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Illusory Causal Crescents: Misperceived spatial relations due to perceived causality

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Abstract. When an object A moves toward an object B until they are adjacent, at which point A stops and B starts moving, we often see a collision—ie we see A as the *cause* of B's motion. The spatiotemporal parameters which mediate the perception of causality have been explored in many studies, but this work is seldom related to other aspects of perception. Here we report a novel illusion, wherein the perception of causality affects the perceived spatial relations among two objects involved in a collision event: observers systematically underestimate the amount of overlap between two items in an event which is seen as a causal collision. This occurs even when the causal nature of the event is induced by a surrounding context, such that estimates of the amount of overlap in the very same event are much improved when the event is displayed in isolation, without a 'causal' interpretation. This illusion implies that the perception of causality does not proceed completely independently of other visual processes, but can affect the perception of other spatial properties.

1 Introduction

The perception of visual events has long fascinated psychologists, as a particularly high-level type of motion processing. One canonical type of visual event is a 'launching' collision: object A moves toward object B until they are adjacent, at which point A stops and B starts moving along the same path (figure 1). A striking thing happens when viewing such a stimulus: beyond these kinematics, we see A as the *cause* of B's motion. This phenomenon has been studied as a paradigmatic case of event perception since the appearance of Michotte's book, *The Perception of Causality* (Michotte 1946/1963).

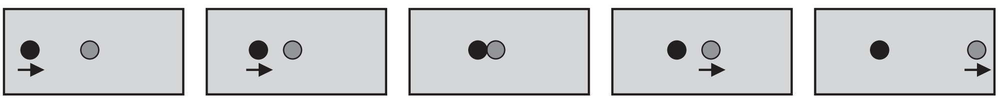

Figure 1. Static frames from a standard causal 'launch' display, wherein we see one object *cause* another's motion.

One of the factors that makes such phenomena so interesting is that, while 'causation' is typically thought of as a high-level conceptual property, numerous experiments suggest that the visual system may itself traffic in causality (eg Costall 1991; Leslie 1986; Leslie and Keeble 1987; Michotte 1946/1963, 1951/1991; Michotte and Thinès 1963/1991; Schlottmann and Shanks 1992; Scholl and Tremoulet 2000; cf also Schlottmann 2000; White 1995). Michotte, for example, stressed that the perception of causality is throughout determined by precise spatiotemporal details of the displays, whereas it is hardly affected by beliefs and intentions. Furthermore, the phenomenon of perceived causality is extremely robust: it occurs in all normal perceivers, across cultures (Morris and Peng 1994), and even in young infants (eg Leslie and Keeble 1987). Phenomenology also supports this view: like the perception of faces or words, the perception of causality in collision events seems largely instantaneous, automatic, and irresistible.

Michotte and his followers worked out many of the factors which mediate the perception of causality, such as the role of absolute and relative speeds, spatial and temporal gaps in the objects' trajectories, differences in the durations and angles of each object's trajectory, etc (eg Boyle 1960; Choi and Scholl, in press; Costall 1991; Gemelli and Cappellini 1958; Gordon et al 1990; Guski and Troje 2003; Hubbard et al 2001; Hubbard and Ruppel 2002; Kruschke and Fragassi 1996; Michotte 1946/1963, 1951/1991; Michotte and Thinès 1963/1991; Natsoulas 1961; Schlottmann and Anderson 1993; Schlottmann et al 2002; Weir 1978; White and Milne 1999; Yela 1952). This research has generally shown that many different spatiotemporal parameters are critical for perceiving causality, but that featural parameters (eg colors, shapes, sizes) play little or no role. These spatiotemporal parameters collectively constitute the information which the visual system uses to infer the existence of causality in collision events (for a recent review, see Scholl and Tremoulet 2000).

1.1 *Causal capture*

Recently, a new class of information used in this process was discovered (Scholl and Nakayama 2002). Whereas nearly all previous studies had focused on the nature of the objects actually involved in the putative collision event, these experiments indicate that contextual information from other nearby objects and events can also influence the perception of causality. In these experiments, observers always viewed a 'launch'-like event which was modified so that the two objects completely overlapped before the first object stopped moving and the second object started moving (figure 2a). The percepts generated by such displays are bistable: a minority of trials are perceived as launches, but most naïve observers perceive this stimulus as a completely non-causal 'pass': one object remains stationary while another passes over it. This occurs despite the salient featural differences: eg, with one red object and one green object, observers perceive a single stationary object which changes from red to green, and a single moving object which changes from green to red.

In the presence of a second nearby event which is an unambiguous launch, however, this identical stimulus is now also seen as a causal launch (figure 2b). This type of 'causal capture' by contextual information was extremely strong: in isolation, the 100% overlap event was seen as causal on only 10.7% of trials, whereas in the presence of the unambiguous 'context' launch it was seen as causal on 92.1% of trials. (Experienced observers who can easily see the 100% overlap event as a causal launch even without a supporting context still find that they can easily see the non-causal 'pass' interpretation intentionally, whereas doing so is close to impossible with the causal context present.) This effect persisted even when only a brief portion of the context was displayed, temporally centered around the moment of 'impact', but the effect was nearly completely destroyed by introducing temporal asynchrony between the two events, such that the unambiguous context launch occurred 200 ms before the moment of complete overlap in the event observers were judging. These data imply that contextual information from other objects and events in a scene can have a large impact on the perception of causality (see also Choi and Scholl, in press).

