Effects of Exercise on Reaction Time to Peripheral Visual Stimuli

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Abstract: - Vision is one of the most important sensory modalities in humans. Visual reaction time (RT) is the time from the appearance of a visual stimulus to the onset of motor output, and it has been used to assess perceptual and cognitive abilities in athletes. Visual field is composed of central and peripheral components. The ability to respond to peripheral visual stimuli as quickly as possible may be relevant to ball sports in which capturing visual information from the periphery of the visual field plays a role in performance. The purpose of this study was to examine effects of acute exercise under normoxia, hypoxia, and hyperoxia on the ability to respond to peripheral visual stimuli. Results showed that: (1) under normoxia, premotor component of RT (Premotor time) to peripheral visual stimuli was vulnerable to exercise as compared with that to central visual stimuli; (2) under normoxia, RT to peripheral visual stimuli increased during exercise at high workloads above the ventilatory threshold (VT) relative to that at rest, while the RT was not affected by exercise at the VT and below the VT; (3) under hypoxia, Premotor time to peripheral visual stimuli increased during exercise at low, moderate, and high workloads, and the increase in Premotor time was accompanied with decrease in cerebral oxygenation; and (4) under hyperoxia, Premotor time to peripheral visual stimuli was not different between at rest and during exercise at high workloads. These findings suggest that exercise at high workloads has detrimental effects on the ability to respond to peripheral visual stimuli unless oxygen availability was increased. Cerebral oxygenation may play a key role in visual perceptual performance during exercise.

Key-Words: - Reaction time, Premotor time, Peripheral vision, Exercise, Cerebral oxygenation, Ventilatory threshold, Hypoxia, Hyperoxia, Near-infrared spectroscopy

1 Introduction

Vision is one of the most important sensory modalities in humans. Visual field is defined as the area perceived by the eyes while people fixate on a point, and it is composed of central and peripheral components. Visual information of an object is provided through both the central and peripheral retina and higher visual areas, each specialized for processing specific types of information [1,2].

Visual reaction time (RT) is the time from the appearance of a visual stimulus to the onset of motor output. Visual RT has been used to assess perceptual and cognitive abilities in athletes. In sports such as football or basketball, a player gathers visual information from the peripheral visual field to see other players and objects beyond the central visual field. Thus, the ability to respond to peripheral visual stimuli as quickly as possible may play an important role in performance. The purpose of this study was to examine effects of acute exercise on the ability to respond to peripheral visual stimuli. This investigation helps to understand human perceptual-motor performance during exercise.

2 Effects of Exercise on Reaction time

2.1 Central vs. Peripheral Visual Stimuli

Twelve participants performed simple RT tasks at rest and during cycling at 65% peak oxygen uptake (VO2). Circular black-and-white checkerboard patterns were presented as visual stimuli (Fig.1a). The participants were asked to respond as quickly as possible to pattern reversal of the visual stimulus by releasing a response button. RT was fractionated into premotor and motor components (Fig.1b: Premotor time and Motor time) based on surface electromyographic recordings [3]. The onset of the electromyographic activity was determined by a computer program combined with visual inspection. It is accepted that Premotor time is a
valid indicator for assessing effects of acute exercise on the central process.

Premotor time to peripheral visual stimuli significantly increased during exercise (mean ± SD; 195.9 ± 27.4 ms) from that at rest (183.7 ± 23.6 ms, p < 0.05). Premotor time to central visual stimuli did not differ between at rest (185.3 ± 26.4 ms) and during exercise (188.4 ± 22.8 ms). These data suggest that the ability to respond to peripheral visual stimuli is vulnerable to moderate to severe exercise, as compared with the ability to respond to central visual stimuli [4].

![Central visual stimuli and Peripheral visual stimuli](image)

**Fig. 1** (a) Circular black-and-white checkerboard patterns. (b) Fractionation of RT into Premotor time and Motor time.

### 2.2 Grade Exercise

Nine participants performed simple RT tasks at rest, during and after graded exercise on a cycle ergometer. Peripheral visual stimuli were presented at 15° to either right or left from the midpoint of the eyes. After warm-up exercise, the participants cycled at 40 watts (W) for 3 min, increasing by 40W every 3 min until 240W in a step-wise manner. During graded exercise, RT measurements were performed 1 min and 30 sec after the start of every increase in workload. RT to peripheral visual stimuli significantly increased during exercise above the VT relative to that at rest, while exercise below the VT and at the VT did not affect RT to peripheral visual stimuli [5]. In contrast, no difference was observed in RT between at rest and after exercise. Furthermore, the increase in RT, which was calculated by subtracting RT at rest from RT at 240W, was negatively correlated with peak VO$_2$ (r = -0.73, p < 0.05). This result indicates that high aerobic capacity attenuates the increase in RT to peripheral visual stimuli during exhaustive exercise.

