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Launching the effect: Representations of causal movements are influenced by what they lead to

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We investigated whether the representation of an observed causal movement is influenced by its observed effect. Subjects watched displays showing collisions between two objects. In this "launching event" (Michotte, 1946/1963), one of the two objects (Object A) started to move and set a second, initially stationary, object (Object B) into motion, which gave a strong impression of apparent causality. The apparent effectiveness of A's movement was manipulated by varying the velocities of A and B. When the velocity of B was higher than that of A, the effectiveness of the collision was high; when it was smaller it was low. Then, subjects were asked to reproduce the velocity of the causal movement. Reproduced velocity followed the velocity of both Object A and Object B, which supports the hypothesis that the effect of a movement is integrated with its apparent cause. However, when apparent causality was reduced by changing the direction of motion of B or by covering the point of collision, the influence of the effect on the representation of the cause persisted, suggesting that retroactive interference may account for the findings. The interference effect could not be reduced to temporal recency or spatial integration and was not obtained in the reverse temporal order (proactive interference). Rather, the two successive movements were blended in memory.

A question that has gone largely unnoticed is how representations of observed movements and their effects are formed. The situation of an observer watching the results of movements in the environment is very common in everyday life: For instance, when watching a football game, a traffic accident, somebody knocking on a door, or a billiards game. Most

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of these movement sequences involve one event that is the cause of another event by some kind of transfer of physical force. In the case of billiards, one ball is hitting another ball at a certain angle and at a certain velocity. As a result of the collision between the two objects, the object that was initially stationary is set into motion. In this particular situation, the motion of the first ball is the cause of the second ball's motion. Conversely, the motion of the second ball is the effect of the first ball's motion.

Two goals were pursued in the present series of experiments. First, we investigated whether and how the representation of an apparently causal movement is influenced by its effect. To this end, we presented subjects with displays that depicted a collision between two objects and probed subjects' memories for the movement of the first, causal movement. Second, we tried to establish whether the phenomenal appearance of the movements—that is, the degree to which the sequence looked causal—contributed to the observed memory-related effects.

When an initially stationary object (Object B) is being set into motion by another moving object (Object A), observers spontaneously describe the sequence as being causal (Michotte, 1946/1963). The movement of Object A is seen as the cause of Object B's movement. With different speed ratios of the two objects, the effectiveness of causal movement changes. For instance, if Object A rolls at a relatively high velocity towards Object B and collides with it, but Object B's velocity after the impact is slow, the effectiveness of the collision is low. In contrast, the effect of A's motion on B is high when Object B's velocity is higher than A's velocity. Thus, one may ask whether a big or small effect of the causal movement will be incorporated into its representation. From other fields of research such as stimulus–response compatibility (e.g., Hommel, 1993), sensorimotor synchronization (Aschersleben & Prinz, 1995, 1997), and infant studies (e.g., Bekkering, Wohlschläger, & Gattis, 2000), there are indications that there is a strong tendency to integrate causes and their effects. In particular, the hypothesis has been entertained that movement control is achieved via their effects (Greenwald, 1970; Harleß, 1861; James, 1890; Lotze, 1852; Prinz, 1997)—that is, for the initiation of a movement, the causally dependent sensory effect is activated. For instance, Aschersleben and Prinz (1997) found that when subjects are asked to perform a movement in synchrony with an auditory signal, the sensory effects of the movement and the movement itself are integrated and temporally averaged to determine response initiation. Therefore, a plausible initial hypothesis is that the representation of the causal movement is influenced by the apparent effect of the movement: A large effect of a causal event will augment the representation of the causal movement, whereas a small effect will have the opposite effect. For instance, subjects' representation of the velocity of a causal movement that produces an effect-movement of a slower velocity will be lower than that for a sequence where the effect-movement is higher than the causal movement.

At least two approaches to how representations of causal movements are formed can be distinguished. The first approach stresses the phenomenal appearance of objects in motion; the second is derived from research on memory interference. The phenomenal approach to the perception of kinematic displays has its roots in an early study of Heider and Simmel (1944), who showed that complex dynamic stimuli involving abstract drawings can be perceived as intentional behaviour of apparent actors. Later, Michotte (1946/1963) used displays featuring abstract geometrical objects to investigate the role of apparent causality. In what Michotte calls the "launching effect", observers see the collision between two objects—that is, Object A starts to move towards Object B, and when the two objects make contact, B starts to move. When asked to describe what they saw, subjects spontaneously report the objects doing something instead of describing mere changes of position over time. The objects are seen as acting in a certain way, for instance, A appears to strike or hit B, and B withdraws or runs away from A. The movement of geometrical objects is seen as intentional in that it can be characterized in terms of causes (to make move) and effects (to be moved). In Michotte's view, observers directly perceive the causal relationship as such—that is, the perception of causality is unmediated by higher level processes. However, this claim was criticized on both methodological and empirical grounds. Joynson's (1971) methodological critique centres on the fact that only a small expert group of less than six observers participated in the experiments. Two empirical arguments were raised against direct perception of causality. First, perception of causality is mediated by individual differences (Beasley, 1968; Boyle, 1960; Gemelli & Cappellini, 1958) and second, perception of causality changes over prolonged exposure to apparently causal or non-causal events (Gruber, Fink, & Damm, 1957; Powesland, 1959). Thus, it seems likely that the perception of causality is learned rather than direct and innate. However, individual differences were hypothesized to have their locus in the weighting of cues, whereas the integration of stimulus variables obeyed an invariant integration rule (Schlottmann & Anderson, 1993). Moreover, factors that are assumed to influence judgements of causality in other domains of learning have no discernable effect on the perception of causality in the launching event (Schlottmann & Shanks, 1992), and infants have been shown to perceive causality (Leslie, 1982; Leslie & Keeble, 1987; Oakes & Cohen, 1990).

In sum, the phenomenal aspect of a collision between two objects is that of an object acting as the cause of the motion of a second object. The perception of these phenomenal roles appears to be well established and may even be innate. From these findings, one may draw the conclusion that it is the phenomenal aspect of movements that is important in the representation of kinematic events such as collisions. If we assume that the speed of the second ball is perceived as the quantitative effect of the movement of the first ball, one may predict that the representation of the first-moving ball will be integrated with the observed speed of the second ball's movement. Thus, if the observer sees the second ball roll at a high speed, a large effect is perceived, which should in turn influence the cognitive representation of the causal movement in such a way that the strength and force of the movement are modified to match the strength of the effect. In other words, the size of the effect is quantified by the velocity of the object being hit. Therefore, the representation of the velocity of the movement producing the effect should be distorted to match the apparent effect strength.

