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The Muscle Oxygen Saturation and Total Hemoglobin Levels at Different Intensities in Highly Trained Adolescents

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ABSTRACT

Introduction: Muscle oxygen saturation and total hemoglobin are important for athletes because of effects on fatique and performance parameters. The purpose of present study is to examine muscle oxygen saturation and total hemoglobin levels at different intensities in highly trained adolescents.
Method: Fourty-four highly trained adolescents (20.18±2.11 years; 73.02±12.20 kg; 180.00±8.03 cm) voluntarily participated this study. A standard general warm-up and later a special warm-up for the lower extremity were applied to the subjects before the measurements. Incremental Cycling Exercises were performed by Monark LC4. Smo2 and THb were evaluated by Moxy Oxygen Monitor. Height was assessed by using a wall-mounted stadiometer. Normality and sphericity tests were done using Kolmogorov-Smirnov and Mauchly's test, respectively. Outliers were determined using boxplots. Descriptive statistics include mean (M) and SDs. To see differences among intensities, Repeated Measure Anova test was used. We analyzed relationship between body composition variables and Smo2 & THb by Pearson correlation test. In all analyzes of the data, the significance level was accepted as $p<0,05$.
Discussion and Conclusion: there was significantly difference both Smo2 and THb values. Smo2 values decreased when exercise intensity increased. In contrary to Smo2 values, THb values increased as intensity increased. But THb values in rest and warm up intensity have no significantly difference. Besides, Smo2 values have significantly positive correlation with body weight. On the other hand, THb values also have negatively significant correlation with body weight, body mass index and body fat.

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INTRODUCTION

To maximize performance need to many different parameters (Lloyd et al., 2015). Performance of athletes is affected by many factors, especially physical and physiological characteristics (Ratamess, 2021). Training is the most important element for maximizing and improving physical and physiological parameters. The way for athletes to maintain their performance at a high level for a long time is through the correct design of training plans and periodizations (Açıkada, 2018).

Each sport branch uses energy and uses energy in a different way during the competition. The energy use required by each age is used at a different level. Among the determining criteria of performance, it is affected by many factors from each other. These factors cause the quality and quantity of performance to take a long time(Alaeddinoğlu, 2021).

Planning and periodization, on the other hand, contain certain principles (Açıkada, 2018; T. O. Bompa and Buzzichelli, 2019). Performance can only be maximized and sustained with training programs planned and scheduled in line with these principles(T. Bompa and Buzzichelli, 2015). Important elements that increase the efficiency of training for high-level performance are the intensity, volume, duration and frequency of the training (Kasper, 2019). Regardless of the physical and physiological to be developed, each training plan is based on these elements and their interrelationships.

KEYWORDS:
muscles,
incremental exercise,
intensity,
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Training science uses different methods to determine load intensity. Commonly used training load determination methods include lactate level, met, heart rate, oxygen usage capacity (Lambert and Borresen, 2010). In the light of scientific studies conducted in recent years, local muscle oxygen saturation and total hemoglobin are preferred as a physiological parameter used to determine the loading elements. Total hemoglobin and muscle oxygen saturation are among the items associated with muscle work performance and efficiency. The training planning of athletes at every age level includes individuality. It is seen that the abilities and physical characteristics of the athletes affect the use of oxygen, increase or decrease in lactate level, training intensity, training and competition performance efficiency. And this situation is closely related to the multifaceted factors that are intertwined with each other(Kıyıcı and Alaeddinoglu, 2022).

