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The flash-lag effect during illusory chopstick rotation

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Abstract. In the 'flash-lag' effect, a static object that is briefly flashed next to a moving object appears to lag behind the moving object. A flash was put up next to an intersection that appeared to be moving clockwise along a circular path but was actually moving counterclockwise [the chopstick illusion; Anstis, 1990, in *AI and the Eye* Eds A Blake, T Troscianko (London: John Wiley) pp 105 – 117; 2003, in *Levels of Perception* Eds L Harris, M Jenkin (New York: Springer) pp 90 – 93]. As a result, the flash appeared displaced clockwise. This was appropriate to the physical, not the subjective, direction of rotation, and it suggests that the flash-lag illusion occurs early in the visual system, before motion signals are parsed into moving objects.

1 Introduction

In the well-known 'flash-lag' illusion (Mackay 1961), a flashed stimulus is presented physically aligned with a continuously moving object, and the flash is visible in a lagging position relative to the moving object (reviewed by Nijhawan 2002). This illusion has been variously attributed to motion extrapolation (Nijhawan 1997, 2001; Khurana et al 2000), differential latency (Whitney et al 2000a, 2000b), postdiction (Eagleman and Sejnowski 2000), temporal averaging (Krekelberg and Lappe 2000), and attentional allocation (Baldo et al 2002). As early as the retina, neural signals from motion can precede signals from a flash, owing to contrast gain control (Berry et al 1999).

In this paper I examine what happens when a brief flash is superimposed on a smoothly moving object that appears to move in one direction but actually moves in the opposite direction (Watanabe et al 2002). Is the flash-lag effect appropriate to the physical or the perceptual direction? To produce this illusory difference in direction, I combined the flash-lag effect with the chopstick illusion (Anstis 1990, 2003), as shown in figure 1. A vertical line and a superimposed horizontal line move in counterphase

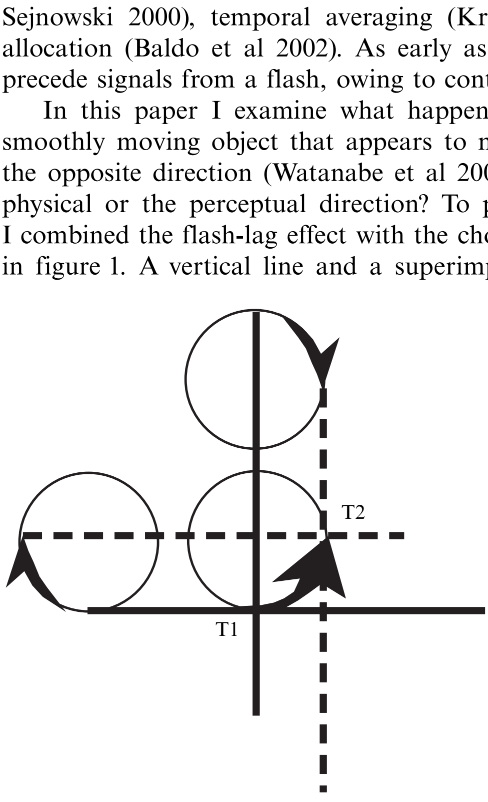

Figure 1. The chopstick illusion. Lines move along clockwise circular paths (thin arrows). The positions of the lines are shown as solid lines at time T1 and as dashed lines at time T2. The central intersection actually moves counterclockwise (thick arrow) but is perceived as moving clockwise (after Anstis 1990, 2003).

along clockwise circular paths, without rotating. The chopstick illusion arises in the central intersection, where the two lines cross. This sliding intersection actually moves counterclockwise around a circle, but it is incorrectly perceived as moving apparently clockwise, as if in step with the lines. In my view, the local motion signals from the intersection are ignored because the sliding interaction is not parsed as an object. Instead, clockwise motion signals from the tips of the lines (terminators) propagate along the two lines, and are blindly assigned to the central intersection, even though the spatial phase is indeterminate. An animated movie of the chopstick illusion can be seen at http://psy.ucsd.edu/~sanstis/Chop.html.

I showed the chopstick illusion to a large number of naive students (Anstis 2003). A movie of the chopstick illusion was projected onto a large screen at the front of a large lecture hall and shown to a class of 208 undergraduate students, who viewed the screen from a great variety of viewing distances and angles. Results were consistent. When shown a movie of figure 1, in which the lines moved clockwise and the central intersection moved counterclockwise, 97% of the observers incorrectly reported the central intersection as moving clockwise. Thus, almost everybody experienced a robust and compelling chopstick illusion.

In the present study, a briefly flashed spot was superimposed on the chopstick intersection in figure 1—an intersection that was really moving counterclockwise but apparently moving clockwise. If the flash-lag effect turns out to be appropriate to the physical direction of rotation, it probably occurs early in the visual system—before motion parsing. If it is appropriate to the illusory direction, it probably occurs later—after motion parsing.

2 Experiment 1

2.1 *Method*

Observers viewed a version of figure 1 in which the intersection followed a circular path of diameter 6 deg at a rotation rate of 0.9 rev. s^{-1}. When each line moved clockwise, their central intersection followed a circular path that also appeared to be clockwise, but was actually counterclockwise. Once on every rotation a white disk was flashed up exactly centered on the intersection. To ensure maximum salience for this disk, it was made white against a black surround, and its diameter was 0.8 deg, substantially larger than the 0.2 deg widths of the moving lines. These moving lines were 13 deg long. The luminances of the spot, the moving lines, and the black background were, respectively, 26, 7.3, and >1 cd m^{-2}. The screen refresh rate was 60 Hz.

Observers gazed at a central fixation point and were asked to report on the perceived position of the flashed disk relative to the intersection. On different trials, the flash could occur at any of eight positions around the trajectory, located at 1:30, 3, 4:30, 6, 7:30, 9, 10:30, and 12 o'clock. The flash was centered on the moving intersection, but the flash-lag illusion shifted its apparent position, either clockwise or counterclockwise. The observer struck two computer keys that displaced the physical position of the flash tangentially, clockwise or counterclockwise, until the flash appeared to coincide spatially with the position of the intersection. In this way she/he nulled out the flash-lag illusion by titrating it against a compensatory spatial offset. When satisfied with the setting, the observer pressed the space bar to record the setting for later analysis and to initiate the next trial.

On each trial the direction of rotation—clockwise or counterclockwise—and the flash position were selected randomly. Thus 16 conditions (2 directions $\times$ 8 positions) were run on each of four naive observers.

2.2 *Results*

Results are shown in figure 2 (mean of four naive observers). Figure 2a shows that when the intersections moved counterclockwise (but appeared to move clockwise), the null position of the flash (open circle in figure 2), at which it appeared superimposed on the intersection, was shifted counterclockwise through a mean angular rotation of $6.3°$ (mean $\pm$ 1 SE $= 6.3° \pm 0.75°$). (SEs are not shown in figure 2 because they were much smaller than the plotted circles.) This counterclockwise shift in the nulling position selected by the observer means that the flash actually appeared to lag clockwise, which is appropriate to the intersection's physical counterclockwise rotation.

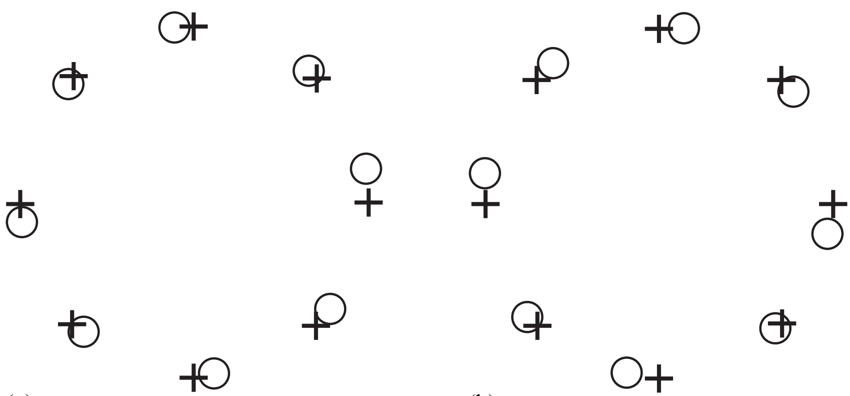

Figure 2. Results of flash-lag experiment (mean of four observers). In (a) the intersections moved counterclockwise but appeared to move clockwise. In (b) the intersections moved clockwise but appeared to move counterclockwise. Crosses show positions of intersection, circles show the nulling flash positions selected by the observers that appeared subjectively superimposed on the intersection. Results are appropriate to the physical, not illusory, direction in which the intersection is circled.

Translated from space into time, these results represent a mean temporal lag of 19.0 ms. So without with nulling offset, each flash would have appeared in a clockwise-shifted position, where the moving intersection had just been some 19 ms before. This clockwise flash-lag effect is appropriate to the physical counterclockwise motion of the intersection, not to its subjective clockwise motion. In figure 2b, when the line tips moved counterclockwise, the corresponding result was a mean clockwise shift of $6.9° \pm 1.09°$, equivalent to a temporal lag of 20.8 ms.

3 Experiment 2

3.1 *Method*

It was noticed that, in figure 2, the effect seemed larger when the flash appeared in the top/bottom and left/right positions than in any oblique positions. I examined some possible reasons for this. It might be related to the fact that at the cardinal positions (3, 6, 9, and 12 o'clock) the rotating lines were tangential and radial to the circular trajectory, but were oblique to it at the other positions (1:30, 4:30, 7:30, and 10:30 o'clock). It might also have occurred because the line ends were inadvertently too close to the intersection, so their direction of motion might have reduced the flash-lag effect that was found. To remedy this, I repeated the measurements at the 'north' and 'northeast' positions (12 and 1:30 o'clock), with the rotating lines either vertical and horizontal, or else oblique. The lines were now longer (17 cm long), so that the line tips were always at least 3 cm away from the intersections (3 cm was the radius of the circular path of the intersections). Remember that 1 cm at the viewing distance of 57 cm subtends 1 deg of visual angle.

Five observers, of whom four were naive to the purpose of the experiment, each made four settings in each of the 4 conditions.

3.2 *Results*

Results are shown in figure 3. First, on averaging across all conditions, figure 3 shows that the flash-lag effect in experiment 2 was still in the direction appropriate to the physical, not the perceived, direction of the rotations of the intersections. However, the effects were nearly twice as large as before—the mean lag was now $12.2° \pm 1.6°$ of rotation (mean $\pm$ 1 SE), which is equivalent to a mean time delay of 39.2 ± 8.2 ms.

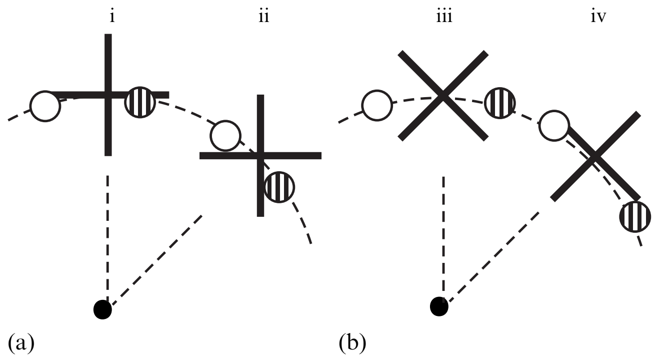

Figure 3. Results from experiment 2 (mean of five observers and 4 conditions). Conventions are the same as for figure 2. Rotating lines were vertical and horizontal in (a) (conditions i and ii), and oblique in (b) (conditions iii and iv). Open (shaded) circles show the null positions at which the flashed disks were set when the intersection was moving clockwise (counterclockwise). Offsets are drawn to scale.

Next, the four conditions were examined separately and shown diagrammatically in figure 3. In conditions i and ii (figure 3a), the moving lines were horizontal and vertical, like a plus sign, and the flash occurred when the intersection was respectively in the north or northeast position. In conditions iii and iv (figure 3b), the moving lines were oblique, like a letter X, and again the flash occurred at the north or northeast position. Thus, to examine the effects of line orientation (+ versus X) I compared conditions i and ii with conditions iii and iv. To examine the effects of position (north versus northeast) I compared conditions i and iii with ii and iv. Finally, to examine the effects of tangential versus oblique lines I compared conditions i and iv with ii and iii.

An analysis of variance showed no significant effect of position (north versus northeast: $F_1 = 0.782$, $p < 0.378$). It also showed no significant effect of having the moving lines tangential or oblique to the circular trajectory ($F_1 = 0.121$, $p < 0.729$). However, for reasons that I cannot explain, the oblique lines forming an X in figure 3b did give a significantly larger effect than the horizontal and vertical lines forming a + in figure 3a ($F_1 = 9.197$, $p < 0.0029$).

4 Discussion

In short, in both experiments 1 and 2 I confirmed that the flash-lag effect was driven by the physical, not the perceived, direction in which the intersections moved. However, the effects were twice as large in experiment 2 (39.2 ms) as in experiment 1 (19 ms).

I conclude that the direction of the flash-lag effect was appropriate to the objective, not the subjective, motion of the intersection. Therefore the flash-lag effect was not influenced by the chopstick illusion, which implies that the flash lag occurs early in the visual system, *before* local motion signals are processed to give parsed moving objects.

Were these results obvious? At a vision conference after I had collected the data, I informally polled some researchers who had published on the flash-lag effect. Opinion was fairly equally divided on whether the flash-lag effect would be (1) absent, (2) appropriate to the true, physical direction of rotation, or (3) appropriate to the illusory direction of rotation. As we have seen, (2) is the correct answer.

5 Conclusions

As for the explanation of the flash-lag effect, there seem to be as many theories as there are theorists. I admit that instead of coming up with one more explanation of the flash-lag effect, I have merely demonstrated its interaction, or rather non-interaction, with a second motion illusion—the chopsticks effect—which itself remains unexplained. However, at the least the results do show very clearly that the flash-lag effect was unaffected by the chopstick illusion, since the results were appropriate to the physical motion of the intersection and not to its perceived direction. This suggests that the flash-lag occurs early in the visual system, before much motion parsing is done, and is perhaps influenced only by very local factors, not by action at a distance, for instance from the line terminators.

Another recent study also places flash lag early in the visual system. Spatial alignment of different face halves results in a configuration that mars the recognition of the identity of either face half (Young et al 1987). Khurana et al (2006) used the flash-lag effect to examine the recognition performance for face halves that were aligned on the retina but were perceived as misaligned, or were misaligned on the retina but were perceived as aligned. They created chimeras consisting of a stationary top half-face initially aligned with a moving bottom half-face. Flash-lag chimeras were better recognized than their stationary counterparts. However, when flashed face halves were presented physically ahead of moving halves, thereby nulling the flash-lag effect, recognition was impaired. Thus, the perceived spatial alignment of face halves (despite retinal misalignment) impaired recognition, whereas perceived misalignment (despite retinal alignment) did not. This shows that face recognition depended upon the perceived, not the physical, alignment of the face halves, implying that the flash-lag process occurs before, and has an effect upon, face recognition. Similarly, I find that the flash-lag process occurs before motion parsing, since motion parsing does not affect the flash lag itself. Their study, and the present one, concur that flash-lag process happens early in the visual system.

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