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Perceived Causality Can Alter the Perceived Trajectory of Apparent Motion

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Abstract

When objects collide, human observers perceive not only motion but also causal relations, such as which object caused the other to move. In the present experiments, we investigated whether such causal interpretations can actually influence the perceived path of apparent motion. Displays contained two alternately flashing motion targets positioned at either end of a semicircular occluder. Two additional "context objects" moved in such a way that the motion targets appeared to collide with and launch them. The collision was manipulated so that it was consistent with apparent motion either along the straight path between the targets or along a curved path passing behind the occluder. Subjects almost exclusively perceived motion consistent with the implied launch, which suggests that causally coherent interpretations can influence basic perceptual processes.

Keywords

motion perception, causality, visual perception, cognition

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Comprehension of physical events in terms of cause and effect is fundamental for making sense of the dynamic physical world. Causal interpretation may involve cognitive inference based on previous experience and real-world knowledge, but at least some situations give rise to more perceptual causal impressions that seem immediate, automatic, and irresistible. When a moving object suddenly stops adjacent to a stationary object and then the stationary object starts to move along the same path that the previously moving object was following, most observers tend to see the motion of the second object as caused by the impact of the first one (the *launching effect*; Michotte, 1946/1963). Ever since Michotte's seminal work, most studies of causal perception have focused on determining the factors that mediate such phenomenological experiences of causality (e.g., Boyle, 1960; Choi & Scholl, 2004, Guski & Troje, 2003; Schlottmann & Anderson, 1993; Scholl & Nakayama, 2004; for a review, see Scholl & Tremoulet, 2000). In such studies, the perception of causality is implicitly considered a global interpretation or "Gestalt" imposed on a visual event. In the experiment reported here, we investigated whether the perception of causality can play a more substantial role in influencing basic perceptual processes.

To assess how the perception of causality influences motion interpretation, we capitalized on the well-known phenomenon of *apparent motion*: Alternate presentations of two spatially distinct objects produce the percept of intervening continuous motion (Kolers, 1972; Wertheimer, 1912/1961). Apparent motion involves an inherent ambiguity of the motion path because an infinite number of potential paths connect the two locations. Observers typically perceive the shortest possible path, generally a straight line. In some circumstances, this shortest-path bias can be overcome to yield a perception of a longer, curved path (Anstis & Ramachandran, 1985; Farrrell & Shepard, 1981; Kim, Feldman, & Singh, 2012; Shepard & Zare, 1983; Shiffrar & Freyd, 1990). The motion-path ambiguity provides an ideal context in which to investigate the influence of perceived causality on motion perception. In the present experiments, we tested whether perceived causality can push apparent motion away from the default shortest path and toward a longer, curved one. As in our previous studies (e.g., Kim et al., 2012), we employed a curved occluder, which establishes a potential "detour" for the motion path. Moving objects are often occluded by other surfaces that they pass behind. But the visual system generally maintains a percept of continuous existence behind occluders, a phenomenon termed *amodal completion* (Michotte, Thinès, & Crabbé, 1964/1991). In the present experiments, we tested whether the perception of momentum elicited by the collision of an apparently moving object with a second object can reciprocally interact with the amodal completion of the first object's motion behind a

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curved occluder to induce a perceived motion path consistent with the direction in which the second object is launched.

In one type of apparent-motion display (see Fig. 1a), two rectangles of the same color (context objects; shown in green) appear immediately above two rectangles of a different color (motion targets; shown in red). The two red rectangles flash in alternation, with a variable interstimulus interval (ISI) between the disappearance of one rectangle and the appearance of the other. As soon as a red rectangle appears, the green rectangle above it moves upward and then reverts to its original position during the ISI. This display is typically interpreted by naive observers in one of two ways. Some observers perceive a red rectangle apparently moving along a straight path between the two positions, with the green rectangles moving up when the red rectangles appear beneath each of them and then moving back down when the red rectangles disappear, without an impression of collision. Other observers see two red rectangles alternately emerging into existence to "push" the green ones upward and then disappearing, without a strong impression of apparent motion. Hence, this display does not seem to simultaneously support both apparent motion (of the red rectangle) and a causal interaction between the red and green objects. However, if a semicircular occluder is included in every frame of the same motion sequence (vertical-launch display; Fig. 1b), observers tend to see the red rectangle moving back and forth behind the occluder and colliding with the green rectangles at each end of the occluder to launch them upward. The red rectangle then appears to reverse direction behind the occluder while the green rectangle "falls" passively down to its original position apparently because of gravity.