On the other hand, it may be possible that observers' representations of cause–effect couplings derive from more general principles of human memory. The predicted pattern of distortion in which some later information (the effect movement) disrupts memories of earlier information (the causal movement) resembles a venerable effect: retroactive interference (for overviews, see Baddeley, 1997; Postman & Underwood, 1973). In classical experiments on retroactive interference (RI), subjects first learned one set of responses to a set of stimuli, called the A–B list of paired associates. Then, subjects learned a second set of responses to the same stimuli, called the A–C list. When these subjects were tested on the A–B list, their performance was inferior to the performance of a control group that did not learn the A–C list. Analogous to the A–B/A–C paradigm, subjects observing a collision event see (or learn) first the velocity of Object A and subsequently the velocity of Object B. Thus, information acquired at a later point in time may affect memories of information acquired earlier. In this case, the phenomenal appearance of the event does not contribute to a distortion of the causal movement's representation by the effect movement.

In Experiment 1, we show that the observed effect of an apparently causal sequence of events affects the representation of the causal movement. In Experiments 2–5 we rule out that the effect is attributable to spontaneous decay, recency, or perceptual fusion. In Experiments 5 and 6, we test whether phenomenal causality or some form of RI explains the integration of cause and effect. Experiment 7 examines whether the effect can be temporally reversed.

EXPERIMENT 1

Experiment 1 investigates how the dynamics of the launching event affect the representation of the apparently causal stimulus. We manipulated the effect of the to-be-reproduced motion of one object (Object A) by varying the velocity of a second object (Object B) launched by A. We used speed ratios that Michotte (1946/1963, p. 111) reports to produce the launching effect. Michotte notes that when the speed of the second movement is lower than that of the first, apparent causality is stronger than in the reverse case. If the second movement is faster, the launching effect is replaced by the triggering effect. In the triggering effect, the later part of the movement of the first object seems to be autonomous and unrelated to the first movement. However, the movement of the second object remains dependent on the first object for its origin and shows strong similarities to the launching effect. Michotte reports that the launching effect is perceived up to a speed ratio of 1:1.8 (first velocity:second velocity). Similarly, Natsoulas (1961) finds the perception of launching to be reduced at a speed ratio of 1:2. Therefore, we use speed ratios ranging between 1:1.68 to 1:0.58, which are all supposed to yield the launching effect.

Method

Participants

A total of 7 students (2 male, 5 female) at the Ludwig-Maximilians University of Munich were paid for their participation. All participants reported normal or corrected vision and no motor impairments. None of the participants was informed about the purpose of the study.

Apparatus

One of two computers was used to generate the stimuli in the present series of experiments. Either a Texas Instruments TIGA video adapter hosted by a 486 PC, allowing for a pixel resolution of 1024H × 768V, or a Matrox Millennium graphics adapter on a Pentium 166 PC, permitting a 1280H × 1024V pixel resolution, was used. The former display was used in Experiments 1, 6, and 7 and the latter display in the remaining experiments. Stimuli were presented on a 40H × 30V cm screen. Displays were updated at a rate of 60 Hz. Movements were recorded by a CalComp Drawing Board III at a resolution of 394 lines per cm. The graphics table was covered by a wooden board that contained a rectangular aperture of 1 × 16 cm. Inside the aperture, a narrow 15-cm opening in a plastic sheet attached to the board guided the tip of the drawing pen.

Stimuli

Object A and Object B were white and yellow discs, respectively. The objects travelled on horizontal uni-dimensional trajectories extending 15 cm. The two objects were positioned at the vertical centre of the screen and measured 0.5 cm in diameter. A white frame similar to the aperture on the graphics table surrounded the trajectory of Object A. The right edge of the frame was at the centre of the screen. Object A travelled from left to right inside the frame until it reached the inner right edge of the frame. Three velocities were used: 7.0, 9.4, and 11.8 cm/s. To make the motion look smooth, Object A reached its target velocity after a brief acceleration phase with a logistic velocity profile. Constant velocity was reached after approximately 1 s, such that more than half the trajectory was passed at a constant velocity. The time it took the object to traverse its trajectory varied from 2.4 s at a velocity of 7.0 cm/s to 1.9 s at a velocity of 11.8 cm/s. While Object A was moving, Object B remained stationary at the outside of the right side of the frame. When Object A reached the inner right edge of the frame, Object B started to move, giving the impression of a collision between A and B. Object B then moved at a constant velocity from left to right and vanished in a yellow filled rectangle 15 cm from the screen centre (see Figure 1).

Procedure

The experiment took place in a dimly lit room. The drawing board was placed in front of the participants at a height that allowed for comfortable drawing movements. Behind the drawing board, the monitor was positioned slightly higher than the drawing board. The participants were seated 70 cm from the monitor. Participants were instructed to imitate the velocity of the white disc (Object A) as closely as possible and always to keep the tip of the pen in the aperture. At the start of each trial, participants aligned the pen position with the rest position of Object A on the screen. To that end, a blue disc was displayed, which moved along the trajectory of Object A according to the pen position on the drawing board. When pen and Object A were congruent for 1 s the blue disc disappeared, and

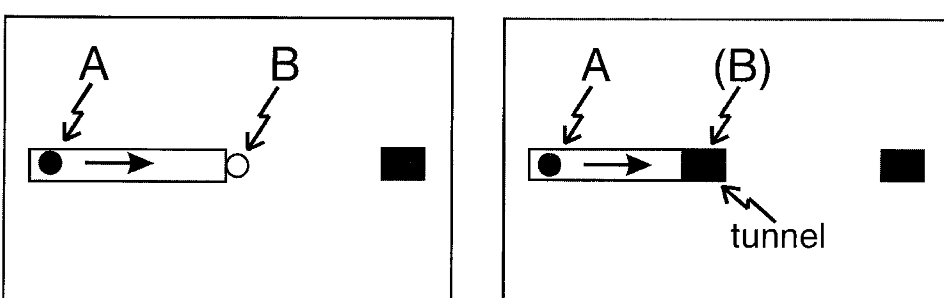

Figure 1. Schematic drawing of our displays. The left panel depicts the "launching effect", the right panel depicts the "tunnel effect" (Michotte, 1963). In the launching effect, A moves toward Object B and appears to set B into motion. In the tunnel effect, apparent causality is eliminated by covering Object B such that no collision between two objects is presented. Instead, a single object appears to move underneath a cover.

Object A started to move. When Object B was completely hidden by the filled rectangle, participants were to reproduce the velocity of Object A by moving the stylus from left to right. When subjects failed to respond within the first 1.5 s, the trial was counted as an error and was repeated at a random position in the remainder of the block. When we used the high-resolution display (Experiments 2–5, and 7), the procedure was improved in the following way: To avoid anticipation errors, an error message appeared when movements were initiated before Object B had vanished. The trial was then repeated at a random position in the remainder of the trial.

