Research Article

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How does isometric exercise affect the haemodynamics of the brain?

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Abstract

Objective: Brain responses during exercise are rarely studied because movement limits imaging techniques. With the development of functional near-infrared spectroscopy (fNIRS), it is assumed that the change in brain oxygenation could be accepted as a change in brain haemodynamics. In terms of exercise studies, aerobic exercise was the main topic. However, isometric exercise significantly increases body wellness, and therefore it began to be a suggested exercise model, especially for the elderly population. Despite these physiologic effects, the haemodynamic effects of isometric exercise in the brain remained unknown. The aim of this study was to show the brain haemodynamic changes during isometric exercises.

Methods: Seven healthy males (mean age: 24.71±3.33 years), who trained regularly, were enrolled in the study. fNIRS measurements were recorded from the forehead, where prefrontal cortex activity is reflected. The participants underwent three different exercises: handstand, squat, and plank. The oxygenation levels collected from the pre-, during-, and post-exercise conditions were evaluated.

Results: According to the fNIRS results, brain oxygenation in the prefrontal cortex increased during exercise in all positions ($p<0.05$). Additionally, the post exercise oxygenation values were observed higher than the pre-exercise conditions.

Conclusion: Haemodynamic changes during isometric exercise have been shown in this study. Brain oxygenation was increased during isometric exercise. In future studies, the brain haemodynamics of positional changes could be investigated as a factor to determine the positional effect during exercises. Also, the cognitive effects of isometric exercise could be a future research topic.

Keywords: Brain oxygenation, fNIRS, isometric exercise, prefrontal cortex

INTRODUCTION

Assessing brain responses during exercise has remained in the dark until the last decade due to the limited imaging techniques. Therefore, the responses of the brain to exercise are not well known. However, the responses to exercise in the human body have been studied deeply in terms of many physiologic parameters. Even the physiologic responses of different types and different periods of exercise are known in detail. In particular, the relationship between dynamic exercises and physiologic parameters (such as lactate, heart rate, and stroke volume) is very well established in exercise physiology. Also, the relationship between isometric exercise and physiologic parameters is very well documented. One of the most surprising results is that isometric exercises have different cardiovascular response patterns when compared with the dynamic exercises (1). Cardiovascular responses during isometric exercise showed different characteristics according to the magnitude and duration of muscle contraction (2). As an example, when the magnitude and duration of voluntary muscle contraction are increased, systolic, diastolic, and mean arterial pressure are rapidly increased (3). These increments are also directly related with cardiac output. Additionally, when the duration of muscle contraction is prolonged, venous blood flow, which is returning to the heart, is reduced due to the increment of intrathoracic pressure. It also reduces stroke volume. All these factors create some changes in the metabolism of the cell cycle (4). Stroke volume and stroke rate increase as soon as the

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muscle contraction ends. On the other hand, during dynamic exercise, under a similar workload, heart rate, cardiac output, and systolic pressure increase while the mean arterial and diastolic pressures slightly increase or remain the same (5, 6). In both exercise conditions, when the intensity is increased, the time to reaching exhaustion and sustainability of exercise is reduced. Also, cardiovascular responses in dynamic exercise slowly return to baseline, whereas the return to baseline is rapid in isometric exercise. These differences between isometric and dynamic exercises have led researchers to focus on possible haemodynamic differences between the two types of exercise.

Recently, with the development of functional near-infrared spectroscopy (fNIRS), researchers have focused on the haemodynamic activity of the brain during or after exercise or even in office conditions (7-10). fNIRS is one of the most promising and may be the only way to monitor brain responses during any type of exercise (11). This method allows non-invasive measurement of the oxy- and deoxyhaemoglobin changes in the brain via an electrode/optode pad, and these parameters are well described in the literature (12). Oxyhaemoglobin (Oxy-Hb) is accepted as an indicator of blood perfusion, whereas deoxyhaemoglobin is accepted as a metabolic indicator (12). There is some evidence to indicate that cerebral blood flow is in some way dependent on various parameters such as blood pressure, cerebral metabolism, and neurogenic activity; however, the relationship of this dependency remains unclear (13). Despite the limited number of studies, an increase of total blood flow in the brain has been established during acute aerobic or exhaustive exercises (14-18). It has been widely accepted that exercise positively affects brain health and cognitive functions. These effects are perhaps thought to be related in part to exercise-induced blood flow changes (14, 15). Generally, haemodynamic responses have been evaluated in pre, during-, and post-exercise conditions using an experimental design, which uses treadmill or cycle ergometer. These responses were also investigated with acute or chronic designs. In these studies, the increment of blood volume and flow has been established and therefore exercise is recommended for protection against some neurodegenerative diseases such as Parkinson's and Alzheimer's diseases (19). Besides the positive effects of isometric exercise, until now, there might be one missing question in the current literature; how does isometric exercise affect the haemodynamic responses of the brain? The current study aimed to establish the haemodynamic responses of the brain before, during, and after different types of isometric exercise using fNIRS.

