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Research article

Fixating at far distance shortens reaction time to peripheral visual stimuli at specific locations

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ABSTRACT

The purpose of the present study was to examine whether the fixation distance in real three-dimensional space affects manual reaction time to peripheral visual stimuli. Light-emitting diodes were used for presenting a fixation point and four peripheral visual stimuli. The visual stimuli were located at a distance of 45 cm and at 25° in the left, right, upper, and lower directions from the sagittal axis including the fixation point. Near (30 cm), Middle (45 cm), Far (90 cm), and Very Far (300 cm) fixation distance conditions were used. When one of the four visual stimuli was randomly illuminated, the participants released a button as quickly as possible. Results showed that overall peripheral reaction time decreased as the fixation distance increased. The significant interaction between fixation distance and stimulus location indicated that the effect of fixation distance on reaction time was observed at the left, right, and upper locations but not at the lower location. These results suggest that fixating at far distance would contribute to faster reaction and that the effect is specific to locations in the peripheral visual field. The present findings are discussed in terms of viewer-centered representation, the focus of attention in depth, and visual field asymmetry related to neurological and psychological aspects.

1. Introduction

When reacting to the external environment as quickly as possible, visual fixation and attention in space have been considered as important factors. In most of the studies regarding reaction time (RT) to visual stimuli presented in the peripheral visual field, both fixation points and visual stimuli have been presented in a fronto-parallel plane (e.g., on the screen of a computer monitor). Therefore, the effects of shifting attention have been mainly discussed within the two dimensions (i.e., horizontal and vertical) (e.g., [1,2]). In actual three-dimensional space, however, the fixation point is not always located on the same plane as peripheral visual stimuli because we usually shift our fixation also in the depth direction. Therefore, the question arises as to whether the fixation distance affects RT to peripheral visual stimuli presented along the horizontal and vertical directions in real three-dimensional space.

Using a spatial cueing paradigm [3], earlier studies in three-dimensional space have indicated that covert attention can be shifted in the depth direction as well as horizontal and vertical directions [4–10]. Especially, some empirical studies in real three-dimensional space have also suggested that it is easier to shift covert attention from far to near than from near to far space and that attention has a viewer-centered spatial distribution [7–9]. Furthermore, it is assumed that the orientation of covert attention operates more efficiently at nearer locations than at farther locations relative to a fixation point [11]. Kimura et al. [12] examined the effect of changing the distance of fixation points on attention in real three-dimensional space when visual stimuli and the fixation points were presented on the central line of sight of participants (i.e., central visual field). However, there has been no study to investigate the effect of changing the distance of the fixation points on RT to peripheral visual stimuli. Based on the earlier findings, it is predicted that RT to peripheral visual stimuli would be shorter if the fixation point is located farther than the fronto-parallel plane containing the visual stimuli. The primary aim of the present study was to examine whether fixation distance in real three-dimensional space affects simple RT for the peripheral visual field.

It has been suggested that visual performance is better in the lower region of the vertical meridian than in the upper region, which is called vertical meridian asymmetry (e.g., [13,14]). For instance, studies have shown that RTs are shorter when visual stimuli are presented in the lower visual field compared with the upper visual field [15–17]. Earlier studies have assumed that the lower visual field has some advantages

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over upper visual field in attentional resolution [18,19], perceptual processing [20,21], and contrast sensitivity [13,22]. Importantly, however, it has also been demonstrated that vertical asymmetries in visual performance are modulated by the distance of visual stimuli relative to a fixation point [23–26]. Considering these findings, it is expected that fixation distance affects peripheral RT in the condition where the distance of the visual stimuli from the observer is constant. In particular, the effect of fixation distance would be different between the upper and lower visual fields. The secondary aim of the present study was to assess whether there are visual field asymmetries in the effect of fixation distance on peripheral RT.

The purpose of the present study was to examine whether fixation distance in real three-dimensional space affects simple RT to visual stimuli presented in the peripheral visual field. Our hypotheses were (1) that overall peripheral RT would be shorter as fixation distance increases, and (2) that the extent of the effect of fixation distance on RT would be dependent on stimulus location in the peripheral visual field.

2. Methods

2.1. Participants

Fourteen male participants (mean ± SD; age = 24.8 ± 3.1 years) volunteered to participate in the experiment. All participants were right-handed according to an abbreviated Edinburgh Handedness Inventory [27] and had normal or corrected-to-normal visual acuity. None of the participants had any known neuromuscular disorder. Participants were informed of the experimental procedures prior to participation in the study, and consented to take part in the experiment. All procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki.

