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ORIGINAL PAPER

Launching, Entraining, and Representational Momentum: Evidence Consistent with an Impetus Heuristic in Perception of Causality

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Abstract Displacements in the remembered location of stimuli in displays based on Michotte's (1946/1963) launching effect and entraining effect were examined. A moving object contacted an initially stationary target, and the target began moving. After contacting the target, the mover became stationary (launching trials) or continued moving in the same direction and remained adjacent to the target (entraining trials). In launching trials, forward displacement was smaller for targets than for movers; in entraining trials, forward displacement was smaller for movers than for targets. Also, forward displacement was smaller for targets in launching trials than for targets in entraining trials. Data are consistent with a hypothesis that the launching effect involves an attribution that the mover imparted to the target a dissipating impetus that was responsible for target motion. Introspective experience of a perception of physical causality in the launching effect might result because behavior of movers and targets is consistent with that predicted by an impetus heuristic.

Keywords Causal perception · Launching effect · Entraining effect · Representational momentum · Impetus · Heuristics · Spatial representation

1 Introduction

Whether causality can be directly perceived or must be inferred from other information has a long history of investigation (e.g., Scholl and Tremoulet 2000; White 1988; Young 1995). The majority of experiments that address perception of

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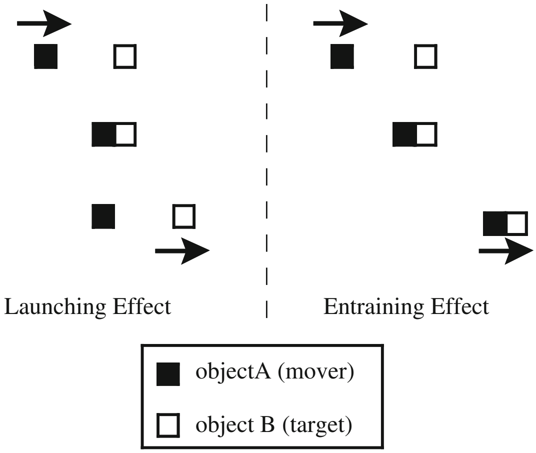

Fig. 1 The stimulus configuration in the launching effect (*left panel*) and the entraining effect (*right panel*). In both effects, object A (the mover) approaches object B (the target), contacts object B, and object B is set into motion. In the launching effect, object A becomes stationary at the moment of contact with object B; in the entraining effect, object A continues to move in the same direction and at the same velocity after contact with object B

causality have involved collection of introspective verbal reports regarding subjective experience of different types of stimuli (e.g., Schlottmann and Shanks 1992; Scholl and Nakayama 2002; White 2007; Young and Falmier 2008). The experiment reported here involved measurement of representational momentum (RM; a displacement in the direction of target motion of the remembered final location of a moving target from the actual final location of that target, for review, Hubbard 2005) of stimuli in two types of displays previously shown to produce different types of causal perception: the launching effect, and the entraining effect. RM offers the possibility of a nonverbal behavioral index or correlate of perceived causality (Hubbard et al. 2001), and the experiment reported here provides the first examination of RM for the initially moving object in the launching effect and for stimuli in the entraining effect. Whether RM for stimuli in launching effect displays or RM for stimuli in entraining effect displays reflects low-level correlates of causality or reflects a heuristic based on impetus was considered.

In a series of landmark studies on perception of causality, Michotte (1946/1963; Thinès et al. 1991) found that observers reported different causal perceptions when viewing different types of displays. Figure 1 illustrates two of these displays in which a moving stimulus, referred to as *object A*, approached and contacted a stationary stimulus, referred to as *object B*, which then began to move. If (object) A stopped moving upon contacting (object) B, and B immediately began moving in the same direction as A's former motion (left panel), observers reported a causal impression such as "A pushed B". If A did not stop moving upon contacting B, but B immediately began moving in synchrony with A (right panel), observers reported a causal impression such as "A carried B along". Michotte referred to the former as the *launching effect* and to the latter as the *entraining effect*. Movement of B was attributed to A in both effects, but in the launching effect, the perceived influence of A on B occurred only at the moment of contact before B moved away, whereas in the entraining effect, the perceived influence of A on B continued for the duration of B's motion. Although Michotte and other researchers referred to stimuli in the launching effect or entraining effect as *object A* and *object B*, for ease of discourse here, object A will be referred to as the *mover*,[1] and object B will be referred to as the *target*.

