

Brief communication

Two-stroke: A new illusion of visual motion based on the time course of neural responses in the human visual system

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Abstract

A sequence of static images presented in rapid succession can create a powerful impression of visual movement, a fact exploited by the visual media (television and cinema) and by animators. A new illusion of movement called “two-stroke” is described, in which repeated presentation of a two-frame pattern displacement can create an impression of continuous forward motion, without the inclusion of any additional pattern displacements. The illusion can be explained by a biphasic temporal impulse response that modifies the stimulus delivered to motion energy sensors. It offers a basis for further research on temporal and motion responses in the visual system as well as a tool for animators and graphic artists to create consistent apparent movement from minimal external stimulation.

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1. Two-stroke motion

The apparent motion seen in sequences of static images is mediated by specialised neural circuits in the visual cortex (Adelson & Bergen, 1985; van Santen & Sperling, 1985; Watson & Ahumada, 1985). A minimal motion sequence requires two frames containing a pattern displacement from the first frame to the second. A single ‘one-shot’ presentation of the two frames leads to the appearance of forward motion. If the two frames are presented continuously in alternation, then observers perceive a repeating cycle of forward and backward motion. Fig. 1A shows two pattern frames (rows 1 and 2) containing a simple shape that displaces rightward from the first frame to the second to create apparent oscillation (arrows) during repeated presentation. However, if a brief pause or inter-stimulus interval (ISI) is added after the second frame (Fig. 1B), observers perceive continuous rightward movement of the shape when the frames are presented in a repeating cycle.

If the ISI is placed between the first frame and the second instead (Fig. 1C), observers perceive continuous leftward movement. This illusion has been demonstrated to large numbers of naïve observers¹, and can be viewed in Supplementary videos. [Supplementary video 1](#) shows a sequence corresponding to Fig. 1A; [Supplementary video 2](#) shows a sequence corresponding to Fig. 1B. Online Flash movies are available at www.lifesci.susx.ac.uk/Home/George_Mather/TwoStrokeFlash.htm.

Fixation at the centre of the illusion display for a short time (about 15 s) is sufficient to build up an after-effect of apparent movement in the opposite direction when the animation is stopped. To view this effect in online materials, use the media control to stop video 1; then fixate at the centre of video 2 for 15 s while it is running; finally transfer gaze to the centre of video 1. A motion after-effect should be seen. Such motion after-effects are strong evidence for

¹ The illusion was presented to international vision scientists at the European Conference on Visual Perception, La Coruna, Spain, August 2005. It was voted one of the top three new illusions in the inaugural International Illusion of the Year competition during the meeting.

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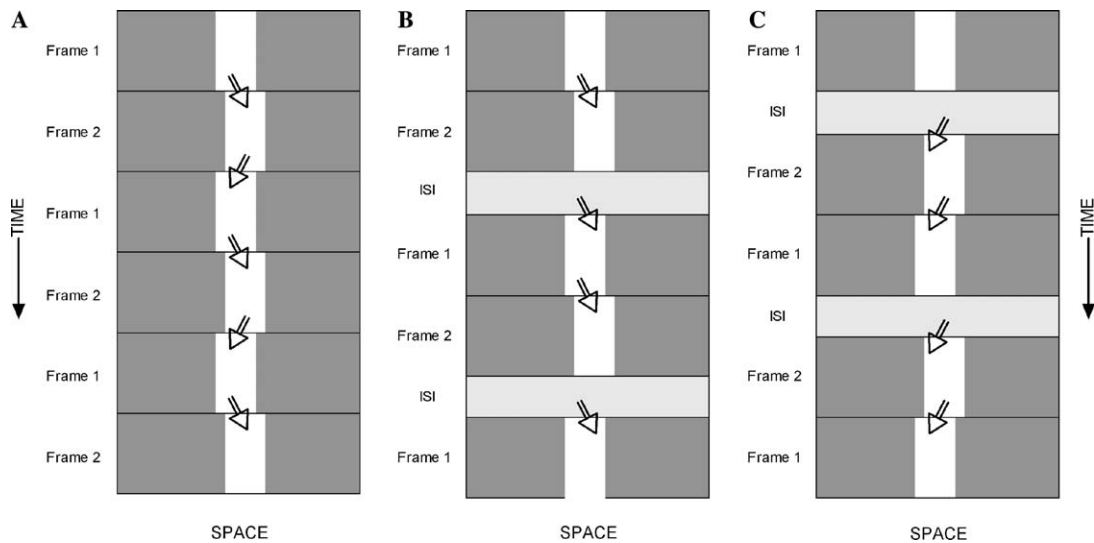


