Attention, Perception, & Psychophysics (2020) 82:1431–1442
https://doi.org/10.3758/s13414-019-01912-3

# The space contraction asymmetry in Michotte's launching effect

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## Abstract

Previous studies have found that, compared with noncausal events, spatial contraction exists between the causal object and the effect object due to the perceived causality. The present research aims to examine whether the causal object and the effect object have the same effect on spatial contraction. A modified launching effect, in which a bar bridges the spatial gap between the final position of the launcher and the initial position of the target, was adopted. Experiment 1 validates the absolute underestimation of the bar's length between the launcher and the target. Experiment 2a finds that in the direct launching effect, the perceived position of the bar's trailing edge that was contacted by the final launcher was displaced along the objects' direction of movement. Meanwhile, the perceived position of the bar's leading edge that was contacted by the initial target was displaced in opposite direction to the moving direction. The magnitude of the former's displacement was significantly larger than that of the latter, displaying a significant contraction asymmetry. Experiment 2b demonstrates that the contraction asymmetry did not result from the launcher remaining in contact with the edge of the bar. Experiment 3 indicates that contraction asymmetry showed a type of postdictive effect; that is, to some extent, this asymmetry depends on what happens after contact. In conclusion, the space between the causal object and effect object contracts asymmetrically in the launching effect, which implies that the causal object and effect object are perceived as shifting toward each other nonequidistantly in visual space.

**Keywords** Spatial perception · Causality · Causal asymmetry · Causal contraction asymmetry

The visual system is equipped not only to perceive the color, shape or motion patterns of objects, it can also perceive some higher-level properties. One of them is causality. For example, observers may report a visual impression of one object causing another to move by bumping into it. This phenomenon is called the launching effect (Michotte, 1963), a canonical type of phenomenal causality.

Many spatiotemporal parameters (such as temporal contiguity and spatial contiguity) are important for the occurrence of causal perception. For the launching effect, the closer the two interacting objects are to each other in terms of time and space—that is, the shorter the time gap between when the launcher stops moving and when the target starts to move (e.g., White, 2014), and the closer the distance between the final location of the launcher and the initial location of the target (e.g., Falmier & Young, 2008; Michotte, 1963)—the easier it is for observers to perceive the interaction as a causal event. In addition, the similarity in the motion directions of the launcher prior to contact and that of the target after contact is also critical to the perceived causality, as the causal impression decreases in line with the increases in the angle that the motion path of the target deviates from that of the launcher (White, 2012). The studies mentioned above demonstrate that low-level parameters affect causal impression.

At the same time, causality can, in turn, influence low-level percepts. For example, Buehner (2012) presented two causal conditions, in which a designated button was pressed either by participants themselves in the self-causal condition or by a machine in the machine-causal condition, followed by a delayed target LED flash, and a baseline condition, in which the target flash appeared just after a signal LED. The task in the three conditions was to anticipate the time at which they expected the target LED to flash. Results showed the target flash was perceived to occur earlier after button pressing in both causal conditions, in which the button pressing and the target flash were perceived as causally related, indicating temporal binding between the action and its subsequent consequence. In conjunction with previous finding that the intentional action

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in the absence of causality fails to elicit temporal bindings (Buehner & Humphreys, 2009), Buehner (2012) concludes that nonintentional mechanical causation (and not intentional action) is necessary to produce temporal binding. It seems that if two events are causally related, observers tend to predict the target event will occur earlier. What is more, causal belief can also result in the reordering of these events (Bechlivanidis & Lagnado, 2016). In such cases, the temporal order can be strongly biased to a causally plausible ordering of events.

Another important task of our visual system is to represent the spatial position relationship of visual objects. However, spatial perception is prone to being distorted by cognitive constructs, such as causal belief. First, the perception of causality influences the memory of the relative position of objects in other collision-like events. In their first experiment, Scholl and Nakayama (2004) presented a test event that was either in isolation or accompanied by one of three contextual events positioned below the test event. The test event was a modified launching-like event, in which the two objects overlapped 60%, 80%, 90%, or 100% of the objects' width before the initially moving object became stationary and the initially stationary object started moving. After the motion ceased, a crescent was presented; participants were then asked to adjust the crescent's width to match the remembered maximal amount of the intersection of the two objects seen during the test event. Researchers found that participants tended to underestimate the amount of the intersection when the test event was presented with an unambiguous launch event. In the second experiment, Scholl and Nakayama (2004) found that decreases in the amount of intersection increased the ratings of causal perception. Thus, the spatial position relationship of two objects seems to be distorted to a causally plausible relationship.

Secondly, causal understanding of a visual event also affects an individual's perception of the relative position of the objects involved in the visual event. For example, Buehner and Humphreys (2010) presented displays containing a stationary bar that bridged a spatial gap between the final location of the launcher and the initial location of the target. After the launcher contacted the bar, the target started moving immediately, or 600 ms later or moved upward immediately. In the fourth condition, the target started moving before the launcher contacted the bar. The later three events were all rated as less causal. After the three objects disappeared, a probe bar was presented; participants were instructed to adjust the probe bar's length to match the length of the bar in the display. The length of the probe bar after adjustment by participants was shorter when target started to move immediately after the launcher contacted the bar than in the other three displays. This was called causal contraction by Buehner and Humphreys, who suggested the result reflected spatial binding of stimuli in a causal display. It seems that the perception of causality actually causes the objects in the event to be organized according to the law of causality.

Apparently, higher-level cognitive concepts can help resolve low-level ambiguities, which are themselves derived from low-level percepts (Buehner & Humphreys, 2010). In addition to causality, studies relating to representational momentum (RM), which refers to the fact that the final location of a moving object is remembered as being forward along the object's direction of movement, have also shown that higher-level concepts (e.g., target identity; e.g., Reed & Vinson, 1996) have a significant effect on lower-level percepts (localization of a target).