1.2 *The current study: Perceived causality yields illusory spatial displacement*

Whereas all these studies have focused on determining the factors which mediate causal perception, few studies have explored the *effects* which the perception of causality can have on other types of visual processing. Here we report a novel illusion which suggests that such effects exist. In particular, we find that the perception of causality can influence the perceived spatial relations among objects in collision-like events.

While running our earlier studies (Scholl and Nakayama 2002), we noticed informally that the 100% overlap event, when displayed along with an unambiguous (0% overlap) causal launch, not only looked causal itself, but also appeared not to involve a full

100% overlap: object A appeared to travel toward B and then stop before completely overlapping B, such that B started to move with a part of it (a thin 'crescent') still uncovered by A. This informal observation makes intuitive sense, since in a real-world collision of this sort with linear paths, the two objects could not physically overlap entirely—even though a partial overlap could be explained in terms of various depth relations or viewing angles. In this paper we experimentally demonstrate and measure this illusory causal displacement.

The critical 'test' event in this experiment involved two bright discs of different colors. One of the disks (A) started out near the edge of the display, while the other (B) appeared near the center of the display. A then moved toward B until they overlapped by some amount, at which point A stopped and B started moving along the same path. When B reached the other edge of the display, it rebounded and headed back toward A, again intersecting A by some amount until B stopped and A started moving back to its original position. This entire back-and-forth motion sequence in the test event cycled indefinitely until observers responded. In contrast to most studies of causal perception, wherein observers are asked to directly report which events appear causal, we simply asked observers to report the amount of overlap between the two objects in an event, with no mention of causality. In reality, this amount was always 100%, 90%, 80%, or 60% of the discs' widths. Rather than asking observers for a numerical estimate, however, we let them indicate this distance directly: in the lower-right corner of the display, a small 'crescent' of a disc the same size as the two moving discs was drawn. Observers used keys on the keyboard to adjust the width of this crescent until it matched the perceived amount of intersection in the main test event. When they were satisfied with this match, they pressed another key to move to the next trial.

We tested four main conditions. The test event used for the intersection judgment was identical across all of these conditions: all that varied was the nature of the contextual information that was present in the display. In the No Context condition (figure 2a), observers judged the intersection of the two objects when the test event was presented in isolation. When the actual amount of intersection is 100%, this stimulus often appears to be a completely non-causal 'pass', wherein a single moving object (which periodically changes colors) passes back and forth over a single stationary object (which also changes colors). (Since these events are inherently dynamic, we encourage readers to view them online, at http://www.yale.edu/perception/causal-crescents/ or at the *Perception* website: http://www.perceptionweb.com/misc/p5172/.)

All other conditions involved a second distinct event presented a short distance below the main event. In the Launch condition (figure 2b), the context event was an unambiguously causal launch which cycled back and forth in tandem with the test event; in this event, the stationary object started moving as soon as a moving object arrived adjacent to it (ie with 0% intersection). Critically, this event was temporally synchronized with the test event, such that the moment of 'impact' in the launch (ie when both objects were adjacent) occurred at the moment of maximal intersection in the test event. A test event with 100% intersection, normally seen as a non-causal 'pass', is 'captured' by this context launch such that it too appears to involve a causal interaction (Scholl and Nakayama 2002). In the Temporal Window condition (figure 2c), only 75 ms of this context launch are displayed on each cycle, temporally centered around the moment of impact. (A full cycle in the test event, in contrast, always takes 750 ms.) This stimulus still exerts a significant amount of 'causal capture'. Finally, the Asynchronous condition (figure 2d) is identical to the Launch condition except that the two events are no longer synchronized: the 'impact' in the context launch event always occurs 200 ms before the moment of maximal intersection in the test event. In our earlier studies, this context completely destroyed the causal capture effect.

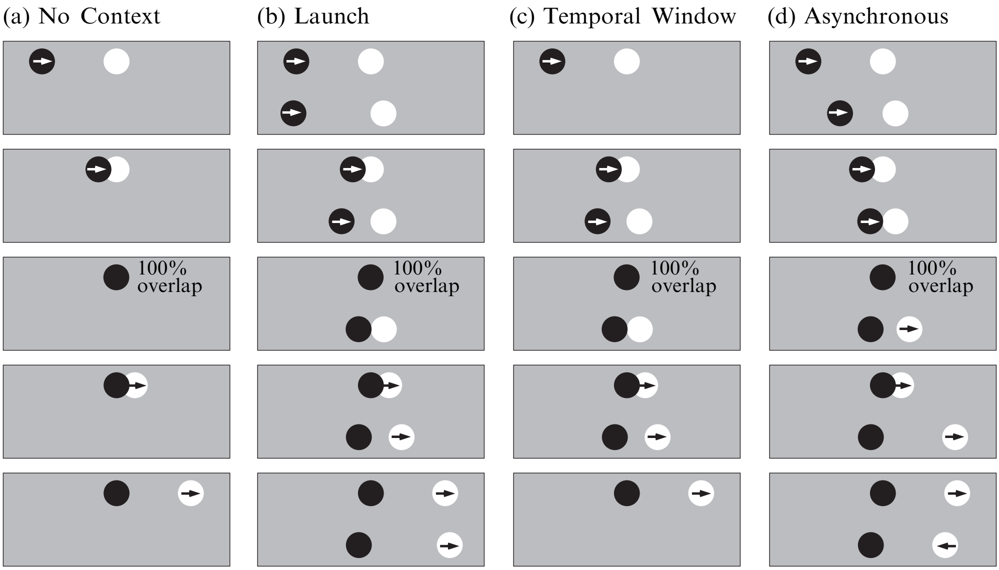

Figure 2. The four main conditions used in experiment 1. Observers always judged the overlap of the two items in the upper test event. Note that while this degree of overlap is always displayed as 100% of the objects' width in this figure, the actual values tested also included 60%, 80%, and 90%. Similarly, only 'overlapping' intersections are displayed here, whereas trials also included 'underlaps', as described in the text. Actual colors were always bright red and bright green, on a black background. Three animations can be seen with a web-browser at the *Perception* website http://www.perceptionweb.com/misc/p5172/; animations of these and other conditions can be viewed at http://www.yale.edu/perception/causal-crescents/.