A closer consideration of the launching effect reveals an important difference between "causality" and "perception of causality". In contemporary studies involving the launching effect, the mover and target are not actual three-dimensional objects, but are typically two-dimensional computer-animated drawings. As such, the two-dimensional mover and target do not possess mass, and so animated motion of the mover and the target are not subject to physical laws governing the motion of three-dimensional objects that do possess mass. Nonetheless, if experimental participants view such displays, those participants have spontaneous and strong impressions that contact from the mover causes motion of the target in the same way that contact from a moving three-dimensional object (e.g., a moving billiard ball) causes another three-dimensional object (e.g., a stationary billiard ball) to move. Thus, in the launching effect, causality is not actually present (i.e., contact from the mover does not convey any force that could cause subsequent motion of the initially stationary target), but is nonetheless perceived to be present. The launching effect demonstrates that perceived causality can differ from and not accurately reflect actual causality, and by examining such phenomena, it should be possible to determine the variables and cognitive processes that influence perception of causality.

Hubbard et al. (2001) presented participants with launching effect displays and with nonlaunching displays, and RM for targets in launching effect displays was smaller than RM for targets in nonlaunching displays. Drawing on McCloskey's (1983) theory of naive impetus and on Michotte's (1946/1963) theory of causal perception, Hubbard et al. (also Hubbard 2004; Hubbard and Ruppel 2002) suggested participants attributed motion of a launched target to an impetus imparted from the mover to the target. Such an impetus caused the target to immediately begin moving, and the impetus dissipated with subsequent target motion. If impetus is the sole source of motion of a launched target, then a launched target would be expected to stop once impetus dissipated below the level needed to sustain motion. Previous research found RM for a (nonlaunched) target decreased if participants expected that target to stop (Finke et al. 1986); thus, it could be hypothesized RM of a launched target decreased because participants expected the target to stop once impetus imparted from the mover had dissipated. Motion of a target in a nonlaunching display was not perceived as solely dependent upon a dissipating impetus imparted from another stimulus; thus, participants did not expect targets in nonlaunching control displays to stop, and RM of such targets was not decreased.

The hypothesis that motion of a launched target is attributed to an impetus imparted from the mover is consistent with Michotte's (1946/1963) findings that perception of causality in a launching effect display was reduced if the (a) latency between when the mover contacted the target and when the target began moving

[1] In previous studies of RM of the target in the launching effect, the initial moving stimulus was referred to as the *launcher*. However, in the current study the term "launcher" is less appropriate (as the initially moving stimulus would not "launch" the target in an entraining effect display), and so the more neutral term "mover" is used.

increased (as impetus is imparted immediately), (b) target moved in a direction different from previous motion of the mover (as impetus is in the direction of mover motion), or (c) target moved a sufficiently far distance (as impetus would dissipate below the level needed to maintain target motion before the target stopped). However, in the launching effect, effects of impetus are confounded with attribution of target motion to the mover, and so it would be desirable to separate effects of impetus and effects of attribution of target motion to the mover. Comparison of the launching effect and the entraining effect provides such a separation, as in the entraining effect, target motion is attributed to the mover (e.g., "object A carried object B along"), but continuing contact of the mover and the target during target motion is not consistent with an attribution that target motion is caused by an initial impetus that subsequently dissipates. Motion of an entrained target would thus not be expected to stop, and so RM of targets in entraining effect displays should be larger than RM of targets in launching effect displays.

An alternative to the impetus hypothesis was suggested by Choi and Scholl (2006), who replicated the decrease in RM for launched targets reported by Hubbard and colleagues, but suggested this decrease resulted from low-level spatiotemporal correlates of causality. Choi and Scholl pointed out that launching effect displays involved two objects and a single continuous motion, whereas nonlaunching displays used by Hubbard and colleagues (and adapted from Michotte 1946/1963) did not involve these properties (e.g., a spatial gap between mover and target disrupted continuity of motion and disrupted causal perception). Choi and Scholl presented a passing display in which targets remained stationary while movers contacted, passed over, and moved beyond those targets; such a passing display involved two objects and a single continuous motion but did not involve launching. RM of passing movers did not differ from RM of launched targets, leading Choi and Scholl to conclude that the presence of two objects and a single continuous motion was responsible for the decrease in RM of launched targets.[2] If this conclusion is correct, then RM of targets in launching effect displays should not differ from RM of targets in entraining effect displays, as both the launching effect and the entraining effect involve two objects and a single continuous motion.