In this paper, we aim to investigate whether causal asymmetry affects the degree of spatial contraction in the modified launching effect.[1] White (2006) argues that when the roles of cause and effect are assigned to the two interacting objects, the importance of the causal object is usually overestimated and the importance of the effect object is often underestimated in bringing about the outcome. This phenomenon is referred to as the causal asymmetry. In the typical launching effect, the launcher is usually rated as more causal (White, 2006, 2007). Observers usually mention the effect of the launcher on the target, while they neglect the effect of the latter on the former. Given the more powerful effect of the launcher perceived in the launching effect, we suppose that the contraction at the causal edge of the bar will be larger than that at the effect edge of the bar if we can distinguish the causal object from the effect object. For convenience, in the present research, the edge of the bar that is adjacent to the supposed causal object is called the causal edge; the edge of the bar that is adjacent to the supposed effect object is called the effect edge.

The causal contraction found in previous studies was derived by comparing the adjusted bar's length with that in other noncausal or less causal events. Thus, it remains unknown whether the adjusted length of the probe bar is shorter than the stimulus bar's actual length. Therefore, the intention of our first experiment was to investigate whether there is a significant underestimation of space between the launcher and the target. Hubbard (2013) concluded that with increases in objects' speeds, the causal impression reported by observers becomes stronger over the range of velocities typically used in studies of the launching effect. Therefore, if spatial contraction is attributed to causal perception, the magnitude of contraction should be larger if the causal perception is stronger. Thus, the second aim of our Experiment 1 was to investigate how the two objects' velocities affect the contraction. Experiment 2's aim was to investigate whether the causal object and the effect object compress the space between them equidistantly in the launching effect. If so, we would refer to this as contraction asymmetry. Previous studies have provided

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[1] In the modified launching effect, a bar bridged the final position of the launcher and the initial position of the target, which is usually referred to as the tool effect. We chose to name it the modified launching effect because the bar was represented as the space between the launcher and the target.

evidence that perceived causality is a type of postdictive effect (e.g., Choi & Scholl, 2006). Therefore, Experiment 3 was designed to examine whether what happens before or after contact is important for the degree of spatial contraction.

**Experiment 1** Experiment 1 tested the prediction that the magnitude of the causal contraction found in Buehner and Humphreys' (2010) research was significantly different from zero. We also investigated whether the degree of causal contraction would be larger when the two objects move faster. Experiment 1 adopted the modified launching effect, in which a bar bridged the spatial gap between the final location of the launcher and the initial location of the target.

## Method

### Participants

Fifteen college students (four males and 11 females) aged 17 to 21 years (*M* = 18.47, *SD* = 0.92) with normal or corrected-to-normal vision were recruited. They were all right-handed and had not previously participated in similar experiments. Participants were compensated with partial course credits.

### Apparatus

The stimuli were displayed upon (and the data were collected by) a Gateway desktop computer connected to a 15-inch color monitor with a refresh rate of 85 Hz and a resolution of 1,024 × 768 pixels. Participants' head and eye movements were not constrained, and the viewing distance was approximately 60 cm. The participants were permitted to adjust this distance slightly for personal comfort reasons.

### Stimuli

The launcher and the target were both green squares that were 40 pixels (~1.14°) in height. The bar was a red rectangle; its width was 40 pixels (~1.14°), while its length varied at 60 (~1.71°) and 70 pixels (~1.99°).

### Procedure

As shown in Fig. 1, the background color was completely white, and the bar remained visible and stationary until all three objects disappeared. The bar indicated the space between the launcher and the target, and its center was presented within the center of the display. The target was initially adjacent to the right (or left) edge (leading edge) of the bar. The launcher would enter from the left (or right) side of the display and move toward the bar at one of two velocities. At the moment of contact with the trailing edge of the bar, the launcher stopped moving, and the target immediately started to move at the same speed as the launcher (the direct launching effect). The launcher always moved for 2.5 s, while the target always moved for 2 s. In the fast velocity condition, the launcher and the target moved for 300 pixels (~8.53°) and 240 pixels (~6.82°), respectively, resulting in a speed of 120 pixels/s (~3.41°/s). In the slow velocity condition, the launcher and the target both moved at a speed of 100 pixels/s (~2.64°/s). Given the different lengths of the bar and the different velocities of the objects, the initial location of the launcher and the final location of the target in one trial could be slightly different from those locations in another trial.

When the target stopped moving, the three objects disappeared simultaneously. After 250 ms, a probe bar with the same height as the previously presented separating bar appeared at the center of the display. The length of the probe was set as one of five lengths relative to the separating bar: −4, −2, 0, +2, or +4 pixels. Probe lengths denoted by a minus sign indicate that the probe bar was shorter than the separating bar by the indicated number of pixels. Probe lengths denoted by a plus sign indicate that the probe was longer than the separating bar by the indicated number of pixels. The zero probe length means that the probe length was the same as that of the separating bar. The changes at the ends of the bar were always equal (e.g., for the +4 probe, the bar extended two pixels to the left and two pixels to the right). Participants were asked to judge whether the probe bar was as long as the separating bar. They were instructed to press the *S* key if they thought the lengths were the same and the *D* key if they thought the lengths were different. Participants then initiated the next trial.

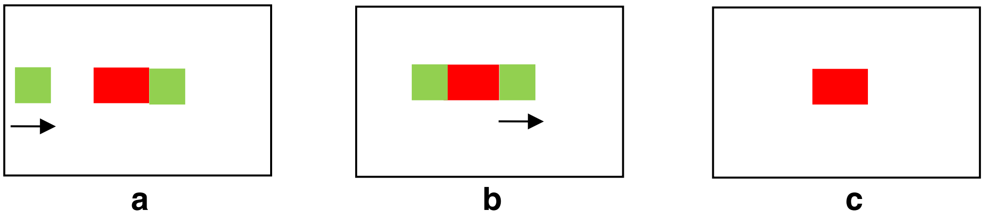

**Fig. 1** The target was initially adjacent to the left (or right) edge of the bar; the launcher moved toward the separating bar (**a**). After the launcher contacted the right (or left) edge of the bar, the target started moving in the same direction (**b**). After the three objects were removed, a probe bar was presented at the center of the display (**c**). (Color figure online)

## Design

Each participant received 240 trials, consisting of 2 velocities (fast, slow) × 2 directions (leftwards, rightwards) × 2 bar lengths (60, 70) × 5 probe lengths (−4, −2, 0, 2, 4) × 6 replications, after a six-trial practice session.

