

The bookend effect

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Abstract

The principle of “common fate” tells us that objects that move together, group together. But what happens when physical paths are shared and illusory paths differ? Here, horizontally aligned targets move up and down over columns containing static, oblique gratings. If all columns share the same orientation, the target group appears to drift in that direction, as per the furrow illusion. However, when the two outer “bookend” targets have a different background orientation from the inner “book” targets, group motion is entirely captured by the bookends. This occurs despite the inner books having discriminable features and recoverable relative motion. What is missing is any sense of their opposing illusory path. We suggest that spatial proximity and common vertical motion help create a single grouped object representation. Since rigid objects tend not to move in two directions at once, the salient bookends dominate our perception of where the group is going.

Keywords

visual illusions, furrow illusion, grouping, crowding, frame effect, perceptual organization

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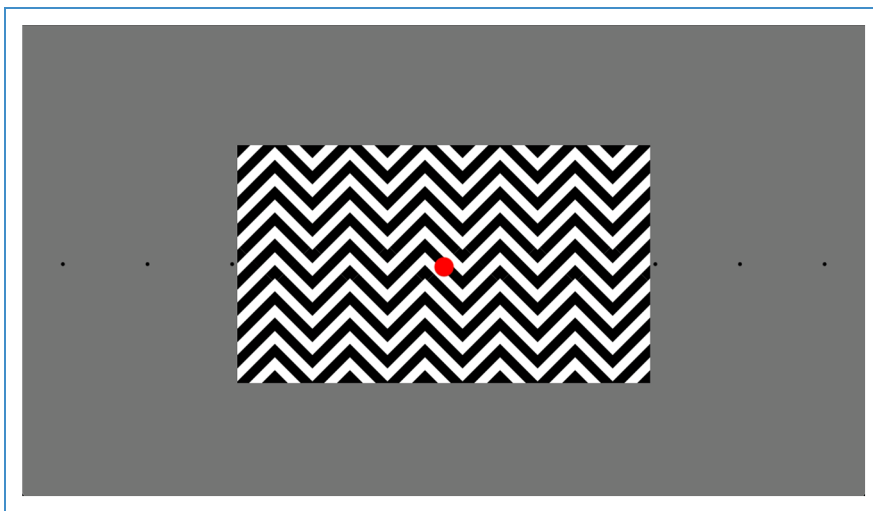
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This short report introduces the “bookend effect,” a novel demonstration of perceptual grouping in which the endpoints of linearly moving arrays appear to capture and control the behavior of internal elements. We discovered the effect during our recent work with the furrow illusion (Anstis, 2012; Riga et al., 2025)—which we describe shortly—and here we focus on furrow displays where elements are arranged horizontally, as books on a bookshelf. We also discuss whether the bookend effect is likely to generalize to other spatial arrangements and other types of motion.

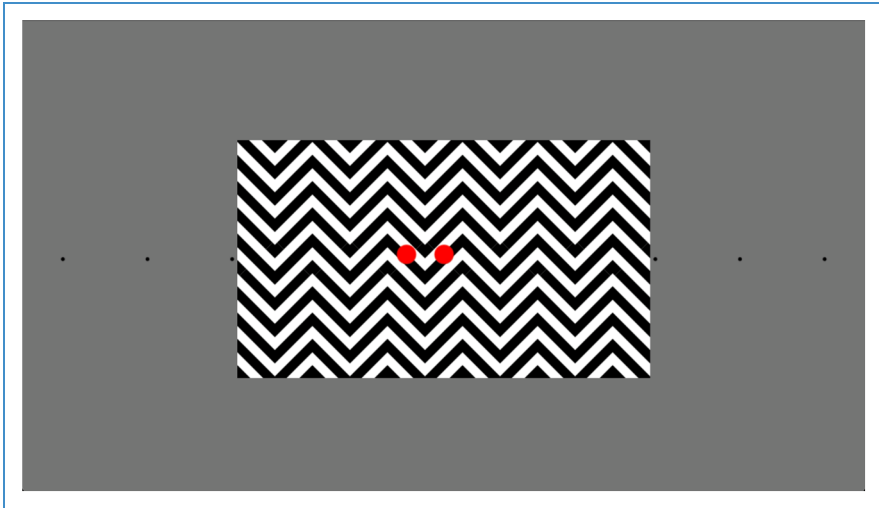
Movie 1 shows the furrow illusion. The red target item is physically moving vertically, as will be clear if you track it with your eyes. Holding fixation peripherally on either the left or right black dot will reveal the illusion. The target now appears to deviate from its veridical path and to follow the oriented black and white lines in the column directly below it. Notice that after four cycles the orientation of the background grid is reversed and the illusory path of motion also switches. The additional columns either side of the target are typically used to crowd or mask the orientation of the grid below the target, and the illusion does not depend on being aware of the inducer orientation (Anstis & Cavanagh, 2018). For the bookend effect, we make use of these additional columns in a slightly different way, as discussed next.