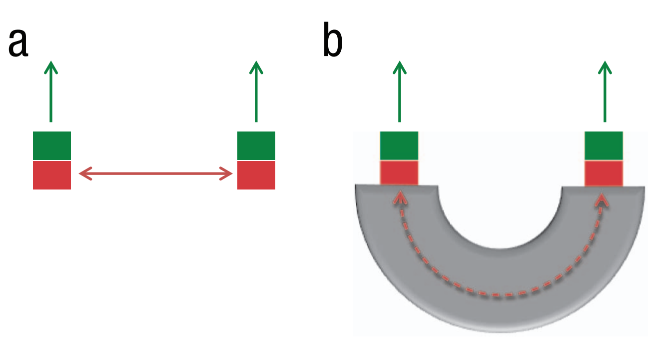

Fig. 1. Examples of two apparent-motion displays. In one display (a), two rectangles of the same color (motion targets; shown here in red) flash alternately below two rectangles of a different color (context objects; shown here in green). As soon as each motion target appears, the context object above it is displaced upward and then reverts to its original position during the interstimulus interval between the motion target's disappearance and the appearance of the other motion target. This creates a percept either of the motion target moving horizontally across the display or of the two motion targets appearing briefly to "push" the context objects upward. In a vertical-launch display (b), a semicircular occluder is added to this paradigm to create the percept of the motion target moving along the curved path behind the occluder from one end to the other and colliding with the context objects at each end.

Experiment 1

In Experiment 1, we tested the effect of perceived causality on apparent motion using several types of context events, including the vertical-launch display (Fig. 2). In bounce displays, the context objects were stationary across the entire motion sequence. In launch displays, as soon as a motion target appeared, the context object above or next to it respectively moved upward (vertical-launch display) or laterally (horizontal-launch display). Horizontal displacement of the context objects is consistent with straight horizontal apparent motion, which appears to launch the context objects horizontally. Similarly, vertical displacement of the context objects is consistent with a curved motion path behind (or through) the occluder that results in vertical motion at the end of the occluder, which appears to launch the context objects vertically. Thus, the question was whether the perceptual interpretation of collision could bias the perceived path of target motion.

Method

Participants. Thirteen Rutgers University undergraduates participated in Experiment 1 for course credit.

Materials and design. The experiment was controlled by a program written with MATLAB (The MathWorks, Natick, MA) using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). Participants were seated in a dark room approximately 60 cm in front of a computer monitor.

Stimuli were computer-generated apparent-motion sequences of two alternately presented motion targets (Fig. 2), each of which was separated in time by two frames of ISI. Motion targets were textured rectangles composed of red-and-white dot patterns (1.00° × 0.61° of visual angle), which appeared on top of the center of each end of an upturned semicircular tube (width = 2.2°) that had a radially white-to-black-gradient color. The diameter of the semicircular tube (equivalent to the separation between the two motion targets) was 5.73°. There were four levels of ISI (100, 233, 367, and 500 ms). Target duration was 150 ms. The semicircular tube remained on screen during the whole motion sequence. The entire stimulus display appeared against a black-and-white background of random dots.

There were five display types (Fig. 2; see Videos S1–S5 in the Supplemental Material available online for animated demonstrations of each display type). In no-context displays, motion targets appeared without context objects (textured rectangles composed of green-and-white dot patterns). In the other four displays, two additional context objects appeared on either side or above the locations of motion targets. In vertical-bounce displays, context objects were placed immediately above each motion target; in horizontal-bounce displays, context objects were placed on the outer side of each motion target. In both types of bounce display, the context objects remained visible across the entire motion sequence without any location change. In vertical-launch displays,