## Results

The probabilities of a *same* response for each probe length for each condition are shown in Fig. 2. We adapt the method used in previous studies examining the representational momentum (e.g., Hubbard & Courtney, 2010; Hubbard, Kumar, & Carp, 2009). As such, estimates of the remembered bar's length are determined by calculating the arithmetic weighted mean (i.e., the sum of the products of the proportion of *same* responses and the difference in length of the probe bar from the separating bar, in pixels, divided by the sum of the proportions of *same* responses) for each participant for each condition. The sign of the weighted mean indicates the direction of space distortion (i.e., a minus sign indicates spatial contraction between the launcher and the target; a plus sign indicates spatial expansion between the two objects). The absolute value of the weighted mean indicates the magnitude of space distortion (i.e., a larger absolute value indicates a larger magnitude of contraction or expansion). A weighted mean that is significantly smaller than zero indicates that causal contraction occurs.

Four of the weighted means under the four conditions were all significantly smaller than zero (these results were corrected using the Benjamini–Hochberg method): $t(14) = -3.89$, $p < .01$, d = −0.99, for the slow leftwards motion ($M = -1.87$, $SD = 1.88$); $t(14) = -2.53$, $p < .05$, d = −0.65, for the slow rightwards motion ($M = -1.88$, $SD = 2.88$); $t(14) = -4.12$, $p < .01$, d = −1.07, for the fast leftwards motion ($M = -6.18$, $SD = 5.80$); and $t(14) = -3.08$, $p < .01$, d = −0.80, for the fast rightwards motion ($M = -1.99$, $SD = 2.50$). The results indicate that the magnitude of contraction was significantly larger than zero. Therefore, the participants "remembered" that the length of the bar connecting the launcher with the target was shorter than the bar's actual length.

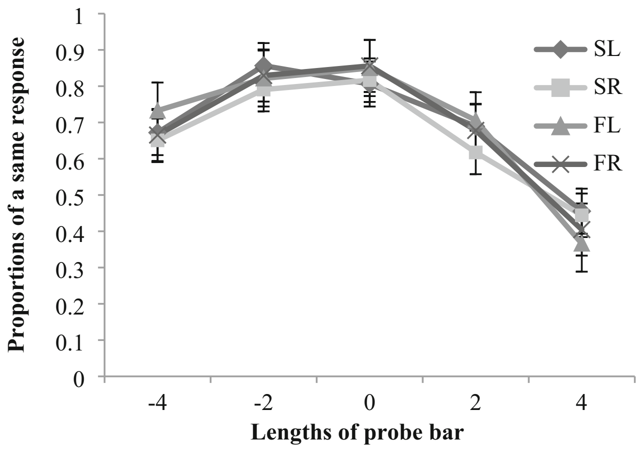

**Fig. 2** The proportions of a same response for each probe length are shown. 'S' indicates slow motion and 'F' indicates fast motion; 'L' indicates leftwards motion and 'R' indicates rightwards motion. Error bars represent standard error

Weighted means were analyzed in a 2 (velocity: fast, slow) × 2 (direction: rightwards, leftwards) repeated-measures ANOVA. The results show that the main effect of velocity was significant, $F(1, 14) = 12.56$, $p < .05$, $\eta_p^2 = 0.473$, $1 - \beta = 0.92$. The mean for fast motion ($M = -4.08$, $SD = 4.88$) was much smaller than that for slow motion ($M = -1.88$, $SD = 2.39$). This result means the magnitude of contraction for fast motion was larger. The main effect of direction was also significant, $F(1, 14) = 14.58$, $p < .01$, $\eta_p^2 = 0.510$, $1 - \beta = 0.96$, and the mean for leftwards motion ($M = -4.03$, $SD = 4.76$) was significantly smaller than that for rightwards motion ($M = -1.93$, $SD = 2.65$), which means the magnitude of contraction for leftwards motion was larger. These effects were qualified by a significant interaction, $F(1, 14) = 10.79$, $p < .01$, $\eta_p^2 = 0.435$, $1 - \beta = 0.98$. Simple effects analysis reveals a significant effect of direction with fast motion ($F = 14.42$, $p < .01$), and the mean for leftwards motion was significantly smaller than that for rightwards motion. There was no difference between directions for slow motion.

## Discussion

Our results show that the lengths of those shorter probe bars were more likely to be judged as the lengths of the actual bars. This finding demonstrates that the spatial contraction in the launching effect is significantly larger than zero. Therefore, in conjunction with previous findings (Buehner & Humphreys, 2010), it is relatively reliable to conclude that the space between the causal object and effect object is significantly compressed. Larger spatial contraction with faster absolute velocity of objects supports the view that spatial contraction is related to causal perception, since causal perception is strengthened when the objects move faster in the launching effect (e.g., White, 2014). Direction also has an impact on spatial contraction, in which leftwards motion appears to result in larger contraction, especially when the launcher and the target move at a quicker velocity. However, the evidence of the impact of direction on causal perception is not conclusive. For example, some studies found that rightwards motion resulted in a higher rating of perceived causality (e.g., Hubbard & Ruppel, 2017); others report an unstable effect of direction on causal perception (e.g., Hubbard & Ruppel, 2018a), or they simply focused on rightwards motion. It is therefore difficult to conclude whether the result detailed above supports or rejects the view that spatial contraction is due to causal perception. Leftwards motion resulting in larger contraction may result from the fact that observers are less familiar with leftwards motion. Since left-to-right is the normal direction of reading (in our culture, at least), our participants may be less likely to track the objects' motion. Instead, they may have paid more attention to the bar and then remembered the bar's length more accurately. However, they were less familiar with the leftwards motion, so they were more likely to track the motion of the objects, and thus may have made more incorrect judgments.

**Experiment 2a** Experiment 2a aimed to investigate whether the magnitude of the contraction at the causal edges was different to that at the effect edges. Like the typical launching effect, we supposed that the object that moved first was the causal object. Thus, the edge of the bar that was contacted with this object was called the causal edge. Because several studies have indicated that in the launching effect the launcher is perceived as more causal than the target, it is possible that the causal edge of the bar is compressed to a much greater degree than the effect edge.

