The effect of good continuation on the contact order judgment of causal events

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When a ball on a pool table moves to hit another ball, people feel the causal impression between the two balls: The first ball causes the second ball’s motion, which is known as the launching effect. Previous research has shown that the causal impression becomes stronger when the two balls have a similar direction of movement. Here, we tested whether this good continuation influenced perception of the contact time between the causal object and the effect object. A variant of Michotte’s visual collision event was used as a stimulus, consisting of two competing cause objects and one effect object. In the display, the two cause objects on the left begin to move and contact the effect object in the center, causing it to move. In Experiments 1 to 4, the contact order of the cause objects and the motion direction of the effect object were systematically varied. The observers were asked to judge which of the cause objects had a more causal relationship and made contact first. The results showed that the observers were more likely to judge a cause object as having a more causal relationship with the effect object when there was good continuation, and they often erroneously judged the cause object as having first contacted the effect object; this effect was maintained with up to approximately 100 ms of delay after contact. These results suggest that good continuation is an important cue that postdictively determines perception of the contact time of a cause object in a short time window.

Introduction

When a ball on the pool table moves to hit another ball, people feel a strong causal impression between the two balls, which is known as the launching effect (Michotte, 1946/1963). Hume (1739/1888) argued that this causal impression is inferred from some core empirical cues such as temporal priority, contiguity, and contingency. In contrast, Michotte (1946/1963) suggested that it is directly perceived without learning or inference. Currently, the controversy has not fully been solved, but investigators largely agree that the causal impression is immediate and automatic (Schlottmann & Shanks, 1992; Scholl & Tremoulet, 2000).

For visual collision events, the effects of a variety of perceptual factors on the strength of the causal impression have been tested (for reviews, see Hubbard, 2013; Scholl & Tremoulet, 2000). In particular, the effects of spatial and temporal factors associated with the cause and effect of objects’ motion on causal impression have been intensively studied. As a brief summary, previous research showed that when (1) a cause object (CO) moved and stopped before the effect object (EO) started to move (temporal priority), (2) no spatial or temporal gap was present between the motion of the two objects (spatiotemporal contiguity), (3) the objects showed a similar direction of motion (directional similarity), or (4) the objects showed similar velocity (speed similarity), the causal impression was strong; otherwise, the causal impression was weakened (Buehner & Humphreys, 2009; Michotte, 1946/1963; Schlottmann & Shanks, 1992; Straube & Chatterjee, 2010; White, 2012; Yela, 1952). Michotte (1946/1963) introduced the concept of good continuation in Gestalt psychology to comprehensively explain the effects of this set of characteristics. The good continuation principle is a phenomenon in which elements tend to be grouped into shapes in a smooth direction, such as straight lines or curves (Koffka, 1935; Wertheimer, 1924/1950). According to Michotte (1946/1963), the principle of good continuation for causal launching states that when such spatiotemporal regularities are satisfied, the movements of the COs and EO are perceived as a single movement from a single object.

In this study, we are particularly interested in good continuation in terms of the similarity of motion direction between the COs and EO. Although good continuation for Michotte was a comprehensive idea...
covering diverse spatiotemporal characteristics, for the sake of convenience, in this study we will use good continuation to mean the directional similarity between the cause and EO in motion. Good continuation in Gestalt psychology is a grouping factor, and in vision studies, it has been widely reported that basic percepts such as the size, distance, brightness, and movement of elements change according to grouping. For example, in the Ebbinghaus illusion, the size of a circle is perceived smaller when it is surrounded by bigger circles, and vice versa. The distances between elements within a group are perceived to be shorter than those of the elements outside the group (Coren & Girgus, 1980). The brightness of an element is perceived to be lighter or darker depending on the brightness of the group to which it belongs (Agostini & Proffitt, 1993). The directional movement of elements is perceived differently according to the whole form in which they are grouped (Ramachandran & Anstis, 1985).

