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Vision Research 46 (2006) 2421–2431
Vision Research
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A positive correlation between fixation instability and the strength of illusory motion in a static display

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Received 19 July 2005; received in revised form 22 November 2005

Abstract

A stationary pattern with asymmetrical luminance gradients can appear to move. We hypothesized that the source signal of this illusion originates in retinal image motions due to fixational eye movements. We investigated the inter-subject correlation between fixation instability and illusion strength. First, we demonstrated that the strength of the illusion can be quantified by the nulling technique. Second, we concurrently measured cancellation velocity and fixation instability for each subject, and found a positive correlation between them. The same relationship was also found within a single observer when the visual stimulus was artificially moved in the simulation of fixation instability. Third, we confirmed the same correlation with eye movements for a wider variety of illusory displays. These results suggest that fixational eye movements indeed play a relevant role in generating this motion illusion.

Keywords: Visual motion; Fixational eye movements; Illusion; Correlation

1. Introduction

It has been pointed out that illusory motion can be seen in a completely static figure (e.g., a figure printed on a sheet of paper) (Faubert & Herbert, 1999; Fraser & Wilcox, 1979; Naor-Raz & Sekuler, 2000). The underlying mechanism of this illusion is currently under debate. Recently, one of the authors (A.K.) has created variants of the illusory figures (bitmap figures are currently available on the internet; see http://www.ritsumei.ac.jp/~akitaoka/index-e.html), an example of which is shown in Fig. 1. We found that the perceived motion was as vigorous as real motion, and wondered what neural mechanism is responsible. The design rule is simple: construct an array of four regions having different luminances in the systematic order, "black," "dark gray," "white," and "light gray" (Ashida & Kitaoka, 2003; Kitaoka & Ashida, 2003). Slow illusory motion is seen between adjacent regions; the perceived direction is in the order described above, but never the other way around (Fig. 2A). Also, the illusion is clearer when the array pattern is repeated in a row such that the patterns comprise a circle (see Fig. 1), and when it is viewed peripherally.

Several investigators have previously paid attention to the motion illusion seen in such an asymmetric luminance gradient, but they have typically used a saw-tooth luminance profile, not the above-mentioned profile. Fraser and Wilcox (1979) noted a large individual difference (and also a genetic similarity) in perceptual strength of the illusion. Faubert and Herbert (1999) reported that the illusion was more vigorous after an eye blink or a saccade. Naor-Raz and Sekuler (2000) found that the illusion became more vigorous in more peripheral observations, for longer durations, and at higher luminance contrasts,

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doi:10.1016/j.visres.2006.01.030

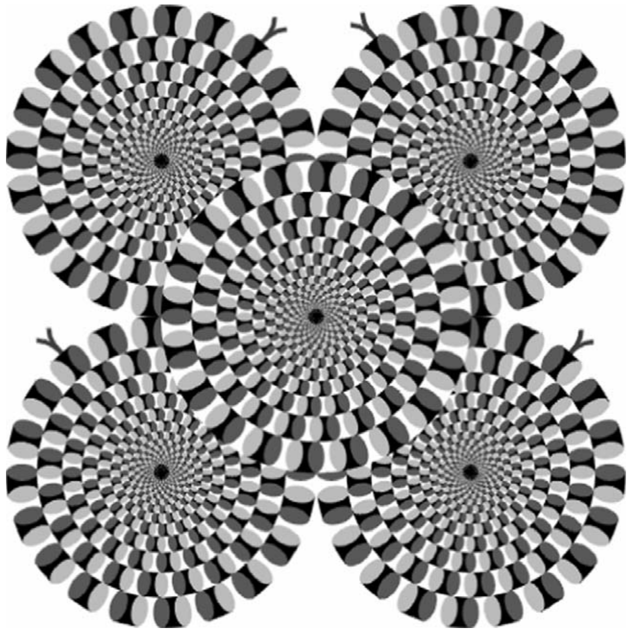

Fig. 1. The "rotating snakes" illusion. When one loosely looks at the center, the outer four disks appear to rotate slowly, with two in the clockwise direction and the other two in the counterclockwise direction.

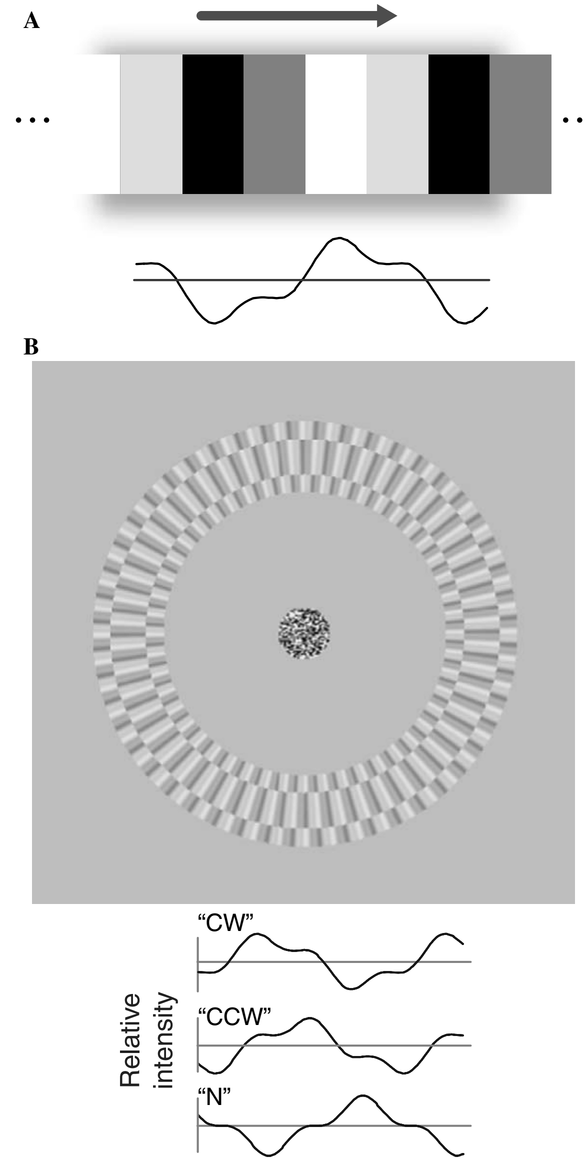

Fig. 2. Schematics of the stimuli. (A) The design rule of the "rotating snakes" illusion. The order of the four luminance levels is critical. This pattern consists of the fundamental and the odd harmonic components. The lower curve shows the luminance profile of the fundamental plus the third harmonic components, with the central straight line indicating the mean luminance. (B) Illustrations of the stimulus configuration and the waveforms used in illusion cancellation. The abscissa indicates polar angle (rightward is clockwise).

and also mentioned the possible involvement of involuntary fixational eye movements. In line with these previous investigations, we argue that a physically static figure for this motion illusion is not static at all on the retina, but is instead always moving in random fashion together with fixational eye movements. The amplitude of fixational eye movements is known to be substantially different among subjects (Murakami, 2004), suggesting that inter-subject variability in perceptual strength as reported by Fraser and Wilcox might be a consequence of the variability of eye movements. In addition, fixation is less stable after a saccade than during steady fixation (Rucci & Desbordes, 2003), which implies that Faubert and Herbert's observation is possibly consistent with oculomotor statistics.

However, no previous studies have offered convincing psychophysical evidence for a relationship between the strength of this illusion and eye movements. Our hypothesis is that illusion strength positively correlates with fixation instability: as gaze fluctuates more, the retinal image of a physically static figure fluctuates more, and these jittery motions on the retina consequently lead to more vigorous impressions of illusory motion (we will later discuss how random image fluctuations are converted to smooth motion impression). To test this hypothesis, it would be ideal to vary a subject's fixation instability in a systematic manner and observe how this affects illusion strength. However, it is not easy to manipulate the amplitude of fixational eye movements of an individual. We therefore recruited a relatively large number of subjects and plotted inter-subject scattergrams. As a result, we found a positive correlation between illusion strength and fixation instability.

The present study is comprised of three experimental sections. In the pilot experiment, we devised a psychophysical method of velocity cancellation to quantify illusion strength in a precisely controlled stimulus. In the main experiment, we concurrently measured cancellation velocity and fixation instability for 22 subjects to see an inter-subject correlation between these quantities. Within a single subject, we also tested the dependence of illusion strength on the magnitude of simulated fixation instability, by actually oscillating the visual stimulus. In the subsidiary experiment, we had 53 subjects rate the perceptual strength of the illusion and also separately measured fixation