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RESEARCH NOTES

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Pupillary response induced by stereoscopic stimuli

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Abstract Besides luminance change, the pupil responds to changes in spatial pattern, color content and target motion. Our experimental results show that transient pupillary constriction can also be elicited by dichoptically viewing a change in stereoscopic stimuli composed of dynamic random-dot stereograms from an initially flat surface to a stationary sinusoidal grating shown in depth. On the other hand, monocular viewing of these stimuli produced no obvious pupillary response. This indicates that the pupillary response in the dichoptic experiment was induced by the stereo information rather than by any change in the monocular stimuli. This finding presents a novel approach for the investigation of stereo perception that can also be applied in the clinical environment.

Keywords Pupil · Stereopsis · Dynamic random-dot stereograms · Stereo vision

Introduction

The pupil is sensitive not only to changes in luminance but also to other visual stimuli, including changes in spatial pattern, color content, and target motion (Barbur et al. 1992; Davson 1990; Drew et al. 2001; Hung and Sun 1988; Sahraie and Barbur 1997; Sun et al. 1981, 1995, 1998a, 1998b; Ukai 1985; Young and Alpern 1980). Due to its involuntary and non-invasive features, the pupillary response has provided an alternative quantitative means to study visual perception in humans (Barbur 2004; Barbur et al. 1999; Weiskrantz et al. 1998). Most investigations in human stereo perception have been based on psychophysical methods (Cumming et al. 1991; Julesz 1964; Nerl et al. 1999; Ogle 1962; Rogers and Cagenello 1989; Tyler 1974) or the relatively costly functional magnetic resonance imaging (fMRI) method (Backus et al. 2001; Tsao et al. 2003). In this work, we present experimental results that show that transient pupillary constriction can be evoked by stereo stimuli composed of dynamic random-dot stereograms (Julesz 1971). This finding provides an objective indicator in the investigation of stereo perception that can also be applied in the clinical environment.

Materials and methods

Stimulus

Three-dimensional perception can be obtained by dichoptically viewing random-dot stereograms. Thus, we used dynamic random-dot stereograms (Julesz 1971) as the stimulus in our pupillary experiments. The dynamic random-dot stereograms (20° width×10° height of visual angle; bright dot, 2′×2′, 60 cd m^{-2}, 20% of overall density; dark background, 0.05 cd m^{-2}) were displayed on a VDT (G520, Sony) placed 57 cm in front of the subject, at a frame rate of 120 Hz. Each pair of stereograms was composed of two successive frames of random-dot patterns. The odd frames were presented to the left eye and the even frames to the right eye by means of a pair of liquid crystal shutter glasses (Andrews and Blakemore 1999), which were synchronized with the vertical blanking signals of the VDT. The uncorrelated random-dot patterns viewed by each eye were changed in every frame, while the overall disparities between the two eyes remained either zero or were sinusoidally modulated (0′ to 32′ uncrossed disparities). Thus, the random-dot patterns in successive frames for each eye were dynamically changing but the disparities between the two eyes were maintained

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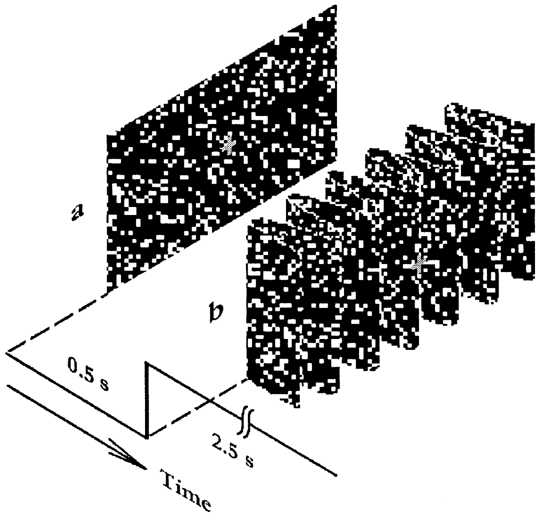

Fig. 1a,b Schematic illustration of the visual stimuli used to test stereo pupillary response. The first 0.5 s of stimulus was a flat surface, with zero disparity, in the fronto-parallel plane (**a**), the following 2.5 s was a stationary sinusoidal grating in depth, with sinusoidally modulated uncrossed disparities from 0′ to 32′, and a spatial frequency of 0.3 cycles per degree in the horizontal direction (**b**). Both the flat surface and stereo grating were composed of dynamic random-dot stereograms (20° width×10° height of visual angle; bright dots, 2′×2′, 60 cd m^{-2}, 20% of total density; dark background, 0.05 cd m^{-2}), generated by a computer program in the C language. A fixation mark of a red cross (20′) was marked in the center of each stimulus. The perceived flat surface was in the fixation plane while the stereo grating intruded into the fixation plane

to provide either a perceived flat surface in the front parallel plane or a stationary sinusoidal grating in depth, with a spatial frequency of 0.3 cycles per degree in the horizontal direction (Schumer and Ganz 1979) (see Fig. 1).

Procedure

Both binocular and monocular control experiments were performed. In the binocular experiments, the initial stimulus, presented dichoptically to the subject, was the flat surface. After 0.5 s, the flat surface was changed to the stereo grating. During the experiments, the subject was instructed to fixate a small red fixation mark (20′ in visual angle) located at the center of the VDT screen, with his head held in position by a chin-and-forehead rest. An infrared pupillometer (Sun et al. 1979, 1981, 1998b) was used to record the pupillary response as well as eye movements. In the monocular control experiments, the stimuli were identical to those in the binocular experiments. The only modification was that one glass of the shutter was kept closed during the control experiments. This ensured that the subject could only view the stimuli with one eye at any particular time.