In the experiment reported here, participants viewed a launching effect display or an entraining effect display. After the display vanished, an auditory cue instructed participants to indicate the final location of the mover or the final location of the target. If the decrease in RM for targets in launching effect displays reported by Hubbard et al. (2001), Hubbard and Ruppel (2002), and Choi and Scholl (2006)

[2] Given that Choi and Scholl found RM of launched targets was decreased relative to RM of nonlaunched targets and RM of passing movers did not differ from RM of launched targets, it is possible RM of passing movers was decreased relative to RM of other types of nonlaunched targets. However, comparison of RM of passing movers and RM of other types of nonlaunched targets was not reported. There are at least two reasons why RM of passing movers might be decreased relative to RM of nonlaunched targets. First, the mover occluded the stationary target in passing displays, and contact with or resistance from the stationary target could have decreased perceived velocity of the mover (cf. braking, Levelt 1962; representational friction, Hubbard 1995, 1998). Second, the stationary target could have functioned as a landmark for judgments of the mover, and given that RM is decreased if a stimulus moves away from a landmark (Hubbard and Ruppel 1999), RM of the mover was decreased (but see Hubbard et al. 2001, for why decreases in RM in launched targets is not due to a landmark effect).

reflects an attribution that impetus from the mover was imparted to the target, then RM of targets in entraining effect displays (whose motion was not attributed to a dissipating impetus and so would not be expected to stop) should be larger than RM of targets in launching effect displays. However, if the decrease in RM for targets in launching effect displays reflects the presence of two objects and a single continuous motion, then there should be no difference in RM for a target in a launching effect display and RM for a target in an entraining effect display. How launching or entraining might influence RM of movers in the launching effect or in the entraining effect is not clear, but examination of RM of such movers might provide constraints for theories of perception of causality and for theories of displacement.

2 Method

2.1 Participants

The participants were 13 undergraduates naive to the hypotheses and who received partial course credit.

2.2 Apparatus

Stimuli were generated by and responses collected upon an Apple Macintosh IIsi microcomputer connected to a Apple RGB monitor. The auditory cue was presented over stereophonic headphones (Kenwood #KPM-210) attached to the microcomputer.

2.3 Stimuli

The mover and target were square shapes 20 pixels (approximately 0.83 degrees of visual angle) in width on a white background. The mover was a black square; the target was a black outline square (white interior). The mover emerged from the left, right, top, or bottom edge of the display and moved toward the target. The target appeared within the central region of the display, and the mover crossed between 45 and 55 % of the display before contacting the target. The target was stationary until contacted by the mover, but immediately upon contact, the target began to move in the same direction and at the same velocity as previous motion of the mover. Motion of upward or downward movers or targets was centered along the horizontal axis of the display, and motion of leftward or rightward movers or targets was centered along the vertical axis of the display. Motion of movers and of targets was generated by shifting movers and targets one pixel between successive presentations,[3]

[3] Michotte (1946/1963) reported the launching effect was maximized if the ratio of mover velocity to target velocity was 3.6:1, but a robust launching effect could still be found if the ratio of mover velocity to target velocity was 1:1. A ratio of 1:1 was chosen for the current experiment to facilitate comparisons of (a) RM of movers and RM of targets, (b) RM in the launching effect and RM in the entraining effect, and (c) the current data with the data of Choi and Scholl (2006), who also used a ratio of 1:1.

resulting in an approximate velocity of 5 degrees/second. Neither movers nor targets exhibited deformation from contact. In launching trials, the mover became stationary upon contacting the target; in entraining trials, the mover continued to move after contacting the target without any change in direction or in velocity (and remained adjacent to the trailing edge of the target). The target in launching trials and the combined mover + target in entraining trials moved 30 pixels (approximately 1.25 degrees of visual angle) before vanishing, and the mover and target were visible for approximately 250 ms after the mover contacted the target. The auditory cue was a 250 or 2,000 Hz tone that sounded for 1 s; the 250 Hz tone signaled participants to indicate the final location of the black square (the mover), and the 2,000 Hz tone signaled participants to indicate the final location of the black outline square (the target). Each participant received 128 trials (2 motions [launching, entraining] × 4 directions [leftward, rightward, upward, downward] × 2 cues [250 Hz, 2,000 Hz] × 8 replications) in a different random order.