Data analysis

Velocity of the reproduced movement was calculated by numerical differentiation after filtering the position data. First, we spline-interpolated the position data to yield a constant sample rate of 125 Hz because the time interval between successive data samples varied between 7 and 11 ms. Then, we applied a second-order Butterworth low-pass filter with a cut-off frequency of 5 Hz in forward and reverse direction, which results in a zero-phase shift filter. Onset and offset of the movement were determined using a velocity criterion of 3 cm/s. Reproduced movements were characterized by two parameters: the peak velocity and the mean velocity of each movement. Mean velocity was computed as the average difference between two successive position samples.

Design

A two-factorial within-subject design was used. The velocity of Object A varied randomly between 7.0 cm/s, 9.4 cm/s, and 11.8 cm/s. The velocity of Object B varied between the same three velocities as those of Object A. Two repetitions of each combination of A's and B's velocities were randomly presented in each of the five experimental blocks for a total of 90 trials.

Results

Mean and peak velocities of the reproduced movement for each combination of A's and B's velocities are depicted in Figure 2. Trials in which the movement was initiated too early or showed irregular movement trajectories (lifting of the pen, pen slipping out of the aperture) were counted as errors and excluded from the analysis (2.6%). An analysis of variance (ANOVA) on peak velocity revealed main effects of Object A's velocity, $F(2, 12) = 43.17$, $p < .0001$, and Object B's velocity, $F(2, 12) = 9.09$, $p < .0039$, indicating that the peak velocity of the reproduced movement increased with the speed of both Object A and Object B. The interaction of A's and B's velocities was not significant ($p > .6$). The same effects of A's velocity, $F(2, 12) = 65.51$, $p < .0001$, and B's velocity, $F(2, 12) = 5.14$, $p < .0244$, were found for mean velocity of the reproduced movement. The interaction was not significant ($p > .65$).

Discussion

The main effect of Object A's velocity on reproduced velocity shows that subjects were able to follow the instructions and reproduce the velocity of the object moving first. Quantitative agreement between the depicted velocity and the reproduced movement was reasonable. Subjects used a more restricted range of velocities (see Figure 2). The

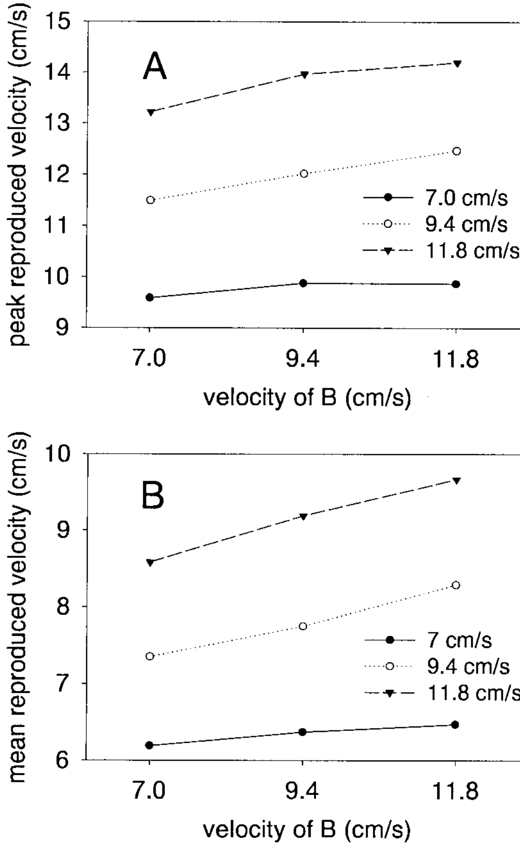

Figure 2. Peak (Panel A) and mean (Panel B) velocities as a function of Object A's and Object B's velocities in Experiment 1. Reproduced velocity increases with the velocity of A and B.

main effect of Object B's velocity indicates that the reproduction of the speed of Object A followed the velocity of B to some degree. That is, uniformly across the different velocities of A, reproduced velocity increased with the velocity of Object B. Two interpretations of the effect are possible. First, one may argue that the observed effect of a causal movement affects its representation. That is, the size of the effect of Object A's motion is integrated into the representation of its velocity. Thus, when Object B moves slowly, A appears to have a weak effect on B; conversely, a high speed of B indicates a large impact of A on B. In memory, the representation of Object A's movement is then distorted to match the apparent strength of the effect. Alternatively, one may argue that the reason for the integration of A's and B's velocities was the RI from a temporally later event.

However, before we continue examining the effect in more detail, it should be ruled out that the observed effect of B's movement is attributable to the different time intervals elapsing during the movement of B at the three different speeds. At faster speeds, the object traverses its trajectory in less time than at slow speeds. Thus, if one believes that shorter time intervals lead to a memory shift toward fast velocities and longer time intervals to a memory shift toward slow velocities, the observed influence of B on A might not be the result of an integration of velocities due to a movement–effect coupling but it would be attributable to variation of a confounded variable—retention interval. To rule out this alternative interpretation, Experiment 2 eliminated Object B's movement from the stimulus and varied the time interval between Object A's coming to a halt and the reproduction of its velocity.

EXPERIMENT 2
Object B invisible

Method

Participants

A total of 7 students (3 male, 4 female) participated, who fulfilled the same criteria as in Experiment 1.

Apparatus, stimuli, design, procedure, and data analysis

These were as outlined in Experiment 1 with the following exceptions: The colour of Object B was changed to black so that the disc was not visible. When the virtual Object B had reached its end position, an auditory signal indicated that subjects were to respond.

Results

Occasional trials (0.2%) that showed irregular movement trajectories were discarded. A two-way within-subject ANOVA on peak velocity showed that the velocity of the reproduced movement increased with Object A's velocity, $F(2, 12) = 26.15$, $p < .0001$, from 14.2 cm/s at the lowest to 15.8 cm/s at the medium and 17.5 cm/s at the fastest velocity of A. No other effects reached significance ($p > .3$). An ANOVA on mean velocity confirmed the effect of Object A's velocity, $F(2, 12) = 29.28$, $p < .0001$. Mean reproduced velocities were 9.3 cm/s, 10.5 cm/s, and 11.4 cm/s for the three velocities of B. No other effects reached significance ($p > .6$).

Discussion

Experiment 2 shows clearly that the effect of B's velocity on the representation of A that we found in Experiment 1 cannot be attributed to different time intervals elapsing between the halt of Object A and the reproduction of Object B. Inserting a blank interval of different durations between movement of A and reproduction did not affect reproduced velocities.

