# Michotte's research on perceptual impressions of causality: a pre-registered replication study

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## Abstract

Michotte (1946/1954/1963) showed that visual impressions of causality can occur in perception of simple animations of moving geometrical objects. In the launching effect, one object is perceived as making another object move by bumping into it. In the entraining effect, the two objects move together after contact and the first moving object is perceived as pushing or carrying the other one. There has been much further research on the launching effect in particular, and citations of Michotte's pioneering work have increased rapidly in recent decades, underlining its importance in contemporary psychology and neuroscience. However, many of the experiments reported Michotte's book, exploring conditions under which launching and entraining do and do not occur, have never been replicated. The methodology, involving mostly a few knowledgeable observers and no statistical analysis, indicates that replication and extension would be desirable, to assess the reliability of the results reported by Michotte and to inspire further research on aspects of these perceptual impressions that have been neglected in more recent research. In this pre-registered replication study, fourteen experiments are planned that replicate and, in some cases, extend experiments reported by Michotte (1946/1954/1963).

Michotte's research on perceptual impressions of causality: a pre-registered replication study

When observing simple animations of moving geometrical shapes, we sometimes have perceptual impressions of causality, of one object making something happen to another object. This was first demonstrated by Michotte (1946/1954/1963). In his stimulus, a black square (object A) and a red square (object B) are visible on a screen, as shown in Figure 1. Figure 1(a) shows the initial locations of the objects. The red square is initially stationary. The black square moves horizontally at constant speed until it contacts the red square, whereupon it stops as shown in Figure 1(b). Without delay the red square moves off at the same speed and in the same direction, as shown in Figure 1(c). This stimulus is deliberately highly abstracted. The objects are simple two-dimensional geometrical forms with little clue to their identity, and there is no visual context. It might be expected that observers would perceive only the objects and their motions. In fact, in Michotte's (1963) words, "observers see object A bump into object B, and *send it off* (or '*launch*' it), *shove it forward, set it in motion, give it a push*. The impression is clear: it is the blow given by A which *makes B go*, which *produces* B's movement" (p. 20). Michotte (1946, 1954, 1963) called this perceptual impression the launching effect (l'effet lancement in the original publication). In a variation on that stimulus, the black square continues to move after contact with the red square, so that the two objects move together, remaining in contact. The reported impression is that the black square pushes or carries the red square. Michotte called this the entraining effect. Launching and entraining are both causal impressions, but are qualitatively different. The entraining impression shows that there is more to perceptual impressions of causality than just the launching effect, and indeed there may be multiple qualitatively distinct visual causal impressions (Hubbard, 2013a; Michotte, 1946/1954/1963; White, 2017). The aim of the present research is to replicate, with extensions in some cases, several of the experiments on the launching and entraining effects reported by Michotte (1946/1954/1963).

Figure 1

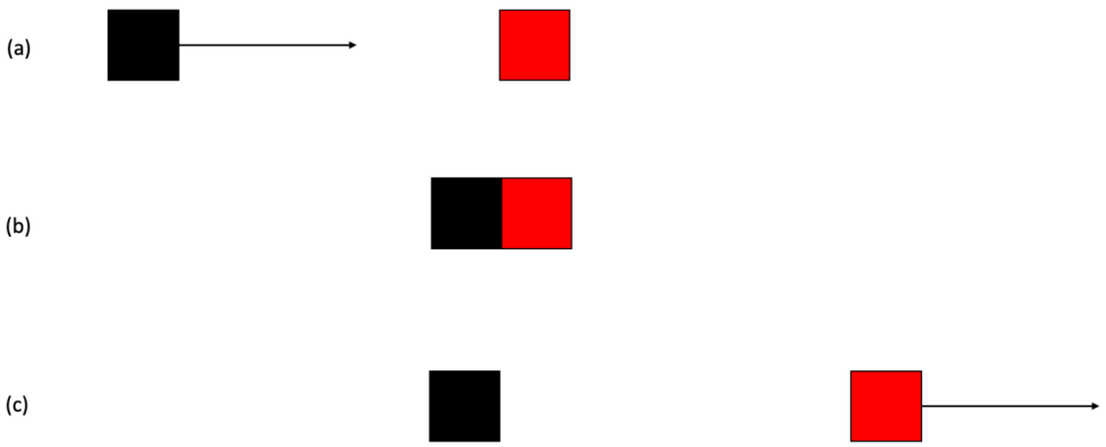


Figure 1. Schematic representation of stimulus for the launching effect used by Michotte (1963). Figure 1(a) shows initial locations of objects and motion direction of the black square. Figure 1(b) shows contact between the objects. At that point the black square stops moving and the red square moves off as shown in Figure 1(c).

The launching effect is well established and has been confirmed in numerous subsequent studies (Gordon, Day, & Stecher, 1990; Hubbard, 2013a, 2013b; Schlottmann, Ray, Mitchell, & Demetriou, 2006; Scholl & Tremoulet, 2000). Evidence from neuroscience, perceptual processing, and developmental studies converges on the conclusion that the launching effect is a perceptual phenomenon, generated in automatic perceptual processing, not a product of post-perceptual cognition. In neuroscience it has been found that typical stimuli for the launching effect activate areas in the visual system of the brain, distinctively from non-causal control stimuli (Blakemore, Fonlupt, Pachot-Clouard, Darmon, Boyer, Meltzoff, Segebarth, & Decety, 2001; Blos, Chatterjee, Kircher, & Straube, 2012; Fugelsang, Roser, Corballis, Gazzaniga, & Dunbar, 2005; Roser, Fugelsang, Dunbar, Corballis, & Gazzaniga, 2005). The perceptual nature of the launching effect is shown by evidence that it can influence other contemporaneous perceptual processing. If a stimulus is presented in which the black square stops before reaching the red square and the gap between them is filled with a stationary object, the size of the gap is underestimated, as compared to non-causal control stimuli (Buehner & Humphreys, 2010). The illusory spatial contraction is greater at the end of the stationary object contacted by the black square than at the other end, further indicating involvement of perceived causality in generating the illusion (Chen & Yan, 2020). The perceived trajectory of apparent motion varies depending on whether the objects in question are causal objects in a launching display or not (Kim, Feldman, & Singh, 2013). Moors, Wagemans, and de-Wit (2017) used a method called continuous flash suppression, in which a dynamic noise stimulus is presented to one eye and a stimulus of interest is presented to the other eye with gradually increasing contrast, until the participant reports detection of any part of the stimulus. Participants did not have to report a causal impression, just any element of the stimulus. Detection occurred sooner for launching stimuli than for non-causal controls, indicating that causality is constructed at an early stage of perceptual interpretation. Typical stimuli for the launching effect induce retinotopic adaptation, meaning adaptation specific to the retinal location to which the stimuli were presented (Kominsky & Scholl, 2020; Rolfs, Dambacher, & Cavanagh, 2013), also indicative of the causal impression being a product of perceptual processing. Developmental evidence further supports the claim that the launching effect is a perceptual phenomenon: infants aged about six months respond to launching stimuli and non-causal controls as if they have a causal impression with the launching stimulus (Kominsky, Strickland, Wertz, Elsner, Wynn, & Keil, 2017; Leslie & Keeble, 1987; Newman, Choi, Wynn, & Scholl, 2008; Muentener & Bonawitz, 2017).

The causal impression does not correspond to what the laws of physics tell us about interactions between inanimate objects. Newton's third law states that objects at contact exert equal and opposite forces on each other. It is as true to say that the red square makes the black square stop as it is to say that the black square makes the red square move. But participants in experiments do not perceive the red square as making the black square stop, and do not mention that possibility in spontaneous verbal reports of their perceptions (Schlottmann et al., 2006). Causality is perceived as going one way, from the black square to the red square (White, 2006). The black square is incorrectly perceived as exerting more force on the red square than the red square exerts on the black square (White, 2007, 2009). The typical stimulus for the launching effect, in which the red square moves at the same speed as the black square, is not even very realistic. Runeson (1983) showed that it lies at one extreme of the range of possibilities allowed by the laws of mechanics, an extreme that would never be encountered in actual collision events. Normally, the object in the role of the red square would move more slowly than the object in the role of the black square, not at the same speed, and the latter would continue to move forward rather than stopping on contact. The typical stimulus for the entraining effect is equally unrealistic because the two objects could only continue to move together without change of speed if the red square had zero mass and the black square adhered to it. Whatever the launching and entraining effects may be, they are not direct or accurate apprehension of what goes on in real inanimate contact events. They are perceptual constructs.

Michotte's research on perceptual impressions of causality has been hugely influential. It has been described as "classic" (e.g. by Guski & Troje, 2003; Hafri & Firestone, 2021; Moors et al., 2017), "seminal" (Choi & Scholl, 2006), it was certainly pioneering, and it continues to influence and inspire research in perception, cognition, developmental psychology, social psychology, cross-cultural psychology, treatment of causality in language, and also in neuroscience (Hubbard, 2013a, 2013b; Scholl & Tremoulet, 2000; Wagemans, van Lier, & Scholl, 2006). Interest in Michotte's research on visual causal impressions is rapidly inceasing. Michotte's book reporting the research was first published in French in 1946, with an extended second edition published in French in 1954, and an English translation of the second edition published in 1963; from this point on only the 1963 edition will be cited because it was the source consulted by the present author. Wagemans et al. (2006) reported that the various editions of the book had, in 2006, been cited 419 times, and they reported data showing a steady increase in citations over the decades. That increase has accelerated since then: at time of writing, consultation of the Web of Science (on Jan. 27th 2023) shows 1382 citations of the book, so the number has more than tripled in just 17 years.

Michotte (1963) reported 95 experiments and numerous additional observations not dignified with experiment numbers. Of the numbered experiments, 44 were concerned with the launching effect, 9 with the entraining effect, and the remainder with various other phenomena such as perception of animal locomotion and qualitative causality (e.g. whether a contact event can be perceived as causing a change in size of an object, without that object moving). Many of the experiments on launching and entraining have never been replicated, and have received little attention in the subsequent research literature. Given the long-standing and ever increasing importance of Michotte's research in general and that on the launching effect in particular (Hubbard, 2013a, 2013b; Thinès, Costall, & Butterworth, 1991; Wagemans et al., 2006), this is an unsatisfactory situation. On the one hand, the reproducability of many of the results described by Michotte (1963) is not known; on the other hand, there is potentially a rich treasure trove of research there, and re-examination of it holds the promise of expanding the scope of research on perceptual impressions of causality. Replication therefore serves the dual purpose of setting some of the results on a firmer footing, or not, as the case may be, and inspiring further research on the topic.

It is not feasible to replicate all of the experiments on launching and entraining. Fourteen experiments will be run in this study: eleven of them are replications or extended replications of Michotte's experiments, one (Experiment 3 below) is based on anecdotal reporting of results by Michotte, and two (Experiments 13 and 14) are novel studies replicating manipulations of gap and delay (described in the next paragraph) but with entraining stimuli. One planned experiment (Experiment 2 below) replicates five of Michotte's experiments in each of which just one stimulus was presented. Another (Experiment 9) replicates and extends three of Michotte's experiments in each of which just one stimulus was presented. There are eight planned experiments on the launching effect and six on the entraining effect.

Experiments on matters peripheral to the causal impression itself, such as the those on the radius of action (the span of movement on either side of the contact event that seemed to observers to have something to do with the contact event) were not selected. Experiments on effects of relative speed of the objects and effects of the direction of the red square motion relative to that of the black square have been replicated and extended (Natsoulas, 1961; White, 2012b), and those variables will not be tested again here. Two variables will be subject to replication attempts here despite the fact that they have been investigated in subsequent research. These are experiments in which the black square stopped before reaching the red square (gap stimuli) and in which there was a delay between the black square contacting the red square and the red square moving off (delay stimuli). Stimuli of both types have been used as non-causal control stimuli in several other studies (e.g. in developmental research using dishabituation methods, such as Leslie & Keeble, 1987, and in neuroscience research, such as Fuglesang et al., 2005). Given the importance of these variables in the literature, and the mixed results of subsequent studies, which will be reviewed under the respective experiment headings below, Michotte's experiments will be replicated as closely as possible, given the unavoidable differences in technology and the lack of exact information about the gap manipulations in Michotte (1963).