1.3 *Predictions and implications*

If perceived causality yields illusory displacements in 'causal capture' displays, then we expect observers to be reasonably accurate when estimating the amount of intersection in the No Context condition, but to systematically underestimate this distance in the Launch condition. Furthermore, if the effect is truly tied to the perception of causality (as opposed to being an effect of any type of context), then we expect these underestimates to persist in the Temporal Window condition, but to be eliminated in the Asynchronous condition. We also explored the importance of the overlap itself—ie when a moving object progressively covers up a stationary object. Half the trials of each type involved such overlaps, whereas the other half employed 'underlaps': when the two objects intersected, the moving object would 'slide under' the stationary object (see figure 3).

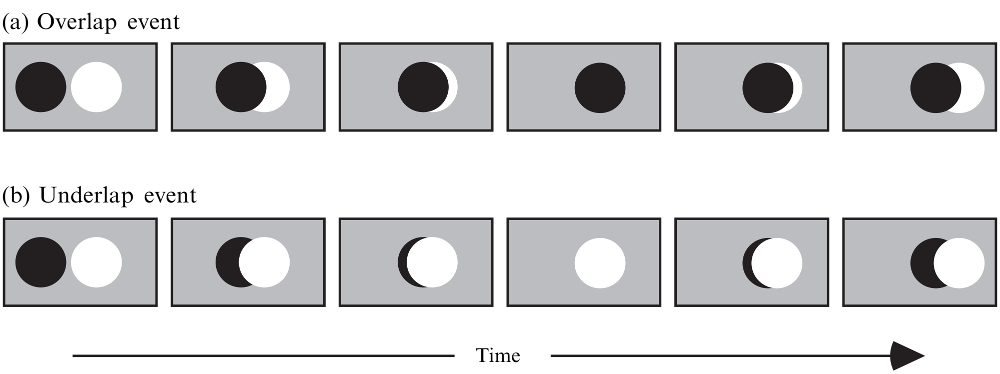

Figure 3. Depictions of (a) 'Overlaps' and (b) 'Underlaps' in a 100% intersection event.

2 Experiment 1: Measuring illusory spatial displacement from perceived causality

2.1 *Method*

2.1.1 *Participants.* Twelve naïve observers participated for payment. All observers had normal or corrected-to-normal acuity and normal color vision.

2.1.2 *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 deg by 25 deg of visual angle. The displays were presented with custom software written with the use of the VisionShell graphics libraries (Comtois 2002). The displays refreshed at 117 Hz, and motion was always perceptually smooth.

Each trial involved either one or two events, each consisting of two objects. All objects were small colored discs, each subtending 2.87 deg, drawn on a black background. One of the objects (randomly chosen independently for each event) was always bright red, and the other bright green (roughly equivalent in luminance). Motion was always in the horizontal plane, as the perception of causality is weaker in other orientations (Michotte 1946/1963). The test event was always vertically positioned such that the lowest point of each object was 2.87 deg above the center of the display. The context event, when present, was always positioned below the test event, such that there was always 2.87 deg (ie the diameter of one object) of vertical blank space between the edges of the objects in the different events.

All conditions involved the same set of test events. One of the circles (A) started out near either the right or left edge of the display (the choice being random on each trial), such that the most extreme edge was 1.04 deg from the display border. The other circle (B) started out near the center of the display, as described below. After 200 ms, A began to move toward the center of the display. When the two objects reached their point of maximal intersection (see below), A stopped moving, and B instantly started moving at the same speed toward the other edge of the display, stopping when its leading edge was 1.04 deg from the display border. Object B then immediately reversed its path and headed back toward the now-stationary A at the same speed. When the two objects had again reached their point of maximal intersection, B stopped moving, and A instantly started moving at the same speed back toward its original position. This entire motion cycle repeated indefinitely until the observer responded. (Whereas Michotte found that a launcher : launched speed ratio of 3.6 : 1 produced the strongest launching percepts, ratios of 1 : 1 also produce robust launching, and we used these here to simplify the repetitive cycling.)

Four amounts of maximal intersection were tested: 60%, 80%, 90%, and 100% of the width of the discs (equal to 1.72, 2.3, 2.58, and 2.87 deg, respectively). The moment of maximal intersection always occurred with the two items exactly centered in the display; this was implemented simply by adjusting the initial position of the initially stationary object (so that, eg, it was perfectly centered in the display on 100% intersection trials, but was presented with its center 2.01 deg from this center line, farther from the other object, in the 60% intersection condition). A full cycle of motion from one end of the display to the other took exactly 750 ms in all cases; accordingly, the objects in trials with smaller maximal intersections moved slightly slower, since they had slightly less distance to cover in the same time. The resulting speeds for each condition were as follows: 100%: 37.92 deg s^{-1}; 90%: 37.53 deg s^{-1}; 80%: 37.16 deg s^{-1}; 60%: 36.39 deg s^{-1}. Finally, this intersection was implemented in one of two ways. On Overlap trials, the moving object always progressively occluded the stationary object (such that A occluded B when the motion was in one direction, but B occluded A on the 'return trip'). On Underlap trials, this pattern was reversed, with the stationary object always progressively occluding the moving object, which appeared to slide under it (figure 3).