Subjects

Three volunteers, with normal or corrected-to-normal visual acuity and normal stereovision, participated in this experiment. The experimental protocol was approved by the local ethical committee and followed the tenets of the Declaration of Helsinki. Each subject provided signed written consent before the experiments.

Results

Binocular experiments

After the onset of the stereo grating, the subject exhibited a fast pupillary constriction following a latency of about 500 ms (see Fig. 2a, second trace). The fast pupillary

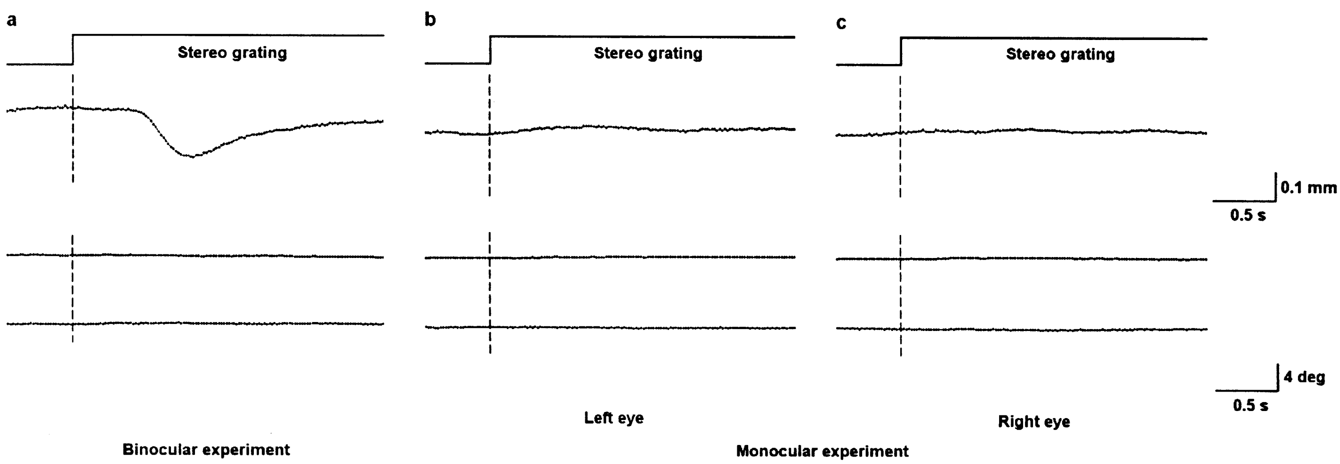

Fig. 2a–c Pupillary responses to the stereo stimuli. **a** Pupillary responses in the binocular experiment; **b**, **c** pupillary responses to the stereo stimuli in the monocular experiments. The subject viewed the stimuli in an identical fashion in both types of experiment, but with only one eye in the monocular experiments. **b** and **c** show the results for the left and right eye views respectively. For all panels, from top to bottom, the first trace shows the onset of the stereo grating; the second trace shows pupil diameter response; the third and fourth traces are horizontal and vertical eye movements monitored simultaneously during the experiments. Each data trace is the average of 30 trials. Calibration bars are shown to the right of the data traces

constriction was immediately followed by a slow redilation, which returned to the initial level. This waveform was similar to that of the pupillary response to dim light, which has been named “pupillary escape” (Lowenstein and Loewenfeld 1969; Sun and Stark 1983). After each trial, the subject reported a perception of the stereo pattern changing from a flat surface to a stationary sinusoidal grating in depth.

Monocular experiments

To examine whether minor change of stimuli luminance, alternation of the patterns, or any change in monocular stimuli could have resulted in an artifactual pupillary response, we performed the monocular experiments as control. In the monocular experiments, we found no obvious pupillary response for both left or right eye viewing conditions (see Fig. 2b,c).

Eye movements recording

To examine the possible effect of vergence eye movement on the observed pupillary response, we monitored the simultaneous eye movements of the subject. No obvious horizontal and vertical eye movements could be found during the experiment period (see Fig. 2a, third and fourth traces).

Discussion

The experimental results presented here show that pupillary response can be elicited by stereoscopic stimuli composed of dynamic random-dot stereograms. In contrast to pupillary responses to pattern, color, and motion, this novel pupillary response can only be evoked by binocular rather than monocular viewing of the dynamic random-dot stereograms. Thus, this pupillary response was not due to any change in monocular stimuli. Moreover, vergence eye movements could not account for this pupillary response since no obvious changes could be found in the simultaneously-recorded horizontal and vertical eye movements. These results indicate that the pupillary response in the binocular experiment was elicited by the stereo information contained in the dynamic random-dot stereograms.

Electrophysiological evidence showed that stereo perception begins with the primary visual cortex (Cumming and DeAngelis 2001; Gonzalez and Perez 1998), so the stereo pupillary response should be mediated by cortical mechanisms in the top-down pathway. The evidence to support this, in our results, was the 0.5 s latency of the stereo pupillary response, which is longer than that of the light response (Barbur et al. 1998). Further studies in animal would be needed to determine the neural pathways involved in this stereo pupillary response.

Due to the fact that patients with amblyopia and certain neurally-impaired patients have damaged stereoscopic vision (Lehmann and Walchli 1975; Mendez et al. 1996; Walraven 1975), the stereo pupillary response, as an involuntary reflex, might be applied in the diagnosis of those dysfunctions.

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