The question that led us to the bookend effect was a simple one: What happens when two furrow targets are placed in adjacent columns that have opposite orientations? Will their shared physical motion—vertical—group the targets, as predicted by common fate (Wertheimer, 1923), or will the opposing illusory motions break the grouping and be seen independently as converging or diverging? The answer is clearly the latter, as can be verified in Movie 2. Both illusory oblique paths are equally visible and the two objects appear to approach and/or recede from each other depending on the orientation of the grid and their position within the animation cycle. Taking this idea one step further, we added a third object, and arrived at the bookend effect.

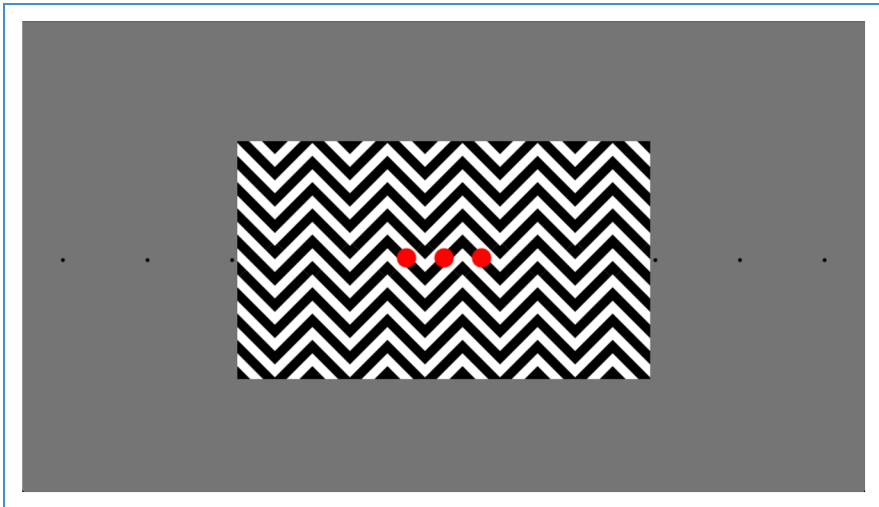
In Movie 3, there are still two possible illusory trajectories. The central “book” object appears on a rightward orientated column, while the two flanking “bookends” have leftward oriented columns. In contrast to Movie 2, however, now only a single “grouped” motion is visible and all three objects move obliquely up and to the left, then down and to the right. The bookends have essentially captured the lone inner book. When the grid reverses after four cycles, the group motion changes accordingly.



Movie 1. The furrow illusion. https://maltacogsci.org/bookend/bookend_movie1.html.



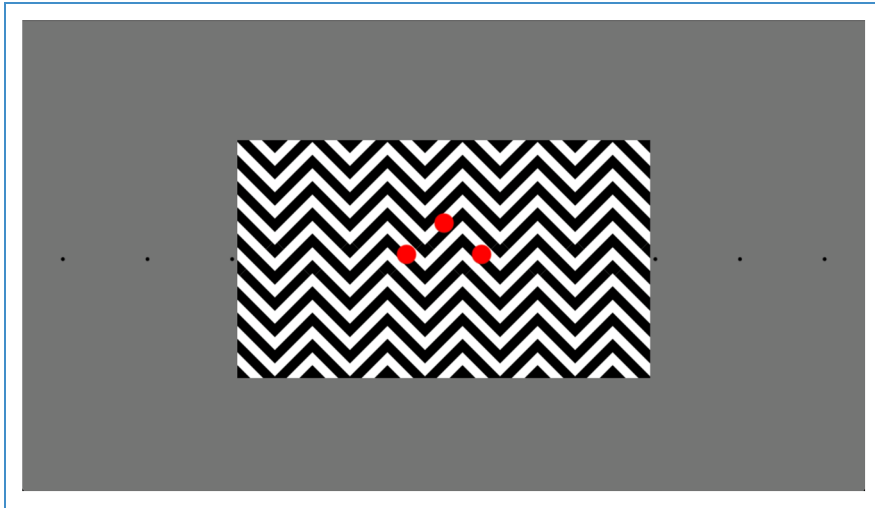
Movie 2. Opposing furrow targets. https://maltacogsci.org/bookend/bookend_movie2.html.