### 2.3 Exercise under Hypoxia

Ten participants performed simple RT tasks at rest, during and after cycling at three different workloads (40%, 60%, and 80% peak VO$_2$) under either normoxia [inspired fraction of oxygen (FIO$_2$) = 0.21] or normobaric hypoxia (FIO$_2$ = 0.16). Peripheral visual stimuli were presented at 10° to either right or left from the midpoint of the eyes (Fig. 2). Cerebral oxygenation during the RT measurement was monitored over the right frontal cortex using near-infrared spectroscopy. The delta Premotor time and delta cerebral oxygenation during exercise were expressed relative to those at rest under normoxia. Under normoxia, Premotor time was significantly longer at 80% peak VO$_2$ (mean ± SD; 214.2 ± 33.0 ms) relative to that at rest (201.0 ± 27.2 ms, p < 0.05). Under hypoxia, Premotor time was significantly longer at all workloads (40%: 216.3 ± 27.8 ms, p < 0.05; 60%: 216.1 ± 28.9 ms, p < 0.05; 80%: 221.5 ± 30.1 ms, p < 0.01) relative to that at rest (202.9 ± 29.7 ms).

![Schematic diagram of peripheral visual stimuli presentation](image)

**Fig. 2** Schematic diagram of peripheral visual stimuli presentation.

![Relationship between delta Premotor time and delta cerebral oxygenation during exercise](image)

**Fig. 3** represents relationship between delta Premotor time and delta cerebral oxygenation during exercise. Delta Premotor time was negatively correlated with delta cerebral oxygenation during exercise (r$^2$ = 0.89, p < 0.01). This result suggests that...
the increase in the Premotor time during exercise is associated with the decrease in cerebral oxygenation.

![Graph showing relationship between delta Premotor time and delta cerebral oxygenation during exercise. Data are expressed as the mean ± SD.]

Fig.3 Relationship between the delta Premotor time and delta cerebral oxygenation during exercise. Data are expressed as the mean ± SD.

### 2.4 Exercise under Hyperoxia

Twelve male participants performed simple RT tasks at rest, during and after cycling with three different workloads (100 W, 150 W, and 200 W) under either normoxia (FIO$_2$ = 0.21) or normobaric hypoxia (FIO$_2$ = 0.28). Peripheral visual stimuli were presented at 10º to either right or left from the midpoint of the eyes. Under normoxia, Premotor time significantly increased at 200 W (mean ± SD; 224.7 ± 34.8 ms) relative to that at rest (213.3 ± 34.1 ms, p < 0.05). In contrast, no difference was found in Premotor time between at rest (214.0 ± 27.0 ms) and at 200 W (213.0 ± 21.6 ms) under hypoxia. Furthermore, Premotor time significantly decreased at 150 W (201.3 ± 22.4 ms) relative to that at rest (p < 0.05). Premotor time did not differ between at rest and after exercise (normoxia: 220.0 ± 34.8 ms, hyperoxia: 213.7 ± 25.1 ms). These results suggest that increased oxygen availability during exercise has beneficial effects on peripheral visual perception [6].

### 3 Discussion

The findings are summarized as follows: 1) the ability to respond to peripheral visual stimuli was vulnerable to moderate to severe exercise as compared with that to central visual stimuli, 2) RT to peripheral visual stimuli increased during exercise at low, moderate, and high workloads under hypoxia, and the increase in Premotor time was accompanied with the decrease in cerebral oxygenation, and 4) Premotor time to peripheral visual stimuli did not increase at high workloads during exercise under hyperoxia.

It has been suggested that arousal level increases as exercise workload increases [e.g. 7,8]. From a psychological point of view, increase in arousal level leads to narrowing of attentional focus [9]. The present results can be accounted for by narrowing of attentional focus. Fig.4 illustrates narrowing of attentional focus induced by exercise. However, physiological mechanisms underlying the increase in Premotor time to peripheral visual stimuli remain to be elucidated.

![Diagram illustrating narrowing of attentional focus induced by exercise.]

Fig.4 Illustration of narrowing of attentional focus induced by exercise.

The present results clearly demonstrated that physiological changes, which occur transiently during exercise above the VT and under hypoxia, affect the ability to respond to peripheral visual stimuli. Exercise above the VT is known to induce hyperventilation. Pronounced hyperventilation causes constriction of the arterioles in the brain [10] and leads to decrease in cerebral oxygenation [11,12]. Thus, it is likely that cerebral oxygenation decreased during exercise above the VT. Furthermore, hypoxia augmented the increase in Premotor time during exercise, and Premotor time to peripheral visual stimuli increased as cerebral oxygenation decreased during exercise. Brain function and tissue integrity are dependent on a continuous oxygen supply, and decrease in cerebral oxygenation means decrease in oxygen availability. Taken together, it can be assumed that the increase in Premotor time during exercise above the VT and under hypoxia is ascribed to the decrease in cerebral oxygenation. Possibly, the decrease in cerebral oxygenation during
exercise attenuated neural output in response to peripheral visual stimuli.

Plausible physiological mechanisms underlying the increase in Premotor time are summarized in Fig. 5. This model is tentative, and further studies are required to clarify the mechanisms.

![Fig. 5 Plausible physiological mechanisms underlying the increase in Premotor time during exercise above the VT and under hypoxia.](image)

4 Conclusion
The present study demonstrated that exercise at high workloads above the VT has detrimental effects on the ability to respond to peripheral visual stimuli. Hypoxia augmented the detrimental effects of exercise on the ability. In contrast, strenuous exercise did not affect Premotor time to peripheral visual stimuli under hyperoxia. Accordingly, it was suggested that cerebral oxygenation plays a key role in visual perceptual performance during exercise.

References: