Spatiotemporal cues for tracking multiple objects through occlusion

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As we move about the world, and objects in the world move relative to us, objects constantly move in and out of view as they are occluded by other objects. Given such disruptions, how does the visual system maintain attention on objects of interest? We used a multiple object tracking task (Pylyshyn & Storm, 1988) to explore the spatiotemporal cues used to track objects through occlusion. Observers tracked four target objects moving among four identical distractor objects, as all objects frequently passed behind static vertical occluders. Across three experiments, we manipulated the way that objects behaved under occlusion, and observed the effect on tracking performance.

When an object passes behind an occluder, the observer must link the preocclusion object to the postocclusion object across a brief disappearance. There are at least two major spatiotemporal features that could be important for making this link. First, the location where the object first disappears might be critical. When an item becomes occluded, a "marker" could be placed at the location where the object disappeared (the marker might also be placed on the expected location of the object's reappearance, based on an extrapolation of the object's path). When an object disoccludes near this marker, it could signal the object's link to the original object. Additionally, the history of the object's motion could be an important feature that could be used to link the two views of the object across the disruption. We might expect a similar angle of disocclusion to be important for establishing this

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link. Furthermore, we might also expect that the object disocclude on the opposite side of where it occluded.

Across three experiments, we tested whether each of these cues was used to link two views of an object across an occlusion. In Experiment 1, objects exited the occluders at the "wrong" location along the occluder's edge (the object reappeared either 2 or 4 object diameters higher or lower than expected). If the linking of the preocclusion object to the postocclusion object requires a marker of the location of the object's disappearance, then increasing this distance should impair performance. In Experiment 2, objects exited the occluders at the "wrong" angle (by turning either 30 or 60 degrees under the occluder). If the pre- and postocclusion objects are linked by matching the new trajectory to the old, then larger angle deviations should lead to a greater impairment in performance. In Experiment 3, objects exited the occluders at the "wrong" side (by either bouncing or reversing direction). If the process linking the pre- and postocclusion objects also relies on a representation of which side of the occluder an object should reappear, then these manipulations should also impair performance.

METHODS

See Figure 1 for a depiction of the displays and manipulations used in each experiment. Subjects were presented with a black computer display containing eight blue circles outlined in white. In Experiments 1 and 2, two vertical occluders spanned the vertical extent of the screen, eight degrees apart. Because Experiment 3 included a manipulation where objects bounced off the occluders, occluders in this experiment were broken into 12 pieces (four columns of three small occluders each) in order to minimize objects getting 'stuck' bouncing between two occluders. In each trial of each experiment, four randomly selected objects flashed several times, and all objects began moving randomly around the display. In each experiment, manipulations of an object's behaviour under occlusion were manipulated across blocks, and subjects were fully informed of the presence, and size of the manipulations present in a block of trials. At the end of each trial, subjects clicked the four objects that they believed corresponded to the flashed targets.

RESULTS

The results of each experiment are depicted in Figure 1. In Experiment 1 ($N = 21$), tracking performance was significantly higher (84%) when objects made only small locations shifts under the occluder, compared to trials where objects made large shifts (72%), $t(20) = 6.3$, $p < .001$. In Experiment 2 ($N = 16$), there was no difference between trials where objects made small

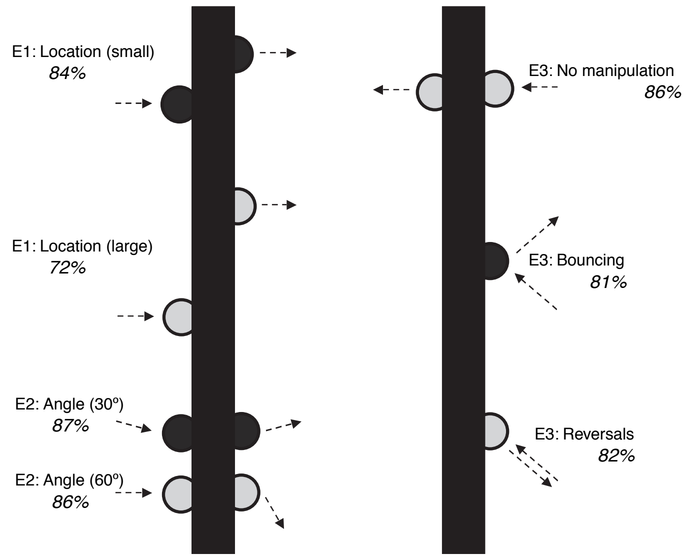

Figure 1. Manipulations of object motion during occlusion for separate conditions in Experiments 1–3, and mean accuracy in each condition. To distinguish conditions, objects are shown in different shades of grey; however, all objects were displayed in blue with white outline.

angle changes under the occluder (87%) compared to trails where the angle changes were large (86%), $t(15) > 0.5$, $p = .65$. In Experiment 3 ($N = 16$), while tracking performance on trials with no manipulations was high (86%), performance on trials where the objects bounced (81%) or reversed direction (82%), was only slightly, but significantly, impaired, $t(15) > 3$, $p < .01$.

CONCLUSION

Experiment 1 showed that when target objects were occluded, performance remained high if the object's location was shifted only slightly during the occlusion, but dropped abruptly if the shift was large. The distance between the original object occlusion and the location of the object's disocclusion appears to be a critical factor in determining whether the two instances are perceived as the same object. Experiment 2 showed that angle changes have no effect on performance, suggesting that the direction of motion of an object was not used to link the pre- and postocclusion instances of an object. Experiment 3 extended this result, showing that when objects reappeared on the wrong side of the occluder (which could be considered an even larger angle change), performance was only mildly impaired. Together, these results suggest that when an object is occluded, the location of the occlusion, but not the angle of motion or side of occlusion, is a critical factor in linking the pre- and postocclusion instances as the same object across occlusion. This simple trick could underlie much of our perception of persisting objecthood when an object disappears from view. These results are consistent with other recent findings suggesting that observers do not extrapolate the motion paths of objects that become temporarily invisible during multiple object tracking. For example, when all moving objects in a display temporarily disappear for short durations (e.g., 200–400 ms), tracking performance is better when the objects reappear near the same location as the disappearance, relative to when they reappear as if they had continued moving while invisible (Fencsik, Horowitz, Klieger, & Wolf, 2004; Keane & Pylyshyn, 2003, 2004).

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