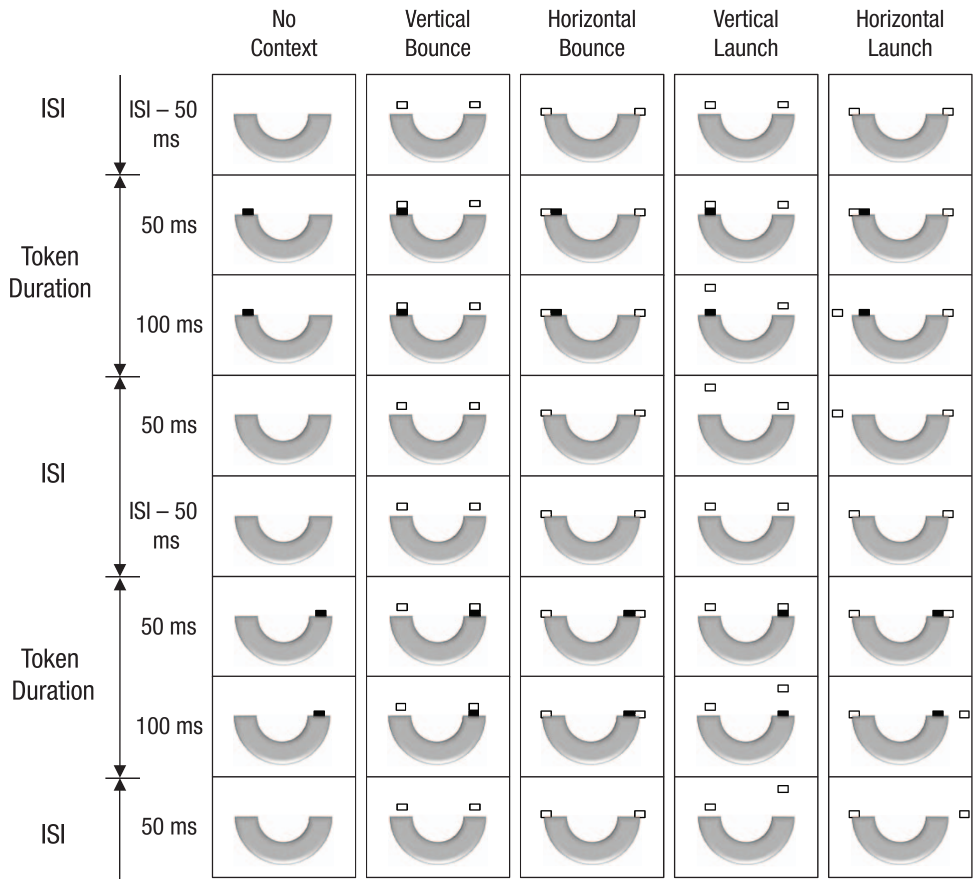

Fig. 2. Apparent-motion displays and trial sequence used in Experiment 1. In each condition, a trial consisted of three cycles of the eight-frame motion sequence illustrated here. In no-context displays, two alternately flashing motion targets (rectangles composed of red-and-white dot patterns; shown here as filled rectangles) appeared without context objects (rectangles composed of green-and-white dot patterns; shown here as unfilled rectangles). In the four remaining displays, context objects remained visible across the entire motion sequence while motion targets continued to appear in alternation. In vertical-bounce displays, context objects appeared immediately above each motion target; in horizontal-bounce displays, context objects appeared on the outer side of each motion target. In vertical-launch displays, context objects appeared immediately above the two motion targets; 50 ms after target onset, the related context object was displaced upward and then drifted back to its original position over the remainder of the interstimulus interval (ISI). In horizontal-launch displays, context objects appeared on the outer side of the two motion targets; 50 ms after target onset, the related context object was displaced laterally and then drifted back to its original position over the remainder of the ISI. In the actual displays, the background was composed of a black-and-white pattern of random dots, and the semicircular occluder had a radially white-to-black-gradient color. Animated versions of each trial type can be viewed in Videos S1 through S5 in the Supplemental Material.

context objects appeared immediately above the two motion targets, and 50 ms after target onset, the context object was displaced upward by 1.8°, and then returned to its original position 50 ms before the next target onset. In horizontal-launch displays, context objects appeared on the outer side of the two motion targets and were displaced laterally by 1.8° for the same duration as in vertical-launch displays.