2.4 Procedure

Participants received 10 practice trials (drawn randomly from experimental trials) at the beginning of the session. Participants initiated each trial by pressing a designated key, and the target immediately appeared. There was a 1 s pause, and then the mover emerged from the left, right, top, or bottom edge of the display and moved toward the target. When the mover contacted the target, the target began to move, and the mover became stationary (launching trials) or continued moving in the same direction and at the same velocity and remained adjacent to the target (entraining trials). The mover and the target simultaneously vanished approximately 250 ms after the mover contacted the target. Immediately after the mover and the target vanished, the auditory cue was presented, and participants indicated the final location of the mover or the final location of the target. Participants used a computer mouse to position the cursor (in the form of a plus sign) over where the center of the mover or the center of the target was when the mover and the target vanished, and participants clicked a button on the mouse to record the display coordinates of the cursor. Participants then initiated the next trial.

3 Results

Average differences (in pixels) between the judged vanishing point and the actual vanishing point for the mover and for the target for each participant for each condition were calculated along the axis of motion, and consistent with previous research, these differences were referred to as *M displacement*. Positively-signed M displacement indicated the judged vanishing point was beyond the true vanishing point (i.e., further in the direction of motion), and negatively-signed M displacement indicated the judged vanishing point was behind the true vanishing point (i.e., in the direction opposite to motion). Absolute value of M displacement indicated the magnitude of displacement, with larger absolute value indicating larger displacement.

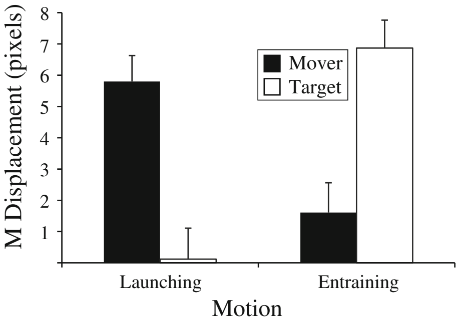

Fig. 2 M displacement as a function of stimulus and type of display. M displacement during launching trials is shown on the *left*, and M displacement during entraining trials is shown on the *right*. M displacement of movers is illustrated by *black bars*, and M displacement of targets is illustrated by *white bars*. *Error bars* reflect the standard error of the mean

M displacement scores were analyzed in a 2 (motion) × 4 (direction) × 2 (cue) repeated measures ANOVA. Motion × Cue was significant, $F(1,12) = 22.62$, $p < .001$. As shown in Fig. 2, M displacement was smaller for targets ($M = 0.12$) than for movers ($M = 5.80$) in launching trials, whereas M displacement was smaller for movers ($M = 1.61$) than for targets ($M = 6.87$) in entraining trials. Least squares comparisons indicated M displacement for launched targets was smaller than M displacement for entrained targets, $t(12) = -4.15$, $p < .002$, and launching movers, $t(12) = 3.49$, $p < .005$, and M displacement for entraining movers was smaller than M displacement for launching movers, $t(12) = 2.58$, $p < .03$, and entrained targets, $t(12) = -3.24$, $p < .008$. Direction influenced M displacement, $F(3,36) = 7.20$, $p < .001$, and least squares comparisons indicated M displacement was smaller for upward ($M = -0.81$) motion than for rightward ($M = 5.84$), $t(12) = 4.23$, $p < .0002$, leftward ($M = 4.37$), $t(12) = 3.51$, $p < .002$, or downward ($M = 4.66$), $t(12) = 3.48$, $p < .002$, motion. No other main effects or interactions approached significance.