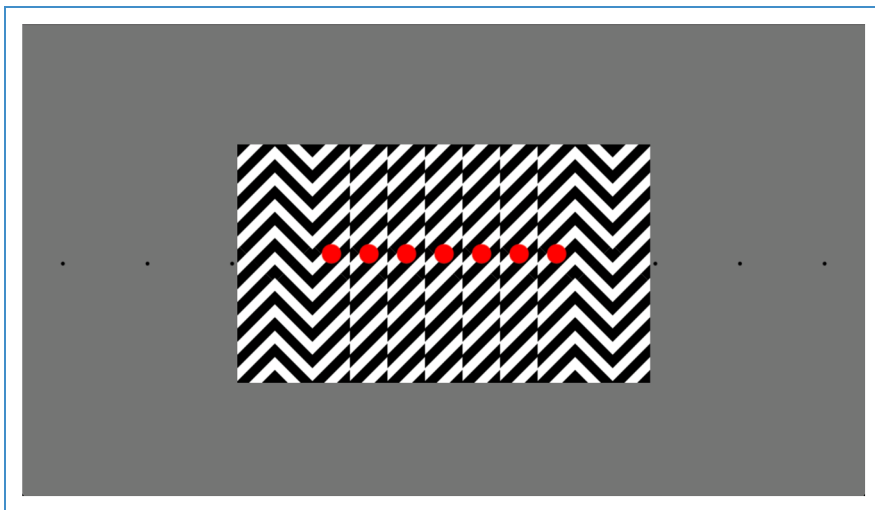
Movie 3. The bookend effect. https://maltacogsci.org/bookend/bookend_movie3.html.

The importance of the linear arrangement of targets for the bookend effect is illustrated in Movie 4. Shifting the central “book” target vertically makes it possible to follow its unique oblique path, or to shift attention to follow the common path of the bookends. It also appears possible to treat all three objects as a single group, which gives rise to a complex rotating or twisting motion. Nevertheless, it is clear that breaking the linear arrangement of the targets also breaks the bookend effect. In the HTML version of the movie, the up and down arrow keys can be used to adjust the vertical separation between the elements to explore this linear dependence further.

Returning to our basic effect in Movie 3. Perhaps it is not very surprising that the bookends dominate the book motion, given that there is a 2:1 ratio. With either a winner-take-all mechanism or an

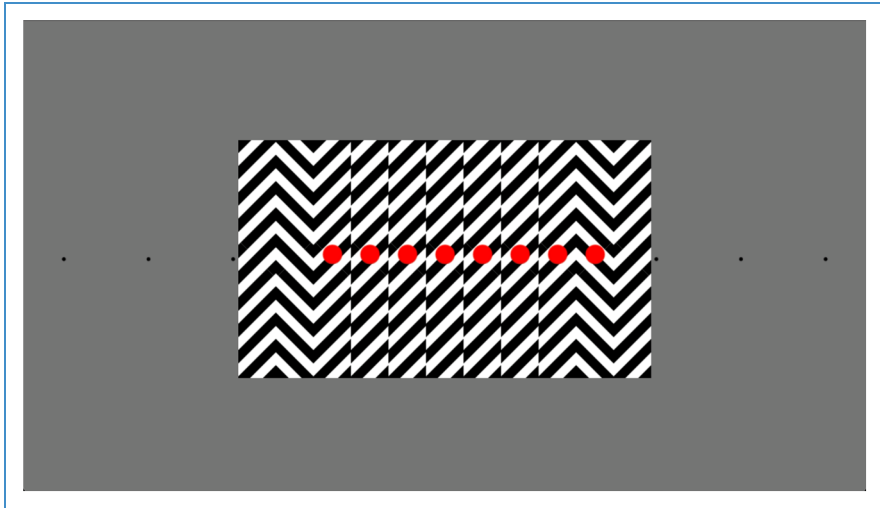


Movie 4. Vertical separation releases the inner book from the bookend effect. https://maltacogsci.org/bookend/bookend_movie4.html.