## Method

### Participants

Sixteen college students (three males and 13 females) aged 18 to 19 years (*M* = 19.56, *SD* = 1.03) with normal or corrected-to normal vision were recruited. They were all right-handed and were compensated with partial course credits for participating.

### Stimuli, apparatus, and procedure

The stimuli, apparatus and procedure were the same as in Experiment 1, with the following exceptions. First, an auditory cue and a cursor—a solid white arrow with black outline—were presented immediately after the three objects vanished. A high tone (7000 Hz) cued participants to position the cursor at the leftmost edge of the bar; a low tone (150 Hz) was the signal to position the cursor at the rightmost edge of the bar. Participants were asked to place the cursor where they thought the leftmost or rightmost edge of the bar had been. The cursor was controlled by the movement of the computer mouse. The cursor was initially invisible, but appeared immediately after the three objects disappeared. The cursor was always presented 40 pixels (~1.14°) above the center of the display. Secondly, a delayed launching effect was added. In this case, after the launcher contacted the bar, the target began to move after 600 ms. White (2014) found that when the delay between when the launcher stopped moving and when the target started to move was beyond 75 ms, the rating of causality dropped off sharply. Therefore, we believe that when the delay is 600 ms, the event should be noncausal, despite the fact that we referred to the event as the delayed launching effect. After positioning the cursor, participants clicked the left button on the mouse to record the coordinates of the cursor. However, we were only concerned with the horizontal coordinate of the cursor.

### Design

Each participant received 160 trials, consisting of 2 velocities (fast, slow) × 2 directions (rightwards, leftwards) × 2 bar lengths (60, 70) × 2 conditions (direct, delayed) × 2 cues (high, low) × 5 replications. The experiment started after participants first received a practice session consisting of eight trials.

### Manipulation check

Another 20 participants (10 for the delayed launching effect, 10 for the direct launching effect) were instructed to rate the causality of one object on the other. Each participant completed two blocks of trials, 2 blocks (Block 1, Block 2) × 2 velocities (fast, slow) × 2 directions (rightwards, leftwards) × 2 bar lengths (60, 70) × 4 replications. In Block 1, participants were asked, "To what extent did the first object (the launcher) cause any motion or change in the second object (the target)?" In Block 2, participants were asked, "To what extent did the second object (the target) cause any motion or change in the first object (the launcher)?" The order of the two blocks was counterbalanced. Participants were instructed to rate on a scale of zero (*no causality at all*) to 100 (*maximum possible causality*).

## Results

Differences (in pixels) between the actual horizontal coordinate of the edge of the bar and the judged horizontal coordinate of the corresponding edge were calculated. For convenience, we refer to the difference as displacement. For the causal edge in the rightwards motion and the effect edge in the leftwards motion, displacement is calculated by subtracting the actual horizontal coordinate from the judged horizontal coordinate. A positively signed displacement indicates that the judged horizontal coordinate was beyond its actual position along the axis of motion and that spatial contraction occurred.[2] For the effect edge in the rightwards motion and the causal edge in the leftwards motion, displacement is calculated by subtracting the judged horizontal coordinate from the actual horizontal coordinate. A positively signed displacement indicates that the judged horizontal coordinate was

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[2] Contraction of the bar is represented here by positive numbers, and expansion of the bar is represented by negative numbers. This is consistent with the direction of the objects acting on the bar. For example, the displacement of the causal edge under the condition of rightwards motion is forward along the launcher's moving direction; this is also the direction of the launcher acting on the bar.

behind its actual position along the axis of motion and that spatial contraction occurred.

First, the data of manipulation check shows that the main effect of source was significant, $F(1, 18) = 92.60$, $p < .001$, $\eta_p^2 = 0.837$, with the square that moved first (the launcher; *M* = 48.01, *SD* = 28.22) rated as more causal than the square that moved later (the target; *M* = 20.42, *SD* = 11.45). The main effect of velocity was also significant, $F(1, 18) = 186.73$, $p < .001$, $\eta_p^2 = 0.912$, with fast motion (*M* = 37.83, *SD* = 26.43) rated as more causal than slow motion (*M* = 30.60, *SD* = 24.45). The significant interaction of source and condition, $F(1, 18) = 50.75$, $p < .001$, $\eta_p^2 = 0.738$, shows that the causal asymmetry of the launcher being rated as more causal than the target only occurred in the direct launching effect ($p < .001$). The significant interaction of velocity and condition, $F(1, 18) = 48.83$, $p < .001$, $\eta_p^2 = 0.731$, shows that the difference of the two velocities was larger for the direct launching effect than for the delayed launching effect.

The magnitude of displacement under each condition for the direct launching effect (see Fig. 3) was significantly larger than zero, except for the displacement of the effect edge under the condition of slow rightwards motion (these results were corrected using the Benjamini–Hochberg method). These results suggest spatial contraction generally occurred at both edges under each condition.

With respect to the delayed launching effect, the magnitude of displacement of each causal edge was significantly larger than zero, while the magnitude of displacement of each effect edge was significantly smaller than zero (see Fig. 3b; these results were corrected using the Benjamini–Hochberg method). These results suggest that there was contraction at the causal edges and expansion at the effect edges under each condition.