M displacement for movers and for targets in launching trials and in entraining trials were compared against zero, and displacement in a given condition significantly larger than zero indicated RM occurred in that condition. In launching trials, M displacement for movers was significantly larger than zero, $t(12) = 5.07$, $p < .0003$, but M displacement for targets did not differ from zero, $t(12) = 0.11$, $p > .90$. In entraining trials, M displacement of movers did not differ from zero, $t(12) = 1.12$, $p > .27$, but M displacement for targets was significantly larger than zero, $t(12) = 6.03$, $p < .0001$.

4 Discussion

Forward displacement of targets was smaller in launching trials than in entraining trials, even though the direction, velocity, and distance of target motion were identical in both types of trials. Indeed, displacement of launched targets did not differ from zero, and experience in judging movers in launching trials or viewing a different type of causality in entraining trials might have enhanced or highlighted the influence of launching on displacement of launched targets. Regardless, the difference in displacement of launched targets and displacement of entrained targets is not consistent with the hypothesis that decreased RM for launched targets is due to the presence of two objects and a single continuous motion, as launching trials and entraining trials each contained two objects and a single continuous motion.[4] The difference in displacement of launched targets and displacement of entrained targets is consistent with the hypothesis that target motion in launching but not in entraining is attributed to a dissipating impetus imparted from the mover upon contact with the target. Additionally, (a) forward displacement was smaller for targets than for movers in launching trials, (b) forward displacement was smaller for movers than for targets in entraining trials, and (c) forward displacement of movers was smaller in entraining trials than in launching trials. Also, and consistent with previous findings (e.g., Hubbard 1990), forward displacement was smaller for upward motion.

Why might observers attribute motion of a launched target to an impetus imparted from the mover? Such an attribution might function as a heuristic that allows observers to predict the behavior of a target (Hubbard 2004). Prediction based on an impetus heuristic requires a single parameter (dissipating impetus), whereas prediction based on a correct understanding of physical principles requires multiple parameters (momentum, friction, etc.). Importantly, prediction based on an impetus heuristic could yield an approximately correct (and adequate) solution (i.e., a stationary target that receives an initial push from a moving object moves a short distance and then stops, a target that receives a larger initial push moves farther before stopping), but would require less effort or fewer resources than would prediction based on a correct understanding of physical principles. Just as RM might reflect subjective consequences of physical principles rather than objective physical principles (Hubbard 1997, 2006), representation of a launching effect might involve an attribution of impetus that reflects subjective consequences of collision (e.g., a pushed object moves a short distance and stops) rather than objective physical principles of collision. Such a notion is consistent with White's (2009) hypothesis visual perception of force in the launching effect is based on subjective experience of haptic interaction with objects and with Hubbard's (2005) claim RM involves prediction of target behavior.

An alternative hypothesis that can be rejected is that differences in displacement resulted from participants visually tracking the moving element of the display and that memory for the location of the non-tracked element of the display was displaced toward the tracked element (i.e., toward the foveated region). Such an oculomotor hypothesis is (a) consistent with larger forward displacement of the mover than of the target in launching trials but (b) not consistent with the lack of displacement of the target in launching trials (as tracking a smoothly moving

[4] It might be argued the combined mover + target in entraining trials was perceived as a single larger object rather than two adjacent smaller objects, and so the latter portion of an entraining trial involved one object and a single motion, whereas the earlier portion of an entraining trial (and all of a launching trial) involved two objects and a single motion. However, the difference between RM of movers and RM of targets in the entraining effect does not support the idea the combined mover + target was perceived as a single object, and Michotte (1946/1963) reported that the segregation of the mover and the target as separate objects continued after contact if a period of previous separation of the mover and target had been observed.

[nonlaunched] target increases forward displacement of that target, Kerzel 2000) or with larger forward displacement of the target than of the mover in entraining trials. Also, such an oculomotor hypothesis is not consistent with previous findings that (a) decreased RM of a launched target does not result from the target simply moving away from the mover (as forward displacement of the target is not decreased when target motion is orthogonal to the direction of mover motion, Hubbard et al. 2001), (b) RM of a launched target decreases as distance traveled by that target increases (Hubbard and Ruppel 2002), and (c) introduction of an unbridged spatial gap between the mover and the target eliminated the decrease in RM typical of launched targets (Hubbard and Favretto 2003).