The experiments reported in Michotte's book were not conducted in accordance with present-day understanding of methodological rigour. In many experiments the only participants were Michotte alone or Michotte and two experienced and knowledgeable colleagues. In a few, a sample of naive observers took part, but the reports are short on information about the participants, the precise instructions given to them, and data recording. There is no statistical analysis. In some experiments (such as the delay experiment) there are reports of percentages of observations falling into one category or another, but that is all. Michotte's preferred approach was experimental phenomenology: the aim was to capture the qualitative features of perception and, in some experiments, how those features varied with stimulus conditions, the ultimate goal being to construct a theoretical account of the perceptual structure of phenomenal causality. Using an experienced observer was considered a more fruitful means of achieving that goal. Without wishing to denigrate experimental phenomenology, the methodology of the research underscores the need for replication.

Most of the stimuli were created using an ingenious mechanical apparatus involving paper discs mounted on a rotating spindle. The "objects" were thick lines painted on the discs, and they appeared as rectangles to the observer because a screen was interposed in front of the discs with the lines, with a narrow slit revealing to the observer just a short segment of each line. This created the appearance of small rectangular objects. When the disc rotated, the objects appeared to move or stay still depending on how the line was painted on the rotating disc. The slit formed a visible track along which the objects appeared to move. A few experiments used a cinematic projection method. The present research will not be an exact replication in that respect, because computer technology will be used instead of Michotte's apparatus. Most studies since Michotte have used computer presentation and the launching effect clearly does occur with that technology. It is possible, however, that technological differences could affect the results; this issue will be addressed in the general discussion in light of the results when they are known.

In visual appearance the stimuli and manipulations will be as similar as possible to those used by Michotte. The object that moved first in the stimulus for the launching effect was a black square and the other object was a red square and those features will be retained, except where object shape is manipulated. The standard size of object used (with the rotating disc method) was 5 mm square. A larger size of 12.4 mm (40 pixels) will be used in the present research, except where object size itself is a manipulated variable. There will be no visible slit or track: the objects will move in an otherwise plain white frame on the computer screen. The viewing distance reported for the basic launching effect experiment was 1.5 metres and that will be retained. In keeping with Michotte's method, movement of the heads of observers will not be restricted.

Instead of spontaneous reports of perceptual impressions, the present research will use rating scales. Rating scale methods have been used in many studies on perceptual impressions of causality (Hubbard, 2013a) and are an accepted method of collecting data on perceptual impressions. For purposes of replication, the rating scales should capture the forms of words used by Michotte when describing the perceptual impressions. There is inevitably a danger that verbal statements may be interpreted by participants in ways that are different from what they meant to Michotte. However, construct validity requires wording of rating scales to be as similar to Michotte's descriptors (in English translation) as possible. The participants cannot be trained in Michotte's method of experimental phenomenology, and in any case it is important that they should be naive to the research and not influenced by possible bias on the part of the researchers. Asking participants to give unconstrained verbal reports of what they perceive (as in Schlottmann et al., 2006) essentially transfers the problem of interpretation from the participant to the researcher. For any kind of statistical analysis to be done, the statements would need to be subjected to content analysis and defining the content categories in advance so as to ensure validity in categorisation of statements to categories is problematic. And participants cannot be guaranteed to focus on the features of the stimulus that are of interest to the researcher: for example, they might not report a causal impression even if they have one, but just report the motions of the objects instead. So rating scales will be used that take the form of verbal statements based on Michotte's descriptors, and participants will rate their degree of agreement or disagreement with each statement. Different statements apply in different experiments so further details are given in the method sections of the respective experiments.

Stimulus variables either investigated or mentioned in Michotte's reports of the experiments will be manipulated, resulting in parametric designs that can be analysed with analysis of variance (ANOVA). A large sample of naive observers will take part and the experiments will be run by an experimenter naive to the research topic, as well as to the specific aims and hypotheses being tested.

To conclude this section with a typographical convention, the experiments in the present paper will be identified with upper case "E" and Michotte's experiments will be identified with lower case "e" (except at the start of a sentence).

## General features of method

Michotte reported that the launching and entraining effects are not always reported by naive observers at first. He claimed that, after a few trials, the causal impressions did start to occur, and that the initial problem was due to the participants not being used to the artificial conditions of the laboratory, probably including the mechanical apparatus used to present the stimuli. Two subsequent studies with naive participants reported low rates of reporting the launching effect (Beasley, 1968; Boyle, 1960). Effects of experience with the stimuli have also been found (Brown & Miles, 1969; Powesland, 1959; Schlottmann et al., 2006; Woods, Lehet, & Chatterjee, 2012). As Scholl and Tremoulet (2000) argued, those findings can be interpreted as response biases, in other words as effects on how people make overt responses about what they perceive, rather than effects on the perceptual impressions themselves. Effects of fatigue and attention may also be involved (Choi & Scholl, 2004). Deodato and Melcher (2022) presented a long series of stimuli in which delay between contact and the second object starting to move was manipulated, and they found effects on strength of the causal impression of individual preceding stimuli going back as far as eleven stimuli from the one in question. Participants may in addition be reluctant to endorse extremes of the rating scale until they have seen a representative sample of the stimuli, to get an idea of the range of variation in them. On the other hand, Bechlivanidis, Schlottmann, and Lagnado (2019) found that gap and delay stimuli shown before participants have observed a typical launching effect stimulus tended to be given high ratings of causality, and those ratings fell significantly after exposure to a typical launching stimulus. More will be said about that study in the introduction to Experiment 4. It is, however, important to the replication study that participants should, as far as possible, report perceptual impressions and not products of post-perceptual processing. Preliminary experience with the stimuli, and carefully worded instructions, are both important to achieving that end. It was, therefore, decided to start by presenting each participant with a sample of six stimuli chosen to illustrate the variety of stimuli that will be encountered. Participants will just view each stimulus, presented in random order, and no response will be elicited from them. Two of the six will be the typical stimuli for the launching and entraining effects.

In experiment 38 Michotte (1963) manipulated the speed of the objects, with both moving at the same speed, from 4 mm/s to 1100 mm/s. He reported: "The most perfect impression of launching is given with speeds between 20 and 40 cm. per sec. [200 to 400 mm/s] and even a little higher" (p. 107). At speeds around 100 - 150 mm/s he reported that "the impact is slight and lacking in vigour" (p. 107), though the launching effect still occurred. With Michotte's apparatus the apparent motion was macroscopically continuous. With computer-generated stimuli that is not the case. The stimulus is a series of static images replaced at the refresh rate (60 Hz in the present study), and at high speeds one image is displaced by several pixels from the previous one. The very high speeds that supposedly gave rise to the strongest impressions of launching are not practical with computer presentation because the large jumps from one frame to the next can give rise to noticeable blur or disrupt the impression of smooth motion. That could disrupt not only motion processing but also perception of contact between the objects. A compromise must therefore be found between the desideratum of high speed and the need for a sharply defined object in motion to be perceived. With the computer to be used for the experiments, that compromise appears optimal at about 124 mm/s. That was therefore adopted as the standard speed for the objects and is used except where indicated otherwise.

## Participants

The participants will be volunteer first-year undergraduate students of psychology at Cardiff University with normal or corrected to normal vision, participating in return for course credit. Michotte's research is not on the undergraduate curriculum so all should be naive to the research topic. In the cohorts from which the sample will be obtained, approximately 80% are female, most are in the age range 18 - 21 years, and most have British nationality. Informed consent will be obtained from all participants and participants will be given a written debrief at the end of the experiment, as well as having the opportunity to ask questions about the research. Ethical approval has been granted by the Ethics Committee of the Cardiff University School of Psychology.

Power analysis is problematic because designs vary between the planned experiments. A sample of studies using launching stimuli and published since 2000 revealed considerable variation in numbers of participants. Several studies reported between 8 and 20 participants (Guski & Troje, 2003; Kim et al., 2013; Kominsky et al., 2017; Mitsumatsu, 2013; Parovel & Casco, 2006; Ryu and Oh, 2018; Scholl & Nakayama, 2002; Vicovaro & Burigana, 2014; Vicovaro, Battaglini, & Parovel, 2020; Zhou, Huang, Jin, Liang, Shui, & Shen, 2012). A few ran more than 20 but had different dependent measures as a between-subject variable, with numbers varying from 14 to 16 for each dependent variable (Hubbard & Ruppel, 2013, 2017; Sanborn, Mansinghka, & Griffiths, 2013). Of the remainder, in ascending order of numbers, Umemura (2017) ran 27; Vicovaro (2018) ran 40; Young, Rogers, and Beckmann (2005) ran 44; Wang, Chen, and Yan (2020) ran 57 with 32 on a causal judgment measure and 25 on a force judgment measure; Young and Falmier (2008) ran 58; Falmier and Young ran 67 in a four-way mixed ANOVA design; Schlottmann et al. (2006) ran 72 in a study where the measure was free verbal reports; Mayrhofer and Waldmann (2016) ran 934 in an online study with 233 or 234 participants allocated to each of four between-subject conditions. Reliability is a major issue in a replication study and there are indications of substantial inter-individual variability in responses (e.g. Schlottmann et al., 2006; Straube & Chatterjee, 2010). For those reasons it was decided to run a sample towards the higher end of the range in recent research, 50 participants. It is anticipated that data from all participants will be included, barring unforeseen events such as technological failure in data recording. If such events occur, further participants will be run until the target number is reached.

## Apparatus and stimuli

Stimuli will be generated on screen using PsychoPy (Version 3; Peirce, 2007), from instruction files written in Excel. Stimuli will be presented on an iMac desktop computer with a screen resolution of 3.226 pixels per mm, at a frame rate of 60 Hz. The overall size of the screen will be 590 width x 330 mm height. The viewing distance will be that used by Michotte, 1.5 metres. Observers in his studies were free to move so that feature of the method is retained in the present study, and for that reason spatial measurements are given in millimetres rather than degrees of arc.

Summary of general features of stimulus presentations:

Stimuli are presented within a blank white frame 1600 width x 800 pixels height, 496 x 248 mm.

Experiments 1 - 8 are based on the typical stimulus for launching as illustrated in Figure 1; Experiments 9 - 14 are based on the typical stimulus for entraining.

Objects are squares except in Experiment 1 where object width is manipulated and in Experiment 8 which follows Michotte's experiment 33 in using circular discs.

Objects are 12.4 mm on each side except in Experiment 1 where object width is manipulated, Experiment 8 where circular discs with 9.3 mm radius are used, and Experiments 3, 11, and 12, where object size is manipulated.

Objects move horizontally from left to right except in Experiment 2 where some stimuli have objects moving from right to left.

The object that moves first is black and the object that moves second is red, except in Experiment 1 where both objects are black.

Speed of motion is 124 mm/s except for some stimuli in Experiments 1, 7, 9, 10, 11, and 12 where object speed or speed ratio is manipulated.

Object motion continues until the red square exits the frame except in two stimuli in Experiment 2 where objects stop within the frame.

Distance moved by each object varies between stimuli and experiments; the minimum distance used is 124 mm.

Variations from the standard features above are detailed in the method sections of the corresponding experiments.

It was noted above that, with computer presentations, apparently moving objects actually jump by some number of pixels from one frame to the next. In all cases stimuli were designed so that exact contact between the two objects occurred; that is, the static frame in which contact occurred showed no gap between and no overlap of the objects.

## Design plan

Data will be analysed with analysis of variance (ANOVA). Specific designs are described under the individual experiment headings and summarised in Table 1. Because of the large number of experiments, the .01 criterion for statistical significance will be used. Where appropriate, post hoc paired comparisons will be carried out using the Tukey test with the significance level set at .05. Effect sizes will be calculated using the partial eta squared measure.