Given these findings, is it possible that a spatiotemporal characteristic is perceived differently as a result of good continuation in causal collision events? The phenomenon of temporal/causal binding is interesting in relation to this question. According to the temporal binding phenomenon, the temporal duration between two causal events that occur successively is perceived shorter than the objective time (for a review, see Faro, McGill, & Hastie, 2013). More specifically, it has been reported that the temporal duration of causes and effects believed to be causally tied are compressed toward each other as compared with the objective time. For example, when participants were asked to estimate the time between pressing a button and a resulting sound, they estimated that the button was pressed later and the sound was heard earlier than the earlier times (Buehner & Humphreys, 2009; Haggard, Clark, & Kalogerias, 2002). A similar effect was also obtained only from visual observation of a light turning on when a machine arm pressed the button, suggesting that intention was not necessary for temporal binding but that causal belief was crucial (Buehner, 2012). Investigators explain this by an inferential mechanism based on the experience of causality. That is, because causally related events are empirically known to be spatiotemporally close to each other, the inferential mechanism depends on prior experience to estimate the actual time, such that temporal illusion can occur; this effect may become clearer when the sensory data are uncertain (Eagleman & Holcombe, 2002).

Temporal binding can be understood in terms of grouping in Gestalt psychology. In other words, causal events are grouped with effect events, thus reducing temporal distance. From this point of view, the study of Buehner and Humphreys (2010) is interesting. They constructed a launching event by placing a spatial gap between the COs and EO and manipulated the temporal properties to provide a different degree of causal impression. Their results showed that the distance between the CO and the EO was perceived closer in the condition in which causal impression was stronger. Thus, this study suggests that spatial compression occurs when two events are grouped by causality, and this can be understood as a grouping effect.

In this study, we examined whether good continuation in a causal launching event affected temporal perception of causal events. To efficiently test the hypothesis, we modified the traditional Michotte collision events, which consist of one CO and one EO colliding. In the new event, two COs (CO1 and CO2) were introduced. As shown in Figure 1, the basic sequence of each animation display is as follows. (1) Initially, CO1, CO2, and EO appear on the monitor, one in the upper corner and one in the lower corner, with the EO located in the center of the screen. When the animation began, CO1 and CO2 moved toward the center at a constant speed and simultaneously stopped when they arrived at the EO. At 17 ms after arrival, the EO began to move in the same direction as one of the COs, and importantly, the EO’s motion direction was congruent or incongruent with the motion direction of one of the COs.

Good continuation in this stimulus example occurs between CO2 and the EO, and previous studies have shown that CO2 is more likely to be perceived as the cause of the EO motion (Michotte, 1946/1963; Straube & Chatterjee, 2010; Woods, Lehet, & Chatterjee, 2012). Building on these findings, the ultimate purpose of the
present study was to examine the temporal distortion between the CO and the EO as a result of this good continuation. In other words, it was expected that if the participant feels a stronger causal impression between one of the COs and the EO resulting from good continuation, they would tend to judge that the CO contacted the EO before the other CO.

Experiment 1 tested whether the stimulus display was valid for confirming the correlation of causality and good continuation. Then, whether good continuation influenced the detection of the arrival order of the COs was evaluated using a two-alternative forced-choice (2AFC) method in Experiment 2 and a three-alternative forced-choice method in Experiment 3. Finally, in Experiment 4, the temporal window was examined to determine the maximum duration at which the good continuation effect was obtained.

Experiment 1: Good continuation effect on causality

Studies have shown that in collision events, the greater the similarity between the motion direction of the hitting object and the resultant object, the stronger the causal impression (Michotte, 1946/1963; Straube & Chatterjee, 2010; White, 2012). To test this proposition with the novel display as a preliminary study, the good continuation effect on causality was tested. It was hypothesized that participants would perceive one of the COs as being more causally related to the EO when the EO moved in a direction similar to that of the CO.

Method

Participants

Eleven college students (4 women and 7 men), who were mostly in their early 20s and taking an Introduction to Psychology course, participated in the study. All participants had normal or corrected-to-normal visual acuity and signed consent forms before participating in the study. All participants provided written informed consent, and the study was approved by the Seoul National University Institutional Review Board (IRB).

Apparatus and stimuli

Experiments were conducted in a quiet, moderately lit room. The animation stimuli were presented on a 24-in. monitor (1,920 × 1,080 spatial resolutions, 120-Hz temporal resolution, 1 ms response time). All animations were created using Adobe Flash in MPEG-4 format (120 FPS) and run in E-Prime 2.0 (Psychology Software Tools).