The data of Experiment 2a were analyzed in a 2 (velocity: fast, slow) × 2 (direction: rightwards, leftwards) × 2 (edge: causal, effect) × 2 (condition: direct, delayed) repeated-measures ANOVA. The results show that the main effect of the condition was significant, $F(1, 15) = 24.29$, $p < .001$, $\eta_p^2 = 0.618$, $1 - \beta = 0.99$, with the direct launching effect (*M* = 4.05, *SD* = 4.89) resulting in larger contraction than the delayed launching effect (*M* = 0.53, *SD* = 4.81). The main effect of velocity was significant, $F(1, 15) = 5.52$, $p < .05$, $\eta_p^2 = 0.269$, $1 - \beta = 0.48$, with fast motion (*M* = 2.56, *SD* = 5.50) resulting in larger contraction than slow motion (*M* = 2.03, *SD* = 4.79). The main effect of direction was also significant, $F(1, 15) = 33.19$, $p < .001$, $\eta_p^2 = 0.693$, $1 - \beta = 0.99$, with leftwards motion (*M* = 3.05, *SD* = 5.11) resulting in a larger magnitude of contraction than rightwards motion (*M* = 1.54, *SD* = 5.11). The main effect of edge was significant, $F(1, 14) = 22.77$, $p < .001$, $\eta_p^2 = 0.603$, $1 - \beta = 0.99$, qualified by a significant interaction of edge and condition, $F(1, 15) = 24.53$, $p < .001$, $\eta_p^2 = 0.621$, $1 - \beta = 0.99$. Simple effect analysis shows that there was contraction at both edges in the direct launching effect; their difference was significant, with larger contraction at the causal edge ($p < .001$). However, there was contraction at the causal edge, while there was expansion at the effect edge in the delayed launching effect. Their difference was also significant ($p < .01$), but their absolute values were not. On the other hand, the contraction at the causal edge was larger for the direct launching effect (*M* = 5.23, *SD* = 5.40) than the delayed launching effect (*M* = 3.81, *SD* = 4.04, $p < .05$). The interaction of velocity and edge was significant, $F(1, 15) = 19.70$, $p < .001$, $\eta_p^2 = 0.568$, $1 - \beta = 0.98$, qualified by a significant three-way interaction of condition, velocity, and edge, $F(1, 15) = 6.24$, $p < .05$, $\eta_p^2 = 0.294$. Simple effect analysis shows that in terms of contraction at the causal edge, fast motion will result in a larger degree of contraction than slow motion will, both in the direct and delayed launching effect ($p < .01$, $p < .05$, respectively). However, we only found contraction asymmetry in the direct launching effect with both velocities. It seems that in the delayed launching effect there was a translation of the bar along the direction of motion. No other main effects and interactions approached significance (*ps* > .05).

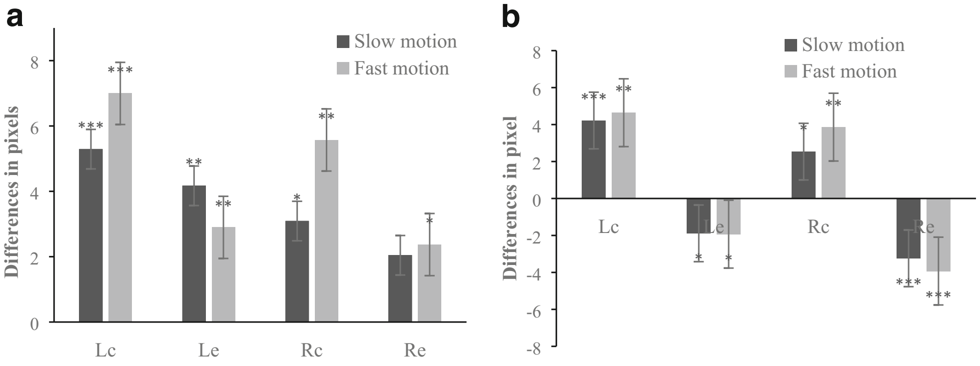

**Fig. 3** The differences (in pixels) between the actual horizontal coordinate of the edge and the judged horizontal coordinate of the corresponding edge of the bar for the direct launching effect (**a**) and the delayed launching effect (**b**) are shown. The 'L' indicates leftwards motion and the 'R' indicates rightwards motion. The 'c' indicates the supposed causal edge and the 'e' indicates the supposed effect edge. Error bars represent standard error. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$

## Discussion

Generally, the analysis of weighted means shows that contraction occurred at both causal and effect edges in the direct launching effect. In the delayed launching effect, contraction occurred at the causal edges, but expansion occurred at the effect edges. The magnitude of the contraction and expansion was not significantly different (the absolute values of the two weighted means were not different; $p > .05$). The effect of direction was found in the positioning task of both conditions, but not in the rating task. This result indicates that the direction does not affect the degree of spatial contraction by affecting the causal impression. It is more likely that there is a similar mechanism underlying the impact of direction on the positioning task in both causal and noncausal conditions.

The most important finding in Experiment 2a is that the magnitude of contraction at causal edges was larger than that at the effect edges in the direct launching effect. Previous studies have validated the causal asymmetry, in which the launcher is perceived as more causal than the target in the launching effect (White, 2006, 2007). Our manipulation check also validates this asymmetry in the direct launching effect, but not in the delayed launching effect. Accordingly, there was contraction asymmetry in the direct launching effect, but merely a translation of the bar in the delayed launching effect. These results suggest that spatial contraction asymmetry should arise from—or at least be related to—causal asymmetry.

The significant interaction of velocity and edge in Experiment 2a shows that the degree of contraction asymmetry increased in line with the objects' velocity, as the causal edge tended to be compressed to a greater degree when the launcher and the target moved quicker. Thus, the velocity of objects not only affects the absolute magnitude of spatial contraction, it also influences the magnitude of contraction asymmetry. It seems that when the causal object moves quicker, its effect becomes stronger. However, the stronger contraction at the causal edges in both conditions that included objects' fast velocity may imply that representational momentum (RM) has an effect on spatial contraction. The magnitude of RM also increases in line with velocity. In addition, Hubbard and Ruppel (2018b) found that the representational momentum of the trailing edge of an object is larger than that of the leading edge of the object, which in turn indicates anisotropy. This anisotropy in the launcher's RM may be conveyed to the bar, resulting in the contraction asymmetry observed in this study. However, this can only account for the results in the direct launching effect, while the results in the delayed launching effect were not consistent with the findings of Hubbard and his colleague. The results in the delayed launching effect seemed to indicate that the launcher just pushed the bar forward in the launcher's moving direction. If we assume that contraction asymmetry is due to the conveyance of the anisotropy in the representational momentum of the launcher, it is hard to explain why Hubbard's findings only explain the results of the direct, but not the delayed, launching effect. Therefore, the difference between the direct and delayed launching effect should result from the perceived causality difference between the two effects which was manifested by the data of the manipulation check. However, the impetus of the launcher can be conveyed through the bar to the target (Hubbard & Favretto 2003), and this may be a prerequisite for the occurrence of the interaction between the launcher and target.