Procedure. Each trial started with a fixation cross for 500 ms, followed by three cycles of the eight-frame motion sequence, then a blank screen. Participants pressed one of two keys to indicate whether the motion target appeared to be moving horizontally or along a curved path behind (or through) the semicircular tube (see Fig. 3a). Participants were additionally asked to rate how strongly and clearly they perceived apparent motion on a 3-point scale. The main dependent measure was the proportion of "curved-path" responses, with a secondary analysis of the motion-quality ratings. Each participant completed a total of 200 experimental trials (5 display types × 4 ISIs × 10 repetitions) presented in random order over four blocks, following 26 practice trials.

Results and discussion

Results of Experiment 1 are depicted in Figure 3b. A 5 × 4 repeated measures analysis of variance (ANOVA) was

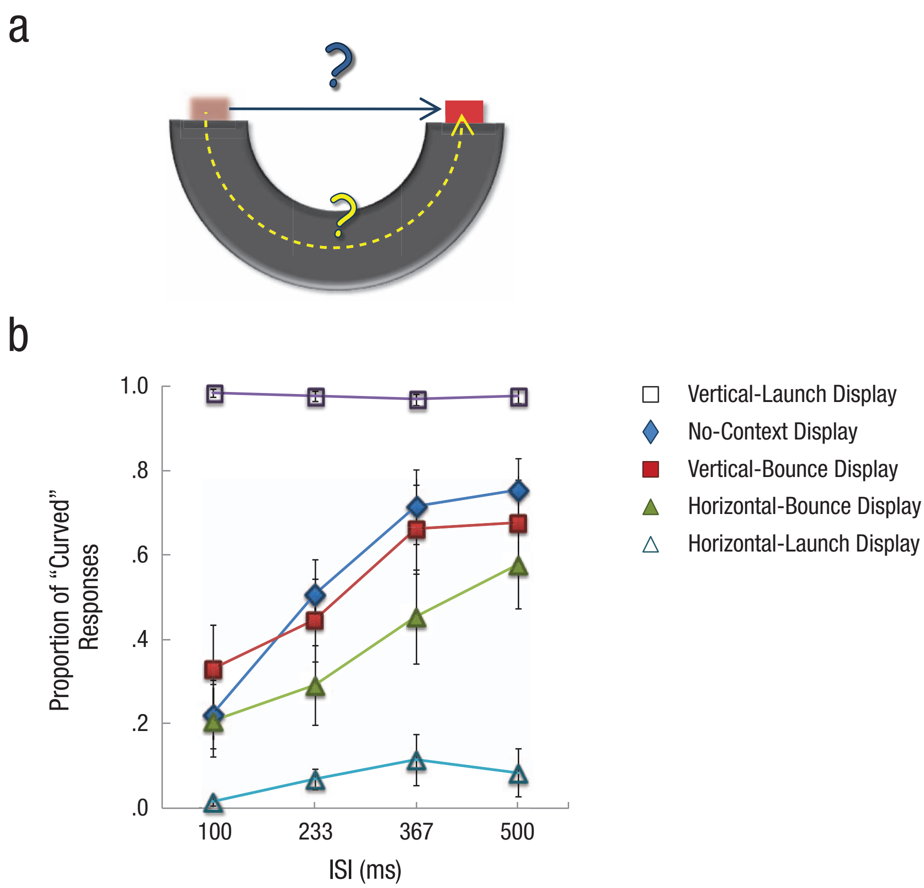

Fig. 3. Illustration of the task and results from Experiment 1. Participants pressed one of two keys to indicate whether they perceived the target object as moving along a straight path (the default shortest path) or a curved path behind the occluder (a). The graph (b) shows the proportion of "curved-path" responses as a function of interstimulus interval (ISI) and display type. Error bars represent ±1 *SE*.

conducted to determine the effects of display type and ISI, respectively, on motion path. The main effect of display type was significant, $F(4, 48) = 5.84$, $p = .006$; observers reported curved-path motion far more when viewing the vertical-launch display ($M = .98$) and least when viewing the horizontal-launch display ($M = .07$) compared with the other three types of displays. Planned comparisons confirmed that the proportion of "curved-path" responses to either launch display significantly differed from the proportion of "curved-path" responses to any other displays, *ps* < .001. That is, apparent motion was perceived far more often in the direction of the launch. The main effect of ISI was also significant, $F(3, 36) = 17.51$, $p < .001$; "curved-path" responses increased with ISI. In the displays in which context objects were absent or stationary, the probability of perceiving curved-path motion increased with ISI—ISI × Display Type interaction: $F(12, 144) = 7.82$, $p < .001$—which suggests that apparent motion can deviate from the shortest path if amodal completion of the motion trajectory behind the curved occluder can "explain" the invisibility of the object during a long ISI (see Kim et al., 2012). However, the identical ambiguous apparent-motion display was perceived unambiguously as either straight-path motion (when context objects moved laterally) or curved-path motion (when context objects moved upward), regardless of the ISI.