As depicted in Figure 2a, two COs (CO1 and CO2) appeared on the left side of the computer monitor, one in the upper corner and one in the lower corner, and the EO was located in the center of the screen. Black (2.58 cd/m²) or green circles (26.4 cd/m², CIE: x = 0.281, y = 0.615) measuring 1.3 cm (1.15") were used as the CO or EO and were displayed on a white background (81.3 cd/m²). When the animation began, the CO1 and CO2 moved toward the center at a constant speed and simultaneously stopped when they arrived the EO. At 17 ms after arrival, the EO moved in the same direction at one of seven angles relative to the horizon line, with a maximum angle of ±45°. A 17-ms delay following
arrival was adopted in light of previous reports that a slight delay induced a stronger collision impression compared with a delay of 0 ms (Michotte, 1946/1963; Schlottmann & Shanks, 1992). All objects were identical, in terms of moving distance (14.1 ± 8.8) and speed (37.64 ± 6.8/s). In all experiments in this study, the stimulus displays were developed based on the same basic animation. Thus, all displays were similar, except for certain spatiotemporal characteristics.

**Design and procedure**

All experiments were conducted individually with each participant. The participants were asked to indicate which CO caused the EO’s motion by clicking the left mouse button for CO1 and the right mouse button for CO2. Before the test trials, the participants performed six practice trials to become familiar with the experiment. In the test trials, 56 (7 EO motion directions × 8 repetitions) trials were randomly presented. The entire procedure lasted approximately 10 min. As depicted in Figure 2b, the monitor was displayed on the floor (to minimize the gravitational bias from up to down) and viewed from a distance of approximately 65 cm. This physical setup was used for all experiments in this study.

**Results and discussion**

As shown in Figure 3, the participants tended to perceive CO1 or CO2 as the cause when it (either CO1 or CO2) moved in a direction similar to that of the EO. Each bar represents the average percentage of trials in which the participant selected CO1 as the cause of the motion of EO. We used the lme4 package (Bates et al., 2014) in the R system for statistical computing (R Development Core Team, 2013) to compute the inferential statistics. We used generalized linear mixed models (GLMMs) for the response rate analyses to account for the binomial distribution of the trial-level responses (Dixon, 2008). In the raw data, response “CO2 first” trials were scored as 0, and response “CO1 first” trials were scored as 1. The betas for the GLMMs are log odds ratios, with higher log odds ratios indicating that a response “CO1 first” is more likely to be selected. In all models, we entered subjects as random effects (random intercept only) to account for the nonindependence of the data, and angle was treated as a continuous variable. Analysis showed an effect of angle, \( \beta = -0.148, z = 11.25, p < 0.001 \), indicating that for every degree of increase in the angle, the odds ratio for a response “CO1 first” decreased by a factor of approximately 0.862.

**Experiment 2: Temporal order judgment with 2AFC**

Based on the results of Experiment 1, Experiment 2 examined whether causality could influence the detection of the temporal order of the COs. In this experiment, the temporal order of the two COs was systematically varied, and participants were asked to judge which CO was the first to arrive at the target location of the EO. For the control condition, a 300-ms temporal gap was inserted between the collision with the EO and the start of the EO’s movement. This temporal gap was expected to weaken the causal impression, which in turn might eliminate the good continuation effect of the CO on temporal judgment because the visual impression of causality virtually disappears when temporal delays are greater than 200 ms (Fugelsang, Roser, Corballis, Gazzaniga, & Dunbar, 2005; Michotte, 1946/1963; Schlottmann & Anderson, 1993; VanRullen & Koch, 2003). Accordingly, this control condition could avoid any response bias (i.e., the possibility that the participants’ responses would be based on the similar motion directions of CO and EO instead of the participants’ perceptions of the actual order).

**Method**

**Participants**

Eighteen college students (2 women and 16 men), who were mostly in their early 20s and taking an Introduction to Psychology course, participated in Experiment 2. One participant did not complete the
experiment because of drowsiness, and the data were not included. The sample size was determined based on the pilot test (N = 19).