Smaller forward displacement for targets than for movers in launching trials is consistent with White's (2007) finding that in a launching effect display the movers were rated as exerting more force than were the targets. However, in the experiment reported here, the mover in a launching effect display was stationary for approximately 250 ms before vanishing, and as noted earlier, RM is usually decreased if participants expect a moving target to stop. Participants did not know prior to when the mover contacted the target whether that trial would involve a launching effect or an entraining effect (i.e., whether the mover would stop moving or would continue to move after contacting the target), and so there was no reason for participants to expect the mover to necessarily stop upon contacting the target. The relatively large forward displacement for a mover that was in a launching effect display and stationary for 250 ms before vanishing (a duration similar to the latency between when a moving target vanishes and RM for that target peaks, e.g., Freyd and Johnson 1987) suggests RM for a stimulus involves properties of memory for previous motion and does not involve properties of perception or oculomotor behavior at the time that stimulus vanishes (cf. Kerzel 2000, 2002).

Smaller forward displacement for movers than for targets in entraining trials was surprising. If two objects of the same mass move at the same velocity, then momentum of the second object should be the same as momentum of the first object; on this basis, RM of targets in entraining trials should have been the same as RM of movers. One hypothesis is that luminance contrast of the mover and target resulted in the mover being perceived as less massive (cf. Nakatani 1989), but implied mass does not influence RM (Hubbard 1997), and so this hypothesis can be rejected. A second hypothesis is that the target might have appeared to block or slow the mover, and this would be consistent with findings RM is decreased if implied friction or resistance is increased (Hubbard 1995, 1998). Regardless, smaller RM for movers than for targets in entraining trials underscores that motion of the target in the entraining effect is not attributed to an impetus imparted from the mover, as a dissipating impetus from the mover could not produce displacement larger than that of the mover. The relationships of displacement of entrained targets to displacement of launched targets and displacement of entrained movers are consistent with a hypothesis that motion of a launched target, but not motion of an entrained target, is due to an attribution of impetus and not consistent with a hypothesis that equal displacement should occur when two objects and a single motion are present.

Smaller forward displacement for movers in entraining trials than for movers in launching trials initially appears inconsistent with findings that RM is determined by final target velocity (Finke et al. 1986), as movers in launching trials were stationary when they vanished, whereas movers in entraining trials were in motion when they vanished. One hypothesis is that smaller forward displacement for movers in entraining trials reflects contributions of landmark attraction (Hubbard and Ruppel 1999). Targets might have functioned as landmarks for judgments of movers, and thus memory for movers was displaced toward those landmarks. Smaller forward displacement of movers in entraining trials than in launching trials might reflect the smaller separation between movers and targets in entraining trials (with a smaller landmark effect) than in launching trials. Such an account is consistent with smaller forward displacement of targets in launching trials than in entraining trials (as a larger landmark effect would more effectively cancel RM of the target) but is not consistent with smaller forward displacement of the mover than of the target in the entraining effect. A second hypothesis, and one which was noted earlier, is that smaller forward displacement for movers in entraining trials (relative to movers in launching trials and targets in entraining trials) could be accounted for if targets in entraining trials were perceived as offering resistance or friction to motion of movers.

Forward displacement in memory for the locations of movers and targets in launching effect displays and in entraining effect displays differed. The data are not consistent with the hypothesis that the decrease in RM for a target in a launching effect results from the presence of two objects and a single continuous motion, but the data are consistent with the hypothesis that motion of a target in the launching effect is attributed to impetus imparted from the mover upon contact with the target and that dissipates with target motion. The data are consistent with Michotte's claim that subsequent motion of the target was attributed to the mover in the launching effect and to the target in the entraining effect. However, impetus is not a valid physical principle, and so an attribution of impetus in the launching effect suggests observers do not perceive causality. Rather, an apparent perception of causality might instead involve (automatic) application of an impetus heuristic that allows an approximately correct and sufficiently adequate prediction of effects of collision. Perhaps observers experience impressions of causality when viewing launching effect displays not because they directly perceive causality, but because behavior of the mover and target in launching effect displays match an impetus heuristic used when predicting outcomes of collision events.

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