However, one possible problem with the direct launching display in Experiment 2a is that the launcher always remained adjacent to the bar after contact. This could influence observers' judgments by giving them the impression that the launcher continues to compress the edge with which it comes into contact. Thus, Experiment 2b was designed to investigate whether this possibility would result in contraction asymmetry in the direct launching effect.

**Experiment 2b** Experiment 2b aimed to investigate whether contraction asymmetry in the direct launching effect results from the causal object remaining in contact with the bar after the two objects both make contact with the separating bar. Michotte (1963) reported an experiment in which Object A contacted Object B as would occur in a launching stimulus. Object A then returned in the direction from which it came, while Object B remained motionless. As White (2009) argued, it is likely that this is an impression of force and not a causality. The possible reason lies in the fact that Object A does not produce any outcome for Object B. Thus, in Experiment 2b, we presented a display that was similar to the conditions in Experiment 2a, except that the launcher returned in the direction from which it came at the moment the launcher came into contact with the bar. We believe this would be perceived as a causal event and that the object that moved first was the main cause for the occurrence of the interaction. Thus, the edge of the bar that came into contact with this object is called the causal edge.

## Method

### Participants

Fifteen college students (one male and 14 females) aged 17 to 19 years ($M = 18.27$, $SD = 0.59$) with normal or corrected-to normal vision were recruited. They were all right-handed and were compensated with partial course credits for participating. One female's data were excluded, as she failed to understand the instructions.

### Stimuli, apparatus, and procedure

The stimuli, apparatus, and procedure were the same as in Experiment 2a, with the following exceptions: As shown in Fig. 4, the launcher and the target always moved at a speed of 120 pixels/s (~3.41°/s, the fast velocity in the previous two studies). The launcher reversed its direction at the moment it came into contact with the bar and moved at the same speed; the movement lasted 2 s.

### Design

Each participant received 80 trials, 2 directions (rightwards, leftwards) × 2 bar lengths (60, 70) × 2 cues (high, low) × 10 replications. Before the experiment began, participants first received a practice session consisting of 12 trials that included examples of each experimental condition.

### Manipulation check

As was the case in previous experiments, another 10 participants were also instructed to rate the extent of the causality of one object on the other. Each participant received 32 trials, 2 blocks (Block 1, Block 2) × 2 directions (rightwards, leftwards) × 2 bar lengths (60, 70) × 4 replications. In Block 1, participants were asked, “To what extent did the objects that moved first cause any motion or change on the object that moved later?” In Block 2, the question was, “To what extent did the objects that moved later cause any motion or change on the object that moved first?” The order of the two blocks was counterbalanced. The rating scales were the same as those used in Experiment 2a.

## Results

The results of the manipulation check indicate that the object that moved first ($M = 68.80$, $SD = 14.65$) was rated as more causal than the object that moved later ($M = 22.44$, $SD = 19.07$), $F(1, 9) = 37.03$, $p < .001$, $\eta_p^2 = 0.804$.

Differences (in pixels) between the actual horizontal coordinate of the edge and the judged horizontal coordinate of the corresponding edge of the bar were calculated as in Experiment 2a. The magnitude of displacement under each experimental condition was significantly larger than zero (see Fig. 5; these results were corrected using the Benjamini–Hochberg method), indicating spatial contraction occurred at both edges under each condition.

The data of Experiment 2b were analyzed in a 2 (direction: rightwards, leftwards) × 2 (edge: causal, effect) repeated-measures ANOVA. Only the main effect of edge approached significance, $F(1, 13) = 8.96$, $p < .05$, $\eta_p^2 = 0.408$, $1 - \beta = 0.81$, with the contraction at the causal edges ($M = 4.51$, $SD = 2.97$) being larger than that at the effect edges ($M = 4.26$, $SD = 3.15$).

## Discussion

As with the direct launching effect in Experiment 2a, the degree of contraction at the causal edges was greater than that at the effect edges. This finding again demonstrates contraction asymmetry. The edge that was contacted by the more causal object was compressed to a much greater degree. The launcher in the Experiment 2b display reversed its direction after it came into contact with the bar. Therefore, this kind of motion pattern would not give participants the impression that the launcher continued to compress the edge. Therefore, this impression is unlikely to be the cause of the causal contraction asymmetry.

**Experiment 3** Experiment 3 was designed to examine whether what happened before or after contact would affect the spatial contraction asymmetry in Experiments 2a and 2b. In previous experiments, participants always saw that the launcher moved first; they may have already assigned the causal role to the launcher and expected it to collide with the bar. This suggests that contraction asymmetry is dependent on what happened prior to contact. Experiment 3 was designed to investigate whether participants could differentiate between the causal object and the effect object, based on what happened after contact. Then they had to determine whether or not this differentiation had any impact on space contraction. Therefore, we presented a slightly different display, in which the two green squares each entered from one side of the display and moved towards the bar; the bar itself remained stationary within the center of the display (as shown in Fig. 6). After they contacted each edge of the bar, one of the green squares returned in the direction from which it came, while the other remained adjacent to the bar. White (2018) found that when the launcher and the targets which were

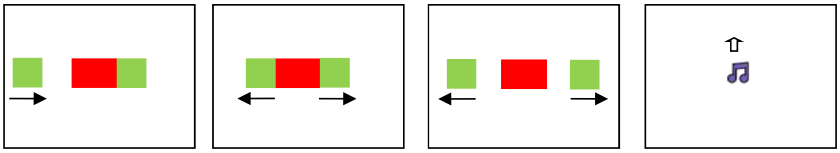

**Fig. 4** The target was initially stationary and remained adjacent to one edge of the bar; the launcher moved toward the bar. After the launcher contacted the other edge of the bar, the target moved off in the same direction as that of the previous launcher, while the launcher immediately reversed its direction. Both objects moved for 2 s before they were removed. (Color figure online)