Table 1

Design plan for all experiments: manipulated variables and statistical tests

| Experiment | Design |
|---|---|
| | Experiments 1 - 8: launching stimuli |
| 1 | Object width (10 widths in equal increments from 0.62 mm to 6.2 mm).<br>Speed of both objects (62 mm/s v. 124 mm/s).<br>Analysed with two-way ANOVA (within-subjects). |
| 2 | Five different visual camouflage stimuli. Each will be analysed separately twice:<br>One-way ANOVA comparison with standard launching stimulus (within-subjects).<br>One-way ANOVA for presence v. absence of fixation point (between-subjects). |
| 3 | Size of black square (2.48 mm v. 12.4 mm v. 93 mm).<br>Size of red square (2.48 mm v. 12.4 mm v. 93 mm).<br>Analysed with two-way ANOVA (within-subjects). |
| 4 | Delay between black square contacting red square and red square moving (13 delays in equal increments from 0 ms to 200 ms).<br>Analysed with one-way ANOVA (within-subjects). |
| 5 | Pause in motion of single object (13 pause durations in equal increments from 0 ms to 200 ms). |

| | |
|---|---|
| | Analysed with one-way ANOVA (within-subjects). |
| 4 & 5 | Results will be subject to correlation analysis to assess similarity in effects of pause and delay. |
| 6 | Gap size (3.1 mm v. 6.2 mm v. 12.4 mm v. 24.8 mm v. 46.5 mm v. 68.2 mm v. 89.9 mm).<br>Object speed (74.3 mm/s v. 124.0 mm/s v. 186.0 mm/s).<br>Analysed with two-way ANOVA (within-subjects). |
| 7 | Speed ratio of black square before contact to red square after contact (2:1 v. 3:1 v. 4:1 v. 6:1)<br>Speed of red square after contact (18.6 mm/s v. 37.2 mm/s v. 74.4 mm/s)<br>Presence v. absence of fixation point (between-subjects).<br>Analysed with three-way mixed design ANOVA. |
| 8 | Stopping location of black disc with five locations.<br>Analysed with one-way ANOVA (within-subjects). |
| | <u>Experiments 9 - 14: entraining stimuli</u> |
| 9 | Speed ratio of black square before contact to red square after contact (2:1 v. 3:1 v. 4:1 v. 6:1).<br>Speed of both objects after contact (18.6 mm/s v. 37.2 mm/s v. 74.4 mm/s).<br>Presence v. absence of fixation point (between-subjects).<br>Analysed with three-way mixed design ANOVA. |
| 10 | Speed of black square before contact (62 mm/s v. 124 mm/s v. 186 mm/s).<br>Speed of both objects after contact (62 mm/s v. 124 mm/s v. 186 mm/s).<br>Analysed with two-way ANOVA (within-subjects). |
| 11 | Speed of small (red) object (62 mm/s v. 124 mm/s v. 186 mm/s).<br>Spatial relations of objects (see Table 2 for details).<br>Analysed with two-way ANOVA (within-subjects). |

12 Speed of large (red) object (62 mm/s v. 124 mm/s v. 186 mm/s).

Spatial relations of objects (see Table 3 for details).

Analysed with two-way ANOVA (within-subjects).

13 Delay between black square contacting red square and both objects moving (13 delays in equal increments from 0 ms to 200 ms).

Analysed with one-way ANOVA (within-subjects).

14 Gap size (3.1 mm v. 6.2 mm v. 12.4 mm v. 24.8 mm v. 46.5 mm v. 68.2 mm v. 89.9 mm).

Object speed (74.3 mm/s v. 124.0 mm/s v. 186.0 mm/s).

Analysed with two-way ANOVA (within-subjects).

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Note: All experiments have multiple dependent measures (see method sections of individual experiments). Each will be analysed separately.

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## Procedure

The experiments will be run in a small windowless laboratory with fluorescent lighting giving a moderate ambient light level. Each experiment will have its own written instructions, including the dependent measures for the respective experiments, and the experimenter will check that the participant has understood the instructions each time. When the participant indicates that they have understood the instructions, the experimenter will show them how to proceed through the stimuli and responses with mouse clicks. Participants will then proceed through the stimuli for each experiment at their own pace, under supervision. Order of experiments will be randomised independently for each participant and order of stimuli within experiments will be similarly randomised. In each experiment, each stimulus will be presented once to each participant. Given the large total number of stimuli, participants will be permitted to take short breaks between experiments.

Initially, a series of six stimuli chosen from the experiments and including typical stimuli for the launching and entraining effects will be presented in random order. Before these are presented, participants will be instructed that the experiments are concerned with their impressions of what they see, not with any thoughts they might have about the stimuli, and that the series of stimuli is to give them an idea of the kinds of stimuli that will be encountered in the experiments. They will be instructed to observe the stimuli and that no response is required, and they will be invited to ask questions if they have any. The experimenter will answer questions, where possible, emphasising if necessary that it is the visual impression of the stimuli that is of interest. The experimenter will be naive to aims and hypotheses so will not be able to give information that might bias participant responses.

## Experiment 1: object width

Experiment 1 is based on experiment 10 in Michotte (1963, p. 49). In experiment 10 the width of the objects was reduced from 5 mm to 1 mm and Michotte reported that the launching effect did not occur. Instead there was an impression that he termed the Tunnel Effect, which is an impression of one object passing over or behind another. Impressions of one object passing over another object have been reported in several experiments by Scholl and colleagues (Choi & Scholl, 2004, 2006; Scholl & Nakayama, 2002, 2004). In those experiments, the object that moved first stopped at a point where it partly or completely occluded the other object, and various manipulated factors influenced whether the first object was perceived as launching the other object or as passing over it. Michotte's experiment 10 is different in that the passing impression was reported when there was no overlap of the objects, and it has not previously been replicated.

## Method

Michotte did not report any variations on the stimulus in experiment 10. Experiment 1 is therefore an extended replication. Stimuli were based on the launching effect stimulus depicted in Figure 1. Object width (of both objects) is varied from 0.62 mm to 6.2 mm in increments of 0.62 mm (2 pixels), resulting in ten different widths. The height of the objects is 12.4 mm in all stimuli. Speed is manipulated with two values, 124 mm/s and 62 mm/s, with both objects moving at the same speed in any given stimulus. Both objects are the same colour (black) so that colour difference could not be used as a cue to interpret what happened.

Written instructions to participants began as follows: "In this experiment you will see a series of short movies, about one or two seconds in duration, each involving two objects, both black rectangles. Each movie will begin with one rectangle moving towards the other. We are interested in what you see when the moving rectangle reaches the other one, the visual impression you have of the movies, not any thoughts you might have about what you are seeing. For each movie you will be asked to rate the extent to which you agree or disagree with each of three statements as descriptions of your visual impression of what happened. The three statements are as follows:

The initially moving rectangle made the other rectangle move by bumping into it.

The initially moving rectangle passed across the other rectangle, which moved little or not at all.

The initially stationary rectangle moved off when the moving one reached it, but it moved independently and its motion was not caused by the other rectangle.

You should rate your agreement or disagreement with each statement as a description of your visual impression, by entering a number from 0 to 10. The more strongly you agree with a statement, the higher the number you should put, up to a maximum of 10. The more strongly you disagree with a statement, the lower the number you should put, down to a minimum of 0 (zero)."

The statement for passing is based on Michotte's description of the Tunnel Effect. The statement for independent motion is also based on Michotte's preferred form of expression - the term "independent(ly)" was used frequently in Michotte (1963) in described impressions of stimuli in which the launching effect did not occur.

## Experiment 2: camouflage

Experiments 20 - 26 were called camouflage experiments by Michotte (1963). The basic principle was to present a typical stimulus for launching but in a context of other movements, by one or both of the two objects themselves or by additional objects. In experiments 22 and 23 one of the objects changed shape without otherwise moving. Experiment 2 is a replication of the other five experiments (20, 21, 24 - 26).

In experiment 20 the red square was the leftmost of a series of five red squares with gaps of 1.5 mm between them. Figure 2 depicts the sequence of events in this stimulus. When the black square begins to move, the rightmost of the red squares starts moving to the right. Each one in turn starts moving with the same velocity at regular intervals, timed so that the leftmost one starts to move when the black square contacts it. The red squares continue to move until they have exited the frame. Thus, it is a standard launching stimulus, but with a visible context of other moving objects. Michotte (1963) reported that the launching effect did not occur with this stimulus, unless the point of contact between the black square and the leftmost red square was fixated.

Figure 2

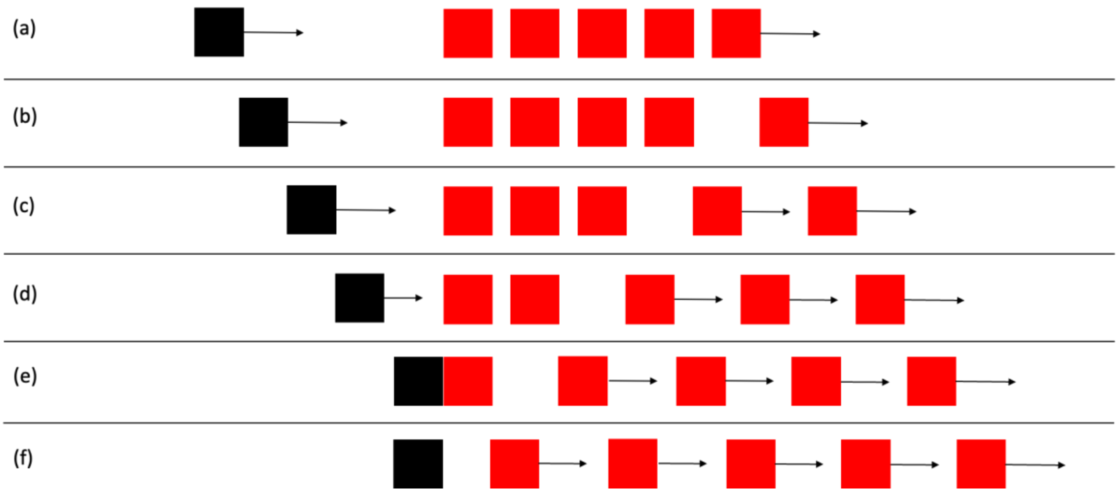


Figure 2. Schematic representation of camouflage stimulus in Experiment 2, based on Michotte (1963, experiment 20). Figure 2(a) shows the first frame of the stimulus: the black square starts to move and the rightmost red square also starts to move with the same velocity. Figure 2 (b) shows these object motions continuing. In Figure 2(c) the next red square has also started to move with the same velocity. Figure 2(d) shows the next red square moving in the same way. Figure 2(d) shows the frame in which the black square contacts the leftmost red square. At that point the fourth red square has also started to move, and the black square stops. Figure 2(e) then shows the leftmost red square moving off as in the standard stimulus for the launching effect (Figure 1). Equal amounts of time elapse between successive onsets of motion in the red squares.

In experiment 21, when the black square started moving, the red square moved to the right then back to its starting position and repeated this, with the motion timed so that it reached its starting position just as the black square arrived there. Apart from that the stimulus was a standard launching stimulus. Michotte reported that the launching effect did not occur "when observers look at the situation as a whole" (1963, p. 74) but that it did occur when the contact point was fixated.

In experiment 24 a third object was added. In the present experiment this object is coloured blue to distinguish it from the other two objects. This object started to the right of the red square and moved toward it, timed so that contact with the red square coincided with contact of the black square with the red square. The third object then continued to move to the left. The motion sequence is schematically depicted in Figure 3.

Figure 3

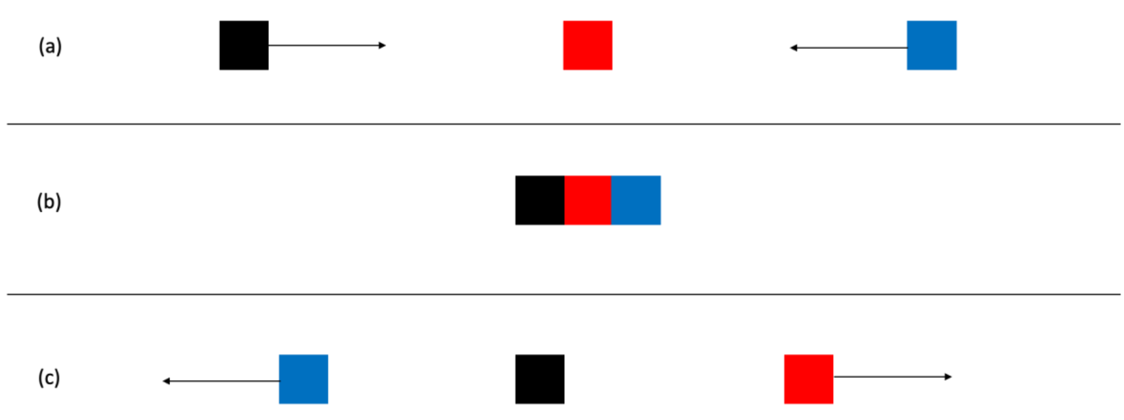


Figure 3. Schematic representation of camouflage stimulus in Experiment 2, based on Michotte (1963, experiment 24). Figure 3(a) shows the first frame of the stimulus with motion directions indicated for the black square and the blue square. Figure 3(b) shows the frame in which the black square and the blue square contact the red square. At that point the black square stops and the red square moves off as in the standard stimulus for the launching effect. The blue square continues to move to the left, passing behind the black and red squares. Figure 3(c( shows the continuing motion of the red and blue squares.