EXPERIMENT 3
Final deceleration of Object B

In Experiments 1 and 2, we found that subjects' representation of causal movements is influenced by their effect. This result is expected if one assumes that cause and effect are integrated because of their phenomenal appearance or because a temporally later event interfered with maintaining a proper representation of the earlier event. However, one may also claim that the effect is solely due to particular salient traces left by the very last part of the sequence. In research on list learning, this effect is referred to as recency effect: When immediately recalling a list of unrelated words, there is a tendency for the last few items to be very well recalled (Glanzer, 1972; Glanzer & Cunitz, 1966; Postman & Phillips, 1965). An explanation of the effect of the later movement on the earlier movement in terms of mere recency is incompatible with Michotte's (1946/1963) notion of the radius of action. In the launching event, the motion of the more "active" Object A launches B into motion. Michotte argued, however, that the impression of A actively pushing B does not persist beyond a certain length of the path travelled by B. For a short distance in the range of 4–6 cm, B appears to move under the influence of A before its movement becomes autonomous (see also Boyle, 1961). If the effect of the velocity of the effect movement can be reduced to the last part of the trajectory, it appears unlikely that the apparent causal nature of the effect is responsible for the integration to occur. The causal nature should be more dominant during the first part of the trajectory, not the last. In contrast, an interpretation in terms of RI is indifferent to the exact location of the interfering information. It claims only that information presented later than the relevant information influences retention.

Method

Participants

A total of 8 students (3 male, 5 female) participated, who fulfilled the same criteria as in Experiment 1.

Apparatus, stimuli, procedure, and data analysis

These were as outlined in Experiment 1 with the following exception: After Object B had traversed half of its trajectory, it decelerated to a velocity of zero within 1.5 s. Thus, the object's end position and the deceleration factor varied with its initial velocity.

Design

The same design as that in Experiment 1 was used with the exception that catch trials (20%) were inserted at random positions within each block to ensure that subjects paid attention to the last part of B's trajectory. In a catch trial, a random combination of A's and B's velocities was shown, and a 0.3-cm disc around the centre of Object B changed its colour from yellow to white for 170 ms at a random point during the second half of the trajectory. Detection of catch trials was difficult and required pursuing Object B's trajectory until the end. The change in colour indicated that subjects should not move. If subjects initiated a movement in a catch trial, an error message appeared.

Results

Mean and peak velocities of the reproduced movement for each combination of A's and B's velocities are depicted in Figure 3. 1.8% of the trials had to be discarded due to anticipations and irregular movement trajectories. In 11% of the catch trials a movement was initiated, indicating a failure to detect the change in colour or an anticipatory movement. Again, a within-subject ANOVA confirmed that peak movement velocity increased with Object A's velocity, $F(2, 12) = 11.72$, $p < .001$, and Object B's velocity, $F(2, 12) = 7.62$, $p < .0058$. The interaction did not reach significance ($p > .11$). The same pattern was obtained for mean velocity. Significant effects of Object A's velocity, $F(2, 12) = 14.34$, $p < .0004$, and Object B's velocity, $F(2, 12) = 6.41$, $p < .0105$ were observed. The interaction was not significant ($p > .07$).

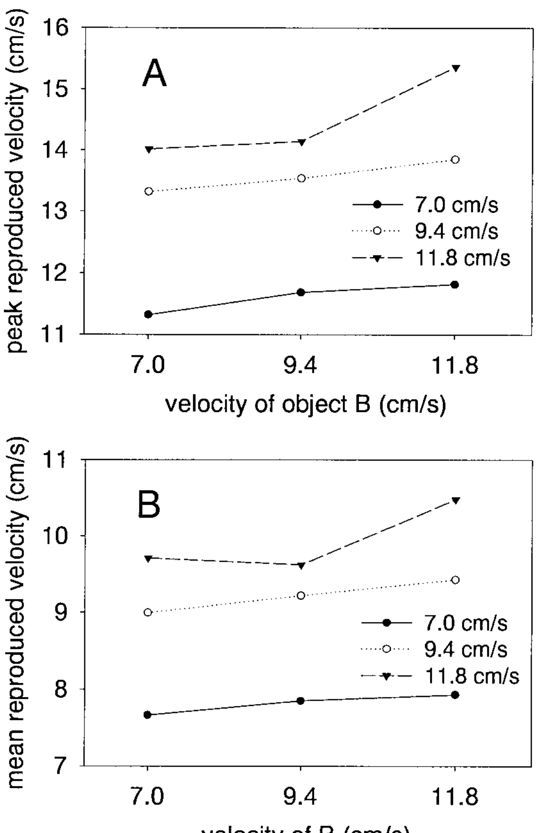

Figure 3. Peak (Panel A) and mean (Panel B) velocities as a function of Object A's and Object B's velocities in Experiment 3. B's final velocity was zero in all cases.

Discussion

We were able to replicate the results of Experiment 1 with a final velocity of zero in all presentations of Object B. However, it is premature to conclude that the recency hypothesis has been ruled out. It may have been the case that the highest final velocity is remembered such that the three distinct velocities of Object B and not the final velocity of zero were remembered. Therefore, we ran another experiment in which Object B accelerated or decelerated at the end of its trajectory. Thus, the final velocity was always either the highest or lowest velocity that was displayed.

EXPERIMENT 4
Final deceleration or acceleration of Object B

Method

Participants

A total of 7 students (3 male, 4 female) participated, who fulfilled the same criteria as in Experiment 1.

Apparatus, stimuli, procedure, and data analysis

These were as outlined in Experiment 1.

Design

A three-factorial within-subject design was used. As in Experiment 1, the velocities of Objects A and B varied randomly between 7.0 cm/s, 9.4 cm/s, and 11.8 cm/s. Two types of velocity change—acceleration and deceleration—were used. In deceleration trials, Object B decelerated to a velocity of zero after it had traversed half of the trajectory displayed in Experiment 1. In acceleration trials, it accelerated to a final velocity of 16.4 cm/s. The acceleration/deceleration phase was shorter (0.5 vs. 1.5) than that in Experiment 3 to ensure that Object B was on screen at the end of the animated sequence. Thus, the disc's end position and the acceleration factor varied with the initial velocity of the disc. One block consisted of the random combination of the 18 different conditions resulting from the factorial combination of A's velocity, B's velocity, and type of velocity change. The number of blocks was increased to six for a total of 126 trials. A proportion of 20% catch trials similar to those in Experiment 3 were included.