METHODS

Participants

The study was conducted at the Brain and Exercise Biophysics Laboratory, Dokuz Eylül University. All recordings were performed with standard room temperature and humidity (25°C, 50% RH) in climate-controlled room. Seven healthy males (mean age: 24.71±3.33 years), who trained regularly, participated to the study. None of the participants had been diagnosed as having a cardiovascular, neurologic, orthopaedic or psychiatric disease before the recording date. The participants had similar years of sport history (14.86±1.12 years), and they were in similar height (180.42±8.31 cm) and weight (78.00±10.31 kg). All of the participants gave informed consent. This study protocol has been approved by the Ethics Committee of Dokuz Eylül University in September 2013 (524-GOA).

Exercise Protocol

The current study contains three different positions of isometric exercise including handstand, half squat, and plank. All participants attended a warm-up session, which took 5 minutes. In all conditions, the haemodynamics of the brain were monitored and recorded from the frontal brain region. For the handstand and half squat positions, the pre-exercise session was recorded in the standing position for one minute, then during the isometric exercise, participants were recorded for one minute. Finally, another one-minute recording was made for the post-exercise condition in the standing position. For the plank exercise, all recordings were made in the supine position. The participants were only in an active position during the isometric exercise. As a whole, each recording lasted 3 minutes per exercise. There were 1-minute breaks between the exercises.

Statistical Analysis

Haemodynamic activities of the brain were recorded using fNIRS devices (fNIR 1100, fNIR Devices, USA). An optode pad was used for the recordings and optodes were placed over the frontal lobe (Figure 1).

Only the central prefrontal area was evaluated because there is no hypothesis about lateralization. Oxy-Hb data were analysed using fNIRSoft (Biopac, USA) and averaged for each period; pre-, during-, post exercise for each type of exercise. For each participant, there were 9 different measurements (3 positions, 3 sessions). The positions were not compared because the positional effect could create confusion (20). Therefore, Friedmann analysis (k-related samples) was employed for each position to compare the differences between sessions if there was any significant result according to the Friedman test. Additionally, the Wilcoxon test was employed for multiple comparisons of sessions (i.e. pre- vs. post-exercise and during- vs. post-exercise). The significance level was accepted as 0.05 for all types of statistical analysis.

RESULTS

In the current study, brain oxygenation was measured using fNIRS from the frontal brain area for handstand, half squat, and plank exercises. The average of Oxy-Hb levels for pre-, during- and post- exercise periods are given in Table 1 and Figure 2 for each exercise position and session.

Table 1. Mean Oxy-Hb for each exercise position is given for each session

	Central Prefrontal Area		
	Oxy-Hb (μM/mL)		
	Pre	Dur	Post
Handstand	1.21 (±0.98)	15.73 (±3.56)*	3.40 (±3.14)#
Half Squat	0.53 (±0.89)	2.66 (±0.65)*	1.05 (±1.59)#
Plank	0.82 (±0.81)	4.82 (±3.94)*	2.98 (±2.41)

Pre: pre-exercise; Dur: during exercise; Post: post-exercise (μM/mL)
*denotes the significance of $p<0.05$ and # denotes the significance of $p<0.01$

Figure 1. a-d. One of the subjects who performed all positions is demonstrated in the plank (a), half squat (b), and the connected fNIRS optode is shown in (c) and handstand exercises (d).

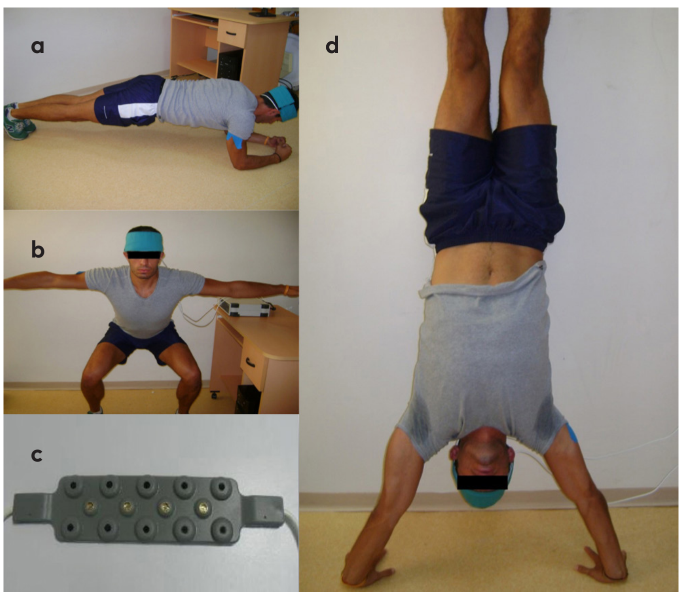
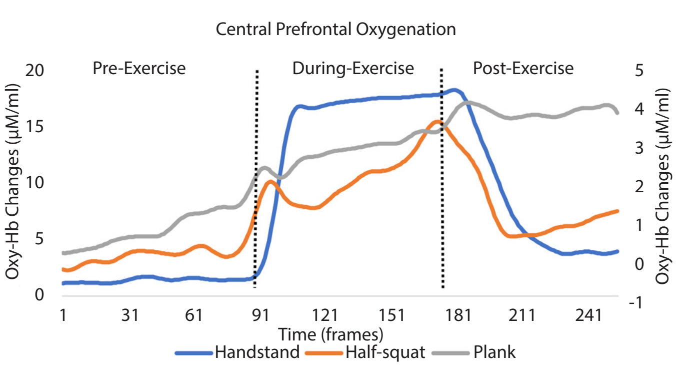