Experiment 25 was similar to the typical stimulus for launching except that, on contacting the red square, the black square returned to its starting point at the same speed. Michotte reported that the launching effect did not occur.

In experiment 26, the red square was initially located further to the right than usual. Both objects started moving towards each other simultaneously. When they came into contact, the black square stopped and the red square moved to the right as in the typical launching stimulus. Michotte reported a strong launching effect with this stimulus.

These experiments are potentially important to any theoretical account of perceptual impressions of causality because the typical stimulus for launching is there in all of them, but (with the exception of experiment 26) the launching effect does not occur. It is important to understand why the launching effect is eliminated by the presence and movement of other objects. Experiment 2 is just a replication of Michotte's experiments, but there would seem to be many possible variations that might shed much light on what is perceived.

## Method

Stimuli matching the descriptions of those used by Michotte and summarised above were constructed. In experiments 20 and 21 Michotte (1963) commented that the launching effect did occur if the point of contact between the black square and the red square was fixated. For this reason, for all of the stimuli a fixation point, a small black cross, is located adjacent to the point of contact and presence v. absence of the fixation point will be manipulated between-subjects with 25 participants in each condition.

It is not easy to prepare instructions for participants in the no-fixation condition that do not carry an implicit demand for them to fixate on the contact point: they are, after all, reporting on their perception of what happens at contact. The instructions for the condition without the fixation point therefore draw on the language used by Michotte, as quoted above: "In this experiment you will see a series of short movies, about one or two seconds in duration, in which two or more moving objects will appear. We are interested in what you see, the visual impression you have of the movies, not any thoughts you might have about what you are seeing. You should look at the movie and the objects in it as a whole. At some point during the movie a black square will contact a red square and the red square will move away. For each movie you will be asked to rate the extent to which you agree or disagree with each of two statements as descriptions of what you saw. The two statements are as follows:

The black square made the red square move by bumping into it.

The red square moved when the black square reached it, but it moved independently and its motion was not caused by the black square."

Instructions for rating agreement or disagreement are as in Experiment 1.

Instructions for the fixation group are similar except that the sentence "You should look at the movie and the objects in it as a whole" was replaced by the following: "You will see a small black cross on the screen. You should look at this cross throughout the duration of the movie and not look anywhere else". These two sentences are underlined to make them salient to the participant. The experimenter will verbally remind participants of this before each movie.

Data for each stimulus will be subject to two analyses. Each will be compared with data from a standard launching stimulus (this will be the 12.4 mm x 12.4 mm size condition from Experiment 3) to assess whether the launching effect is significantly reduced by the camouflage manioulation. And presence v. absence of fixation point for each stimulus will be analysed.

## Experiment 3: object size

On pp. 82 - 83 Michotte (1963) discussed variations in object features and reported that variation in colour, size, and shape did not affect the occurrence of the launching effect. In relation to object size he did not number any experiments but reported that "various" experiments were run using the projection method in which the objects were circles ranging from 2 to 28 cm in diameter. He commented, "In the normal conditions for these experiments - in particular when the point of impact is fixated throughout - the Launching Effect is produced consistently. Sometimes, admittedly, there are differences of degree in this impression, and there are also individual variations between subjects" (p. 82). But, he concluded, "no difference in size, within the limits used... is found to be absolutely incompatible with the Launching Effect" (p. 82). This rather inexact account leaves open the possibility that the launching effect might vary depending on object size, so Experiment 3 was designed to test this. The reference to a fixation point also suggests that fixation might make a difference to the perceptual impression so the experiment was designed to test that as well.

## Method

Three sizes are used, squares of 2.48 mm, 12.4 mm, and 93 mm, manipulated independently for each object. As in Experiment 2, presence v. absence of a fixation point is manipulated between subjects with 25 participants in each condition. The design, therefore, is a 2 between (presence v. absence of fixation point) x 3 within (size of black square) x 3 within (size of red square) design.

Instructions to participants in the no-fixation condition are similar to those for Experiment 1 but with two differences. The statement that both rectangles were black was replaced with a statement describing the objects as a black square and a red square and the black and red square terminology is used throughout the instructions. The two statements in Experiment 2, the launching and independent motion statements, are used here as well. Instructions to participants in the fixation condition are similar to that except that the instructions for fixation from Experiment 2 were added. As in Experiment 2, the experimenter will verbally remind participants of the need to fixate the cross.

## Experiment 4: delay

Experiment 4 is a replication of experiment 29, in which delay was introduced between the black square contacting the red square and the red square starting to move. Michotte used 13 delays in increments of 14 ms from 14 ms to 182 ms. This cannot be exactly replicated with the present technology because the time span of a single frame is 16.7 ms, so 13 delays in increments of 16.7 ms are used, from 0 ms to 200.0 ms.

Michotte (1963) reported that, even with a delay of 70 ms, reporting of the launching effect was reduced and, with a delay of 154 ms, it was all but extinguished. He reported that, at intermediate delays, the launching effect occurred but with some time lag: "Object B [the red square] 'sticks' to object A [the black square]; its departure takes place only after some delay" (p. 92). This "delayed launching" impression was the predominant response with delays around 98 ms. After that it declined and perception of independent motion increased. Replication therefore requires inclusion of a statement based on Michotte's description of this delayed launching impression.

Several subsequent studies have manipulated delay. Three studies presenting incremental delays similar to those used by Michotte (1963) found similar rapid declines in reported perceptual causality as delay increased beyond 50 ms to about 200 ms (Deodato & Melcher, 2022; Sanborn et al., 2013; Woods et al., 2012) . Results of other studies suggest that sensitivity to delay might not be as acute as Michotte (1963) reported. Meding, Bruijns, Schölkopf, Berens, & Wichmann (2020) had a delay manipulation with several delays from 0 ms to 400 ms and found a decline in ratings as delay increased, but even with zero delay the mean rating was not much above the mid-point of their scale. Guski and Troje (2003) found a steeper decline from a higher mean at zero delay. Schlottmann et al. (2006) presented a launching stimulus with a delay of 1250 ms and found that 8% of 72 participants gave spontaneous descriptions suggestive of physical causality. However, considering only those who saw the delay stimulus before any of the others, 50% (6/12) gave physical causality responses. Bechlivanidis et al. (2019) used a stimulus with 250 ms delay. If the delay stimulus was the first one presented, mean ratings were above 60 on a 101-point scale. If the delay stimulus was then presented again after a typical launching stimulus with zero delay, mean ratings were significantly lower, and below the scale mid-point. This change in ratings suggests that at least some participants, were, initially, reporting a post-perceptual judgment rather than a perceptual impression: a perceptual impression would not change significantly after only three stimulus presentations. The likelihood of post-perceptual judgment being involved was increased by the wording of the question for the rating task, which was that used by Schlottmann et al. (2006), except for a change in the colour of the second object: "Do you have the impression that red somehow made blue move?" (Bechlivanidis et al., 2019, p. 789). The word "somehow" invites speculation which is perhaps undesirable in a study of perception and "having an impression" can refer to non-perceptual cognitive processes in common parlance - e.g. "I had the impression that he didn't like me".

Overall, therefore, results for delay manipulations have been variable. It seems likely that wording of the statement or question to be rated is of some importance and merits further investigation. As a first step forward, this study was designed to replicate as closely as possible the stimuli that Michotte used, and with a form of wording in the instructions that emphasised the need to report a visual impression. Comparison of such a form of words with those used in the other studies cited here should be a priority for future research.

## Method

There is a single variable, delay at contact, with 13 delays ranging from 0 ms to 200.0 ms in increments of 16.7 ms. Instructions to participants are as in Experiment 3 (non-fixation condition) except that three statements are presented for rating, as follows:

"The black square made the red square move by bumping into it.

The black square made the red square move by bumping into it, but the red square seemed to 'stick' to the black square briefly before moving off.

The red square moved when the black square reached it, but it moved independently and its motion was not caused by the black square."

The second of these was designed to capture Michotte's description of the delayed launching impression.

## Experiment 5: pausing of a single object in motion

This was a replication of experiment 30. In that experiment there was just a single object that moved for a distance equal to that of the motions of the black and red squares in experiment 29. A pause in the movement was introduced partway through. Pause durations were manipulated in the same way as delay durations in experiment 29. Michotte (1963) reported that short pauses were not perceived; that is, motion was perceived as continuous. At pauses of moderate duration, a percept of discontinuity was reported "which is still compatible with the unity of the whole, i.e. the 'movement in two stages'" (p. 96). That impression peaked with a pause duration of 70 - 87 ms. With longer pause durations there was an impression "of a halt, or definite pause, and together with this the impression of two separate movements" (p. 96). The importance of this experiment is that the effect of delay in experiment 29 was closely correlated with the effect of a pause in experiment 30. The launching effect was reported for delay durations that matched pause durations where motion was reported as continuous. At pause durations where motion was perceived as discontinuous (in experiment 30), the percept of delayed launching tended to occur (in experiment 29); and, at durations where motion was perceived as having two components with a halt between them (in experiment 30), the percept of independent motion tended to dominate (in experiment 29). This suggests that the perceptual impression of causality might depend critically on perception of continuity of motion across the two objects, which could be important to an understanding of the launching effect. Experiment 5 was therefore designed with a single object in motion and with incremental pause durations matching those used in Experiment 4. Results will be correlated with those of Experiment 4.

## Method

The experiment involves stimuli in which a black square moves across the screen on the same motion path as the combined motions of the black and red squares in the corresponding animations in Experiment 4. Halfway through this motion (equivalent to the point of contact between the objects in the Experiment 4 stimuli) a pause is introduced with 13 durations increasing in increments of 16.7 ms from 0 ms to 200.0 ms. Thus, the pause durations in this experiment matched the delay durations in Experiment 4. Three statements were created for the rating task designed to reflect Michotte's descriptions of the impressions that occurred.

Written instructions to participants read as follows: "In this experiment you will see a series of short movies, about one or two seconds in duration, each involving one moving object, a black square. We are interested in what you see, the visual impression you have of the movies, not any thoughts you might have about what you are seeing. For each movie you will be asked to rate the extent to which you agree or disagree with each of three statements as descriptions of what you saw. The three statements are as follows:

The motion of the black square seems continuous without any break or pause.

The motion of the black square seems like a single movement but in two stages with a brief discontinuity or pause in the middle.

There is an impression of two separate movements with a halt or definite pause in the middle."

Instructions for rating agreement or disagreement were as in the previous experiments.

## Experiment 6: gap

This is based on experiment 31 in which the projection method was used. The first moving object (a circle of light 35 mm in diameter) stopped before reaching the initially stationary object (a similar circle of light). Michotte reported that the launching effect could occur despite the presence of a gap between them. The reporting of results is anecdotal but it is clear that speed was a critical factor, and that the launching effect could occur despite the presence of a substantial gap if the speed was sufficiently great: Michotte reported that even a gap of 500 mm "did not necessarily make the causal impression disappear" (p. 100). Yela (1952) ran a study with 250 naive participants and found that the numbers reporting the launching effect fell from 100% with zero gap to 28% with a 90 mm gap. In a further study Yela (1952) replicated Michotte's delay manipulation and found that the effect of delay on the launching effect was similar for all gap sizes, up to a maximum of 50 mm. Yela concluded that "The impression of pushing [launching] is bound to continuity in time, but indifferent to continuity or discontinuity in space" (p. 146). Some studies since then have reported very low causal ratings with even quite small gaps (Fugelsang et al., 2005; Sanborn et al., 2013; Schlottmann & Anderson, 1993; Schlottmann et al., 2006). Perhaps the most extreme result was that reported by Sanborn et al. (2013): with speeds ranging from 60 mm/s to 150 mm/s, ratings in their causal judgment task were low with gaps as small as 2 mm.[1] There is a striking contrast between these recent results and those reported by Michotte (1963) and Yela (1952).

This brief review indicates that there is some uncertainty about the effect of gaps on the causal impression, and particularly about the role of object speed. Some studies have used gap stimuli as non-causal controls for launching effect stimuli (Cohen & Amsel, 1998; Falmier & Young, 2008; Fugelsang et al., 2005; Leslie, 1982; Roser et al., 2005); the results reported by Michotte (1963) and Yela (1952) suggest that this might be inadvisable unless the gap is large and the speeds are high.