Results

Mean and peak velocities of the reproduced movement for each combination of A's and B's velocities are depicted in Figure 4. In 3.1% of the trials, movement initiation was anticipatory or the movement trajectory was irregular. In 14% of the catch trials a movement was initiated indicating failure to detect the change in colour or an anticipatory movement. A three-way within-subject ANOVA revealed that peak movement velocity increased with Object A's velocity, $F(2, 12) = 9.26$, $p < .0037$, and Object B's velocity, $F(2, 12) = 5.02$, $p < .0237$, but not with the final velocity change of the object ($p > .13$).

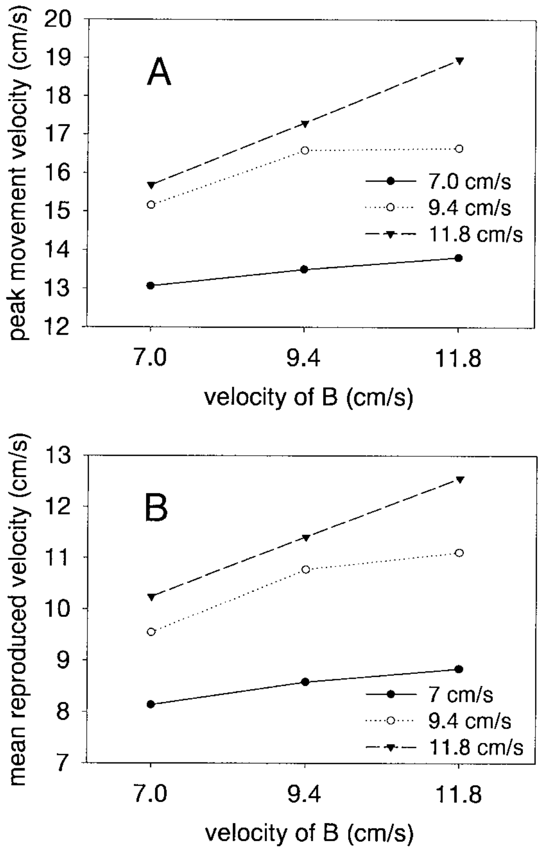

Figure 4. Peak (Panel A) and mean (Panel B) velocities as a function of Object A's and Object B's velocities in Experiment 4. B's final velocity was either zero or 14.2 cm/s.

No other effects reached significance ($p > .48$). Also, significant effects of A's velocity, $F(2, 12) = 8.71$, $p < .0046$, and B's velocity, $F(2, 12) = 9.83$, $p < .003$, on mean velocity were obtained. The effect of final velocity change did not reach significance ($p > .13$). No other effects reached significance ($p > .18$).

Discussion

Although the final velocity was either higher or lower than the velocity of Object B, it did not exert any appreciable effect on reproduced velocity. Given that observers largely detected the catch trials despite the difficulty of the task, it seems implausible that the null effect of final velocity can be explained by observer's attempts to ignore the final part of B's trajectory. Rather, the somewhat smaller effect of Object A's velocity on reproduced velocity indicates that the final change in velocity degrades observers' representation of the initially seen movement. However, it was not the last-seen velocity that distorted memory traces of A's speed but the movement following briefly after the collision.

This finding is consistent with Michotte's (1946/1963) notion of the radius of action but is also consistent with an interpretation in terms of RI.

To discriminate between the two hypotheses, it is necessary to eliminate or reduce the apparent causal impression of the displays. If apparent causality is reduced, the distortion of the first-seen movement by the later movement should be absent if the phenomenal character of the display is relevant. In contrast, RI should be unaffected by this manipulation.

EXPERIMENT 5
Horizontal and vertical motion of Object B

The goal of Experiment 5 was twofold. First, we examined whether a manipulation that affects the phenomenal aspect of the display has an effect on how representations of the causal movement are formed. To this end, we presented sequences in which the apparent causality of the display was diminished but not completely absent. If the phenomenal appearance of the display counts, the integration of A's and B's velocities should be less pronounced than under conditions where the sequence looks causal. On the other hand, if RI explains the effect, the manipulation of apparent causality should be ineffective. The second goal was to test whether perceptual fusion may account for our findings. In the previous experiments, Objects A and B moved horizontally from left to right on a continuous line. At the point of collision, Object A stopped moving and B started to move. Thus, it may be the case that the velocities of A and B are perceptually fused around the point of impact. Two arguments favour this account. First, the movement paths of the two objects are aligned horizontally. Second, the motion offset and motion onset are spatially and temporally contiguous. Both conditions are necessary for perceptual fusion to take place. To rule out this possibility, we separated the movement directions of A and B. While A moved horizontally from left to right, B moved from the point of impact downward. Michotte (1946/1963, pp. 101–103) notes that the impression of launching weakens substantially if the movement paths of A and B deviate from a horizontal line because the bending of the path destroys the unity of the whole event. Similarly, Beasley (1968) reports that the number of observers reporting a causal impression decreases with vertical motion of the second disc.

Method

Participants

A total of 10 students (3 male, 7 female) participated, who fulfilled the same criteria as in Experiment 1.

Apparatus, stimuli, procedure, and data analysis

These were as outlined in Experiment 1 with the following exception. Because the final part of a vertical 15.5-cm trajectory was off-screen, the trajectory of Object B was shortened to 13.5 cm.

Design

A three-factorial within-subject design was used. As in Experiment 1, the velocity of Objects A and B varied randomly between 7.0 cm/s, 9.4 cm/s, and 11.8 cm/s. Two directions of motion of Object B were possible: Object B could move either horizontally from its starting position to the right or vertically from the starting position to the bottom. Within each of the eight blocks, one repetition of the 18 possible combinations of A's and B's velocities and direction of motion was presented. A proportion of 20% catch trials was included to make sure that subjects did not try to ignore the second object. On a catch trial, the colour of the centre of Object B (0.2 cm) was changed to red in the second half of the disc's trajectory.

Results

Mean and peak velocities of the reproduced movement are depicted in Figure 5. Occasional trials (0.2%) that showed irregular movement trajectories were discarded. In 5% of the catch trials a movement was initiated indicating failure to detect the change in colour or an anticipatory movement. A three-way within-subject ANOVA on peak velocity showed that the velocity of the reproduced movement increased with the velocity of Object A, $F(2, 18) = 58.67$, $p < .0001$, and of Object B, $F(2, 18) = 6.03$, $p < .0099$. These effects were modified by an interaction of A's and B's velocities, $F(4, 36) = 2.75$, $p < .0429$, indicating that the influence of Object B was smaller at the slowest velocity of A. Moreover, peak movement velocity was higher when Object B moved down than when it moved from left to right, $F(1, 9) = 11.35$, $p < .0083$. The interaction of direction and A's velocity approached significance, $F(2, 18) = 3.18$, $p < .0655$. No other effects were significant ($p > .5$). An ANOVA on mean velocity confirmed these results. Effects of A's velocity, $F(2, 18) = 69.25$, $p < .0001$, B's velocity, $F(2, 18) = 6.3$, $p < .0084$, direction of B's motion, $F(1, 9) = 6.06$, $p < .036$, and a significant interaction of A's and B's velocities, $F(4, 36) = 2.8$, $p < .04$, were obtained. No other effects reached significance ($p > .16$).