Figure 2. Average central prefrontal oxygenation for pre-exercise, during-exercise and post-exercise conditions of half-squat, plank and handstand positions. To simplify the demonstration, the oxygenation levels of each exercise were merged into the single figure with two different oxygenation axes. The left y-axis belongs to the oxygenation level of the handstand exercise, and the right y-axis belongs to the oxygenation level of the plank and half-squat exercises.



The comparison between the pre-, during-, and post-handstand conditions revealed significant differences in Oxy-Hb levels ($p<0.01$). For further comparisons, the Wilcoxon test was employed. According to the Wilcoxon test results, there were significant differences between pre- and during-handstand, during- and post-handstand comparisons in Oxy-Hb levels (each $p<0.05$).

The comparison between the pre-, during-, and post-half squat conditions showed significant differences in Oxy-Hb levels ($p<0.05$). According to further comparisons, there were significant differences between the pre- and during-half squat, post- and during-half squat positions in terms of Oxy-Hb in the central area (each $p<0.05$).

The comparison between the pre-, during-, and post-plank positions indicated a significant difference in Oxy-Hb in the central prefrontal area ($p<0.05$). This significant difference was only present on the pre- vs. during-plank positions ($p<0.05$).

DISCUSSION

In this present study, it was found that the brain oxygenation changed over pre-, during-, and post-exercise conditions. To our knowledge, this is the first study to show the haemodynamics of the brain during different types of isometric exercise. Therefore, the current study contributes important information to the literature. According to the results of this study, it is clear that the one-minute isometric exercise increased oxygenation in the frontal brain area and this increment was partially maintained after the exercise.

In the literature, it was assumed that isometric exercise had less motor activity in the brain when compared with dynamic exercises. Also, isometric exercise constitutes a lower heart rate and stroke volume, and higher blood pressure values when compared with similar levels of dynamic exercises. However, isometric exercise still causes higher blood flow in the frontal lobe, despite the strain in the circulation system during the exercise. This result raises questions about the relationship between the systemic and brain blood flow control mechanisms. It is known that the systemic and brain blood flow mechanisms are not correlated, but also, there is not sufficient evidence about the independency of the two systems.

In the current study, brain oxygenation increased as the exercise intensity increased. This kind of isometric exercise causes an increase in heart rate, arterial pressure, and muscle circulation, a decrease in stroke volume and stable peripheral resistance. In the related literature, it is reported that oxy-, deoxy-, and total-haemoglobin levels change by neuronal and metabolic activities (15, 21–23). Albeit isometric exercise has lower neuronal and metabolic activation, similar changes were observed in brain haemodynamics during isometric exercise when it was compared with dynamic exercise (24). This kind of haemodynamic change could originate from reticular activation (25). In particular, some dramatic changes were observed in the current study during the handstand position. These changes can be caused by the larger muscle contractions as well as positional differences of the head (20, 26). In the current study, we measured the baseline activities of the brain in the desired positions of exercises, except for the handstand position. Therefore, the authors did not prefer to compare the positions of exercise. However, the positional effect can be discussed as a topic for further studies. Additionally, the gravitational effects on haemodynamics can be a topic of new research to test fNIRS under extreme conditions. On the other hand, all of the results were derived from the outer part of the prefrontal cortex. Signal depth is the main limitation of fNIRS. With the current technology, infrared light can penetrate around 1 to 3 cm to the brain and only limited areas of the cortex can be reached. With the development of new systems and enhanced signal detectors, future studies can acquire new information from the rest of the brain and reveal the mysteries that are hidden in the deeper structures.

One of the important findings in the current study is that the haemodynamic responses were very stable during isometric exercises when compared with supramaximal exercises (18). The data seem to be unaffected by artefacts originating from muscle contractions, sweating, and position changes. This could be an advantage to investigate the brain responses during and after exercise, especially by means of cognitive performance. In the literature, some correlations have been reported between physical performance and cognitive performance (14–16, 18, 27). Generally, oxygenation values after exercise were observed higher than pre-exercise oxygenation values (18). In the current study, it was also observed that oxygenation rose during exercise and reduced after exercise. However, the post-exercise oxygenation values were still higher than the pre-exercise values. Therefore, it could be possible to work with cognitive test batteries to test the effects of isometric exercise on cognition in future studies.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Dokuz Eylül University (No: 2013/32-17, Date: 5/9/2013).

Informed Consent: Verbal and written informed consent was obtained from participants who participated in this study.

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Conflict of Interest: The authors have no conflicts of interest to declare.

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