Movie 5. Multiple inner books. https://maltacogsci.org/bookend/bookend_movie5.html.

averaging approach, we might expect perception to favor the bookends. Movie 5 demonstrates that the bookend effect does not in fact depend on numerical supremacy. Here we have changed the layout of the grid, so that the middle seven columns have the same orientation, instead of alternating. This provides a very strong impression of group motion that follows right-oriented lines. After four cycles, the grid layout does not change, but now we add two bookends, which have leftward orientation. Despite the very strong signal from the seven inner books, the bookends again dominate. In the HTML version of the movie, pressing the “h” key will “hold” the display in its current state, with or without bookends. You can also reverse the grid orientation with the “g” key and use the arrows to adjust vertical offsets.



Movie 6. Removing one bookend. https://maltacogsci.org/bookend/bookend_movie6.html.

To verify that *both* bookends are required to control group motion, and to provide some initial data, we had four psychophysical observers watch displays in which we systematically varied the transparency level of the far bookend from an alpha level of 0.1, where it was barely visible, to an alpha level of 1.0, where it was fully opaque. Movie 6 presents the extreme case where the left bookend is removed/added after every four cycles. When fixating at the right side of the screen, you should at first experience the standard bookend effect, this time with the grid oriented so that the uniform captured motion is initially up and to the left. After four cycles, the far-left bookend is removed. There is now a more complex pattern of motion, with the targets appearing to contract during the downward portion of the motion and expand away from each other during upward motion. We asked our observers to report which of these two percepts—uniform bookend capture versus contraction—expansion—they were experiencing as a function of far-bookend transparency. As can be seen in Figure 1, the results show a very consistent switch at around 50% transparency.

Hopefully, the above demonstrations establish the bookend effect as a potentially interesting topic for further investigation. There are clearly many open questions: What mechanisms give rise to such strong capture and control? Is the effect limited to the furrow illusion? Can it be generalized to other illusory motion displays? Or even to other types of real-motion or multielement static arrays? How else can it be manipulated and measured? In the remainder of this paper, we offer some initial thoughts on the above. We also provide online Table 1, that contains some additional demonstrations and display ideas based on our ongoing research. The table can be accessed at https://maltacogsci.org/bookend/bookend_table1.html, or via the Open Science Framework (OSF) page. Note that double clicking/touching within any table demo will reverse the grid orientation. A single click at the top of a target column will hide that target. Clicking at the bottom will hide the column grid.

It seems clear that some sort of frame effect is occurring here, as discussed in the classic work of Duncker (1929) and Johansson (1950). That is, the motion of the terminating bookends may be treated as a frame of reference within which only the relative motion of the inner books is evaluated. If the common vertical motion shared by all elements is factored out during this process, the opposing illusory horizontal motion of the inner books may be treated as an additional motion feature—that while still visible—is assigned no role in computing an overall path for the entire group of targets. Fixating above the display in any of the movies will make this residual horizontal motion more