Discussion

As in previous experiments, we obtained a clear effect of Object A's and Object B's velocities on reproduced velocity. The persistence of the effect of Object B's velocity even if the motion paths of A and B were orthogonal rules out perceptual fusion as an explanation. If the two movement trajectories are not aligned, integrating the two motions into a single motion seems implausible. Moreover, the integration of the first and second motions was not modified by direction of motion. That is, the influence of B's motion on the reproduction of A's motion was not influenced by whether the scene looked causal or not. Rather, an illusory feature of the downward movement entered memories for the causal movement. Prior research demonstrated that physically equal velocities are perceived differently depending on the direction of motion (Avery & Day, 1971; Brown, 1931). Vertical motion is judged to be faster than physically equal horizontal motion, a fact that is referred to as the horizontal–vertical velocity illusion. Thus, the pattern of results suggests that the vertical movement condition, which gives only a weak impression of causality, strongly affects memories for the causal movement. Therefore, it appears that phenomenal causality does not contribute to the integration of the two movements.

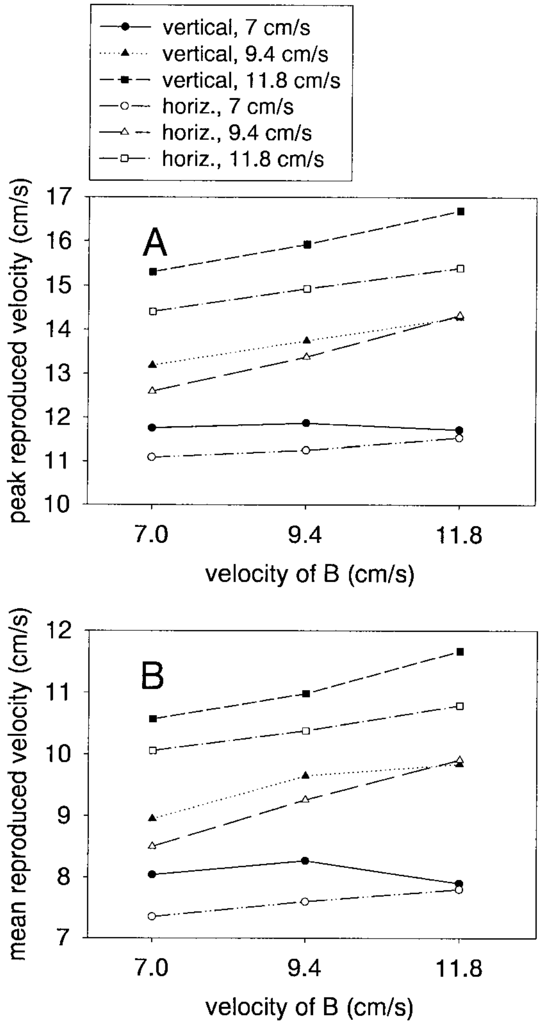

Figure 5. Peak (Panel A) and mean (Panel B) velocities as a function of Object A's and Object B's velocities and direction of Object B's movement in Experiment 5. B could move from the point of impact downward or to the right.

However, a possible objection to this conclusion is that the causality manipulation was not strong enough to affect the integration of cause and effect.

EXPERIMENT 6
Eliminating apparent causality

In order to manipulate apparent causality more clearly, we aim not for the reduction of apparent causality, but for its complete elimination. If apparent causality is absent, the integration of cause and effect movement should not occur if the phenomenal character of the display is decisive. The difficulty in testing this prediction lies in the possible confounds of the required manipulations. In most cases, eliminating causality implies that the spatio-temporal pattern be vastly changed—that is, by delaying the motion of the second motion or inserting a gap between the two movements. However, the task of reproducing the velocity of the first moving object is solved by virtue of a memory representation of its velocity and requires adequate perception of the velocity of the objects. Changing the spatio-temporal pattern may perturb either perception or memory representation of the velocity of the object moving first in ways that are unrelated to the cause–effect relationship of interest.

A solution to the problem is an experiment undertaken by Michotte (1946/1963, pp. 68–69), which he refers to as the "tunnel effect". In this experiment, an object moves from left to right, vanishes behind another object and reappears on the other side of it (see Figure 1). Phenomenally, the object is seen to enter a tunnel and to emerge after a certain time on the other side. Similarly, one may perceive the trajectory of the object to be covered for a certain distance. If the time between vanishing point and reappearance of the object is short, the movement of the object appears continuous (Burke, 1952; Michotte, 1946/1963, p. 69). Under no circumstances is the sequence perceived as causal. Either the continuous motion of one object or the discontinuous motion of one or more than one object is perceived. Thus, the tunnel effect provides an excellent opportunity for studying the effects of a temporally succeeding motion on the reproduction of a prior movement in the absence of apparent causality. In particular, by covering the point of impact we are able to eliminate the impression of causality while the spatio-temporal pattern remains unchanged. Instead of a collision between two objects, the same display yields the impression of the continuous motion of one object. If the phenomenal appearance of objects is decisive in the backward influence of one movement on the representation of a temporally preceding movement, then no effect of the second motion is expected. In contrast, RI should persist but may be altered by the specifics of the stimulus display.

Method

Participants

A total of 10 (all female) participated, who fulfilled the same criteria as in Experiment 1.

Apparatus, stimuli, procedure, and data analysis

These were as outlined in Experiment 1 with the exception that both objects (A and B) were white. A white rectangle measuring 1 cm in width covered Object B in its resting position and the final position of Object A.

Design

The same design as that in Experiment 1 was used. A proportion of 20% catch trials was included. In a catch trial, the colour of a 0.16-cm disc around the centre of Object B was changed to red during the second half of the trajectory.

Results

Mean and peak velocities of the reproduced movement are depicted in Figure 6. Occasional trials (0.5%) that showed irregular movement trajectories were discarded. In 2% of the catch trials a movement was initiated indicating failure to detect the change in colour or an anticipatory movement. A two-way within-subject ANOVA on peak velocity confirmed a significant effect of Object A's velocity, $F(2, 18) = 8.54$, $p < .0025$, indicating that the reproduced velocity followed the speed of A. The influence of Object B's velocity was not significant, $F(2, 18) = 1.78$, $p < .1977$. A significant interaction of A's and B's velocities emerged, $F(4, 36) = 3.30$, $p < .0211$. Separate ANOVAs for each velocity of Object A showed that B's velocity produced a non-significant trend for the slow and medium velocities of A ($p < .073$ and $p < .06$, respectively) but not for the highest velocity ($p > .7$). A second, two-way ANOVA on mean velocity confirmed the effect of A's velocity, $F(2, 18) = 10.13$, $p < .0011$. B's velocity produced a linear trend on mean reproduced velocity, which failed to reach significance,

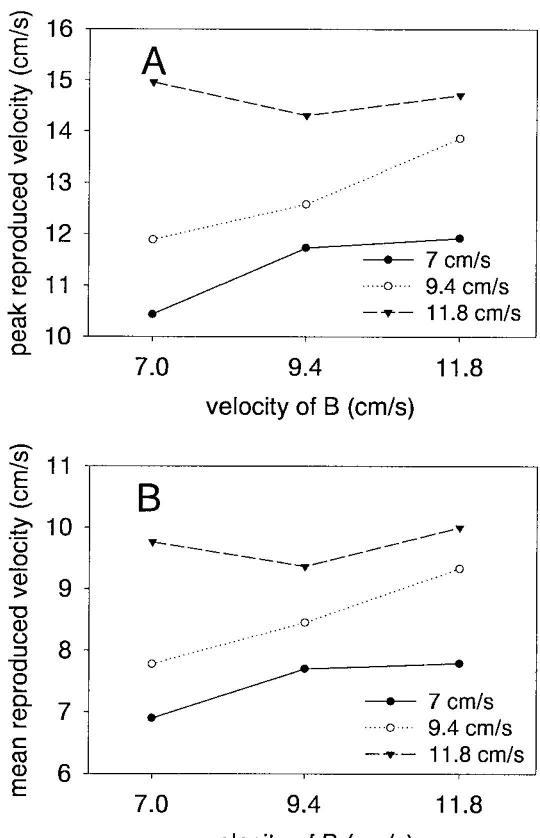

Figure 6. Peak (Panel A) and mean (Panel B) velocities as a function of Object A's and Object B's velocities in Experiment 6. Apparent causality was eliminated by covering Object B.

$F(2, 18) = 3.04$, $p < .0729$. A significant interaction of A's and B's velocities, $F(4, 36) = 2.86$, $p < .0372$, was obtained. Separate ANOVAs for each velocity of Object A showed that mean reproduced velocity was significantly affected by B's velocity at the medium velocity of A ($p < .02$) but not at the lowest and highest velocities (ps $> .13$).

Discussion

In Experiment 6, the uniform effect of Object B's velocity on the representation of A's velocity observed in the previous experiments failed to reach significance. However, we obtained a significant interaction between A's and B's velocities indicating that Object B did affect the representation of A's velocities. Separate ANOVAs and inspection of the data pattern in Figure 6 shows that the effect of B's velocity is present for the medium velocity of A. Although largely diminished, the effect of the second velocity on the representation of the first object's velocity was still present. An additional between-experiment ANOVA indicated that there was no significant difference between Object B's effect in Experiment 1 and that in Experiment 6, for both mean and peak velocities, Fs < 1. This finding is at odds with the assumption that the phenomenal aspect of the objects—that is, their roles of cause and effect—are responsible for the effect. If the causal roles of the first and second motions had produced the effect of a temporally later velocity on the representation of a temporally prior velocity, then this effect should have completely disappeared in Experiment 6. Any impression of causality was absent in Experiment 6, therefore any influence of the causally dependent motion on the representation of A has to be attributed to factors other than phenomenal causality. The persistence of a weaker effect, however, supports the notion of RI. Note, however, that the experiment constituted a particularly strict test of the phenomenal-distortion hypothesis: By covering the collision between the two objects, the impression of a single object passing through a tunnel was created. The phenomenal identity of the object in the first and the second part of the motion definitively promotes the integration of the two movement velocities into the movement of a single object. In light of the possible integration of the two movements, the effect of the second motion on the representation of the first motion is surprisingly small. In Experiment 1, where the first and the second movements were carried by distinct objects, the integration of the two objects was much more pronounced, as the significant main effect of Object B's velocity on the reproduction of Object A's velocity shows. Nonetheless, the complete absence of apparent causality cannot be reconciled with indications of an effect of B's velocity on the reproduction of A. Therefore, we conclude that observers' representations of an apparently causal event are influenced by what it leads to; however, the effect may arise from RI between the temporally prior and the later aspects of the event.

EXPERIMENT 7
Reproduction of Object B

The aim of Experiment 7 was to examine whether proactive inhibition can be obtained in the present paradigm. Proactive interference occurs when new learning is disrupted by old information. For instance, learning of new words is disrupted by prior learning of words (e.g., Keppel & Underwood, 1962; Peterson & Peterson, 1959). Similarly, the representation of Object B's velocity may be distorted by the prior perception of Object B's velocity. To test this interpretation, we asked subjects to watch the same sequence as that in the previous experiments but to reproduce the velocity of Object B.

Method

Participants

A total of 7 students (3 male, 4 female) participated, who fulfilled the same criteria as in Experiment 1.

Apparatus, stimuli, design, procedure, and data analysis

These were as outlined in Experiment 1 with the exception that subjects were instructed to reproduce the velocity of the second disc.

Results

Trials in which the movement was initiated too early or showed an irregular movement trajectory were counted as errors and excluded from the analysis (3%). Peak reproduced velocity increased as a function of Object B's velocity, $F(2, 12) = 84.44$, $p < .0001$, from 11.1 cm/s at the slowest to 13.9 cm/s at the medium and 17.3 cm/s at the fastest velocity of B. No other effect reached significance ($p > .16$). Mean reproduced velocity also increased as a function of B's velocity, $F(2, 12) = 108.72$, $p < .0001$. Mean reproduced velocities were 7.2 cm/s, 9.4 cm/s, and 11.6 cm/s for the three velocities of B. No other effects were significant ($p > .18$).

Discussion

We obtained a clear effect of Object B's velocity on the velocity of the reproduced movement, but no effect of A's velocity. Thus, proactive interference is not obtained for memories of movements in a collision event.

GENERAL DISCUSSION

In the present series of experiments we tested the hypothesis that the representation of a causal movement is influenced by its effect. We displayed collisions between two objects where the movement of one object (A) appeared to be the cause of the movement of a second object (B). When subjects were asked to reproduce the velocity of the causal object, A, we found responses to be influenced by the velocity of Object B, which moved as a result of A's colliding with it (Experiment 1). The velocity of Object B indicated the effectiveness of the collision, therefore, the distortion of memories for A's velocity reflects a tendency to match the apparent strength of the collision with its cause. In further experiments, it was demonstrated that the effect cannot be attributed to different retention intervals (Experiment 2), recency of B's velocity (Experiments 3 and 4), or low-level spatial integration (Experiment 5). To investigate whether the integration of apparent cause and effect was due to the phenomenally causal nature of the event, we reduced (Experiment 5) and eliminated (Experiment 6) causality. The integration of the two movements persisted, however, such that we conclude that the phenomenal aspect of the display contributes little to the effect. Even when completely eliminating the apparent causal nature of the display, we find that the velocity of the last-seen movement affects memories for the causal movement. Our primary hypothesis—namely, that causal movements are influenced by their effects—has been well supported. The mechanism producing this effect, however, appears not to be related to the phenomenal aspect of the display, but rather reflects more general properties of memory. Thus, the more general conclusion to be drawn from our results is that within a two-phase motion sequence, the representation of the velocity of the first motion is influenced by the second.

Theories of retroactive interference

How do our findings relate to other memory-related phenomena? The classical two-factor theory of interference (Melton & Irwin, 1940) attributes RI to two separate processes: to the unlearning of the to-be-remembered item and to the competition between responses associated with the same item. In the present experiments, unlearning seems to play a minor role. When Object B's movement was not visible in Experiment 2, such that the time interval between the presentation of Object A and the participants' recall of A's velocity was the same as in Experiment 1 but with no interference of a second velocity, reproduced velocity was solely a function of A's velocity. It is hard to imagine how different time intervals elapsing between presentation and reproduction may account for the direction of the distortion—that is, for faster reproduced velocities with shorter retention intervals (faster movements of an invisible Object B). Moreover, the subjects' "unlearning" the velocity of A by virtue of "learning" the velocity of B can be ruled out, because subjects were obviously still capable of reproducing A's velocity. The second factor identified in the two-factor model of RI, competition, seems to be a more promising candidate for an explanation of the present results. According to a competition account, the two velocities are independently represented, and they compete in determining the response. Thus, in a number of trials, the subject actually reproduces the velocity of Object B when asked to reproduce A's velocity. In an analysis of variance, this behaviour would show up as a main effect of B's velocity. Given that no qualitative data, such as yes/no or multiple-choice responses, were collected, it cannot be determined on a trial-to-trial basis whether one or the other alternative was selected. However, the failure to obtain proactive interference in Experiment 7 speaks against such an interpretation. Here, subjects had to reproduce the velocity of the second object. If the competition of two independently represented velocities accounted for RI, A's velocity should have interfered with the reproduction of B's velocity in the same way as did B's velocity in the reverse case. However, no such effect could be determined. The reproduction of B's velocity was unaffected by the speed of A.

False post-event information

Loftus showed in a series of classic studies (e.g., Loftus, 1979; Loftus, Miller, & Burns, 1978) that misleading information presented after a to-be-remembered event impairs memory reports of the event. In a test of memory for the original event, subjects are likely to select items presented after the critical event. Loftus (1977) argued that in some cases, memories for the original item and information presented afterwards were blended into a mixed representation. In Loftus (1977) subjects who had received wrong information about an object appearing in a sequence of slides showed a colour shift from the original colour to the wrong post-event colour. The results indicated that elements of the original information were in memory but had been shifted toward the misleading colour information.

Some parallels and differences between the research on false post-event information and our investigations of collision events are evident. First, similar to research on misleading post-event information, we find that memory representations of an event are affected by information presented at a later point in time. Importantly, the direction of the memory shift follows the information presented at a later point in time. In our experiments, the remembered velocity of an object shifts into the direction of a temporally succeeding velocity—that is, we find effects of Object A's and Object B's velocities. Thus, the memory shift is qualitatively similar to findings by Loftus and colleagues because the remembered velocity represents a blend of the two velocities.

Second, unlike research on false post-event information, we sidestep the problem outlined by McCloskey and Zaragoza (1985) that subjects' responses in Loftus (1977) may represent deliberate compromises between original and post-event information. In our experiments, subjects were explicitly asked to reproduce the velocity of A after viewing the movement of A and B. The main effect of A's velocity shows that subjects followed our instructions and were able to reproduce its velocity. Evidence for accurate memories of the to-be-remembered event is important for the claim that blending took place. Otherwise, it is not so much blending but rather response bias that might explain the results. A study of false post-event information explicitly dealing with memories for observed velocities suffers from this interpretational ambiguity. In Loftus and Palmer (1974), subjects were shown movies of traffic accidents, and then they answered questions about the accident. Then, subjects were asked to estimate the velocities of the vehicles. In the question about the velocities, different verbs were used to refer to the collision between the two cars. Whereas the actual velocity of the cars contributed little to the velocity estimates, the kind of question had a marked influence. Thus, subjects appeared to have relied on information outside of the to-be-remembered event, suggesting that their initial perception of the velocities was poor. In contrast, our experimental design ensured that subjects formed a memory representation of the velocity that was to be reproduced. Subjects were instructed to reproduce the velocity of the first object (A), and the reproduced velocity shows a clear effect of A's velocity. Thus, even though subjects manifest a stable representation of the first-seen velocity, we still find influences of a velocity presented later in time. Therefore, both velocities leave traces in subjects' memories, which corroborate the claim that the information was blended. Rather than being completely overwritten by new information, information about the first-seen velocity is altered by the second movement. The blending of two consecutively presented velocities may also underlie the increase in discrimination thresholds for velocities induced by a distractor velocity: Magnussen and Greenlee (1992) consecutively presented two gratings moving at different speeds. The subjects' task was to decide whether the first and the second velocities were the same. They found that when a distractor velocity was presented during the retention interval for reference velocity, discrimination was more difficult. It appears plausible that the first velocity and the distractor velocity were blended in memory, resulting in worse performance.

In sum, the present investigation demonstrates that representations of causal movements are influenced by their effects. The velocity of an apparently causal movement was shifted in the direction of its effect. The phenomenal causal relation between the two movements did not contribute substantially to the effect. When apparent causality was reduced by changing the direction of motion of the second object or when it was absent as in the Michotte's (1946/1963) tunnel effect, the influence of Object B's velocity persisted. Thus, in a two-phase motion sequence, the representation of the first phase is influenced by the second. We suggest that the two velocities are blended in memory. However, the blending of velocities cannot be reduced to recency of the second movement or to perceptual fusion of the two movements.

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