispheric asymmetries (see Halpern & Kelly, 1993). The consistent ordering of direction magnitudes was observed regardless of whether or not there was a visible linkage between the launcher and the target, and this suggests that the effect of direction was due to processes related to representational momentum and not due to processes related to the tool effect. The magnitude of M displacement was less consistent across experiments. Comparison of Figs. 3, 5, 6, 8, and 10 suggests that M displacement in target only trials was relatively larger in Experiment 1 than in Experiments 4 and 5, and was relatively larger in Experiments 4 and 5 than in Experiments 2 and 3; it may be that differences between target only trials and other trial types influenced M displacement in target only trials in each experiment.

The overall pattern of M displacement across experiments is consistent with naïve impetus theory. Decreases in M displacement attributable to imparting of impetus from the launcher were observed in Experiments 1 and 4 and not in Experiments 2, 3 and 5; in Experiments 1 and 4, a visible conduit for the passage of impetus from the launcher to the target was available, whereas in Experiments 2, 3 and 5, a visible conduit from the launcher to the target was not available. The presence of a launcher per se did not influence M displacement of a target unless there was a visible connection between the launcher and the target; in the absence of the intermediary, there was no transference of impetus between the launcher and the target, and thus no decrease in M displacement of the target. However, impetus is not a valid physical principle, and so why would observers "believe" in impetus? Although this question is considerably broader than the current investigation, the experiments reported here, in conjunction with the findings of Michotte (1946/1963, 1951/1991) and Hubbard and Ruppel (2002), suggest a possible answer: A physical object set into motion immediately following contact from another object typically does not move under its own power, and friction with the surface a launched object moves across or the medium a launched object moves through will inevitably slow and stop such an object. More to the point, characteristics attributed to impetus are consistent with the subjective experience of physical principles in a world in which friction is always present; indeed, such an inevitable influence of friction may be responsible for the characteristic of impetus noted earlier that friction is inside (intrinsic to) a target.

One potential consequence of the notion that impetus imparted to a target during launching begins to immediately dissipate is that the further a launched target travels, the less remaining impetus that target possesses. Therefore, a moving intermediary that had been launched and that traveled a longer distance would dissipate more impetus prior to imparting any remaining impetus to the target (cf. Hubbard & Ruppel, 2002). Why then did the distance traveled by the moving launcher in Experiment 1 (or the length of the stationary intermediary in Experiment 4) not influence M displacement of the target? One possibility consistent with the introspections of Michotte's observers is that the intermediary is perceived as an extension of the launcher rather than as a separate object that had been launched by the launcher's impetus. As an extension of the launcher, movement of (or through) the intermediary would not lead to dissipation of the energy of the launcher, because the energy of the launcher would presumably be more autonomous (or at least not as dependent upon an initial allotment of impetus that would subsequently dissipate). If an object begins to move after being contacted by a launcher, then whether or not that object exhibits a subsequent decrease in impetus may be influenced in part by the perceived interactions of that object with any subsequent objects: if the object is perceived as a target or recipient, then impetus would dissipate, whereas if the object is perceived as an intermediary or tool (and thus as an extension of the launcher), then impetus would not dissipate.

The impetus notion is useful in accounting for findings in displacement in memory and in perception of causality. Just as representational momentum may reflect an incorporation of the subjective effects of momentum (or impetus, cf. Kozhevnikov & Hegarty, 2001) in the representation of a single target (see Hubbard, 1999), the launching effect and the tool effect may reflect an incorporation of the subjective effects of momentum (or impetus) in the representation of colliding targets. The similarities in the roles of impetus in displacement in memory and in perception of causality suggests that these processes may reflect similar mechanisms (or a single more general mechanism), and confidence in such an idea is strengthened by arguments that both representational momentum (Kelly & Freyd, 1987; Finke & Freyd, 1989; Hubbard, 1995b) and the perception of causality (Scholl & Tremoulet, 2000) involve at least some automatic responding and perhaps modular processing. The possibility of a similar mechanism underlying displacement in memory and underlying perception of causality is underscored by the finding that reports of Michotte's observers regarding their perception of causality are mirrored by displacement patterns in memory for the target: Hubbard et al. (2001) demonstrated that the magnitude of forward displacement tracked causal perception in the simple case of the launching effect, and the experiments reported here demonstrate that the magnitude of forward displacement tracks causal perception in the more complex case of the tool effect.

The current experiments, along with those in Hubbard et al. (2001) and Hubbard and Ruppel (2002), demonstrated that displacement in general, and representational momentum in particular, can tell researchers something about the perception of causality. What can experiments on displacement of launched targets tell researchers about representational momentum and displacement? Consistent with previous findings (e.g., Cooper & Munger, 1993), the data do not support a strong momentum metaphor. Both launched and unlaunched targets moved at the same velocity, and a strong momentum metaphor would have predicted an identical level of displacement for launched and for unlaunched targets. Consistent with Verfaillie and d'Ydewalle (1991), the data suggest that displacement reflects higher-order event structure rather than local motion characteristics. Along these lines, the data are also consistent with numerous demonstrations that nontarget context can influence displacement (Hubbard, 1993, 1995a; Hubbard & Ruppel, 1999) and that beliefs concerning the target and target motion can influence displacement (e.g., Freyd & Jones, 1994; Reed & Vinson, 1996; Vinson & Reed, 2002). By demonstrating that displacement may be related to attributions of impetus, the current experiments suggest that displacement reflects subjective aspects of physical principles rather than internalizations of the objective principles per se (cf. Hubbard, 1997). Perhaps most importantly, the current experiments may signal a shift in the focus of studies involving representational momentum; previously, researchers were trying to understand representational momentum per se, whereas in the current investigation, representational momentum was used as a tool for the investigation of other processes.

The data reported here suggest a role for the intermediary in displacement of the target in a tool effect display. Displacement of the target was decreased when a visible intermediary bridged the gap between the final location of the launcher and the initial location of the target, whereas displacement of the target was not decreased when a visible intermediary did not bridge the gap between the final location of the launcher and the initial location of the target. The magnitude of displacement of the target paralleled perceptions of causality reported by Michotte's observers; when motion of the target was attributed to the launcher, displacement was decreased, whereas when motion of the target was perceived as more autonomous, displacement was not decreased. The decrease in displacement of the target when motion was attributed to the launcher may result from a perception that the impetus of the launcher was imparted to the target. The distance between the final location of the launcher and the initial location of the target did not influence displacement of the target if a moving or stationary intermediary bridged the gap between the launcher and the target, and this is consistent with reports by Michotte's observers that such an intermediary was perceived as an extension of the launcher rather than as a separate or autonomous object. Overall, the data and hypotheses discussed here reconcile findings from the literature on representational momentum and displacement with naïve impetus theory and with Michotte's previous findings regarding the phenomenology of the tool effect.

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