All participants had normal or corrected-to-normal visual acuity and signed consent forms before participating in the study. The participants did not participate in any other experiments in this study. All participants provided written informed consent, and the study was approved by the Seoul National University IRB.

**Stimuli and procedure**

In this experiment, CO1 and CO2 started to move simultaneously; however, their arrival times at the target location of EO differed by one of six temporal differences, specifically, 0, 8, 17, 25, 33, and 42 ms. Thus, the relative speeds of the COs varied slightly, from 43.6 cm/s (38.43°/s) to 49.2 cm/s (43.37°/s), although they started to move at the same time. At 17 ms after arrival, the EO started to move at the speed of 49.2 ms/s (43.37°/s), and EO moved only in either a +45° or a −45° direction because in Experiment 1, the effect of the CO’s direction was not gradual; it was categorically determined by the directional similarity with the EO because we wanted to reduce the number of conditions in the direction and focus more on verifying the temporal characteristics. In the comparison conditions, there was a 300-ms temporal delay between the collision with the EO and the start of the EO’s movement.

All experiments were conducted individually with each participant. The participants were asked to indicate which of the two COs arrived first at the target location of the EO by clicking the left mouse button for CO1 and the right mouse button for CO2 (2AFC method). Importantly, the participants were asked to focus on a fixed point (0.71° × 0.71°) in the red and to disregard the motion of the EO as much as possible. Before the test trials, the participants performed 12 practice trials to become familiar with the experiment. During the practice trials, the EO always moved in the horizontal direction, and feedback was provided to inform the participant whether the response was correct or incorrect. In the test trials, each participant was tested 12 times in each set of conditions over the course of four sessions. During each session, all 44 conditions (2 EO motion directions × 2 EO start delay conditions × 11 arrival temporal differences between COs) were tested three times each in random order. Each session lasted approximately 10 min, and the participant could rest after a session.

**Results and discussion**

The averaged results are shown with line graphs in Figure 4a. Each point represents the percentage of “CO1 first” responses at a given temporal order condition, averaged across all participants. The participants tended to perceive that a CO arrived first when its trajectory was the same as that of the EO. For statistical comparisons, each individual participant’s points of subjective simultaneities (PSSs) were fitted and calculated together. The maximum-likelihood
method (Myung, 2003) was applied as an objective function, and fitting was accomplished with the MS Excel Solver, which implements the generalized reduced gradient algorithm for optimizing nonlinear problems (Oh, 2015). As shown in Figure 4b, the PSSs statistically differ only for the 17-ms condition not the 300-ms condition. A $2 \times 2$ factor repeated-measure analysis indicated that the primary effect of congruent motion trajectories of CO and EO, $F(1, 16) = 10.45, p = 0.001, \eta^2_p = 0.395$, and the interaction between motion direction and delay was significant, $F(1, 16) = 10.46, p = 0.001, \eta^2_p = 0.395$. Subsequent paired $t$ tests indicated that the congruence of the motion trajectories of the CO and EO was significant only for the 17-ms delay condition, $t(16) = -3.34, p = 0.001$, Cohen’s $d_z = 0.81$, and not for the 300-ms delay condition, $t(16) = -1.99, p = 0.062$, Cohen’s $d_z = 0.48$, thus excluding the response bias explanation. Together, Experiment 2 results suggest that the action of an EO’s motion automatically involves the arrival of a CO in the manner in which the time of the CO is earlier than the time of the other CO in competence.

**Experiment 3: Temporal order judgment with 3AFC**

In Experiment 2, a 2AFC method was used. With this method, one might note the possibility of response bias. Specifically, when it was perceptually ambiguous concerning which of the COs arrived first, the participant might simply respond that the CO showing the same motion trajectory to the EO arrived first. Thus, in this experiment, a three-alternative forced-choice (3AFC) method was introduced. Following previous studies, a third choice, “simultaneous or not sure,” was added to the two previous choices, “CO1 first” and “CO2 first” (García-Pérez & Alcalá-Quintana, 2012; Stelmach & Herdman, 1991).

**Method**

**Participants**

Twenty-three college students (8 women and 15 men), who were mostly in their early 20s and taking an Introduction to Psychology course, participated in Experiment 3. All participants had normal or corrected-to-normal visual acuity and signed consent forms before participating in the study. The participants did not participate in any other experiments in this study. All participants provided written informed consent, and the study was approved by the Seoul National University IRB.