The rated quality of apparent motion was higher with stationary context objects ($M = 1.77$) than without context objects ($M = 1.50$) and highest with moving context objects ($M = 2.49$), $F(4, 48) = 36.32$, $p < .001$. That is, the causal context substantially enhanced the percept of apparent motion.

These results suggest that observers attributed the displacement of the context object to a collision with the motion target (Michotte, 1946/1963), with the direction of the momentum implied by this collision decisively influencing the perceived direction of apparent motion. In the vertical-launch displays, a potentially ambiguous contact between the motion target and the context object was interpreted so as to be consistent with the momentum conveyed by the perceived motion behind the curved occluder. This inferred momentum then served as an "explanation" of the motion of the context object.

Experiment 2

In Experiment 2, we wished to rule out a potential alternative explanation of these results based on motion priming. Motion priming typically results from motion seen prior to or concurrently with the target motion (e.g., Anstis & Ramachandran, 1987; Pantle, Gallogly, & Piehler, 2000). In contrast, because of the nature of our displays, the choice of motion path was affected by a context motion that occurred after the target motion. Nevertheless, in Experiment 2, we tested three new displays similar to the vertical-launch display used in Experiment 1 but with different spatial or temporal patterns of context events (Fig. 4). These displays were designed to weaken the causal percept but not to substantially diminish motion priming. If the percept of curved motion in the vertical-launch display was simply the result of priming, these displays should elicit it at least as frequently as the vertical-launch display did.

Method

Participants. Nine new Rutgers University undergraduates participated for course credit.

Design and procedure. Diameter (i.e., target separation) and width of the semicircular tube were 4.5° and 1.9° of visual angle, respectively, from a viewing distance of 100 cm. Motion

