

Research Article

CAUSAL CAPTURE: Contextual Effects on the Perception of Collision Events

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Abstract—*In addition to perceiving the colors, shapes, and motions of objects, observers can perceive higher-level properties of visual events. One such property is causation, as when an observer sees one object cause another object to move by colliding with it. We report a striking new type of contextual effect on the perception of such collision events. Consider an object (A) that moves toward a stationary object (B) until they are adjacent, at which point A stops and B starts moving along the same path. Such “launches” are perceived in terms beyond these kinematics: As noted in Michotte’s classic studies, observers perceive A as being the cause of B’s motion. When A and B fully overlap before B’s motion, however, observers often see this test event as a completely noncausal “pass”: One object remains stationary while another passes over it. When a distinct launch event occurs nearby, however, the test event is “captured”: It too is now irresistibly seen as causal. For this causal capture to occur, the context event need be present for only 50 ms surrounding the “impact,” but capture is destroyed by only 200 ms of temporal asynchrony between the two events. We report a study of such cases, and others, that help define the rules that the visual system uses to construct percepts of seemingly high-level properties like causation.*

Consider a shape (A) that moves toward a stationary shape (B) until they are adjacent, at which point A stops and B starts moving along the same path. The perception of this type of collision event is striking: Beyond the objective kinematics of such “launches,” observers see A cause B’s motion. Such phenomena were first studied in the early 1900s, and were brought to the attention of many psychologists by Michotte in 1946, in his book *The Perception of Causality* (1946/1963).

Causal perception of this sort lies at an interesting intersection between perception and cognition. Unlike other visual properties such as color, shape, and motion, causality is typically thought of as a higher-level conceptual property of the world (e.g., White, 1995). Yet, as Michotte and many researchers following him have noted, the apprehension of causality often seems to be largely perceptual in nature. Like the perception of faces or words, for instance, the perception of causality from collision events is phenomenologically instantaneous, automatic, and largely irresistible (Leslie, 1986; Michotte, 1946/1963; Scholl & Tremoulet, 2000; cf. Schlottmann, 2000). As Michotte emphasized, causal percepts are highly dependent on the spatiotemporal details of the displays, but are largely impervious to beliefs or intentions. At the same time, these critical display details are opaque to introspection: Causal perception seems just to happen, without any awareness of the factors that mediate it. The perception of causality appears to occur in all normal human observers—across cultures (e.g., Morris & Peng, 1994) and even in very young infants (e.g., Leslie &

Keeble, 1987)—and causal perception and causal judgment can even pull in opposite directions (Schlottmann & Shanks, 1992). All of these considerations suggest that the human visual system may be involved not only in recovering the physical structure of the world, but also in recovering its causal structure (Scholl & Tremoulet, 2000).

THE CURRENT STUDY

In this article, we report a new contextual effect on the perception of causality in simple collision events. The global question that motivated this study is the same one that fascinated Michotte: What information determines whether the visual system will interpret a dynamic stimulus as causal? In other words, what are the “rules” that the visual system uses to infer the existence of causality?

Michotte and his followers studied many of the basic parameters of simple collision events that mediate causal perception. These included the absolute and relative speeds of the two objects; differences in the nature, duration, and angles of their trajectories; the impact of spatial and temporal gaps in the objects’ trajectories; the effects (or lack thereof) of differences in the colors, shapes, and sizes of the two objects; and many similar factors (e.g., Boyle, 1960; Costall, 1991; Gemelli & Cappellini, 1958; Gordon, Day, & Stecher, 1990; Hubbard, Blessum, & Ruppel, 2001; Kruschke & Fragassi, 1996; Michotte, 1946/1963, 1951/1991; Michotte & Thinès, 1963/1991; Natsoulas, 1961; Schlottmann & Anderson, 1993; Weir, 1978; White & Milne, 1999; Yela, 1952). All of these studies, however, focused on the properties of the two objects actually involved in the putative collision event. No previous studies, to our knowledge, have explored whether remote contextual information—that is, information from other distinct objects and events—can cause an otherwise ambiguous event to be perceived as causal.

Observers in the present study reported the causal status of a test event that was identical across most conditions. What varied was the nature of the visual context presented along with this test event, and we were interested in whether the properties of the other objects and events in this context would influence whether the test event was perceived as causal. If so, we would conclude that the catalogue of the rules used by the visual system to infer the existence of causality would have to be expanded, to include this new category of contextual effects.

EXPERIMENT 1: CAUSAL CAPTURE

Our basic demonstration of the causal-capture effect involved four conditions. In each, observers simply judged whether they perceived the test event was a causal *launch* (in which the arrival of one moving object caused the motion of the other object) or a noncausal *pass* (wherein one moving object simply passed over another stationary object).

In the *launching* condition (Fig. 1a), a single event was presented: One object moved until it was adjacent to another object in the center of the display, at which point the first object stopped and the second object started moving. The *passing* condition (Fig. 1b) was identical ex-

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cept that the two objects overlapped completely before the first object stopped and the second object started moving. Presented alone, this stimulus is often perceived as a noncausal pass: One object remains stationary while another is seen to pass over it (despite the fact that this interpretation requires each object to change color). The remaining two conditions (as well as all of the other conditions reported in later experiments) also used this pass stimulus as the test event, but in addition they employed a second distinct event presented a short distance below the main event. In the *launch-context* condition (Fig. 1c), this context event was a standard causal launch (i.e., 0% overlap), and was temporally synchronized so that the two objects in the context event were adjacent to each other at the same moment that the two objects in the test event were completely overlapped. Finally, in the *single-context* condition (Fig. 1d), the context event was a single object that moved across the entire screen (changing color when it reached the center), such that it was always immediately below the moving object in the test event. This last condition allowed us to begin to distinguish general effects of the presence of a context event from the particular effects of a causal context. Because these events are inherently dynamic, we encourage readers to view the actual events with a Web browser, at <http://www.yale.edu/perception/CausalCapture/>.

Method

Participants

Fourteen naive observers participated for course credit or payment. All observers were undergraduates, and all had normal or corrected-to-normal acuity and normal color vision.

Materials

All displays were presented on a Macintosh iMac computer. Observers were positioned approximately 51 cm from the monitor, without head restraint, such that the display subtended approximately 33.4° by 25° of visual angle. The displays refreshed at 117 Hz, and motion was always perceptually smooth.

Each trial involved either one or two events, each consisting of either one or two objects. All objects were small colored discs, each subtending 2.87°, drawn on a black background. For two-object events, one randomly chosen object was bright red, and the other bright green. For single-object events, the object was randomly set to either red or green. Motion was always in the horizontal plane, because the perception of causality is weaker in other orientations. The test event was always vertically positioned such that the lowest point of each object was one item-diameter above the center of the display. The context event, when present, was always positioned below the test event, such that there was always one item-diameter of vertical blank space between the edges of the objects in the different events.

There were four distinct conditions. The launching condition employed only a test event, with no context event. One of the discs (A) started out near either the right or the left edge of the display, while the other disc (B) started out with one of its edges (that closest to object A) aligned with the center of the display. After 200 ms, A began to move at 34.09°/s toward the center of the display. When the two objects became adjacent, A stopped moving, and B instantly started moving at the same speed to the other edge of the display. Both discs disappeared 200 ms later, and the screen stayed blank until a response was made. The entire duration of motion was 750 ms. (Whereas Mi-

chotte, 1946/1963, found that an A:B speed ratio of 3.6:1 produced the strongest launching percepts, a ratio of 1:1 also produces robust launching, and we used this ratio here to simplify comparisons across conditions.)

The passing condition was identical, except that object B started out with its center aligned with the center of the display, and the two objects overlapped completely before A stopped and B started moving. During the period when the two objects were overlapped, A always appeared in front of B (cf. Scholl & Nakayama, 2002). The entire duration of motion was again 750 ms, and speeds were thus 37.92°/s. In the launch-context condition, the test event was identical to that in the passing condition, and the context event was identical to the test event used in the launching condition. The motions in the two events were synchronized such that the two objects in the test event completely overlapped at the same moment that the two objects in the context event were adjacent. The test event in the single-context condition was also identical to that in the passing condition, but the context event consisted of a single object that traveled across the width of the display. The initial location and speed of this item were such that it always appeared immediately below the moving item in the test event. In addition, during its trajectory the item changed color at the point of overlap in the test event.

Procedure

On each trial, observers simply viewed the display and reported via a key press whether they had perceived the test event as a causal launch or as a noncausal pass, as described. Observers completed 20 trials of each of the four conditions, for a total of 80 trials; all trials were presented in a random order, different for each observer.

Results

The percentages of trials that were perceived as causal launches are shown in Figure 1, under the depiction of each condition. In the passing condition (without a context event), only 10.7% of trials were perceived as causal launches by our naive observers. In contrast, in the critical launch-context condition, in which observers reported the causal status of the identical test event, 92.1% of trials were reported as causal. (As expected, 100% of trials in the launching condition were perceived as causal launches.) In the single-context condition, however, only 5% of trials were perceived as causal. With effects of this magnitude, statistics are largely beside the point, but a single-factor repeated measures analysis of variance (ANOVA) confirmed that there was a significant effect of condition, $F(3, 39) = 490.13$, $p < .001$, and additional planned comparisons confirmed that each individual value differed from all others.

Discussion

This experiment confirmed the existence and strength of the causal-capture effect: The identical ambiguous test event was perceived as a causal launch on only a small minority of trials in isolation, but over 8 times as often when in the presence of an unambiguously causal launch event. In other words, the context event appeared to “capture” the causal status of the test event, making it too appear as robustly causal. (Experienced observers who can easily see the 100%-overlap event as a causal launch even without a supporting context may note that they can at least see the “pass” interpretation intentionally when the causal context is absent, whereas doing so is close to impossible

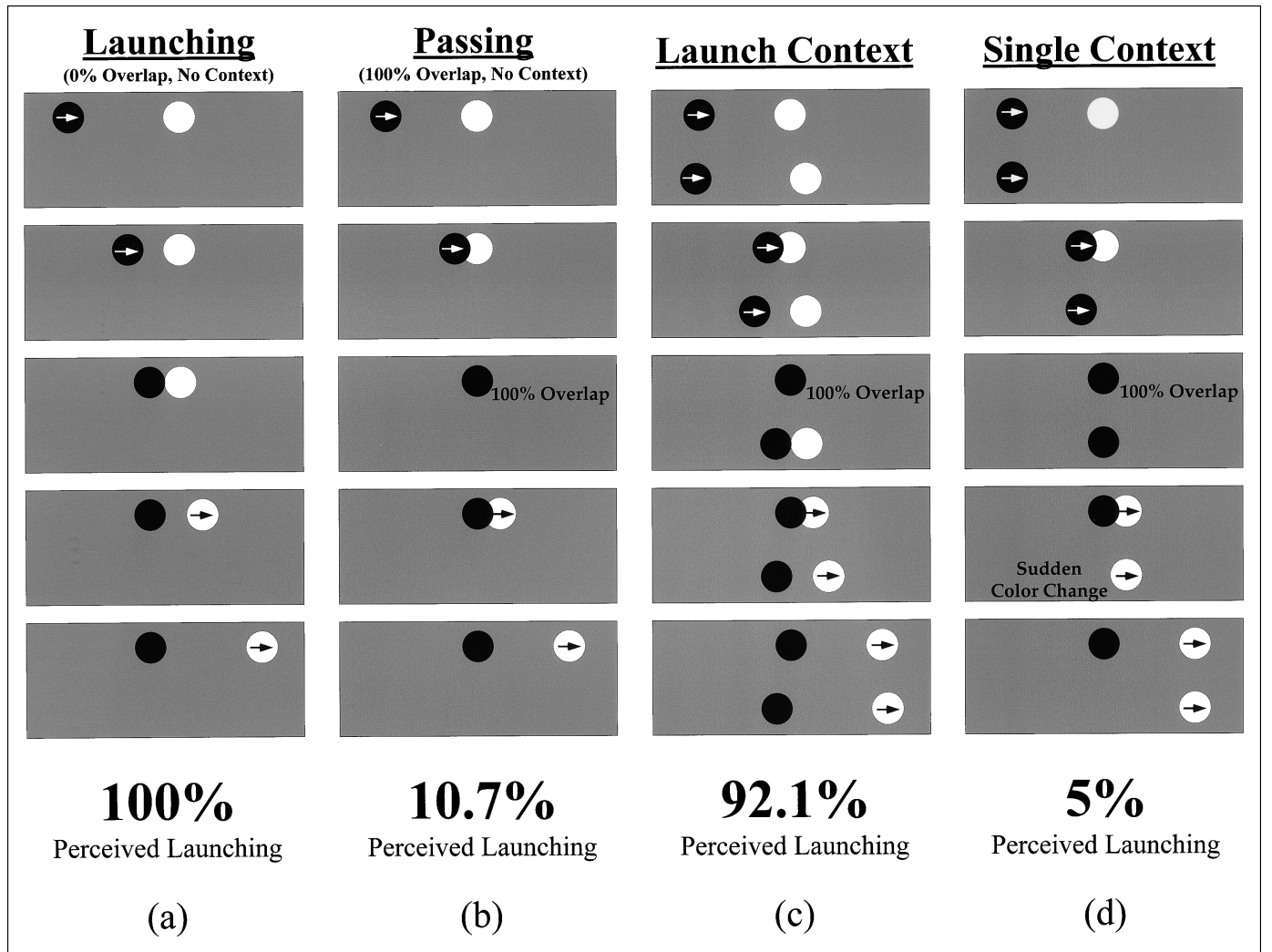


Fig. 1. Depictions of the four conditions used in Experiment 1, and the resulting percentages of perceived causal launches. Arrows indicate motion. All actual objects were either red or green, as described in the text. Observers always judged the causal status of the upper event, which is identical in (b), (c), and (d). Animations of these and other conditions can be viewed with a Web browser at <http://www.yale.edu/perception/CausalCapture/>.

with the causal context present.) This result implies that the visual system takes information from other distinct contextual objects and events into account when inferring the causal status of an event. This effect was not due simply to the presence of any contextual information, because the test event was seen as causal even less often (5%) in the presence of an unambiguously noncausal context event (i.e., a single moving item that changed color).¹

1. Further evidence that the causal nature of the context is crucial for this capture phenomenon comes from another condition (run with a separate group of 14 observers) wherein the context consisted of a sudden flash of a single object, presented for just two frames at the moment of complete overlap in the test event. This flash was salient and likely to capture attention, yet only 25% of trials were perceived as causal. Although this is a much larger percentage than in the passing condition without the flash, it is still about 65% fewer trials than in the launch-context condition, confirming a role for the causal status of the context event.

EXPERIMENT 2: EFFECTS OF CONTEXT DURATION

We next explored how much of the context event is necessary to induce causal capture. All trials employed the standard 100%-overlap test event (likely to be perceived as a noncausal pass in isolation), and used a 0%-overlap context event (i.e., an unambiguous causal launch). However, the objects in the launch event were presented for only a portion of each trial's duration, temporally centered around the moment when the two items in the test event were completely overlapped.

Method

This experiment was identical to Experiment 1, except as reported here. The same 14 observers from Experiment 1 participated in this and each subsequent experiment, with the order of experiments counterbalanced across observers. There were four possible durations for the context event: either the full 750 ms of the test event or only 500,

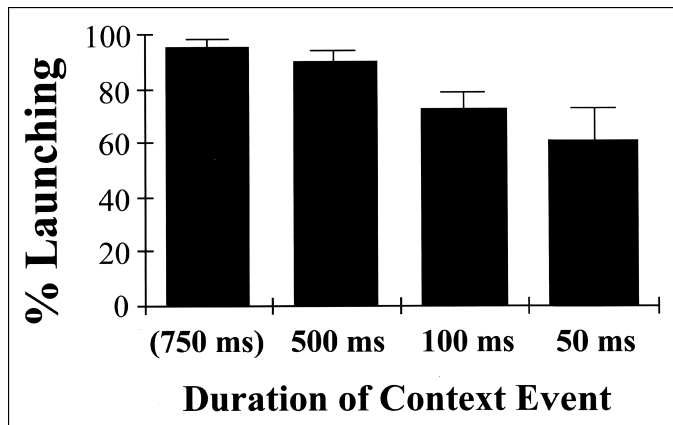


Fig. 2. Percentages of causal launches perceived for each of the context durations used in Experiment 2. (Note that the 750-ms condition, which was rerun in this experiment, is the full duration also used in Experiment 1.)