There were four distinct conditions, which varied the nature of the context event underneath the test event. The No Context condition was presented exactly as described above, with no additional context event. In the Launch condition, the context event was an unambiguous launch. This launch was displayed exactly as in the test event described above, except that the stationary object began to move (and the moving object stopped) the moment they became adjacent—ie with 0% intersection. A cycle of this event again took exactly 750 ms, such that it was always synchronized with the test event: it reversed at the same moments, and the two objects in the context event were always adjacent at the moment of maximal intersection in the test event. (The initially central object thus started out with one of its edges aligned on the center line, and both objects moved at 34.09 deg s^{-1}.) Motion always occurred in the same direction as in the test event, since this configuration produces stronger 'causal capture' than opposite motion directions (Scholl and Nakayama 2002). The context event in the Temporal Window condition was identical to that in the Launch condition, except that only 75 ms of the event was displayed, 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 only appeared after the motion in the test event had already begun (and then disappeared before the completion of the test event's motion). The context event in the Asynchronous condition was identical to that in the Launch condition, except that the moment when the two objects were adjacent (ie the moment of 'impact') in the context event always occurred 200 ms prior to the moment of maximal intersection in the test event. This was implemented by having the objects move at the same speeds, but moving the initial position of the initially moving object closer to the initially stationary object by 6.8 deg. This ensured that the launch always occurred in the same spatial location, but varied in time relative to the moment of maximal intersection in the test event.

2.1.3 *Procedure.* Rather than asking observers for numerical estimates of the amount of intersection between the two objects in the test event, observers indicated this amount directly in a matching task. In the lower-right corner of the display, a bright-blue 'crescent' of a disc the same size as the discs used in the motion events was displayed (implemented by drawing a black disc over a colored disc in the same horizontal plane so that only a thin crescent of the blue disc was visible). This crescent was always aligned so that the left edge of the blue circle was visible, while the concave edge of the crescent faced the right edge of the display. Observers used keys on the computer keyboard to adjust the width of this crescent. At its maximal width, the crescent was a full circle; at its minimal width, it was invisible. One set of keys adjusted the width of the crescent by relatively large steps (0.42 deg, or 8 pixels, measured at its center), while another set made fine adjustments (0.05 deg, or 1 pixel). On each trial, observers adjusted the width of the crescent until it matched the amount of maximal intersection which they perceived in the test event. (A percept of less than 100% intersection implies that observers see a thin crescent of one of the discs which is never occluded; it is this width that was matched to the width of the adjustable crescent.) Observers adjusted the width of the crescent in this way on every trial in an unspeeded manner until they were satisfied that the match was as close as possible to their percept of the test event, at which point they pressed another key on the keyboard to initiate the next trial.

Each observer completed 24 trials of each context condition, for a total of 96 trials. Of the 24 trials of each context type, 12 were 100% intersection trials, and 4 each were 90%, 80%, and 60% intersection trials. (Three times as many 100% intersection trials were presented in an effort to compensate for possible task demands. Since the illusory displacement we predict involves 100% intersections being misperceived as less-than-100% intersections, we included many more actual 100% trials, to encourage full 100%

responses.) Half the trials of each degree of actual intersection were Overlap trials, and half were Underlap trials. All 96 trials were presented in a different random order for each observer.

2.2 *Results*

2.2.1 *Baseline underestimates.* Observers' accuracy at judging the amount of intersection in the test event is shown in figure 4, categorized by context condition and amount of actual intersection. These accuracy values are plotted as the magnitude of the underestimates (ie the actual intersection minus the perceived intersection); the vertical axis on this graph measures these underestimates as percentages of the width (ie the diameter) of the objects. Though all conditions yielded underestimates (each significantly different from zero, all ps < 0.05), inspection of figure 4 suggests that the magnitude of these underestimates depended greatly on the condition and amount of actual intersection, in systematic ways.

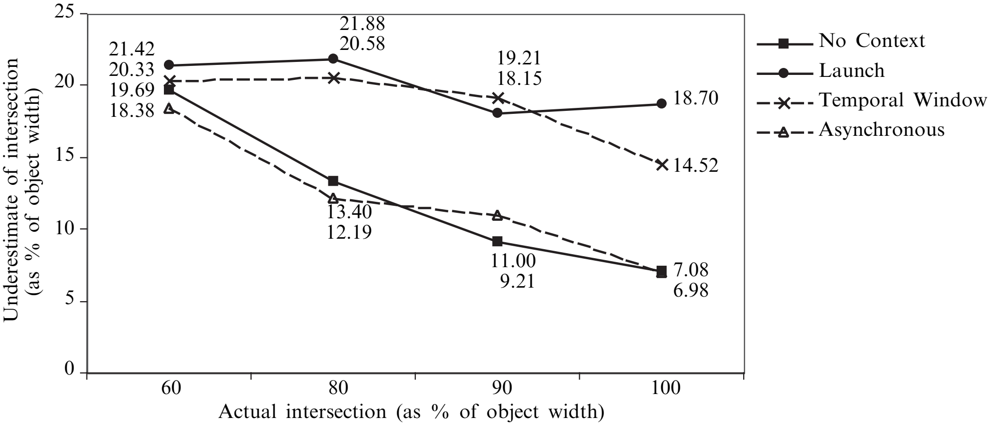

Figure 4. Observers' accuracy in experiment 1 at judging the amount of intersection in the test event, expressed as the magnitude of the resulting underestimates—ie the actual intersection minus the perceived intersection. These data are categorized by context condition and amount of actual intersection, and plotted as percentages of the fixed width (ie the diameter; 2.87 deg) of the object. The magnitude of the illusory causal displacement is thus the underestimate in the Launch condition minus the underestimate in the No Context condition.

These impressions were confirmed by an initial repeated-measures analysis of variance conducted with three factors: context type (No Context, Launch, Temporal Window, Asynchronous), amount of actual intersection (60%, 80%, 90%, 100%), and type of intersection (Overlap, Underlap). This analysis yielded reliable main effects for each factor, and a significant interaction between context type and amount of intersection (context type: $F_{3,33} = 16.44$, $p < 0.01$; amount of intersection: $F_{3,33} = 3.81$, $p = 0.02$; type of intersection: $F_{1,11} = 9.44$, $p = 0.01$; context type $\times$ amount of intersection: $F_{9,99} = 2.15$, $p = 0.03$). No other interactions (ie all those involving the type of intersection) were significant (type of intersection $\times$ context type: $F_{3,33} = 0.09$, $p = 0.97$; type of intersection $\times$ amount of intersection: $F_{3,33} = 0.86$, $p = 0.47$; three-way interaction: $F_{9,99} = 1.43$, $p = 0.19$).

Overall, observers' underestimates of the amount of intersection in the test events were more severe for overlapping intersections than for 'underlapping' intersections (16.32% versus 12.62% of the width of the objects). Since this factor did not interact with any others, however, in the remainder of this section we report analyses which collapsed over this difference.

2.2.2 *Measuring the illusory displacement due to causal capture.* Illusory spatial displacement due to perceived causality was apparent in that the underestimates of the overlapped area in the test events were on average nearly twice as extreme when the test event was presented along with a context launch event than when it was presented in isolation (19.59% versus 10.59%; $t_{11} = 5.18$, $p < 0.001$). As is suggested in figure 4, this was also the case for each individual amount of actual intersection (all ps < 0.02) except at the 60% value ($t_{11} = 1.05$, $p = 0.32$). The magnitude of the illusory causal displacement is thus the underestimate in the Launch condition minus the underestimate in the No Context condition.

Relative to the No Context baseline, illusions of displacement were also present for the Temporal Window condition, but not for the Asynchronous condition. The underestimates in the Temporal Window condition exceeded those in the No Context condition both overall ($t_{11} = 5.16$, $p < 0.001$) and for each degree of actual intersection (all ps < 0.03), again except for 60% ($t_{11} = 0.39$, $p = 0.7$). In contrast, the underestimates in the Asynchronous condition never reliably differed from those in the No Context condition, either overall ($t_{11} = 0.18$, $p = 0.86$) or for any individual intersection amount (all ps > 0.4). In addition, the underestimates in the Temporal Window condition were never reliably different from those in the Launch condition (all ps > 0.5), except at actual intersections of 100% (where Launch underestimates were more extreme by 4%; $t_{11} = 2.2$, $p = 0.05$).

2.3 *Discussion*

Beyond an overall baseline tendency to underestimate the degree of intersection between the two items in a launch-like event, this experiment confirmed the existence of illusory spatial displacement due to perceived causality: underestimates were systematically higher for the identical stimulus when it was presented in the context of an unambiguous causal launch, compared to when it was presented in isolation. The magnitude of this illusion was considerable—on average around 10% of the objects' widths. We hypothesize that this is due to the fact that the test event appears robustly causal in the presence of such a context, but tends not to otherwise.(1)

A critical role for causal perception in producing this illusion—as opposed to an effect which can be induced by any type of context—is indicated by comparisons with other two conditions. In the Temporal Window condition only a brief portion of the context launch was displayed; however, this still induces robust causal capture, and so here this condition also produced illusory causal displacement. On the other hand, no causal capture is observed when the test event and the context launch are asynchronous (Scholl and Nakayama 2002), and correspondingly the underestimates obtained here in this condition were no different than the baseline when the test event is presented in isolation.

(1) Why were there any underestimates at all for the 100% overlap test event when presented in isolation, if it was perceived as a non-causal pass? We expected some underestimates here simply because such an event is still perceived by naïve observers as a causal launch on 10.7% of trials (Scholl and Nakayama 2002). In addition, this proportion of trials may have been amplified in this experiment by the necessity of focusing on the point of overlap (in order to make the amount-of-intersection judgment); we have informally noticed that such focused attention increases the number of causal percepts induced by such trials, though not to the level induced by a context Launch event (cf Choi and Scholl, in press). Moreover, we note in passing that the magnitude of the crescents illusion itself appears to vary directly with eccentricity, with greater illusory displacement for less central target events presented with a launch context event which is still fairly foveal. If so, then the present results are a testament to the strength of the illusion in most observers, since the response method encouraged direct fixation of the overlapping area to be estimated. We do not report data relevant to this observation here, but readers can test this impression themselves by fixating at different positions when viewing the online demonstration movies.

3 Experiment 2: The perceived causality of partial-overlap events

Experiment 1 clearly demonstrates that the perception of causality can affect other visual processes—in this case causing the relative positions of the two objects involved in an event to be misperceived. However, some aspects of the data from experiment 1 invite further exploration. In particular, why did the underestimates induced by causal capture persist with overlaps of less than 100%? We initially predicted that the illusion would only occur for 100% overlaps, but the data also clearly show robust effects of the added causal contexts for both 80% and 90% overlaps (though not for 60% overlaps). This surprised us: the illusion is perceptually salient with test events involving 100% overlap, because of the categorical perceptual shift from complete overlap to incomplete overlap. In test events with incomplete actual overlap, however, this becomes a more quantitative measure, and so is more difficult to appreciate phenomenologically. We thus had no reason to predict this aspect of the results.

In experiment 1, we presented the data in terms of both (a) 'baseline' underestimates and (b) those additional underestimates due to the addition of the causal context event. In characterizing only these latter additional underestimates as due to perceived causality, though, we may have undersold the role of causal perception. In short, there may have been less of an opportunity for 'causal capture' to strengthen the underestimates of overlap in the events which already enjoyed less partial overlap (ie 60%–90%), simply because those events were *already* often perceived as causal, even in isolation. Indeed, phenomenology suggests that decreasing overlap (from 100% to 60%) yields increasing causal percepts when the event is presented in isolation. This would predict the critical data from experiment 1: the *difference* in underestimates between Launch condition trials and No Context trials should progressively decrease with decreasing overlap, simply because the test events with smaller overlaps are already perceived as causal.

While this view seems intuitively plausible, no experiments to our knowledge have ever measured the strength of causal perception when the objects in the putatively causal event overlapped only partially. As such, in this experiment we directly assessed the degree of causal perception for such events, using the same 60%, 80%, and 90% overlap events from experiment 1.

3.1 *Method*

3.1.1 *Participants.* Fifteen naïve observers, none of whom had taken part in experiment 1, participated for course credit or payment.

3.1.2 *Materials.* The apparatus and stimuli were identical to those used in the partial-overlap conditions of experiment 1, except that the events did not continuously cycle back and forth: rather, each event occurred only once (in a randomly chosen direction, left-to-right or right-to-left), after which a keypress triggered the next trial. Both No Context and Launch trials were presented for each degree of partial overlap—60%, 80%, and 90%—and only Overlap trials were used.

3.1.3 *Procedure.* Our method of assessing causal perception was derived from our earlier studies of 'causal capture' with full-overlap events (see Choi and Scholl, in press; Scholl and Nakayama 2002). On each trial, observers simply viewed the display, and reported via a keypress whether they had perceived the test event as a causal launch (wherein one object moves until it is adjacent to another object in the center of the display, at which point the first object stops and the second object starts moving) or as a non-causal pass (wherein one object remains stationary while another is seen to pass over it, despite the resulting color change in both objects). Observers completed 20 trials of each of the 6 conditions (both No Context and Launch trials for each of

3 degrees of overlap), for a total of 120 trials; all trials were presented in a random order, different for each observer.

3.2 *Results*

The percentages of trials in each condition that were perceived as causal launches are shown in figure 5, along with the comparable data for 100% overlap events from Scholl and Nakayama (2002). Inspection of this graph suggests that all degrees of overlap were highly likely to be seen as causal launches when presented with the unambiguously causal context event—replicating the 'causal capture' phenomenon (Scholl and Nakayama 2002). In addition, however, the graph suggests that the partial-overlap test event was increasingly likely to be seen as a causal launch, even in isolation, as the actual degree of overlap decreased—a huge increase of over 55% from 90% overlap events (33.0% perceived launches) to 60% overlap events (88.3% perceived launches). These observations were borne out by statistical tests, all of which yielded highly significant effects. A 2×3 repeated-measures analysis of variance revealed main effects of both degree of overlap ($F_{1,14} = 66.15$, $p < 0.001$) and context type ($F_{1,14} = 89.49$, $p < 0.001$), as well as a significant interaction ($F_{1,14} = 24.69$, $p < 0.001$). Additional planned comparisons revealed that each degree of overlap yielded a percentage of perceived launching that was significantly different from both others, for No Context trials (all ps < 0.001), Launch trials (all ps < 0.03), and all trials combined (all ps < 0.001). Finally, each degree of overlap yielded a percentage of perceived launching that was higher for Launch trials than for No Context trials ($p = 0.032$ for 60%, $p < 0.001$ for 80% and 90%).

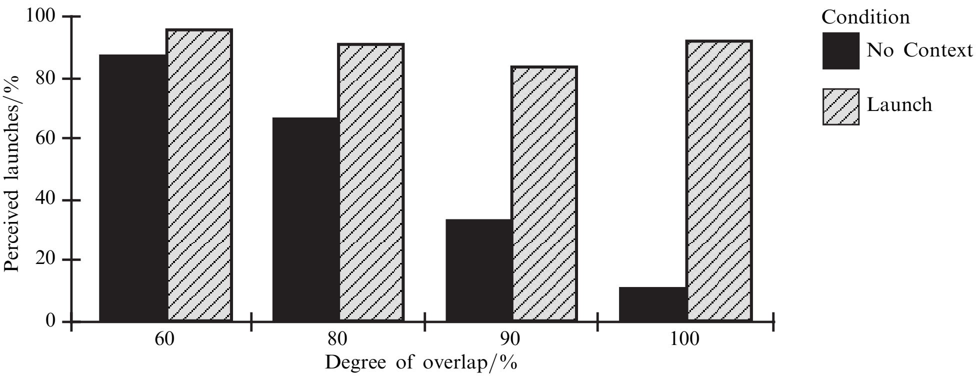

Figure 5. Percentages of trials in each condition of experiment 2 that were perceived as causal launches. The additional data for 100% overlap events, reported in Scholl and Nakayama (2002), are presented for comparison.

3.3 *Discussion*

This experiment confirmed that a partial-overlap event is increasingly likely to be perceived as a causal launch in isolation, as the degree of overlap between the two objects decreases (ie as it becomes more similar to a normal 0% overlap launching event). This increase in perceived causality mirrors the corresponding *decrease* in the underestimation of overlap due to 'causal capture' in experiment 1. If we thus assume a maximal possible underestimate of overlap due to perceived causality of around 20%, we can potentially explain *all* of the observed underestimates in experiment 1 as a result of perceived causality. This explanation comes in three parts: (a) The baseline underestimates are due to the perceived causality of the test events in isolation. With increasing actual overlap, causal percepts of these events are decreasingly likely (experiment 2), and as a result the baseline underestimates decrease (experiment 1; see the downward slope of the bottom two lines in figure 4)—from a maximum of around

20% at 60% overlap (seen as causal in isolation on over 85% of trials) to a minimum of around 7% at 100% overlap (seen as causal in isolation on only 11% of trials; Scholl and Nakayama 2002). (b) Causal percepts of the test event are always highly likely when the test event is presented along with the unambiguously causal context event (experiment 2), however; and as a result underestimates of around 20% overlap are observed in experiment 1 for *all* degrees of actual overlap. (c) As a result, the additional effect of 'causal capture' on the underestimates of intersection reported in experiment 1 *increases* with increasing overlap, simply because it is increasingly less subject to a ceiling effect of approximately 20%.

In short, all of the underestimates of the amount of intersection between the two objects in experiment 1 may be attributed to causal perception—a mixture of perceived causality due to only partial overlap, and perceived causality due to 'causal capture'.

4 General discussion

The studies reported here demonstrate an illusion which depends on the perception of causality. Observers viewed various types of displays in which two objects moved relative to each other on a horizontal plane: One object (A) initially began toward one side of the screen, while the other object (B) began near the center of the screen. A then began to move toward B, until they were either adjacent or until they overlapped by some degree, at which point A stopped and B started moving along the same path. When the two objects overlap completely, observers tend to perceive this event in terms of a single moving object passing over a single stationary object (a 'pass'). When B begins moving as soon as A becomes immediately adjacent to it, however, observers perceive a causal 'launching' collision: A is seen to be the *cause* of B's motion.

The central result of this study was a demonstration of the Causal Crescents illusion: the perceived causality between two objects in a collision results in a systematic underestimation of the amount by which the two objects overlapped during the event. The most extreme case of this illusion involved two objects which overlap completely. This degree of full overlap is easily perceived when the two objects are presented in isolation. The presence of a nearby event which is unambiguously causal (via 0% overlap), however, results in 'causal capture', such that the full-overlap event is also seen as a robustly causal 'launching' event. The Causal Crescents illusion here consists of an additional effect of this perceived causality: the two objects in the full-overlap event no longer seem to overlap completely. Rather, object B seems to move before being completely covered by object A, ie while a thin 'crescent' of object B is still visible under object A.

The experiments reported here suggest for three reasons that this illusion of incomplete overlap is due to the perception of causality: (a) First, perceived causality is increasingly likely with decreasing actual overlap between the two objects, and as a result the underestimates become more severe with decreasing overlap. (b) Second, even objects which enjoy a large degree of actual overlap (80% – 100%) can be seen as causal launches on a majority of trials when in the presence of an unambiguously causal context event (the 'causal capture' phenomenon), and consequently even these events result in large underestimates when such context events are present. (c) Finally, when various other types of context events were tested, only those context events which result in robust perceived causality were able to increase the underestimates of overlapping in the test events. These effects collectively indicate that the perception of causality does not proceed completely independently of other visual processes, but can affect the perception of other spatial properties. Moreover, the extent of the

Causal Crescents illusion was considerable: with maximally causal displays, the width of the illusory 'crescent' was over 20% of the widths of the objects themselves.[2]

4.1 *The heuristic nature of the Causal Crescents illusion*

The Causal Crescents illusion is only perceptually apparent when the two objects actually overlap completely. Here one can easily perceive the illusion owing to the added 'causal capture' event. Without the additional event, the two objects appear to overlap fully; with the additional event, they appear to overlap except for a thin crescent which remains uncovered. This effect has an obvious explanation based on the likelihood of various actual events given certain patterns of retinal input. In particular, a causal 'launch' cannot actually occur between two objects (say, billiard balls) whose retinal projections fully overlap at the moment where one starts moving and the other stops moving in a linear collision. At most, the two billiard balls can partially overlap—leaving an uncovered crescent on the retina—if the linear path of motion occurs in a non-frontoparallel depth plane. (And, of course, when the two billiard balls collide in the same frontoparallel depth plane, they will not perceptually overlap at all at the moment of 'impact'.) This suggests a simple categorical explanation for the Causal Crescents illusion: the visual system, when led by other means to perceive an event as a causal collision, effectively 'refuses' to see the two objects as fully overlapped, because of an internalized constraint to the effect that such a spatial arrangement is not physically possible. As a result, a thin crescent of one object remains uncovered by the other one—as would in fact be the case in a straight-on billiard-ball collision where the motion occurs at an angle close to the line of sight.