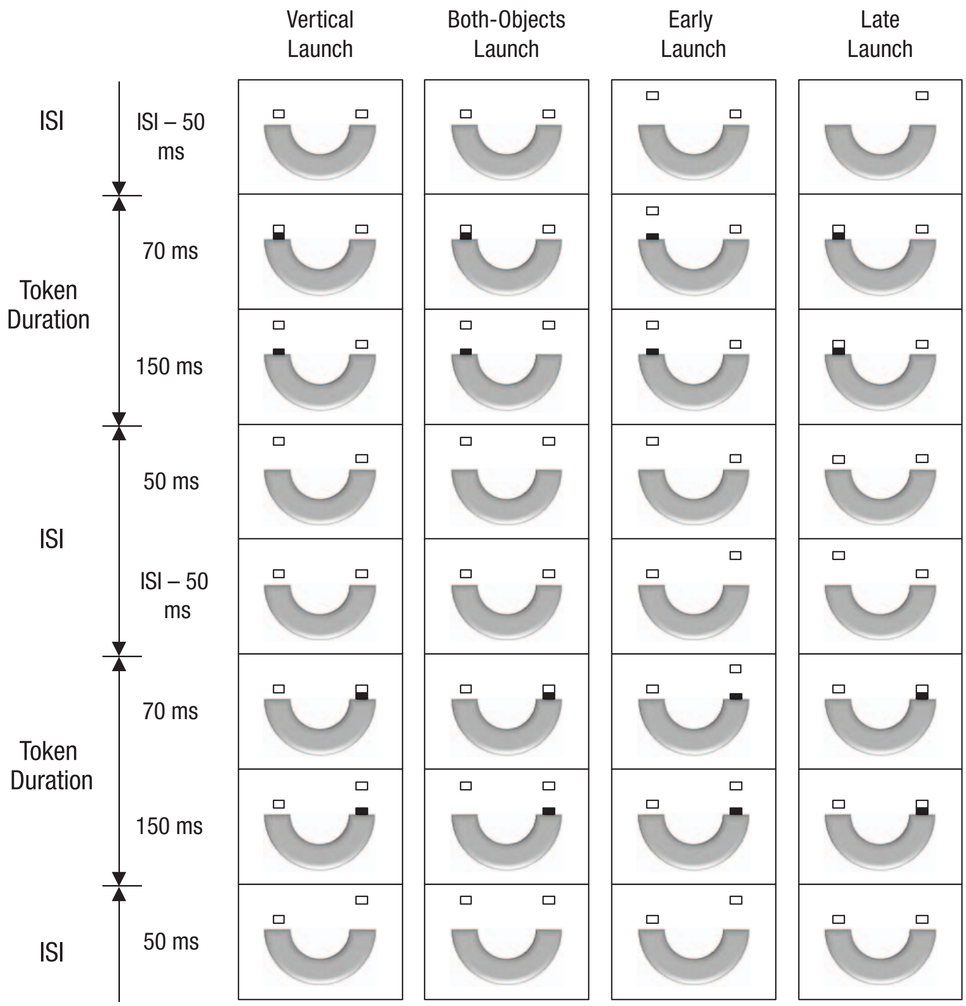

Fig. 4. Apparent-motion displays and trial sequence used in Experiment 2. In each condition, a trial consisted of three cycles of the eight-frame motion sequence illustrated here. In all four conditions, context objects (rectangles composed of green-and-white dot patterns; shown here as unfilled rectangles) remained visible across the entire motion sequence while flashing motion targets (rectangles composed of red-and-white dot patterns; shown here as filled rectangles) appeared in alternation. In vertical-launch displays, context objects appeared immediately above the location of two motion targets; 70 ms after target onset, the context object was displaced upward and then drifted back to its original position over the remainder of the interstimulus interval (ISI). In both-object-launch displays, both context objects were displaced upward and reverted to their original positions together in synchrony at every target onset. In early-launch displays, each context object moved upward 50 ms after offset of the previous target (ISI − 50 ms before the onset of the next target) and then continued to float until the next context object moved upward. In late-launch displays, the context object above each motion target was displaced upward 50 ms after each target offset and reverted to its original position at the next target onset. In the actual displays, the background was composed of a black-and-white pattern of random dots, and the semicircular occluder had a radially white-to-black-gradient color. Animated versions of each trial type can be viewed in Videos S6 through S9 in the Supplemental Material.

targets subtended 0.77° × 0.47°. The target duration was 220 ms, and there were three ISIs (150, 300, and 450 ms).

The four displays used in Experiment 2 are depicted in Figure 4 (see Videos S6–S9 in the Supplemental Material for animated demonstrations of each display). The vertical-launch display was identical to that used in Experiment 1, except that context objects were displaced upward by 1.55° 70 ms after each target onset. In Experiment 2, we employed three new displays. In the both-object-launch display, both context objects were displaced upward and reverted to their original positions together in synchrony at every target onset. In the early-launch display, each context object moved upward (ISI − 50 ms) before each target onset (i.e., 50 ms after previous target offset) and then continued to float until the next context object moved upward. In the late-launch display, the context object above each motion target was displaced upward 50 ms after each target offset and reverted to its original position at the next target onset. Procedures were the same as in Experiment 1.

Results and discussion

Results of Experiment 2 are presented in Figure 5. Participants reported curved-path motion more often when viewing the vertical-launch displays (M = .94) than when viewing the early-launch displays (M = .64), late-launch displays (M = .56), and both-object-launch displays (M = .50), $F(3, 24)$ = 3.81, p = .023. Planned comparisons showed that the vertical-launch display produced significantly more "curved-path" responses than did all other displays, $ps \leq .02$, but no other pairwise difference was significant, $ps > .05$. As in Experiment 1, the main effect of ISI was significant, $F(2, 16) = 7.68$, p = .005. The ISI × Display Type interaction was marginally significant, $F(6, 48) = 1.97$, $p = .089$. Motion-quality ratings were significantly higher for the vertical-launch display ($M = 2.55$) than for the early-launch display (M = 2.06), late-launch display ($M = 1.85$), and both-object-launch display ($M = 2.18$), $F(3, 24) = 7.44$, $p = .001$.

