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Motion-induced position shifts are influenced by global motion, but dominated by component motion

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ABSTRACT

Object motion and position have long been thought to involve largely independent visual computations. However, the motion-induced position shift (Eagleman & Sejnowski, 2007) shows that the perceived position of a briefly presented static object can be influenced by nearby moving contours. Here we combine a particularly strong example of this illusion with a bistable global motion stimulus to compare the relative effects of global and component motion on the shift in perceived position. We used a horizontally oscillating diamond (Lorenceau & Shiffrar, 1992) that produces two possible global directions (left and right when fully visible versus up and down when vertices are occluded by vertical bars) as well as the oblique component motion orthogonal to each contour. To measure the motion-induced shift we flashed a test dot on the contour as the diamond reversed direction (Cavanagh & Anstis, 2013). Although the global motion had a highly significant influence on the direction and size of the motion-induced position shift, the perceived displacement of the probe was closer to the direction of the component motion. These findings show that while global motion can clearly influence position shifts, it is the component motion that dominates in setting the position shift. This is true even though the perceived motion is in the global direction and the component motion is not consciously experienced. This suggests that perceived position is influenced by motion signals that arise earlier in time or earlier in processing compared to the stage at which the conscious experience of motion is determined.

1. Introduction

The earliest demonstration of an interaction between motion and position encoding was probably Fröhlich's (1923) discovery that the starting position of a moving object appeared to be shifted along the motion trajectory. More than 70 years later, Nijhawan (1994) expanded on earlier observations by Mackay (1958), and showed that a briefly presented, stationary stimulus is perceived as lagging behind a moving stimulus, although they are physically aligned (the flash lag effect; Nijhawan, 1994). Two other groups reported that even when the stimulus itself did not move, the motion of a texture inside it shifted the perceived position of the stimulus (De Valois & De Valois, 1991; Ramachandran & Anstis, 1990). Moreover, if the stimulus with the internal motion then actually does move, the perceived trajectory deviates strongly from the physical trajectory (the infinite regress illusion; Tse & Hsieh, 2006). Two further versions use a briefly presented "flash" stimulus, one in which the flash is presented adjacent to a moving stimulus (the flash drag effect; Whitney & Cavanagh, 2000) and one in which the flash occurs on the moving stimulus itself (the flash jump effect; Cai & Schlag, 2001a; Cai & Schlag, 2001b; Sundberg, Fallah, & Reynolds, 2006). In both cases, the flash is seen displaced in the direction of the motion.

In recent years, several important advances have been made towards understanding how and why these illusions occur, and many of them may in fact be caused by the same underlying mechanism (Eagleman & Sejnowski, 2007). In the experiments reported here we focus on a specific aspect of the illusions that is still not well understood, namely the exact nature of the motion signals driving the position shifts. We use a particularly strong motion-induced position shift that has been called the "flash grab effect" (Cavanagh & Anstis, 2013). This effect occurs when a moving stimulus undergoes a direction reversal, and a flash is briefly presented at the same time and position as the reversal. The flash is strongly shifted in the direction of motion after the reversal. This perceived shift can be up to 10 times larger than the flash drag

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effect, up to several times the physical size of the flash and several degrees of visual angle (Cavanagh & Anstis, 2013).

Several studies have shown that motion-induced position shifts do not require low-level motion that drives early, direction-selective neurons (Hubel & Wiesel, 1962), but can also be generated by high-level motion and global motion. High-level motion refers to stimuli that are seen to move even though they do not drive early motion-selective units. These stimuli either have no net motion of luminance-defined features (e.g., motion of texture-defined contours; Cavanagh & Mather, 1989) or their luminance features jump too far to stimulate low-level detectors (Anstis & Mackay, 1980). Global motion refers to the direction that an object is seen to move even though many or all of its constituent contours have component motion directions (the directions orthogonal to each local contour) that are very different (Nakayama & Silverman, 1988).

Several reports have shown that position shifts are not driven solely by local, image-level motion signals. A pattern containing global motion (plaids or dynamic Gabor arrays) produced shifts corresponding to the global direction rather than the two local component directions (Hisakata & Murakami, 2009; Mather & Pavan, 2009; Rider, McOwan, & Johnston, 2009). Similarly, two studies have demonstrated that shifts can be driven by second-order motion (Bressler & Whitney, 2006; Pavan & Mather, 2008). Position shifts can also be induced by high-level motion signals generated during anorthoscopic perception (Watanabe, Nijhawan, & Shimojo, 2002) and by objects moving behind an occluder (Watanabe, Sato, & Shimojo, 2003) in the near-absence of low-level motion signals. The flash drag effect can even be elicited along the perceived motion path (Shim & Cavanagh, 2004) with a bistable apparent motion quartet stimulus, where there is no net motion energy in the image. Furthermore, a recent study using the flash grab effect found that when one of two overlapping transparent surfaces moving in opposite directions is attended, the flash grab effect will correspond to the attended surface (Tse et al., 2011) even though the two low-level motion signals are equal and opposite in direction. Even implied motion, induced by static photographs, can lead to a flash drag effect (Pavan et al., 2011).