Exact replication of experiment 31 is not possible, partly because of technological differences and partly because of the inexactness in the reporting of manipulations and results (Michotte, 1963). Also, the largest gaps used by Michotte (1963) are greater than the size of the screen to be used for the present experiment. It was decided to sample a range of gaps up to the maximum used by Yela (1952), 90 mm. Given the likely importance of object speed, speed (of both objects) was also manipulated.

## Method

There are two independent variables. Gap size is manipulated with seven values, 3.1 mm, 6.2 mm, 12.4 mm, 24.8 mm, 46.5 mm, 68.2 mm, and 89.9 mm. Three speeds are used, 74.3 mm/s, 124.0 mm/s, and 186.0 mm/s, with both objects having the same speed in any given stimulus. This makes a 7 within (gap size) x 3 within (speed) ANOVA design.

The instructions needed to be modified to take account of the fact that the black square does not come into contact with the red square. The first paragraph of the instructions therefore read as follows: "In this experiment you will see a series of short movies, about one or two seconds in duration, each involving two objects, a black square and a red square. Each movie will begin with the black square moving towards the red square. We are interested in what you see when the black square stops moving and the red square starts moving, the visual impression you have of the movies, not any thoughts you might have about what you are seeing. For each movie you will be asked to rate the extent to which you agree or disagree with each of two statements as descriptions of your visual impression of what happened. It may still be possible to have a visual impression that the black square made the red square move, even when they do not come into contact. You should rate your agreement or disagreement with each of the statements based just on your visual impression, not on what you think is possible". The two statements were as follows:

"The black square made the red square move.

The red square moved independently and its motion was not caused by the black square."

## Experiment 7: chasing

This is based on experiment 17. In that experiment the two objects started moving at the same time and in the same direction. The black square moved faster than the red square and caught up with it. When the black square contacted the red square the former stopped and the latter continued to move. The stimulus resembles the typical stimulus for launching except for the motion of the red square prior to contact. Michotte (1963) reported that the launching effect occurred with these stimuli but not so much if the black square's speed was only a little faster than that of the red square. Michotte also claimed that the launching effect occurred if the speed of the red square did not change after contact, and even if the red square slowed down after contact. Speeds and distances moved cannot be exactly the same as those used by Michotte (1963), but a range of speed ratios was devised that overlaps with the range used by Michotte. To achieve this, the speed of the red square before contact was held constant at the 37.2 mm/s and the speed of the black square was manipulated.

### Method

In this experiment, the red square moves before contact at 37.2 mm/s and the speeds of the black square are set to bring about speed ratios of 2:1, 3:1, 4:1, and 6:1. After contact the red square moves at either 74.4 mm/s, 37.2 mm/s (the same as the speed before contact), or 18.6 mm/s.

In addition, a fixation manipulation is included as a between-subjects variable with 25 participants in each of two conditions. Participants will be instructed to fixate the black square in one condition and the red square in the other. This was so that the design of this experiment would be similar to that of Experiment 9, described below, where a fixation condition is required because Michotte (1963) commented that what was perceived depended on which object was fixated. Experiment 9 the same as Experiment 7 but with entraining rather than launching stimuli. Michotte did not mention fixation in connection with experiment 17, but it could be enlightening to see whether launching and entraining are similarly affected by differences in fixation, so in that respect this experiment is an extended replication. This results in a 2 between (fixation, black square v. red square) x 4 within (speed ratio) x 3 within (red square post-contact speed) ANOVA design.

Speeds are at the slow end of the range used by Michotte but the limited size of the computer screen imposes certain constraints on speed: if both objects are in motion at speeds that are not very different, for one to catch up with the other requires a lot of space, especially if the speeds are fast. This is not an exact replication, therefore, but it should suffice to determine whether the launching effect can occur when the red square slows after contact.

Wording of statements for the rating task is problematic in this experiment. It would not be right to have a statement saying that the black square made the red square move because participants might disagree with this on the grounds that the red square was already in motion before contact occurred. Therefore statements referring explicitly to the motion of the red square after contact were constructed. In the black square fixation condition there is a further sentence reading "Please keep your gaze on the black square all through the movie". In the red square fixation the same wording is used except that "red" was substituted for "black". The experimenter will verbally remind participants of this before each movie.

Written instructions are similar to those for the non-fixation condition of Experiment 3, with two exceptions. The instructions for fixation described above were inserted, and two statements are presented for rating, as follows:

"The motion of the red square after contact was brought about by the black square bumping into it".

"The motion of the red square after contact was independent of that of the black square and not caused by the black square".

## Experiment 8: vertical displacement of motion path

In the typical stimulus for the launching effect, as depicted in Figure 1, the black square contacts the red square full face on. In experiment 33, Michotte (1963) used the projection method and the objects were circles. The first moving object's path was vertically displaced. In Michotte's words: "Object A sets off and takes up position immediately above or below B and in contact with it. At this moment B starts to move in its turn, and follows a route parallel to the prolongation of the route followed by A" (1963, p. 101). Michotte reported that the launching effect did not occur with this stimulus. This kind of displacement has not been investigated since Michotte's research. Part of the reason for replicating the study is that it is a different type of gap stimulus. Michotte (1963) and Yela (1952) found that the launching effect can occur even with substantial gaps in the horizontal plane. This experiment will show whether the same is the case for gaps in a different plane of motion. This could have relevance to theoretical accounts of the launching effect. This is an extended replication, with five different stopping positions for the black disc, as described in the method section and depicted in Figure 4.

### Method

Michotte used discs in experiment 33, so in this experiment black and red discs with 9.3 mm radius are used instead of the black and red squares. In one movie the black disc stops at a point where it is vertically aligned and in contact with the red disc. In four other movies the black disc follows the same motion path but stops two diameters before the red square, one diameter before, one diameter after, and two diameters after. This is therefore a one-way ANOVA design with five values. Figure 4(a) shows the starting locations of the objects and the direction of the black disc's motion. Figure 4(b) shows the five locations at which the black disc stops moving. When the black disc stops moving, the red disc moves off horizontally as the red square does in Figure 1.

<u>Figure 4</u>

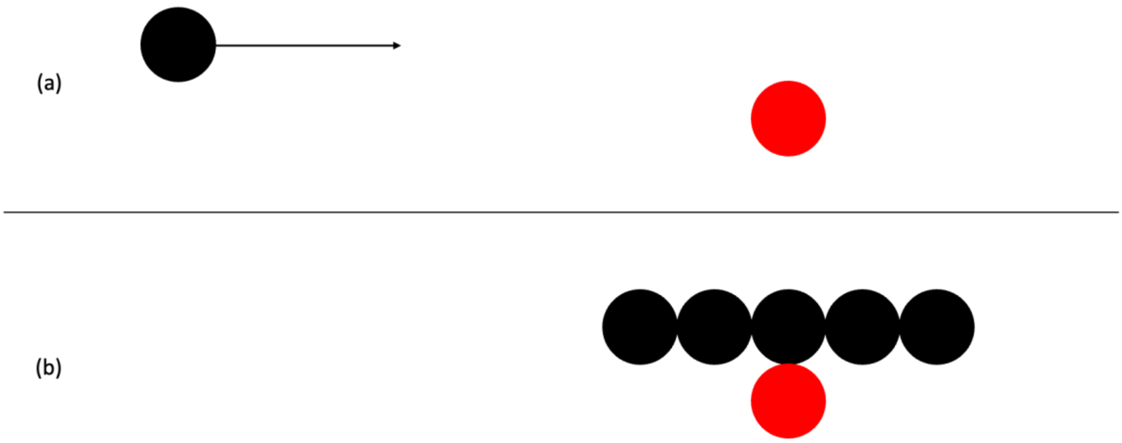


Figure 4. Schematic representation of stimuli used in Experiment 8. Figure 4(a) shows the first frame of the stimulus and the motion direction of the black square. Figure 4(b) shows the five different locations at which the black square stopped. In each case the red square started to move horizontally to the right as soon as the black square stopped.

Wording of the statements for the participants is problematic here as well. It cannot be said that the black disc makes the red disc move by bumping into it because, in some movies, the black disc does not contact the red disc. Also, Michotte (1963) reported that an impression called "triggering" occurred with the displacement stimulus. This refers to an impression that one object "touches off' or initiates the motion of the other object, which is nonetheless perceived as moving independently. Three statements were therefore constructed with these considerations in mind.

Instructions to participants are as in Experiment 6 except that the objects are identified as a black and a red disc, respectively, and three statements are used, as follows:

"The black disc brought about the motion of the red disc".

"The black disc triggered or initiated motion in the red disc, which then moved independently."

"The red disc moved off when the black disc stopped moving, but it moved independently and its motion was not caused by the black disc."

## Experiment 9: entraining with chasing

In experiments 48, 49, and 55, both objects were in motion from the start. The black square moved faster than the red square and caught up with it. When contact was made, the two objects moved together as in the typical stimulus for entraining. In experiment 48 they moved at the red square's original speed. That is, the speed of the red square did not change at contact. Michotte (1963) reported that the entraining effect occurred if the black square was fixated but not if the red square was fixated. In experiment 49, after contact they moved at the black square's original speed. Michotte reported that, when there was a great difference in speed between the two objects before contact, the entraining effect occurred. When the difference in speed was small, the movements of the objects could be perceived as independent of each other. Nothing was reported about fixation. In experiment 55, after contact the two objects moved more slowly than the red square had been moving before contact. Michotte reported that the results were similar to those of experiment 49, in that the entraining effect occurred but its occurrence depended on which object was fixated.

### Method

The manipulation of motion in experiments 48 and 49 was similar to that in experiment 17, which was the model for Experiment 7, except that the black square continued to move and remained in contact with the red square after contact. For that reason, Experiment 9 was designed as an entraining version of Experiment 7. The design is therefore a 2 between (fixation, black square v. red square) x 4 within (speed ratio, 2:1 v. 3:1 v. 4:1 v. 6:1) x

3 within (speed of both objects after contact, 74.4 mm/s v. 37.2 mm/s v. 18.6 mm/s). Stimuli are similar to those in Experiment 7 except that the black square continues to move after contact, at the same speed as the red square, so that they remain in contact.

This is an entraining effect experiment so the wording of the statement describing a causal relation reflects Michotte's descriptors for the entraining effect, which refer to the black square carrying or pushing the red square or taking the red square along with it (Michotte, 1963, p. 21). Written instructions are similar to those for the respective black square and red square fixation conditions of Experiment 7 except that two statements are presented for rating, as follows:

"After contact the black square pushed the red square or carried the red square along with it."

"The motion of the red square after contact was not caused by the black square".

Experiment 10: entraining with relative speed manipulation

In experiment 54 the relative speed before and after contact was manipulated. Michotte (1963) described two variations, one in which the speed was four times faster after contact than before, and another in which the opposite was the case. Michotte reported that the entraining effect occurred with both variations: "this character is largely independent of a change in speed at the moment when the objects come into contact" (p. 159). This is different from what happens with the launching stimulus, where relative speed made a considerable difference to the occurrence of the causal impression (Michotte, 1963; Natsoulas, 1961), but there has been no replication of this experiment.

Method

The stimuli are variations on the typical stimulus for entraining; i.e., the red square is stationary until the black square contacts it. This is an extended replication of Michotte's experiment 54 in that three speeds are used both for motion of the black square before contact and for motion of the two conjoined objects after contact. The three speeds chosen are 62 mm/s, 124 mm/s, and 186 mm/s. These are manipulated orthogonally for the black square before contact and the two objects after contact, resulting in a 3 x 3 ANOVA design which replicates the speed ratios used by Michotte. Written instructions are as in Experiment 9, except that the fixation instruction was omitted and three statements are presented for rating, as follows:

"After contact the black square pushed the red square or carried the red square along with it."

"After contact the red square pulled or dragged the black square."

"The motion of the red square after contact was not caused by the black square and the red square did not pull or drag the black square."

## Experiment 11

Experiments 11 and 12 together constitute an extended replication of experiment 52. Experiment 50 should be described first. In that experiment, a disc 50 mm in diameter was visible in front of a 100 x 150 mm white screen. Both objects started to move horizontally at the same speed and at the same time. Michotte (1963) reported that the stimulus was perceived as a single object with the disc "constituting 'part of' the screen" (p. 152). In experiment 52 the screen moved 10 - 20 mm and then the disc began to move, again with the same velocity as the screen. With this stimulus Michotte reported an entraining effect, with the screen pushing or carrying the disc. Michotte concluded that temporal priority of motion of the screen was essential in determining the occurrence of the entraining effect.