For the both-object-launch display, motion priming should be stronger because both context objects prime the target motion in the vertical direction. However, the causal percept should be weakened because two context objects' common motion cannot be explained by a collision with a motion target. In addition, early or late launch should selectively weaken the causal impression because causality perception is sensitive to the timing of the launched object's motion onset (Michotte, 1946/1963), but priming is presumably relatively insensitive to the exact timing of the priming motion. Therefore, the reduced curved-motion percept in the new displays cannot be explained by motion priming. Curved-path motion was still almost exclusively associated with a causal launch.

General Discussion

The path of apparent motion can be influenced by physical constraints, such as object permanence (Gerbino, 1984), occlusion (Anstis & Ramachandran, 1985; Kim et al., 2012), rigidity (Kolers & Pomerantz, 1971), and biomechanics (Shiffrar & Freyd, 1990). The present finding adds another regularity of nature to the list: mechanical causality. Human observers can experience an impression of causality even when the objects involved are not real, and no interaction between them is actually taking place (Michotte, 1946/1963; White, 2006). In spite of this illusory character, perceived causality seems to reflect a reliable mapping between kinematic properties of the stimulus and a physically plausible configuration of forces (Hecht, 1996; Runeson & Frykholm, 1983). Hence, phenomenological causality seems to incorporate real-world regularities to disambiguate impoverished sensory data.

It is interesting that the influence of causal interpretation on perceived motion in our displays was retrospective; that is, the context objects' displacement occurred after the target

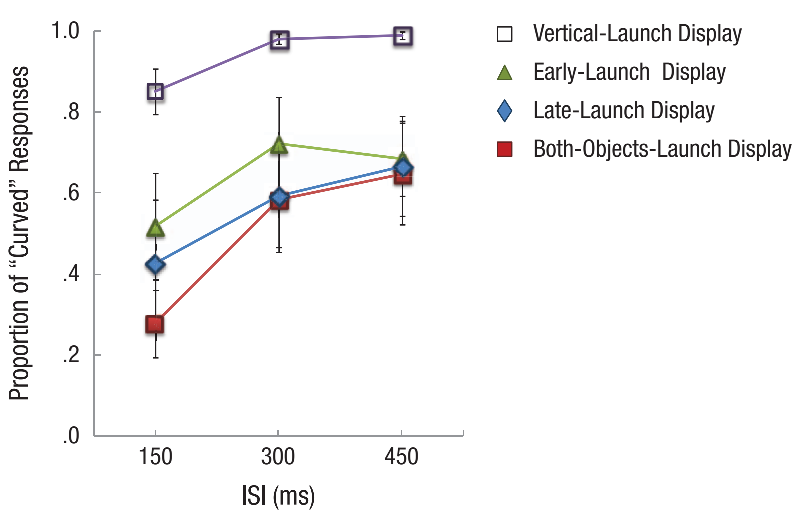

Fig. 5. Results from Experiment 2: proportion of "curved-path" responses as a function of interstimulus interval (ISI) and display type. Error bars represent ±1 *SE*.

appeared. In a physical collision, the motion of the launching object necessarily precedes the motion of the launched object. But, in our displays, the perceived path of the launching object was affected by the direction of the *subsequent* motion of the context object (the launched object). The visual system appears to reconstruct the most likely causal antecedent (i.e., the most plausible motion path) to explain the observed consequent (i.e., the displacement of the context object) ex post facto. This result is consistent with findings of previous studies suggesting postdictive processes in the perception of both apparent motion (Eagleman & Sejnowski, 2003; Kolers & von Grünau, 1976) and causal collisions (Buehner & Humphreys, 2010; Choi & Scholl, 2006). This retrospective character is broadly reminiscent of Bayesian inference, often referred to as "inverse probability" because it involves estimating causes retrospectively from their effects.

The phenomenon uncovered in these experiments is unusual in demonstrating that causal perception can interact with the dynamics of visual motion, both influencing and being influenced by the motion percept and the amodal motion path, and making an integral contribution to the phenomenology of visual motion. Causality is conventionally regarded as a high-level property that emerges later than low-level percepts such as motion contiguity in space-time (cf. Buehner & Humphreys, 2010; Scholl & Nakayama, 2004). But our results suggest that perceived causal relations among visual items are not merely a summary interpretation imposed on motions already determined by perceptual processes, but rather may make a potentially fundamental contribution to the disambiguation of the underlying sensory signal itself.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

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