Fig. 1. Two-stroke motion. (A) Illustrates standard apparent motion; (B and C) illustrate two-stroke motion. (A) A white rectangle shifts rightward from frame 1 to frame 2. When the two frames are presented repeatedly in alternation, they create an impression of to-and-fro movement (arrows). (B) If a brief blank inter-stimulus interval (ISI) is inserted at the transition between frame 2 and frame 1, the direction of apparent motion during the transition reverses, so that presentation of the whole sequence creates an impression of continuous forward motion (arrows). (C) If the blank ISI is inserted between frame 1 and frame 2, presentation of the whole sequence creates an impression of continuous backward motion (arrows).

unidirectional excitation in neural motion sensors (Mather, Verstraten, & Anstis, 1998).

2. Explanation

The illusion is called “two-stroke” apparent motion because it requires only two pattern frames². Its explanation requires two propositions:

- (a) that the biphasic temporal impulse response of the visual system generates a contrast-reversed neural image in the visual system during the blank ISI;
- (b) that reversed apparent motion is generated when the contrast-reversed neural image is combined with the initially positive image generated by the next pattern frame.

2.1. Biphasic impulse response

In bright conditions, the visual system’s response to a brief flash (impulse) shows an initial positive phase (excitation) followed by a brief negative phase (inhibition). The impulse response plotted in Fig. 2 is based on a standard model derived from a large body of psychophysical data (Watson, 1986). During the brief ISI in two-stroke displays the negative phase of the impulse response generates a con-

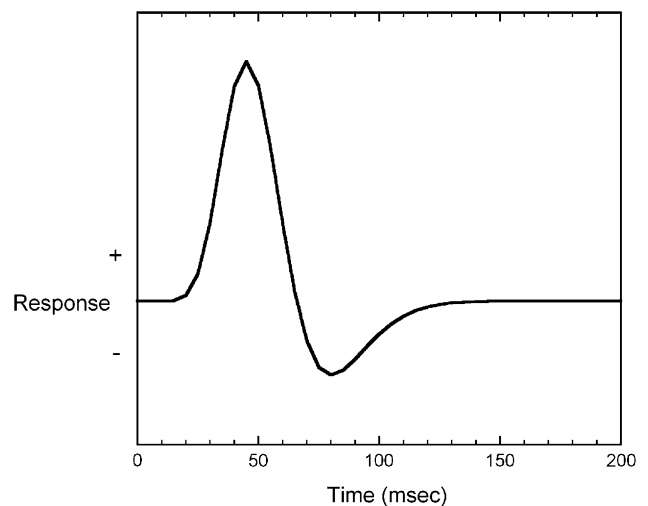


Fig. 2. Temporal impulse response of the visual system. The visual system’s response to a brief flash of light at time zero shows an initial positive phase (excitation) followed by a negative phase (inhibition). The curve is based on a model derived from a large body of psychophysical data on flicker detection (Watson, 1986).

trast-reversed neural image of the preceding frame in the visual system (e.g., frame 2 in Fig. 1B). The contrast-reversed neural image is then combined with the positive response to the following frame at the stage of motion energy detection to generate a motion signal.

2.2. Reversed apparent motion

It is well known that when one frame in a two-frame motion display is contrast-reversed, the perceive motion is also reversed (Anstis & Rogers, 1975). So the transition

² It is arguable that the illusion should be called “three-stroke” rather than “two-stroke”, since it contains three frames. The “two-stroke” nomenclature was favoured because only two frames contain pattern information; the motion illusion can be generated from any arbitrary pattern displacement provided that just two pattern frames are available.

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