Michotte (1963) did not report any variations on those experiments, except for one in which the disc oscillated a little while moving horizontally (experiment 51). Preliminary investigations by the present author suggested that both the initial location of the small object relative to the large one, and the location of the small object at the time at which its motion began, might make substantial and qualitative differences to the perceptual impression: the large object might be perceived as launching, pushing (entraining), or pulling the small one depending on their spatial relations. Similarity in speed of the two objects also appeared to be important to the occurrence of these impressions.

Running experiments on this was deemed important for two reasons. One is that there has been no subsequent investigation of this kind of stimulus and Michotte's experiments 50 and 52 have, as far as this author has been able to discover, never been mentioned since their publication. Michotte's account implies that it is not necessary, for entraining to occur, that the black square should approach and contact the red square: in experiment 52 the disc is visibly superimposed on the screen, the entrainer, all the time. So replicating that result would be worthwhile. The other is that the appearance of qualitative differences in perceptual impression depending just on the spatial relations between the objects may be important to a full understanding of perceptual impressions of causality. The research literature since Michotte (1963) has been heavily dominated by the launching effect and qualitatively different causal impressions have been comparatively neglected (Hubbard, 2013a, 2013b). There is a possibility that all of them should be considered together as a single explanandum. For that reason, Experiments 11 and 12 were designed as an extended replication of experiment 52.

## Method

The large object in the stimuli for this research is a 186 mm black square and the small object is a 12.4 mm red square. Assuming horizontal motion of objects from left to right, and assuming that the small object starts moving at some time after the large object has started, several combinations of initial spatial relation of the objects and spatial relation when the small object starts moving are possible and will be tested in this experiment. These are listed in Table 2. In addition, the speed of the small object relative to that of the large one is manipulated, being either slower, the same as, or faster. The large object moves at 124 mm/s and the small one moves at 62 mm/s, 124 mm/s, or 186 mm/s. Orthogonal manipulation of this variable with the seven spatial arrangements described in Table 2 yielded a 3 x 7 ANOVA design with a total of 21 stimuli.

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Table 2

Spatial relations between the large object and the small object in stimuli to be used in Experiment 11

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1. The small object is initially located to the right of the large object and starts to move when the large object contacts it. (This is the kinematic pattern for the typical launching stimulus.)
2. The small object is initially located to the right of the large object and starts to move when superimposed on the large object and not in contact with any edge of it.
3. The small object is initially located to the right of the large object and starts to move when outside but in contact with the rear of the large object.
4. The small object is initially located to the right of the large object and starts to move when outside and beyond the rear of the large object.
5. The small object is initially located superimposed on the large object and starts to move after a delay but when still superimposed on the large object.
6. The small object is initially located superimposed on the large object and starts to move when outside but in contact with the rear of the large object.

7. The small object is initially located superimposed on the large object and starts to move when outside and beyond the rear of the large object.

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Figure 5 schematically depicts the seven stimuli where both objects move at the same speed. In that figure, stimuli are numbered in accordance with their numbering in Table 2, so they form a visual complement to the verbal descriptions in Table 2. In Figure 5 the relative sizes of the objects are not proportional to what is in the actual stimuli (because of the small size of the red square), but the spatial relations depicted are accurate. In the actual stimuli, when the red square is within the boundaries of the black square, it is superimposed on the black square so that it remains visible at all times. Figure 5(a) shows the first frame of each stimulus. Figure 5(b) shows the first frame in which the red square starts to move. When both objects then move at the same speed, that spatial relation is maintained for the remainder of the stimulus. The arrows in Figure 5(b) represent motion of both objects, not just the large square.

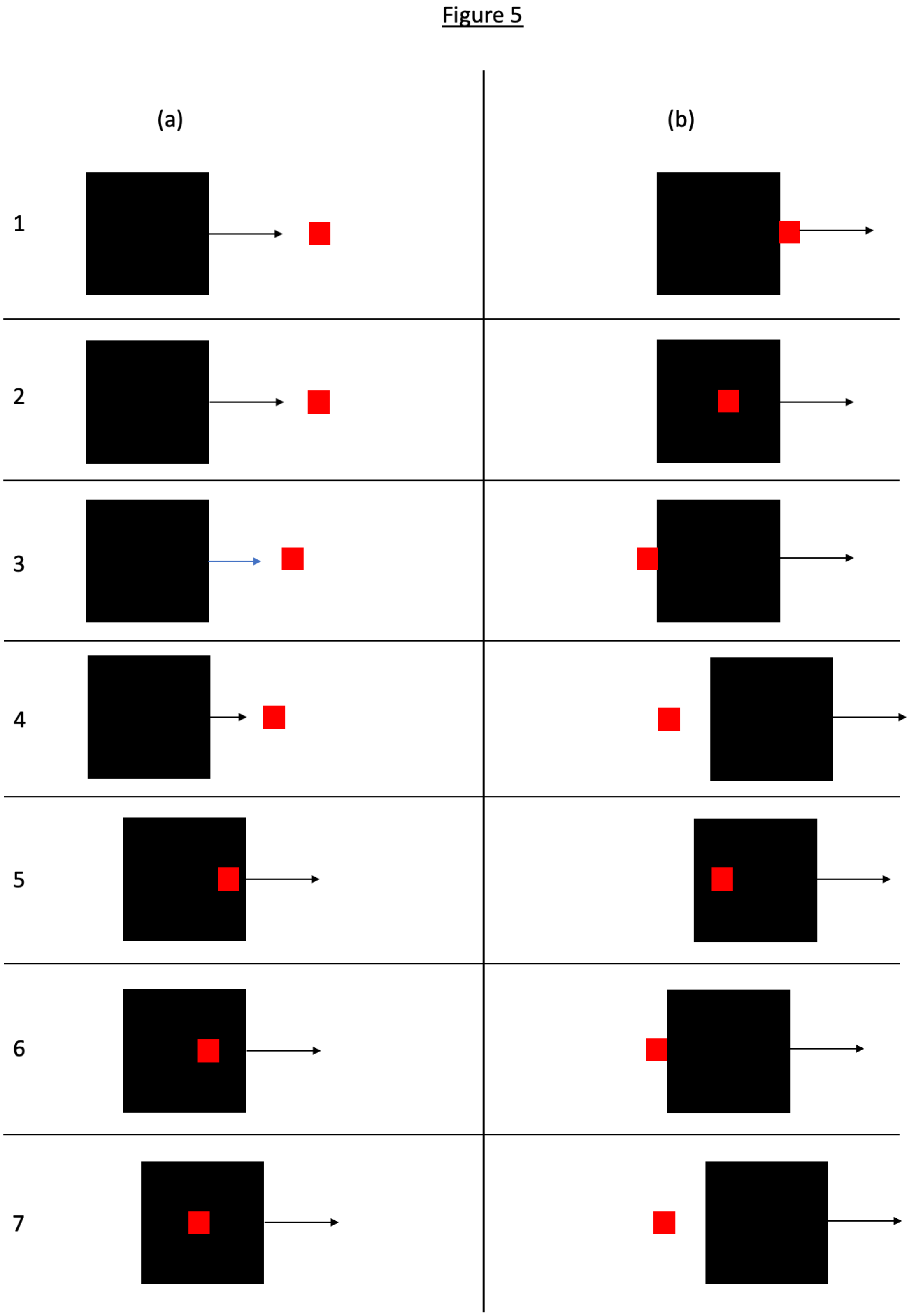


Figure 5. Schematic representation of seven stimuli used in Experiment 11. Stimuli are numbered from 1 to 7 and these correspond to stimulus numbers in Table 2 where verbal descriptions of the stimuli are given. Figure 5(a) shows the first frame of each stimulus with the motion direction of the black square indicated. Figure 5(b) shows the spatial relation between the two squares when both are in motion. Since both squares move with the same velocity, the

spatial relations depicted in Figure 5(b) persist throughout the duration of motion of both objects.

An example stimulus is schematically depicted in Figure 6. This is for the stimulus in which the small red square is initially located to the right of the large black square and starts to move when outside but in contact with the rear of the large square, with both objects moving at the same speed (no. 3 in Table 2 and Figure 5).

Figure 6

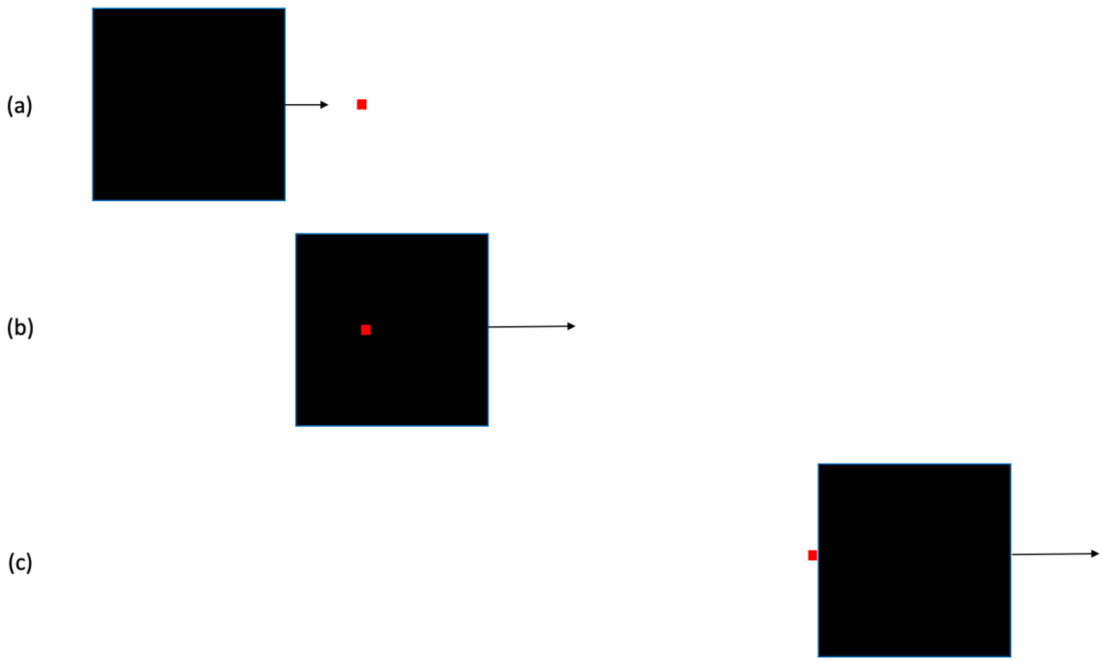


Figure 6. Schematic representation of a stimulus used in Experiment 11. This is number 3 as shown in Figure 5 and Table 2. In this figure, unlike in Figure 5, the objects are shown with the correct proportional difference in size. Figure 6(a) shows the first frame with the motion direction of the black square indicated. Figure 6(b) shows an intermediate point in the motion of the black square; the red square, still motionless at this point, is superimposed on the black square so that it remains visible throughout. Figure 6(c) shows the spatial relation between the objects when both are in motion.

The stimulus depicted in Figure 6 has kinematic features that resemble those of experiment 56, one of three experiments on what Michotte called the traction effect. The stimulus begins like a launching stimulus, and with objects of identical sizes, but the black square passes the red square; as soon as it has done so, the red square starts moving and the two objects continue in contact at the same speed as in the stimulus for the entraining effect.

Michotte (1963) reported that "we see object A pass over object B, hook it on behind and tow it" (p. 160). So it is possible that an impression of pulling or towing may occur with this stimulus. Visual impressions of pulling have been investigated further since Michotte's studies (White, 2010; White & Milne, 1997), and for that reason the three experiments on the traction effect were not selected for replication here. However, the stimulus emerges naturally from the manipulation of spatial relations between the objects in this experiment and the next one, so it is included here.

Written instructions are similar to those for Experiment 10 except that four statements are presented for rating, as follows:

"The black square made the red square move by bumping into it." [This is the descriptor for the launching effect, similar to that used in experiments on launching above.]

"The black square pushed the red square or carried the red square along with it." [This is the descriptor for the entraining effect, similar to that used in experiments on entraining above.]

"The black square seemed to pull the red square, as if they were connected in some way." [This is a descriptor for the pulling impression, adapted from wording used in a study of the pulling impression by White and Milne (1997, p. 582).]