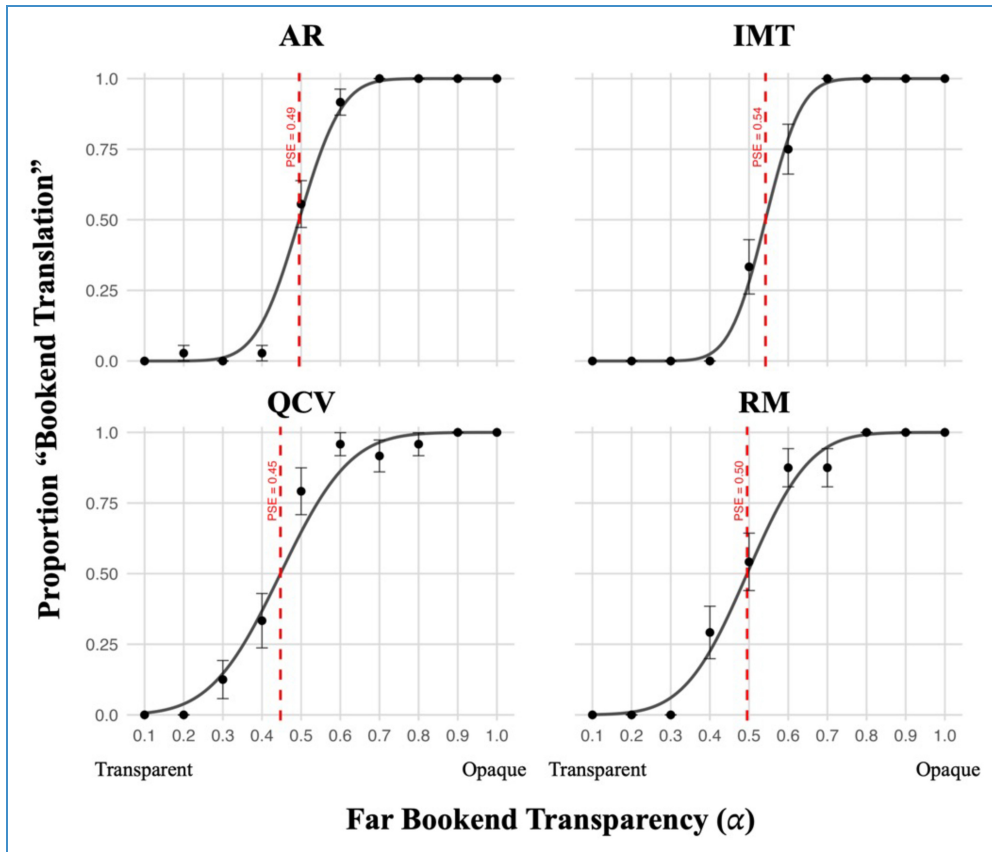


Figure 1. Data from four observers who were asked to report whether they perceived uniform bookend translation versus contraction–expansion as a function of far-bookend transparency level. Data are arbitrarily plotted as a proportion of bookend translation responses. An alpha level of 0.1 is almost transparent, and alpha level of 1.0 is fully opaque. Individual points of subjective equality (PSE; red lines) cluster around 0.5. See the linked Open Science Framework (OSF) page for methods and raw data.

visible. Notice that it seems to stream across the inner books, in a direction opposite to the horizontal trajectory of the bookends. The puzzle in the context of the bookend effect is why this opposing motion is effectively ignored when assigning a direction to the entire group.

Comparing online Table 1a (the canonical bookend effect) with online Table 1b (Johansson’s relative motion display), highlights the importance of spatial proximity. In the real-motion display of online Table 1b, there needs to be a gap between the physical oblique paths, to avoid their colliding. If such a gap is added to a bookend display, as in online Table 1c, the grouping is weakened and the horizontal motion contrast of the inner books becomes more apparent. This suggests that the spatial proximity of the inner books with each other and with the bookend plays a crucial role in constraining such horizontal movement and more generally in helping to group all of the elements into a single object.

Spatial proximity may also act to reduce the saliency of the inner books in other ways, via ensemble mechanisms (Whitney & Yamanashi Leib, 2018) or crowding (Whitney & Levi, 2011), for example. As already noted, crowding of background orientation with single targets would not be expected to block the component illusory motion of individual inner books (Anstis & Cavanagh,

2018). Of course, it remains a possibility that in displays with multiple elements, as here, crowding is modulated in other ways as a function of overall group structure (Herzog et al., 2015).

Access to the precise object properties of the inner books, however, does not appear to influence the illusion. As can be seen in online Table 1d to f, they can differ from the bookends in terms of size, shape, orientation, color or luminance, and still be captured by them. We should note of course that reducing bookend visibility will suppress or modulate the effect. This is true for the transparency adjustments reported in Figure 1 (see also online Table 1g), but would also be expected to occur with other visibility manipulations, such as extreme size reduction. The relationship between a bookend's detectability and its ability to capture the inner books will be an interesting avenue to explore.