Whereas this categorical shift (from fully to non-fully overlapped) is easily appreciated when viewing the displays, our results indicate that the illusion also occurs even when the two objects do not actually fully overlap—in which case the illusion is not perceptually obvious. In particular, we observed underestimates of the amount of intersection between items which truly overlapped by only 60%, 80%, and 90% of their areas—and such underestimates for the last two conditions were further amplified by an added causal context event. How can we explain this? Why would the visual system underestimate the amount by which two objects intersect in this situation when they actually intersect only partially? Such events, in any case, do not present the apparent impossibilities that were taken above to motivate the illusion in the 100% overlap event, and the answers to these questions remain elusive. In any case, it appears to be a general rule that the overlap between two objects is underestimated during a collision. Perhaps this reflects a heuristic of sorts, the sense of which is made most clear in the 100% overlap event. Because of the constant operation of this heuristic, however, underestimates are observed even for collisions in which the objects are seen to clearly overlap by a significant amount, situations which may be relatively rare in experiences of real-world collisions.

[2] The illusory crescents which result from these displays bear a passing resemblance to similar 'crescent' percepts which can occur in the context of the flash-lag effect. Across several variations of this effect, the relative spatial positions of a moving object and a static flashed object are misperceived (eg Nijhawan 1994). In particular, the two objects appear misaligned even when they are in fact perfectly aligned, as a result of a perceptual lag for static flashed objects, relative to moving objects. Recently, Khurana et al (2000) employed a variant of such displays in which a black ring moves about a circular path. When a white disc is momentarily flashed within the black ring (such that the outer edge of the white disc is perfectly adjacent to the inner black edge of the ring at all points), observers nevertheless perceive the two stimuli as only partially overlapped—such that a thin crescent of the ring still appears 'unfilled'. Prevailing theories of the flash-lag effect appeal to lower-level mechanisms of motion extrapolation rather than higher-level phenomena such as perceived causality, but it may prove interesting to explore the ways in which these two classes of phenomena might interact.

4.2 *A new tool for studying causal perception?*

The existence of illusory displacement due to perceived causality seems theoretically important for at least two reasons. The first reason has to do with the nature of the dependent measure used here. The perception of causality has fascinated psychologists ever since Michotte, partially because causation, in the context of visual processing, seems so ineffable and irreducible. Precisely these aspects, however, have frustrated the development of sensitive methodological tools to measure causal perception. Nearly all studies of causal perception have relied on a method in which observers are simply asked directly whether they perceive an event as causal (for a notable exception, see Kruschke and Fragassi 1996). This has sometimes led to skepticism about this work (especially by readers who have not directly experienced the effects): despite the phenomenological strength of causal perception, *reports* of it may be affected by many higher-level factors involving task demands. As such, methodological critiques of this work appeared soon after the publication of Michotte's seminal book (eg Joynson 1971; also cf Boyle 1972; Montpellier and Nuttin 1973), and have continued to this day (eg Schlottmann 2000; White 1995).

In contrast, our observers in experiment 1 were never asked about causality. Rather, our instructions focused simply on measurements of spatial overlap, and never mentioned 'causal launching' or 'non-causal passing'. Nevertheless, the results we obtained here with test events involving 100% overlap precisely mirrored the degree of 'causal capture' obtained when observers were asked to directly report whether they saw the test event as causal (experiment 2; cf Scholl and Nakayama 2002). This is still a perceptual report, of course, but it is much less abstract, and closer to standard psychophysical investigations of visual perception. This work thus corroborates the results obtained with direct reports of causal perception, with a converging (though correspondingly indirect) task.

4.3 *Conclusions: The effect of causality*

The second theoretical implication of this illusion has to do with the peculiar isolation that work on the perception of causality has had relative to other studies of perception (Choi and Scholl, in press). Nearly all studies of the perception of causality to date have focused in some way on the *causes* of causal perception—ie on the factors which mediate it. In contrast, very few studies have focused on the *effects* which causal perception might have on other aspects of visual cognition. Even the previous research on 'causal capture' (Scholl and Nakayama 2002) focused only on the effects of causal perception on other judgments of causality (ditto for related work on 'bouncing versus streaming'; eg Sekuler and Sekuler 1999; Watanabe and Shimojo 2001).

The present illusion, however, demonstrates that the perception of causality can also affect other types of visual processing—in this case the perception of spatial relations among moving objects. To our knowledge, only in one other study such *effects* of causality have ever been explored: Hubbard et al (2001) employed causal perception in a study of representational momentum, a phenomenon wherein observers view a moving object which is suddenly extinguished, and are asked to indicate the spatial position where the object offset. The typical result of such studies is that subjects mistakenly indicate that the object appeared further along its trajectory than the location where it actually disappeared—as if the representation had continued 'moving' for a moment after the actual stimulus disappeared (eg Freyd and Finke 1984; for a review, see Hubbard 1995). When a moving object is seen as just having been causally 'launched' by another object, however, it gives rise to less representational momentum than when the same motion appears in isolation—perhaps because the perception of causality entails a type of visual expectation that the object will stop sooner of its own accord, after the original 'impetus' from the collision dissipates (Hubbard et al 2001).

Together with this study of representational momentum, the illusory causal displacement observed in the present study suggests that the perception of causality may have repercussions for several other types of visual processing, and that in this way the study of causal perception may become more integrated with mainstream work on perception.

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