2.2. Apparatus

The experiment was conducted in a dimly illuminated room. The participants were seated in front of a horizontal table. Their head was immobilized by an adjustable chin rest and head support in order to control for vestibular system contribution to the participants' responses. Eye level was set at 40 cm above the table.

The experimental setup is depicted in Fig. 1. A fixation point and imperative visual stimuli were presented by illuminating light-emitting diodes (LEDs) attached to aluminum frames. The LEDs were 3 mm in diameter and radiated a yellow (590 nm) light. The illumination pattern of the LEDs was controlled by a peripheral interface controller (PIC16F84, Microchip Technology Inc., USA). The fixation LED was located in the participants' mid-sagittal plane and in line with the eye level. The fixation LED was located at distances of 30 cm (Near condition), 45 cm (Middle condition), 90 cm (Far condition), or 300 cm (Very Far condition) from the center of the eyes. The four stimulus LEDs were positioned at a viewing distance of 45 cm from the center of the two eyes, and at 25° to the left, right, upper, and lower directions from the sagittal axis including the fixation LED.

In the present study, the participants were asked to release a button with their right index finger. To record participants' RT, we used a surface electromyographic (EMG) apparatus (4 Assist, Co. Ltd., Tokyo, Japan). The active electrode was placed on the right extensor digitorum communis muscle. The left and right eye movements were monitored separately with a head-mounted eye tracker (EMR-8b, NAC Inc., Tokyo, Japan). This system measured the horizontal and vertical position of the left and right eye as well as eye blinks with an infrared corneal reflection system at a sampling frequency of 30 Hz. The system has an optimal resolution of 0.1° and a linear range of ± 20°. Calibration of left and right eye movement responses were performed by recording the output of the eye movement monitor at five known positions before and after each experimental block. Using the gaze direction of each eye and the individual inter-ocular distance, the vergence angles of the stimuli were calculated for each participant to confirm whether the participants fixated correctly as instructed.

2.3. Procedure

Participants performed the RT task under the following four fixation distance conditions: Near, Middle, Far, and Very Far conditions. Before the beginning of each trial, participants were asked to keep pressing a button down with their index finger. A trial began with the illumination of the fixation LED, which participants then fixated on. After a

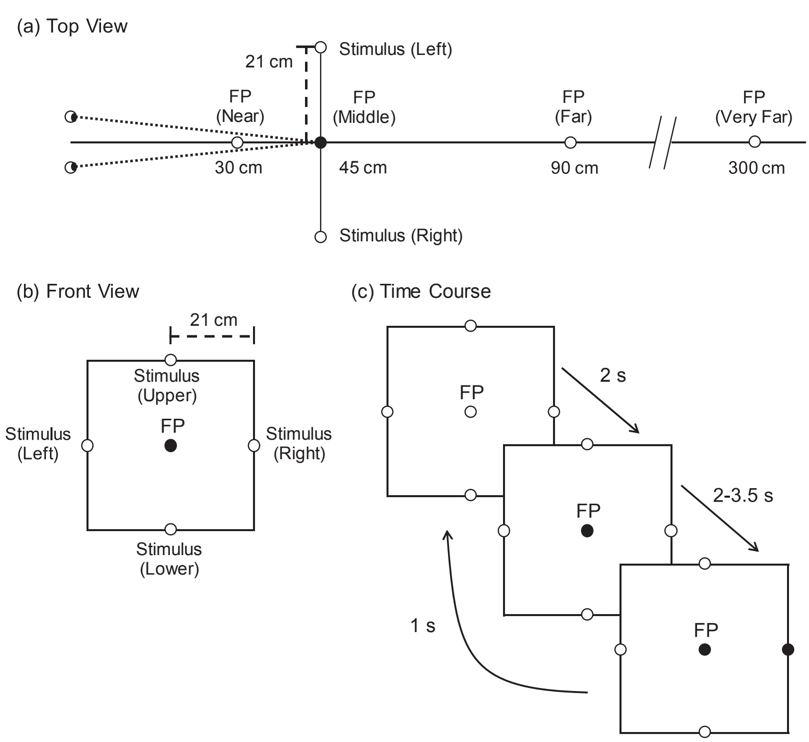

Fig. 1. A schematic illustration of the experimental setup. The top view (a) and front view (b) of the experimental setup, and the time course (c) of the experimental procedure. Participants fixated at one of the four fixation LEDs (30, 45, 90, and 300 cm in distance from the center of the two eyes). When one of the four visual stimulus LEDs was illuminated, the participants released a button with their right index finger as quickly as possible.