It seems unlikely that the bookend effect is specific to the precise furrow displays we have presented here. The effect is equally strong with both peep-hole furrow displays (Riga et al., 2025) and the pinstripe furrow displays used by Thornton and Riga (2024), as can be seen in online Table 1h to i. Going beyond the furrow illusion, our informal observations with related displays in which perceived direction is also influenced by local motion—such as the infinite regress (Tse & Hsieh, 2006), curve-ball (Shapiro et al., 2010), and double-drift (Lisi & Cavanagh, 2015) illusions—also show clear bookend capture. Online Table 1j, for example, shows a variant of the double-drift (Lisi & Cavanagh, 2015) illusion implemented as a bookend display. There is still an overall impression of a group “whole” moving in a direction jointly determined by the orientation of the bookend local motion and the global path. The opposite oblique path, which should arise via the combination of the inner books' local motion and the global path, is still being completely overridden. Nevertheless, compared to the furrow displays, the residual horizontal motion streaming across the inner books appears to be more salient. This suggests that the furrow illusion may be particularly good at suppressing or masking this additional motion feature, making the global capture more prominent. It will certainly be interesting to explore a wide range of other motion/position illusions that might be susceptible to a bookend effect. For a chronological list of such effects, see Table 1 in Thornton et al. (2025).

Does the bookend effect extend to other dynamic displays where the global percept does not necessarily rely on combining local and global motion? Online Table 1k shows a linear group of figures modeled after the bistable quartet displays of Ramachandran and Anstis (1985). The aspect ratio of the bookend rectangles has been set to bias horizontal motion, whereas the inner books are more likely to independently favor vertical motion. When explicitly paying attention to the bookends, their behavior does appear to influence the interpretation of the inner books, consistent with the “entrainment” effects of Ramachandran and Anstis (1985). However, the “automatic” capture of the inner books without any attentional effort as is seen in the furrow displays does not really occur here. Moreover, attending to the inner vertical motion can entrain vertical motion in the bookends, suggesting a qualitative difference.

Although we are clearly only in the very early days of trying to understand the bookend effect, there seem to be some general principles to consider. First, the critical items in the display need to form a coherent whole that can be perceived without needing to inspect individual elements, whether bookends or inner books. Whether this grouping into a single-object representation involves coarse-grained figure-ground mechanisms, low spatial frequency channels or veridical-motion common fate, remains to be seen. We are also not yet sure whether peripheral viewing—as used in our furrow displays—has additional consequences, but it is clear that it helps in terms of scale/resolution, in creating a gestalt.

Second, the group needs to have emergent properties or behaviors that can be modulated by varying or omitting the bookends. Again, we do not know at this stage whether having a dynamic display is crucial. Clearly, motion not only drives our current illusory effect, but also strongly binds the items together as a group as well as providing strong kinetic edges for the bookends themselves. But of course, it remains possible that static emergent properties such as global orientation or color

contrast could be susceptible to bookend-like effects. Also, as many compelling static illusions—such as the Müller-Lyer and the Elusive Arch—crucially rely on the influence of figure endpoints, this may be an interesting avenue for future research (Müller-Lyer, 1889; Todorović, 2014).

Finally, we suspect there is an influence of processing hierarchy with this illusion. That is, bookend features that emerge at the same or a higher level of visual processing than the inner books will dominate, but the illusion will be broken when this order is reversed. For example, online Table 1l shows a configuration where the bookends have an illusory trajectory and the inner books physically move vertically over a uniform gray background. There is still a strong bookend capture effect, with the illusory motion dominating the veridical inner book motion. Online Table 1m, however, shows the opposite configuration where the bookends have physically vertical motion and the inner books have a common illusory trajectory. The veridical bookend motion seems less able to capture the inner books, and if anything, seems to be intermittently grouped with their illusory oblique motion. Understanding the significance of this apparent hierarchy effect is the main focus of our ongoing research.

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Patrick Cavanagh: Investigation; Methodology; Supervision; Validation; Writing – review & editing.

Ian M. Thornton: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Writing – original draft.

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Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Supplemental Material

Supplemental material for this article is available online. All movies, source code, details of experimental methods, data, and analyses are available on the Open Science Framework (OSF) associated with this work at: <https://osf.io/78aq2>.

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