**Results and discussion**

All experiments were conducted individually with each participant. The participants were asked to indicate which of the two COs arrived first at the target location of the EO by clicking the left mouse button for CO1, the right mouse button for CO2, and the middle mouse button for simultaneous arrival (3AFC method). The participants were also asked to focus on the fixed point in red and to disregard the motion of the EO as possible. Before the test trials, the participants performed 12 practice trials to become familiar with the experiment. During the practice trials, the EO always moved in the horizontal direction, and feedback was provided to inform the participant whether the response was correct or incorrect. In the test trials, each participant was tested 10 times in each set of conditions over the course of four sessions. During each session, all 44 conditions (2 EO motion directions $\times 2$ EO start delay conditions $\times 11$ arrival temporal differences between COs) were tested twice (short session) or three times (long session) in a random order. Each session lasted approximately 7 (short session) or 10 (long session) min, and the participant could rest after a session.

The data from one participant were excluded from the analysis because his PSS was outside of the range of conditions. However, no difference was found when his data were included. As shown in Figures 5a and 5c, the results are largely similar to those of Experiment 2 (i.e., the participants tended to perceive the CO showing the same motion direction to the EO as arriving earlier), although the strength was slightly decreased. For statistical comparisons, each individual participant’s PSSs were fitted and calculated together. PSSs were counted separately for “CO1 first” responses and “CO2 first” responses. The maximum-likelihood method (Myung, 2003) was applied as an objective function, and fitting was accomplished using the MS Excel Solver (Oh, 2015), which implements the generalized reduced gradient algorithm. As shown in Figures 5b and 5d, the PSSs statistically differed for the 17-ms condition but not for the 300-ms condition. A $2 \times 2$ factor repeated-measure analysis indicated that the interaction between motion direction and delay was significant both for “CO1 first” responses, $F(1, 21) = 9.48, p < 0.01, \eta^2_p = 0.311$, and for “CO2 first” responses, $F(1, 21) = 8.68, p < 0.01, \eta^2_p = 0.292$. Subsequent paired $t$ tests indicated that the congruence between the motion trajectories of CO and EO was significant only for the 17-ms delay condition and not for the 300-ms condition for both “CO1 first” responses, $t(21) = -2.53, p = 0.019$, Cohen’s $d_z = 0.54,$
and “CO2 first” responses, \( t(21) = -2.39, p = 0.02, \) Cohen’s \( d_z = 0.51. \)

Thus, the Experiment 3 results indicated that the results of Experiment 2 are unlikely to be affected by any response bias or by guessing.

Figure 5. Experiment 3 results. (a, c) The mean rates of “CO1 first” responses and “CO2 first” responses across all participants. (b, d) The PSSs statistically differ for the 17-ms condition but not for the 300-ms condition for both “CO1 first” responses and “CO2 first” responses. The error bars represent within-subjects 95% confidence intervals (Cousineau, 2017).

**Method**

**Participants**

Twenty-four college students (9 women and 15 men) who were mostly in their early 20s and taking an Introduction to Psychology course, participated in Experiment 4. All participants had normal or corrected-to-normal visual acuity and signed consent forms before participating in the study. The participants did not participate in any other experiments in this study. All participants provided written informed consent, and the study was approved by the Seoul National University IRB.

**Stimuli and procedure**

In this experiment, CO1 and CO2 always started to move simultaneously and arrived at the target location simultaneously. The EO moved at either a +45° or −45° angle after the collision and started to move after one of 10 temporal delays ranging from 17 ms to 167 ms in steps of 17 ms. In addition to this experimental
condition, there were catch trials in which CO1 and CO2 had actual temporal differences of 642 ms.

All experiments were conducted individually with each participant. The participants estimated which of the two COs arrived first at the target location while focusing on a fixed point and disregarding the motion of the EO. The participants clicked the left mouse button for CO1 and the right mouse button for CO2. Before the test trials, the participants performed eight practice trials to become familiar with the experiment. In the test trials, each participant was tested 10 times under each set of conditions over the course of two sessions. During each session, all 20 conditions (2 EO motion directions × 10 EO start delay conditions) were tested five times each in a random order, with 12 times for the catch trials. Each session lasted approximately 10 min, and the participants could rest after a session.

Results and discussion

According to the analyses, all 24 participants achieved accuracy rates greater than 70% in the catch trials ($M = 93\%, SD = 9.35$). For statistical convenience, participants’ responses were divided into two categories depending on the congruency between the motion direction of the CO and EO. If participants responded “CO1 first” when the EO moved in the $-45^\circ$ direction, the responses were combined into the congruent direction. If they responded “CO1 first” when the EO moved in the $+45^\circ$ direction, the response rate for the congruent direction – the response rate for the incongruent direction; $p < 0.05, **p < 0.01$. The error bars represent within-subjects 95% confidence intervals (Cousineau, 2017).

The Experiment 4 results indicated that the effect of good continuation on the time perception of the CO can last up to approximately 120 ms after the collision. As shown in Figure 6, this effect gradually decreased as the delay increased, which appears to be due to a reduction of causal impression. Michotte (1946/1963) found that, as the delay increased, the observers’ impressions changed from causal launching to seeing independent motions of the two objects at around 112 ms (Experiment 29). Thus, the gradual decrease of the good continuation effect in Figure 6 seems to result from the role of causal impression that mediated between good continuity and contact time perception.
The purpose of this study was to examine, in collision events, whether the perception of the contact time of COs was influenced by good continuation in motion with the EO. The results showed that a CO in good continuation with the EO was more likely to be perceived to contact the EO first before the other competing CO, confirming the hypothesis. Since Michotte (1946/1963), most studies have examined how temporal and spatial features influence causal impressions. In contrast, the present study is particularly meaningful in that it newly demonstrates how these factors affect the perception of each other.

In the present study, the temporal delay of the contact between the COs and EO was a maximum of 42 ms. This delay is within the temporal range in which the observers reported causal launching in Michotte (1946/1963) and previous studies. Thus, it can be assumed that the strength of spatiotemporal contiguity of the CO1 and CO2 may be nearly equivalent across all trials regardless of the direction of EO motion. If so, the major factor determining causal impression seems to be good continuation rather than spatiotemporal contiguity. In terms of cue reliability (Jacobs, 2002), considering that spatiotemporal contiguity and good continuation are all reliable cues for causal impression, the causality evaluation results in Experiment 1 seem to result from the combinatorial work of both cues. However, the effect of good continuation on the contact order of the COs found in Experiments 2 to 4 are not explained simply by the cue combination. Additional knowledge of the relationship between the two cues is needed: If two objects move in succession and in a similar direction, the first CO touches the EO before the other CO. A billiard ball that is hit by another ball can move in many different directions as well as the straight direction, depending on the contact point (White, 2012). In contrast, in daily life, we have learned that good continuation always guarantees the first contact of a CO. In this point of view, CO contact is a poor predictor for good continuation, whereas good continuation is a good “postdictor” for a CO’s first contact. Thus, a causal mechanism might resolve the uncertainty of the contact order of the COs, depending on the prior knowledge of the relation between contact and good continuation. This explanation is consistent with the Bayesian approach for understanding perceptual processing (Ernst & Bulthoff, 2004). Taken together, the present study suggests that spatiotemporal contiguity and good continuation primarily contribute to causal impression and that causal impression subsequently determines the relative contact time between the COs and the EO.

Logically, contact between the CO and the EO occurs first, followed by good continuation between the two objects. Therefore, the effect of good continuation on the contact order of the COs is a reversal of the actual sequence; later events affect the perception of earlier events that have already occurred. Thus, this suggests a hypothetical short time window in which the spatiotemporal properties of the CO and EO are postdictively integrated. Similarly, Choi and Scholl (2006) found that causal launching effects were induced by contextual motions after the fact already occurred. In their studies, a first ball (A) moved and overlapped with a stationary ball (B), and the participants tended to see A passing through B. However, when another stationary ball (C), which was located near and above B, started to move after the overlapping of A and B, the perception of the participants changed, and they saw causal launching: A caused B’s motion. This postdictive phenomenon occurred up to about 200 ms after the overlap of A and B. Choi and Scholl (2006) suggested that the conscious perception of the world is not an instantaneous moment-by-moment construction but an integration of information that is presented within a short temporal window. Although the output of the postdictive process in Choi and Scholl (2006) differs from that of the present study (causal impression vs. contact order), both studies suggest a hypothetical short temporal window for the causal mechanism.

One may argue that temporal binding and the results of this study are contradictory because the time of the causal event was shifted to the later direction in the temporal binding phenomenon, whereas the time of the causal event in the present study was shifted to the earlier direction. However, for some reason, it is not correct to directly compare the concept of time used in the two studies. First, in the temporal binding studies, time in the cause and effect events is measured quantitatively by an objective clock that is unrelated to the two events. On the other hand, in the present study, time is measured relatively between the competing causal objects in terms of order. For example, there is an objective time record of two athletes in the Olympic 100-m run; there is also a record of the order of who came first. Thus, it is meaningless to compare the two records directly. Second, the temporal binding phenomenon is mainly based on action research; methodologically, only the time dimension is highlighted, whereas the spatial dimension is disregarded. On the other hand, the arrival event in the present study is a phenomenon in which time and space are simultaneously considered. Therefore, the causal contexts of the two phenomena are different, and it is difficult to compare them directly. Both phenomena do not violate the commonly known causal laws and are consistent with physical reality.

Previous studies have shown that specific eye movements were not necessarily required for causal impression of collision events (Badler, Lefèvre, &
Missal, 2012; Jansson, 1964). Apart from causal impression, was there any possibility in Experiments 2 to 4 that the contact order of the COs was influenced by any eye movement that followed the COs or EO? In the present experiments, the participants were required to focus on the fixation point, and it was unlikely that eye movement was systemically involved in contact order judgment. Also, there are some reasons suggesting that eye movement does not account for our results, even if we accept that eye movement occurred. One could argue that the participant strategically followed one of the COs and therefore may have judged the CO to contact the EO first because of attentional benefits for the perceptual process of the CO, as found in previous studies (McDonald, Teder-Sälejärvi, & Hillyard, 2000; Stelmach & Herdman, 1991). However, although both COs start to move separately, they converge at the EO around the collision area, and they are closely formed on the fovea. Thus, any overt or covert attentional benefit based on location would occur only rarely. Furthermore, this account cannot explain why the attentional benefit occurs only for the CO that has good continuation with the EO. What if the participants follow the EO and are asked to judge the contact order of the COs? In previous studies in which the participants were asked to actively follow the EO, the latency of saccadic eye movement for following the EO was faster in the physically possible causal condition than in the physically impossible causal condition (Badler, Lefèvre, & Missal, 2010; Wende, Theunissen, & Missal, 2016). Accordingly, if the participants in our study judged the contact order of the COs based on eye movement latency, the CO that showed good continuation with the EO would be judged to contact the EO first, as they would have a stronger causal relation. However, unlike those previous studies, there were two COs in the present experiments, such that it would be difficult to expect any CO to show good continuation. Also, in those previous studies, the latencies of saccadic eye movement were greater than 150 ms after collision. Good continuation effects in the present experiments were observed only with a much shorter time delay to the start of the EO motion, and the accuracy was almost perfect when the delay was greater than 120 ms. Badler et al. (2012) also found that the latencies of saccadic eye movement following the EO did not differ between the 0-ms delay condition and 300-ms delay condition when the EO showed a physically possible motion pathway, though the causal impression differed as causal impression versus noncausal impressions, such as with the motion of two objects. Taken together, it seems unlikely that the good continuation effect observed in the present study can be accounted for by eye movement.

In practical terms, our study can account for certain visual errors in daily events when two or more causal objects in motion are involved. One such example is when two soccer players are competing for a ball using their body parts, such as their heads or feet, and the movement of the ball takes it out of the field of play. According to our study, the referees or spectators may perceive that the player whose direction of movement is most similar to that of the ball is the cause and that this player touched the ball first, even when the other player actually touched the ball first.

**Keywords:** good continuation, contact order, causality, collision

**Acknowledgments**

Commercial relationships: none.
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