100, or 50 ms. The durations less than the full 750 ms were all temporally centered around the middle of the event, such that the moment of the launch was always displayed, but the objects in the context event appeared only after the motion in the test event had already begun (and then disappeared before the completion of the test event's motion). Twenty trials of each context duration were presented, in a different random order for each observer.

Results and Discussion

The results of this experiment are presented in Figure 2. A single-factor repeated measures ANOVA indicated a significant effect of the context event's duration, $F(3, 39) = 8.81, p < .001$. Further planned comparisons confirmed that each condition yielded a percentage of perceived launches that was reliably different from the others, except that the shortest two durations did not reliably differ: 750 ms versus 500 ms, $t(13) = 2.26, p = .042$; 500 ms versus 100 ms, $t(13) = 4.94, p < .001$; and 100 ms versus 50 ms, $t(13) = 1.13, p = .28$. Beyond this significant effect of context duration, perhaps the most striking result is the extremely small magnitude of the effect—in other words, how strong the causal-capture effect was even at the shortest duration. Even the 50-ms context duration still resulted in 60.7% of trials being judged as causal, which is 50% more than when the test event was presented alone in Experiment 1.

We conclude that the effect of context duration is minimal in relation to the main causal-capture effect, and that causal capture seems to occur so long as the unambiguous launch in the context event is clearly perceived. This is consistent with White's (1988) observation that all of the information critical to the perception of causality is integrated over less than 250 ms in a chunk at the iconic processing stage, and is therefore "automatic" rather than "controlled" (in the sense of Shiffrin & Schneider, 1977).

EXPERIMENT 3: EFFECTS OF TEMPORAL ASYNCHRONY

In Experiment 2, only a portion of the context event was presented, but it was still always temporally centered such that the causal launch in the context event occurred at the same moment as the total overlap

in the test event. We explored the importance of this temporal synchrony by having the unambiguous launch in the context event (i.e., the moment when the two objects were adjacent) occur a variable time before the moment of complete overlap in the test event.

Method

This experiment was identical to Experiment 2, except as reported here. The context event in all trials was identical to that in the launch-context condition of Experiment 1, except that the actual launch (i.e., the moment when the two items were adjacent) occurred either 0, 50, 100, or 200 ms before the moment of complete overlap in the test event. This temporal asynchrony was implemented by having the objects move at the same speeds as in Experiment 2, but moving the initial position of the initially moving object in the context event closer to the initially stationary central object. This ensured that the launch always occurred in the same spatial location, but varied in time.

Results and Discussion

The results of this experiment are presented in Figure 3. A single-factor repeated measures ANOVA indicated a significant effect of context asynchrony, $F(3, 39) = 62.86, p < .001$. Further planned comparisons confirmed that each condition yielded a percentage of perceived launches that was reliably different from the others, except that the two largest temporal asynchronies did not reliably differ: 0 ms versus 50 ms, $t(13) = 4.93, p < .001$; 50 ms versus 100 ms, $t(13) = 7.31, p < .001$; 100 ms versus 200 ms, $t(13) = 1.76, p = .103$; and 50 ms versus 200 ms, $t(13) = 8.56, p < .001$.

The temporal asynchronies introduced in this experiment greatly attenuated the causal-capture effect. Even a 50-ms asynchrony reduced the percentage of perceived causal launches by more than 15%, and only a 200-ms asynchrony reduced this value so much that only a small minority (20%) of trials were perceived as causal launches.

EXPERIMENT 4: EFFECTS OF DIRECTIONAL PHASE

In each of the previous experiments, the motion in the context event was always in the same direction as the motion in the test event.

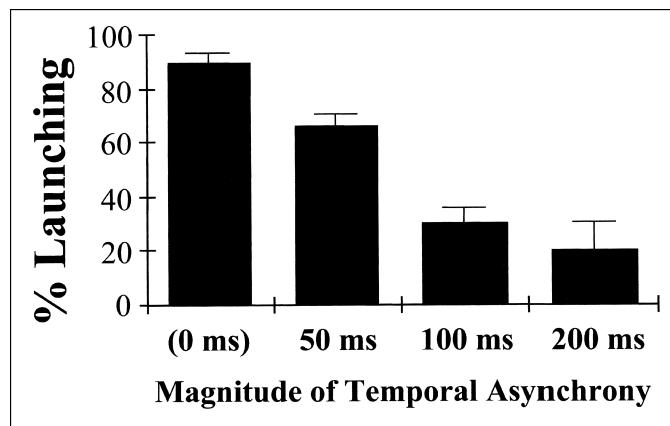


Fig. 3. Percentages of causal launches perceived for each of the context asynchronies used in Experiment 3. (Note that the 0-ms condition, which was rerun in this experiment, is the fully synchronized condition also used in Experiment 1.)

Despite the fact that objects in each event were always separated by a full item-diameter from those in the other event and were seen as clearly distinct objects, it is possible that the causal capture observed might have largely depended on grouping imposed by this type of common fate. In this experiment, we tested whether this similarity in motion direction is critical.

Method

This experiment was identical to Experiment 2, except as reported here. The test event in all trials was identical to that in the passing condition of Experiment 1. We tested four different context events. The *same-direction launch* condition was identical to the launch-context condition of Experiment 1, and the *same-direction single* condition was identical to the single-context condition of Experiment 1. In the other two conditions—the *opposite-direction launch* and the *opposite-direction single*—we simply reversed the direction of motion in each of these context events, which made them mirror images while preserving the temporal synchrony.

Results and Discussion

The results of this experiment are presented in Figure 4. Inspection of these data suggests (a) that directional phase had a large effect on causal capture, but that (b) this difference was not present in the single-context trials because of floor effects, and (c) a significant degree of causal capture still occurred even with opposite-direction launch-context trials. These impressions were verified in a repeated measures ANOVA with context type (launch vs. single) and directional phase (same vs. opposite) as within-subjects factors. Both main effects were highly significant, $F(1, 13) = 97.2, p < .001$, for context type and $F(1, 13) = 37.92, p < .001$, for directional phase, as was their interaction, $F(1, 13) = 49.17, p < .001$. Further planned comparisons confirmed that the two launch-context directions differed reliably, $t(13) = 6.94, p < .001$, but that the two single-context directions did not differ, $t(13) = 0.57, p = .57$.

This pattern of results suggests that grouping due to similarity in motion paths is a major factor driving the causal-capture effect, but that a moderate amount of causal capture is still obtained even with opposite directions of motion in the two events. (In other pilot studies with a different group of observers, we have also observed large

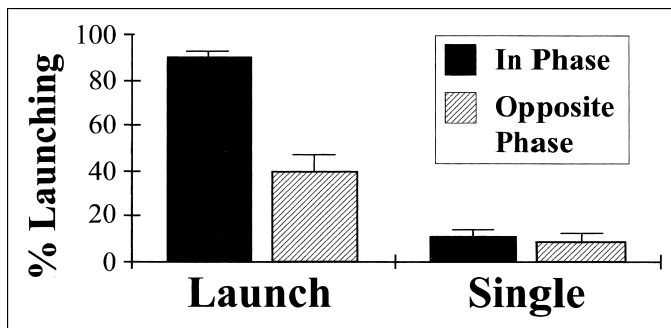


Fig. 4. Percentages of causal launches perceived for each of the conditions in Experiment 4. The launch-context and single-context conditions were each presented with the objects in the context event moving in the same direction as the objects in the test event or in the opposite direction.

causal-capture effects with events that employed motion in the same direction, but used different speeds and initial positions to weaken position-based grouping.)

GENERAL DISCUSSION

The fundamental result of this study is its demonstration of the causal-capture phenomenon. The critical stimulus employed was the pass event, wherein a moving object (A) overlapped completely with a stationary object (B) before A stopped and B started moving. In isolation, this event was perceived most often as one moving object simply passing over another stationary object. In the presence of an unambiguous collision event nearby, however, the passing stimulus was captured, so that it too was seen as a causal collision. This effect demonstrates that the perceived causal status of a given event can be affected by information from other distinct objects and events in a dynamic scene. Moreover, the surprising strength of the causal-capture phenomenon implies that such contextual information not only is used, but also can play an extremely strong role (and can actually promote the perception of causality, rather than attenuating it as in “camouflage” experiments; cf. Michotte, 1946/1963, Experiments 20 and 21).

Experiments 2 through 4 explored the nature of causal capture in more detail. Causal capture was observed even with very briefly presented context events (Experiment 2), but for strong effects to be obtained, the two events had to be temporally synchronized (Experiment 3) and in the same direction (Experiment 4). These results further support the notion that the causal interpretation is perceptual, at least insofar as they indicate a strong dependence on fairly low-level details of the displays, which has been touted as a prime characteristic of perceptual processing in this context (see Scholl & Tremoulet, 2000).²

Why Is There Causal Capture?

Why does causal capture exist? We suggest that this effect is broadly compatible with the general tendency of the visual system to avoid coincidences when inferring the structure of the world from visual images (Marr, 1982). It is as if the visual system functioned in accord with the following reasoning: If the test event is completely noncausal, then it is a coincidence that the moment of overlap occurred at precisely the same moment as the impact in the unambiguous context collision. Given that such coincidences are unlikely, the test event must have been a causal launch too (and, further, must not have actually involved a complete overlap; cf. footnote 2). This type of explanation

2. The influence of causal capture is also apparent in a related illusion that we explored (Scholl & Nakayama, 2002) by asking observers simply to judge the amount by which the two items in the test event overlapped at the center of the screen, with no mention of causality. Observers were fairly accurate in judging the amount of overlap when the test event was presented in isolation. In precisely those conditions in which causal capture was observed in the present experiments, however, observers in our other study underestimated the amount of overlap in the test events, judging that the two objects did not entirely overlap before the second object began to move. (Systematic underestimates with causal contexts were also observed in cases—not included in the current study—in which the objects did not overlap entirely in the test event.) These additional experiments highlight the strength and influence of causal capture: In addition to affecting the perceived causal status of an event, contextual information about the causal status of other objects and events can influence the perceived spatial relations among the objects in that event.

Causal Capture

also accounts for the effects of duration and synchrony: Because the critical factor underlying the putative coincidence is the moment of “impact” (cf. Sekuler & Sekuler, 1999), the effect should obtain whenever the impact is visible, but a temporal asynchrony should weaken the effect by eliminating the coincidence that needs to be accounted for. The assessment of such coincidences is likely to be continuous rather than dichotomous (perhaps implementing a type of Bayesian inference; cf. Knill & Richards, 1996), as is indicated by the gradual erosion of causal capture with increasing temporal asynchrony.

This general type of explanation is continuous with that offered for other related context effects, such as entraining in apparent motion displays with multiple bistable quartets (Ramachandran & Anstis, 1983), or the perception of bouncing versus streaming in ambiguous motion displays (e.g., Sekuler & Sekuler, 1999). However, we emphasize that the causal-capture effect does seem to require a specifically causal context event: We have also observed capture effects in bouncing versus streaming displays, but such capture can also be induced by noncausal contexts such as sudden flashes (Watanabe & Shimojo, 2001), which have little effect on causal capture.

A similar coincidence-avoidance principle is presumably at work in other common percepts of causality, even in situations that do not involve collisions. It is common, for instance, to see two unrelated events as being causally connected simply because they happened to occur simultaneously—for example, a streetlight turning on just as you honk your car horn. In such cases, you know there is no causal connection, but often still reflexively perceive one—perhaps because of the operation of a similar coincidence-avoidance principle.

Conclusions

The experiments reported here introduce a new type of contextual effect on the perception of causality, in which the perception of a causal relation is promoted by contextual information from other distinct objects and events in a dynamic visual scene. Collectively, these experiments contribute to the larger project, begun by Michotte, of determining the nature of the rules used by the visual system to perceive causality. In particular, the causal-capture phenomenon reported here suggests that a new class of contextual rules may be critical to this process.

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