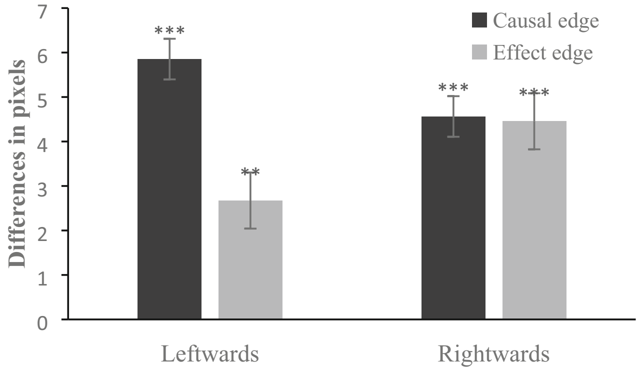

**Fig. 5** The differences (in pixels) between the actual horizontal coordinate of the edge and the judged horizontal coordinate of the corresponding edge of the bar in Experiment 2b are shown. Error bars represent standard error. $^{*}p < 0.05$. $^{**}p < 0.01$. $^{***}p < 0.001$

four objects that shared similar kinematics properties moved toward each other, participants reported a strong causal impression. Therefore, we believed that the display in Experiment 3 would be perceived as a strong causal event. We supposed that the object that did not reverse its direction was the more causal object, because its extent of change of the motion state was smaller than that of the other object (White, 2006). Thus, the edge of the bar that was contacted by this object is called the causal edge.

## Method

### Participants

Sixteen college students (six males and 10 females) aged 18 to 20 years ($M = 18.75$, $SD = 0.58$) with normal or corrected-to normal vision were recruited. They were all right-handed and were compensated with partial course credits for participating.

### Stimuli, apparatus, and procedure

The stimuli, apparatus and procedure were the same as the direct launching effect condition in Experiment 2a, with the following exceptions: As shown in Fig. 6, the launcher and the target were both initially in motion at a speed of 120 pixels/s (~3.41°/s, the fast velocity in the previous two studies). After they contacted the bar, one reversed its direction and moved for 2 s; the other one remained still until it vanished along with the separating bar.

### Design

Each participant received 80 trials, 2 reversed directions (rightwards, leftwards) × 2 bar lengths (60, 70) × 2 cues (high, low) × 10 replications. Direction was defined according to the moving direction of the target after it came into contact with the bar. Prior to the experiment, participants received a practice session consisting of eight trials that included examples of each experimental condition.

### Manipulation check

Another 10 participants again rated the extent of the causality of one object on the other. They received two blocks of 32 trials, 2 reversed directions (rightwards, leftwards) × 2 bar lengths (60, 70) × 2 blocks (Block 1, Block 2) × 4 replications. The questions in both blocks were similar to those in Experiment 2a. In Block 1, participants were asked, “To what extent did the object that did not reverse its direction cause any motion or change on the reversed object?” In Block 2, participants were asked, “To what extent did the reversed object cause any motion or change on the object that did not reverse its direction?” The rating scales were the same as those used in Experiment 2a.

## Results

The data of manipulation check was analyzed first. The results show that the object ($M = 61.17$, $SD = 25.19$) that remained stationary after contact was rated as more causal than the reversed object ($M = 21.30$, $SD = 18.72$), $F(1, 9) = 20.53$, $p < .01$, $\eta_p^2 = 0.243$.

The differences (in pixels) between the actual horizontal coordinate of the edge of the bar and the judged horizontal coordinate of the corresponding edge of the bar were calculated as in Experiments 2a and 2b. The magnitude of displacement under each experimental condition (see Fig. 7) was significantly larger than zero (these results were corrected using the Benjamini–Hochberg method). These results indicate spatial contraction occurred at both edges under each condition.

The data of Experiment 3 were analyzed in a 2 (direction: rightwards, leftwards) × 2 (edge: causal, effect) repeated-measures ANOVA. Only the main effect of edge reached significance, $F(1, 15) = 4.81$, $p < .05$, $\eta_p^2 = 0.243$, $1 - \beta = 0.44$,

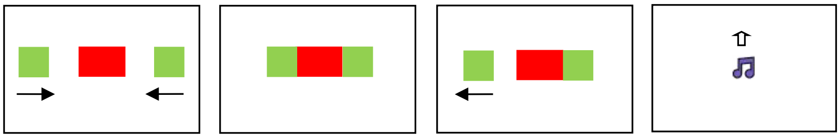

**Fig. 6** An example of experimental conditions of Experiment 3 is shown. The two objects moved for 2.5 s before contacting the bar, and the left object reversed the direction. (Color figure online)

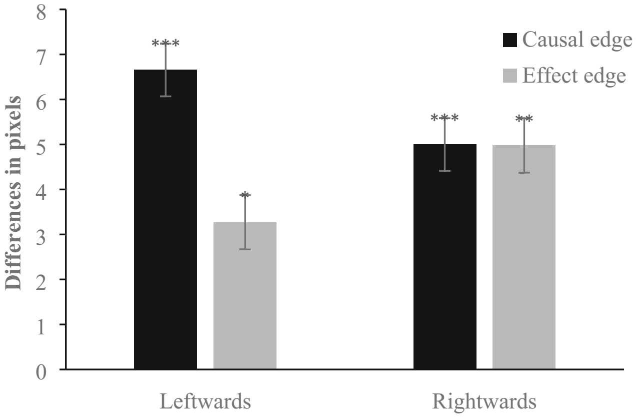

**Fig. 7** The differences (in pixels) between the actual horizontal coordinate of the edge and the judged horizontal coordinate of the corresponding edge of the bar in Experiment 3 are shown. Error bars represent standard error. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$

with the contraction at the causal edges ($M = 5.83$, $SD = 4.57$) being larger than that at the effect edges ($M = 4.12$, $SD = 4.99$).

## Discussion

We found the green square that remained adjacent to the bar after the two green squares coming into contact with the bar was rated as more causal, which indicates the presence of causal asymmetry. This may be because the state of the green square that returned in the direction from which it came was changed much more than that of the green square that remained still (White, 2006). It is important that we also found the existence of spatial contraction asymmetry, in which the magnitude of contraction at the causal edge was significantly larger than that at the effect edge. Therefore, prior motion of the launcher is not necessary to the presence of contraction asymmetry. A similar effect was also found in the causal asymmetry. For example, Hubbard and Ruppel (2013) found that the object that smashed into fewer fragments at the moment of contact was rated as more causal, regardless of whether that object moved first. Some postdictive effects have also been found in phenomenal causality (Choi & Scholl, 2006). Therefore, the causal contraction asymmetry was to some extent dependent on what happened after the contact—namely, postdictive.