"The motion of the red square was independent of that of the black square and was not caused by it in any way." [This is adapted from the independent motion descriptor used in other experiments above.]

## Experiment 12

This experiment was designed to be as similar as possible to Experiment 11 but with inversion of object size. That is, the object that moves first would now be the small object. Because of the disparity in sizes, the stimuli are not quite the inverse of those used in

Experiment 11. The manipulations of spatial relations are described in Table 3. Schematic depictions of the stimuli are presented in Figure 7.

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Table 3

<u>Spatial relations between the large object and the small object in stimuli to be used in Experiment 12</u>

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1. The large object is initially located to the right of the small object and starts to move when the small object contacts it. (This is the kinematic pattern for the typical launching stimulus.)
2. The large object is initially located to the right of the small object and starts to move when the small object is superimposed on it and not in contact with any edge of it.
3. The large object is initially located to the right of the small object and starts to move when the small object is outside but in contact with the front of the large object.
4. The large object is initially located to the right of the small object and starts to move when the small object is outside and beyond the front of it.
5. The large object is initially located with the small object superimposed on it and starts to move when the small object is still superimposed on it.
6. The large object is initially located with the small object superimposed on it and starts to move when the small object is outside but in contact with the front of the large object.
7. The large object is initially located with the small object superimposed on it and starts to move when the small object is outside and beyond the front of it.

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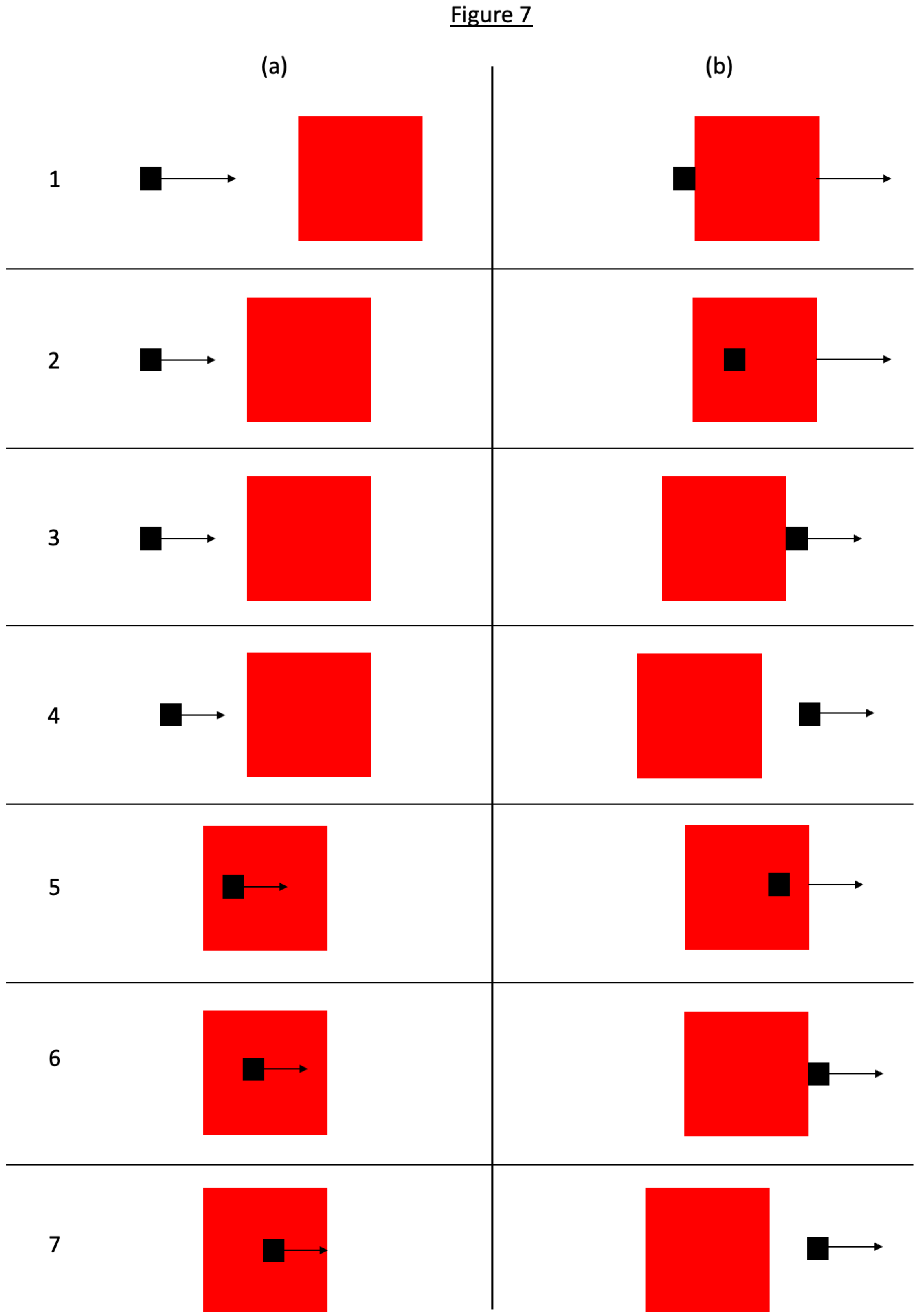


Figure 7. Schematic representation of seven stimuli used in Experiment 12. Stimuli are numbered from 1 to 7 and these correspond to stimulus numbers in Table 3 where verbal descriptions of the stimuli are given. Figure 7(a) shows the first frame of each stimulus with the motion direction of the black square indicated. Figure 7(b) shows the spatial relation between the two squares when both are in motion. Since both squares move with the same velocity, the

spatial relations depicted in Figure 7(b) persist throughout the duration of motion of both objects.

## Method

Speed of the large object relative to that of the small one is manipulated, being either faster, the same as, or slower, with the same speeds as in Experiment 11. This again results in a 3 x 7 ANOVA design with a total of 21 stimuli. As in Experiment 11, when the small object is within the boundaries of the large one it is superimposed on the large one so as to be visible throughout. Written instructions, including the statements to be rated, are the same as in Experiment 11.

## Experiment 13: delay with entraining stimuli

Effects of delay and gap manipulations have featured prominently in the history of research on the launching effect but not in studies of the entraining effect (Hubbard, 2013a). Bélanger and Desrochers (2001) presented entraining stimuli with either a gap of 40 mm between the objects or a delay of 1000 ms between the first object contacting the second one and the two objects starting to move together. They reported that a sample of adults perceived the typical entraining stimulus as more causal than the gap and delay stimuli but did not give any statistical information. A sample of infants aged about 6 months did not show significant discrimination between the entraining stimulus and the delay and gap stimuli. Experiment 13 was therefore designed to fill this evident gap in the literature by replicating the delay manipulation used in Experiment 4 but with entraining instead of launching stimuli.

## Method

The method is as for Experiment 4 except that entraining stimuli are used instead of launching stimuli, and the following statements are used for the rating task:

"The black square pushed the red square or carried the red square along with it."

"The red square seemed to pull the black square, as if they were connected in some way."

"The motion of the red square was independent of that of the black square and was not caused by it in any way."

Since the two objects remain in contact in entraining stimuli, the statement referring to the red square briefly sticking to the black square before moving off was not appropriate for this experiment.

## Experiment 14: gap with entraining stimuli

There has been no published study of effects of gap on the entraining effect, so this study was designed to fill the gap in the literature by replicating the gap manipulation in Experiment 6 but with entraining instead of launching stimuli.

### Method

The method is as for Experiment 6 in all particulars except that entraining stimuli were used instead of launching stimuli.

## Interpretation of results

Since this is a replication study, a key theme in the interpretation of results will be assessing the fit with the findings reported by Michotte (1963) and discussing possible reasons for any failures to replicate. It is anticipated that methodological differences between Michotte's research and the present studies may be a relevant factor, especially the use of computer technology instead of the disc and projection methods. Michotte's use of a small sample of knowledgeable observers in many experiments might also be a relevant consideration. That in turn touches on the issue of whether the results show perceptual impressions, or whether and to what extent post-perceptual processing, expectancies, and other non-perceptual factors might influence reported impressions. Issues raised in the introductions to particular experiments will be discussed in light of the results. This applies particularly to the delay and gap manipulations in Experiments 4 and 6, where the results of the replication studies may help to interpret and understand the variation in results of other studies using similar manipulations. Parametric manipulations of variables may help to define boundary conditions for the occurrence of the launching and entraining effects. Experiments 1 (object width manipulation) and 8 (vertical displacement of motion path) for launching, and experiments 13 (delay) and 14 (gap) for entraining, are examples that could be revealing in that respect. The extended replications in Experiments 11 and 12 may show qualitative changes in perceptual impressions, encompassing launching, entraining, and pulling, and suggest that a full theoretical account of perceptual impressions of causality would need to incorporate those other kinds of impressions, and the factors that govern the shift from one kind to another, into an integrated explanation. Further discussion of what this might involve will depend on the results.

Several theoretical accounts of visual impressions of causality have been published (Hubbard, 2013b; Michotte, 1963; Scholl & Tremoulet, 2000; White, 2017). In a replication study, discriminative testing of hypotheses is not a primary aim. However, some hypotheses make predictions that could be confirmed or disconfirmed in the present studies. These will be briefly discussed here, with anticipation of more thorough treatment in light of the results.

Michotte (1963) argued that, in any case where a visual causal impression occurs, the motion of the target (the red square) is perceived as a continuation of the movement of the first moving object, which is perceptually independent of the spatial displacement of the target. Simplifying somewhat, the key to this is kinematic integration, which occurs when the stimulus has Gestalt properties. In the case of the launching effect, kinematic integration depends on the Gestalt principle of good continuation (Wagemans, Elder, Kubovy, Palmer, Peterson, Singh, & von der Heydt, 2012). With dynamic stimuli, good continuation refers to the perpetuation of the motion properties of the first moving object in the target, which means that motion continues without a break in space or time, and without change in its properties. Thus, the launching effect is predicted to occur when the mover contacts the target and, without delay, the target starts moving with the same speed and direction as the mover. The launching effect should be weakened or absent if there is substantial delay at contact, gap between the objects, and vertical displacement of motion path, and the present experiments will provide tests of all of those. For entraining, kinematic integration is explained by the Gestalt principle of common fate. This just means that the impression depends on the two objects sharing the same motion properties after coming into contact. This will be tested, for example, by Experiments 11 and 12 where entraining would not be predicted to occur when the objects move at different speeds after contact. The delay and gap manipulations (Experiments 13 and 14) should not significantly affect entraining, however, because the objects share the same velocity when the red square starts moving in both cases.

Other authors have argued that there is an innate perceptual module for the launching effect (Leslie & Keeble, 1987; Scholl & Tremoulet, 2000). The module is brought into operation by definable stimulus conditions, and the causal impression occurs when it operates. For the launching effect, those conditions are the typical features of the stimulus for launching, as depicted in Figure 1. The module hypothesis predicts that the launching effect should occur whenever those features are present. For this, Experiment 2 may provide critical evidence because the typical features of the stimulus for launching are present in all the stimuli and the module hypothesis therefore predicts that the launching effect should occur for all of them.

Michotte (1963) claimed that, in most cases, the launching effect did not occur, though this depended on fixation. Experiment 2 may therefore provide results of importance for evaluating the module hypothesis.

In two more hypotheses, perceptual impressions of causality are derived from experiences of interactions between the body and other objects. In one version, actions on objects yield information about forces and causality, mainly through proprioception (Proske & Gandevia, 2012), and these experiences are stored in long term memory, where they function as a kind of template for interpreting visual information about interactions between objects (White, 2009, 2012a). The causal impression is the proprioceptive impression of acting on an object, activated and applied in interpretation of what is visually perceived. In another version, forces applied to the surface of the body are detected through proprioception; that is, instead of actions on objects, objects acting on the actor are the source of visual impressions of causality (Wolff & Shepard, 2013). Both hypotheses depend for their testability on empirical propositions about the kinds of experience that support acquisition of causal impressions. They do not define precisely what those experiences are, and so it is not easy to generate and test predictions from either account. It has been argued that the entraining effect is the kind of perceptual impression that could only result from experiences of actions on objects because the kinematics of a typical stimulus for entraining are not possible for inanimate objects (Runeson, 1983; White, 2017). The entraining effect, therefore, might be the best available evidence in favour of the actions on objects hypothesis. It is not likely, however, that the present replication study could generate evidence that would be decisive for either of these experience-based hypotheses.