These previous studies focused on demonstrating an effect of global or high-level object motion that was different from what would be expected based on purely local component motion signals, especially when component motion signals were absent or nulled. Here we examine what happens when both component and global motion signals are available. We wanted to determine the extent to which global and component motion contribute to the shift, by pitting the two types of motion against one another in the same stimulus. If motion-induced position shifts are not influenced by component motion whatsoever, shifts in perceived position should follow the global motion direction.

Our stimulus was created by combining a well-known bistable moving diamond stimulus (Lorenceau & Shiffrar, 1992) with the flash grab effect. We presented two diamonds that moved horizontally back and forth across the screen under conditions that induced differences in perceived motion direction (see Fig. 1A–B). According to Lorenceau and Shiffrar (1992), when the diamonds are shown without occlusion, or with visible occluders, the diamonds appear to move horizontally. When the occluders are the same color as the background, however, the diamond line segments appear to move vertically and independently, presumably because terminator motion measured at the line end-points dominates the conscious motion percept (McDermott, Weiss, & Adelson, 2001). Importantly, although these conditions produced very different global motion percepts, the component motion along the line segments at the position where the motion-induced position shift was to be tested was always identical and orthogonal to the orientation of the line.

To test the position shift, a dot probe was flashed in the middle of the line segment at the time of each motion reversal (see Fig. 1A). The two diamonds alternately reached the same reversal position and the probe was flashed at that same physical location. Depending on which diamond was moving, the probe was either red or blue. Since the two diamonds moved away from the probe location in opposite directions, the red and blue probes were shifted in opposite directions, doubling the size of the effect (see Fig. 1C). To report the position shift, participants adjusted a pair of dots to mimic the direction and distance of the offset they saw between the two colored dots. This resulted in a highly robust, basic position-shift effect with a motion stimulus that was seen with one of two different global motion directions, without any difference in component motion signals at the flash location.

2. Methods

Six participants (3 males; ages 18–23, mean age = 20.4) took part in a control experiment that measured motion direction. Eleven additional participants (5 males; ages 19–23, mean age = 20.4) took part in the main experiment, which measured position shift direction. All were members of the Dartmouth College community with normal or corrected to normal vision, who volunteered to participate. Each participant gave written informed consent prior to the experiment according to the guidelines of the IRB and Department of Psychology at Dartmouth College. All were naïve to the purpose of the experiment, and received $10/h in compensation.

Participants viewed the visual stimulus from a distance of 57 cm, in a darkened room, constrained by a chin rest. The stimuli were presented on a Mitsubishi Diamond Pro 2070SB CRT monitor (1600 × 1200 pixels, at a 60 Hz refresh rate), and generated using the Psychophysics Toolbox, version 3, on a PC running MATLAB R2010a (Brainard, 1997; Pelli, 1997) in an Ubuntu Linux operation system.

Three versions of the oscillating diamond stimulus were used. In the “complete diamond” version, the diamonds were shown without occlusion, which, according to Lorenceau and Shiffrar (1992), leads to an unambiguous percept of a diamond moving back and forth horizontally (see Fig. 1B). In the “line segment” version, the diamond moved left and right horizontally while its vertices were occluded by three vertical bars that had the same color as the background (see Fig. 1B). In this version, the line segments are often seen in independent vertical motion (Lorenceau and Shiffrar (1992), entrained by the vertical terminator motion measured at visible line segments endpoints (McDermott, Weiss, & Adelson, 2001). Finally, in the “outline occluders” condition, a thin yellow outline was added to all the occluder regions to make them appear visible and separate from the background. Lorenceau and Shiffrar (1992) reported that the horizontal motion of the diamond was seen once again in this case because the visible occluders “explained” the vertical terminator motion by making those terminators extrinsic to (i.e. not belonging to) the moving line segments.

To test the extent to which these three versions of the diamond stimulus could produce the expected motion percepts, a perceptual control experiment was run in which participants indicated the motion direction that they perceived for each of the three versions by rotating a dumbbell indicator to align it with the perceived direction. A fixation cross (0.81° vis. angle in width and height) was presented in the center of the screen. We used two diamond stimuli (height: 19.2° vis. angle, width: 28.8° vis. angle) that moved in an interleaved fashion (two diamonds were used to double the size of the position shift in the main experiment from what would be elicited by a single diamond). One diamond was centered at a starting position ~4.1° vis. angle to the left of fixation, and another