## General discussion

### Causal contraction

Buehner and Humphreys (2010) found apparent spatial binding between the launcher and the target in the launch event, compared with less causal or noncausal events. However, they were interested in relative underestimation, while we wondered whether there is an absolute underestimation of space between the launcher and the target. As we expected, significant spatial contraction was found in the launch event in Experiment 1. Almost all participants tended to provide more *same* responses with regard to the causal event when the probe bars were shorter than the separating bar. That is, the bar that bridged the spatial gap between the causal object and the effect object was remembered as shrinking significantly. In addition, we also found that spatial contraction increased in line with the objects' velocity, and as expected, this was the case in Experiment 2a. Previous researchers have established that causal impression tends to strengthen when the objects move quicker in the launching effect (e.g., White, 2014); the results of our manipulation checks also showed this. Therefore, those findings support the view that spatial contraction in the launch event is induced by the participants' perceived causality. Spatiotemporal attributes are important for causal impression (e.g., Michotte, 1963). In addition, spatiotemporal contiguity may signal the presence of a causal interaction (Young & Sutherland, 2009). Thus, when human beings perceive an interaction of objects as a causal interaction, it is possible that the lower-level properties (such as perception and localization) are subject to higher-level properties that people have (such as causality). In this way, observers' responses may be biased.

### Causal contraction asymmetry

White (2006) found causal asymmetry in the launching effect, in which the launcher was rated as more powerful than the target. Thus, it is possible that the causal object compressed the space between the causal object and the target object more than the effect object did. To investigate this hypothesis, we first investigated whether there was a more causal or powerful object in the interaction we presented in our last three experiments. The results show that the objects that moved first in Experiments 2a and 2b and the object that did not reverse its direction in Experiment 3 were rated as more causal in term of causing the motion or change of the other object. The displays in Experiments 2a and 2b were similar to the typical launching effect; the prior motion of the causal object may also be the reason for the causal asymmetry. However, the two objects in Experiment 3 were in motion prior to contact. One possible reason for the presence of causal asymmetry is that in order to make one object reverse its direction of movement, the other object should be more powerful.

Participants in Experiment 2a were instructed to position where they thought the leftmost edge (the supposed causal edge for rightwards motion and the supposed effect edge for the leftwards motion) and the rightmost edge (the supposed effect edge for rightwards motion and the supposed causal edge for the leftwards motion) of the bridge bar had been immediately after the bar disappeared. We measured the difference between the horizontal coordinates of the edges as positioned by the participants and their actual horizontal coordinates. Consistent with the results of Experiment 1, contraction occurred at each edge in the direct launching effect. However, in the delayed effect, contraction occurred at the causal edge, while expansion occurred at the effect edge. This indicates that the causal object and the effect object have an effect on each other in the direct launching effect, but they do not affect each other in the delayed noncausal event. The important finding of Experiment 2a is that the mean magnitude of contraction at the causal edges was significantly larger than that at the effect edges in the direct launching effect. However, this was not the case with the delayed launching effect. Together with the causal asymmetry we found in the direct launching effect, we believe that contraction asymmetry may be induced by, or at least related to, causal asymmetry. What is more, contraction asymmetry is not related to the possible impression that the launcher continued to compress the bar (Experiment 2b). However, we found that the contraction at the causal edge in the causal event was larger than the contraction in the noncausal event. If the noncausal event was regarded as a baseline condition, then we will find that the contraction effect increases at the causal edge. Accordingly, the expansion at the effect edge contracts to such a degree that the effect actually reverses direction when causality is perceived. If this was true, the perceived causality would then have a greater impact on the effect side. The key point is to discover which of the translation and the contraction asymmetry occurs first in visual processing. Although this question needs further investigation, previous studies provide evidence that the causal event enters to an individual's awareness earlier (Moors, Wagemans, & De-Wit, 2017). The authors indicated that "early visual processing identifies some spatiotemporal properties as a 'proto-causal' representation, which requires further elaboration before a truly causal inference is made." Young and Sutherland (2009) also demonstrated the distinctive nature of classic launching stimulus during visual processing. Thus, we believe that participants may be more sensitive to the direct launching effect and quicker to identify its uniqueness. Therefore, causal asymmetry contraction might occur first, and the causality asymmetry is powerful in explaining our results.

In Experiment 3, even though the two green squares were in motion before contact, the motion of one of the two green squares after contact indicated that the one that made the other move in a reverse direction was more powerful. The results show that what happens after contact is more important for contraction asymmetry. More generally, it is how we assign the causal and effect roles to the objects that matters. By integrating information before and after contact, we distinguish the causal object from the other object. Also, the causal object is perceived as the predominant one and more responsible for the motion of the effect object. To cause an interaction to occur, the predominant object continues to move toward the less dominant one; the latter passively waits for the collision from the former and then reacts to the collision. All in all, in our experiments, the amount of space between the causal object and effect object contracted asymmetrically, thereby implying that the causal object and effect object shift to each other nonequidistantly in visual space

**Conclusions** Apparently, spatial perception can be influenced by perceived causality, as previous researchers have indicated (e.g., Buehner & Humphreys, 2010; Scholl & Nakayama, 2004), as well as perceived causal asymmetry, as we have shown. In this study, we verify the spatial contraction and find the contraction asymmetry in a launch-like event. However, in some other causal events, there would be spatial expansion. One example would be the reaction effect, in which the target starts to move before being contacted by the launcher. It seems that the target wants to escape the launcher's contact. Although this spatial expansion requires further investigation, it is possible that when an event is regarded as a causal event, the spatial position relationship between objects involved in this event is distorted to a causally plausible relationship. In addition, the perception of space contraction or expansion will depend on the type of perceived causality.

**Open practices statement** The data for all experiments is available at https://github.com/CyyZjx/data-for-APP. None of the experiments was preregistered.

**Funding** This work was supported by the MOE (Ministry of Education in China) Project of Humanities and Social Sciences under Grant (19YJA190009).

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