Footnote

This is probably attributable to the instructions. Participants were told to decide whether the movie "came from a real collision of the blocks or a random combination of the variables. A real collision looks like the blocks actually collide" (p. 421). It is likely, therefore, that participants just judged whether the blocks came into contact or not and judged that a real collision did not occur if they did not perceive contact. This is probably not a study of the launching effect at all.

## References

Beasley, N. (1968). The extent of individual differences in the perception of causality. *Canadian Journal of Psychology, 22,* 399-407.

Bechlivanidis, C., Schlottmann, A., & Lagnado, D. A. (2019). Causation without realism. *Journal of Experimental Psychology: General, 148,* 785-804.

Bélanger, N. D., & Desrochers, S. (2001). Can 6-month-old infants process causality in different types of causal events? *British Journal of Developmental Psychology, 19,* 11-21.

Blakemore, S.-J., Fonlupt, P., Pachot-Coulard, M., Darmon, C., Boyer, P., Meltzoff, A. N., Segebarth, C., & Decety, J. (2001). How the brain perceives causality: an event-related fMRI study. *Neuroreport, 12,* 3741-3746.

Blos, J., Chatterjee, A., Kircher, T., & Straube, B. (2012). Neural correlates of causality judgment in physical and social context - the reversed effects of space and time. *Neuroimage, 63,* 882-893.

Boyle, D. G. (1960). A contribution to the study of phenomenal causation. *Quarterly Journal of Experimental Psychology, 12,* 171-179.

Brown, H. V., & Miles, T. R. (1969). Prior stimulation and the perception of causality. *Quarterly Journal of Experimental Psychology, 21,* 134-136.

Buehner, M. J., & Humphreys, G. R. (2010). Causal contraction: spatial binding in the perception of collision events. *Psychological Science, 21,* 44-48.

Chen, Y., & Yan, B. (2020). The space contraction asymmetry in Michotte's launching effect. *Attention, Perception, and Psychophysics, 82,* 1431-1442.

Choi, H., & Scholl, B. J. (2004). Effects of grouping and attention on the perception of causality. *Perception and Psychophysics, 66,* 926-942.

Choi, H., & Scholl, B. J. (2006). Perceiving causality after the fact: postdiction in the temporal dynamics of causal perception. *Perception, 35,* 385-399.

Cohen, L. B., & Amsel, G. (1998). How infants perceive a simple causal event. *Developmental Psychology, 29,* 421-433.

Deodato, M., & Melcher, D. (2022). The effect of perceptual history on the perception of causality. *Journal of Vision, 22,* (11), No. 13, 1-8.

Fugelsang, J. A., Roser, M. E., Corballis, P. M., Gazzaniga, M. S., & Dunbar, K. N. (2005). Brain mechanisms underlying perceptual causality. *Cognitive Brain Research, 24,* 41-47.

Gordon, I. E., Day, R. H., & Stecher, E. J. (1990). Perceived causality occurs with stroboscopic movement of one or both stimulus elements. *Perception, 19,* 17-20.

Guski, R., & Troje, N. F. (2003). Audiovisual phenomenal causality. *Perception and Psychophysics, 65,* 789-800.

Hafri, A., & Firestone, C. (2021). The perception of relations. *Trends in Cognitive Sciences, 25,* 475-492.

Hubbard, T. L. (2013a). Phenomenal causality I: varieties and variables. *Axiomathes, 23,* 1-42.

Hubbard, T. L. (2013b). Phenomenal causality II: integration and implication. *Axiomathes, 23,* 485-524.

Hubbard, T. L., & Ruppel, S. E. (2013). Ratings of causality and force in launching and shattering. *Visual Cognition, 21,* 987-1009.

Hubbard, T. L., & Ruppel, S. E. (2017). Perceived causality, force, and resistance in the absence of launching. *Psychonomic Bulleting and Review, 24,* 591-596.

Kim, S.-H., Feldman, J., & Singh, M. (2013). Perceived causality can alter the perceived trajectory of apparent motion. *Psychological Science, 24,* 575-582.

Kominsky, J. F., & Scholl, B. J. (2020). Retinotopic adaptation reveals distinct categories of perception. *Cognition, 203,* 104339, 1-21.

Kominsky, J. F., Strickland, B., Wertz, A. E., Elsner, C., Wynn, K., & Keil, F. C. (2017). Categories and constraints in causal perception. *Psychological Science, 28,* 1649-1662.

Leslie, A. M. (1982). The perception of causality in infants. *Perception, 11,* 173-186.

Leslie, A. M., and Keeble, S. (1987). Do six-month-old infants perceive causality? *Cognition, 25,* 265-288.

Mayrhofer, R., & Waldmann, M. R. (2016). Causal agency and the perception of force. *Psychonomic Bulletin and Review, 23,* 789-796.

Meding, K., Bruijns, S. A., Schölkopf, B., Berens, P., & Wichmann, F. A. (2020). Phenomenal causality and sensory realism. *i-Perception, 11,* (3), 1-16.

Michotte, A (1946). *La perception de la causalité.* Louvain: Études de Psychologie.

Michotte, A. (1954). *La perception de la causalité* (2nd éd.). Louvain: Études de Psychologie.

Michotte, A. (1963). The perception of causality (T. R. Miles & E. Miles, trans.). London: Methuen. (English translation of Michotte, 1954).

Mitsumatsu, H. (2013). Stronger discounting of an external cause by action in human adults: evidence for an action-based hypothesis of visual collision perception. *Journal of Experimental Psychology: General, 142,* 101-118.

Moors, P., Wagemans, J., & de-Wit, L. (2017). Causal events enter awareness faster than non-causal events. *PeerJ, 5,* e2932.

Muentener, P., & Bonawitz, E. (2017). The development of causal reasoning. In M. R. Waldmann (Ed.), *Oxford Handbook of Causal Reasoning* (pp. 677-698). Oxford: Oxford University Press.

Natsoulas, T. (1961). Principles of momentum and kinetic energy in the perception of causality. *American Journal of Psychology, 74,* 394-402.

Newman, G. E., Choi, H., Wynn, K, & Scholl, B. J. (2008). The origins of causal perception: evidence from postdictive processing in infancy. *Cognitive Psychology, 57,* 262-291.

Parovel, G., & Casco, C. (2006). The psychophysical law of speed estimation in Michotte's causal events. *Vision Research, 46,* 4134-4142.

Peirce, J. (2007). PsychoPy - Psychophysics software in Python. *Journal of Neuroscience Methods, 162,* 8-13.

Powesland, P. F. (1959). The effect of practice upon the perception of causality. *Canadian Journal of Psychology, 13,* 155-168.

Proske, U., & Gandevia, S. C. (2012). The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force. *Physiological Review, 92,* 1651-1697.

Rolfs, M., Dambacher, M., & Cavanagh, P. (2013). Visual adaptation of the perception of causality. *Current Biology, 23,* 250-254.

Roser, M. E., Fugelsang, J. A., Dunbar, K. N., Corballis, P. M., & Gazzaniga, M. S. (2005). Dissociating processes supporting causal perception and causal inference in the brain. *Neuropsychology, 19,* 591-602.

Runeson, S. (1983). On visual perception of dynamic events. *Acta Universitatis Upsaliensis: Studia Psychologica Upsaliensia*. Uppsala, Sweden.

Ryu, D., & Oh, S. (2018). The effect of good continuation on the contact order judgment of causal events. *Journal of Vision, 18*(11)*, 5*, 1-12.

Sanborn, A. N., Mansinghka, V. K., & Griffiths, T. L. (2013). Reconciling intuitive physics and Newtonian mechanics for colliding objects. *Psychological Review, 120,* 411-437.

Schlottmann, A., & Anderson, N. H. (1993). An information integration approach to phenomenal causality. *Memory and Cognition, 21,* 785-801.

Schlottmann, A., Ray, E., Mitchell, A., & Demetriou, N. (2006). Perceived social and physical causality in animated motions: spontaneous reports and ratings. *Acta Psychologica, 123,* 112-143.

Scholl, B. J., & Nakayama, K. (2002). Causal capture: contextual effects on the perception of collision events. *Psychological Science, 13,* 493-498.

Scholl, B. J., & Nakayama, K. (2004). Illusory causal crescents: misperceived spatial relations dut to perceived causality. *Perception, 33,* 455-469.

Scholl, B. J., & Tremoulet, P. D. (2000). Perceptual causality and animacy. *Trends in Cognitive Science, 4,* 299-309.

Straube, B., & Chatterjee, A. (2010). Space and time in perceptual causality. *Frontiers in Human Neuroscience, 4,* No. 28, 1-10.

Thinès, G., Costall, A., & Butterworth, G. (Eds.), *Michotte's Experimental Phenomenology of Perception.* Hove, East Sussex: Lawrence Erlbaum.

Umemura, H. (2017). Causal context presented in subsequent event modifies the perceived timing of cause and effect. *Frontiers in Psychology, 8,* No. 314, 1-9.

Vicovaro, M. (2018). Causal reports: context-dependent contributions of intuitive physics and visual impressions of launching. *Acta Psychologica, 186,* 133-144.

Vicovaro, M., Battaglini, L., & Parovel, G. (2020). The larger the cause, the larger the effect: evidence of speed judgment biases in causal scenarios. *Visual Cognition, 28,* 239-255.

Vicovaro, M., & Burigana, L. (2014). Intuitive understanding of the relation between velocities and masses in simulated collisions. *Visual Cognition, 22,* 896-919.

Wagemans, J., Elder, J. H., Kubovy, M., Palmer, S. E., Peterson, M. A., Singh, M., & von der Heydt, R. (2012). A century of Gestalt psychology in visual perception: I. Perceptual grouping and figure-ground organization. *Psychological Bulletin, 138,* 1172-1217.

Wagemans, J., van Lier, R., & Scholl, B. J. (2006). Introduction to Michotte's heritage in perception and cognition research. *Acta Psychologica, 123,* 1-19.

Wang, Y., Chen, Y., & Yan, B. (2020). The causal and force perception and their perceived asymmetries in flight collisions. *Frontiers in Psychology, 11,* No. 1942, 1-12.

White, P. A. (2006). The causal asymmetry. *Psychological Review, 113,* 132-147.

White, P. A. (2007). Impressions of force in visual perception of collision events: a test of the causal asymmetry hypothesis. *Psychonomic Bulletin and Review, 14,* 647-652.

White, P. A. (2009). Perception of forces exerted by objects in collision events.

*Psychological Review, 116,* 580-601.

White, P. A. (2010). The property transmission hypothesis: a possible explanation for visual impressions of pulling and other kinds of phenomenal causality. *Perception, 39,* 1240-1253.

White, P. A. (2012a). The experience of force: the role of haptic experience of forces in visual perception of object motion and interactions, mental simulation, and motion-related judgments. *Psychological Bulletin, 138,* 589-615.

White, P. A. (2012b). Visual impressions of causality: effects of manipulating the direction of the target object's motion in a collision event. *Visual Cognition, 20,* 121-142.

White, P. A. (2017). Visual impressions of causality. In M. R. Waldmann (Ed.), *Oxford Handbook of Causal Reasoning* (pp. 245-264). Oxford: Oxford University Press.

White, P. A., & Milne, A. (1997). Phenomenal causality: impressions of pulling in the visual perception of objects in motion. *American Journal of Psychology, 110,* 573-602.

Wolff, P., & Shepard, J. (2013). Causation, touch, and the perception of force. *Psychology of Learning and Motivation, 58,* 167-202.

Woods, A. J., Lehet, M., & Chatterjee, A. (2012). Context modulates the contribution of time and space in causal inference. *Frontiers in Psychology, 3,* No. 371, 1-9.

Yela, M. (1952). Phenomenal causation at a distance. *Quarterly Journal of Psychology, 4,* 139-154.

Young, M. E., & Falmier, O. (2008). Launching at a distance: the effect of spatial markers. *Quarterly Journal of Experimental Psychology, 61,* 1356-1370.

Young, M. E., Rogers, E. T., & Beckmann, J. S. (2005). Causal impressions: predicting *when*, not just *whether. Memory and Cognition, 33,* 320-331.

Zhou, J., Huang, X., Jin, X., Liang, J., Shui, R., & Shen, M. (2012). Perceived causalities of events are influenced by social cues. *Journal of Experimental Psychology: Human Perception and Performance, 38,* 1465-1475.

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