The Moxy oxygen monitor is a lightweight, small device that is used cutaneously to measure muscle oxygen saturation and total hemoglobin level using near-infrared spectroscopy (NIRS). The device can be used in both healthy and patients (Grassi and Quaresima, 2016). Moxy is an invasive device used to measure local blood flow and muscle oxygen saturation. The desaturation rate during exercises of Moxy has been reported to be reliable, reproducible and valid measure of muscle oxidative metabolism (Hamaoka et al., 1996; Southern et al., 2014; Zhang et al., 2020). Moxy is a device that works using NIRS technology. In this way, Moxy can directly measure the microcirculation of hemoglobin in blood vessels and the oxygen-dependent absorption of myoglobin in the muscle cytoplasm (Muthalib et al., 2010). With its data storage and telemetric capacity, the Moxy device has the capacity to provide real-time information about the use of oxygen in the muscles during exercise (Crum et al., 2017). With the Moxy device, it is possible to measure the absolute or relative concentration values of oxyhemoglobin (O2Hb), deoxyhemoglobin (HHb) and total-hemoglobin (tHb = O2Hb + HHb) (Ferrari et al., 2011) obtained by using these data, and finally muscle oxygen saturation (Smo2= [O2Hb/(O2Hb+ HHb)]x100) (Feldmann et al., 2019). All values obtained are due to the absorption of NIRS lights in large blood vessels with high hemoglobin levels. The data obtained generally represent tissue capillaries, arterioles and venules (Ferrari et al., 2004). Previous evidence stated that there are changes in muscle oxygen saturation (SmO2) and reoxygenation time depending on exercise characteristics. For example, concentric exercises caused a greater increase in Smo2 and shorter reoxygenation than eccentric exercises (Timón et al., 2017). Smo2 could also influenced the velocity and intensity of exercise and the number of repetitions prior to fatigue, in addiction to series recovery strategies (Gómez-Carmona et al., 2020). Taken as a whole, the range of muscle NIRS parameters can provide information regarding changes in key dynamic physiological indicators, such as blood flow, oxygen extraction, and oxygen consumption. Ve egzersize adaptasyon, egzersiz performansı ve egzersiz töleransı gibi konularda bilgi verebilir (McManus et al., 2018). At the same time, this method can be used as an alternative to other training intensity determination methods because it is low-cost NIRS-based device (Born et al., 2017; Cornachione et al., 2014; McManus et al., 2018). In addition to loading intensity, moxy device data can also be helpful when deciding recovery, rest intervals, volüme, frequency and number of set (Design, 2015; Pereira et al., 2007). Besides, NIRS-based Moxy is an invasive method used to examine the energy demands of muscles. therefore, during any exercise, Smo2 measurements can provide information about the energy needs of the muscle(Davis et al., 2020).

Thus, the objective of this study was to evaluate the SmO2 and THb levels at rest, after warm up, during execution phases depending on the load intensities during incremental cycle exercise.

METHOD

Subjects

Fourty-four highly trained adolescents (20.18±2.11 years; 73.02±12.20 kg; 180.00±8.03 cm) voluntarily participated this study. All subjects were selected from those who did moderate and vigorous exercise at least three days a week. They had to meet the conditions of not having undergone any surgery in the last year, not having experienced a sports injury, and right-handed dominant. After the subjects were determined, we informed the subjects about the study. All tests were conducted according to the principles expressed in the Declaration of Helsinki. Ethics approval was obtained for the study from Ataturk University ethics committee.

Experimental Approach to the Problem

All subjects were tested under the same conditions. Subjects visited just once laboratuvary for measurement. When subjects visited laboratuvary, we informed them about the tests. The height and weight measurements were firstly conducted. After the height and weight measurements, a warm-up protocol was applied before incremental cycle exercise. Each subject completed a bout of cycling exercise protocol. All tests were performed afternoon and the tests took a total of 10 days, with five people per day. All tests were carried out in the same air-conditioned lab which was set to 21°C and 1890 m altitude in Erzurum to ensure consistency. Subjects were asked to refrain from heavy physical activity, caffeine and alcohol in the twenty-four hours prior to trials. We informed all subjects about research aim and tests in this study. All subjects applied a familiarisation session prior to trials. With this familiarsation, We verified cycling sitting height, holding distances and positions.

Warm-Up Procedure

A standard general warm-up and later a special warm-up for the lower extremity joints and muscles were applied to the subjects before the measurements. At general warm-up, a 5-minute jogging was performed with 20-30% of the maximal oxygen capacity. After the general warm-up, a short stretch covering all joints was performed and the general warm-up was completed. Then, 10 minutes of special cycling warm-up was performed in order to enable the subjects to work with maximum during the test and to minimize the risk of injury. The special warm-up focuses heavily on lower limbs.

Instruments

1. Incremental Cycling Exercises were performed by Monark LC4 (Monark Exercise AB, Sweden).
2. Smo2 and THb were evaluated by Moxy Oxygen Monitor (Moxy, Fortiori Design LLC, Minnesota, USA)
3. Height was assessed by using a wall-mounted stadiometer (Seca Stadiometer 282, Seca GmBH & Co Kg, Hamburg, Germany).
4. Weight was assesed by using Tanita TBF-300 (TANITA, Middlesex, UK).

Procedure

We performed conducted all tests at Ataturk University Sport Sciences Application and Researh Center. Height measurements were done bare feet on a flat platform in an anatomical position. In body weight measurements, the subjects only wore running shorts. The moxy oxygen monitor was attached to the rectus femoris muscle of the dominant limb. Prior to attach moxy oxygen monitor, in order to obtain high quality data, the rectus femoris muscle where it will be placed were cleaned. The steps followed during the preparation of the leather surface are listed below. First of all, the location and surroundings where the moxy will be placed were cleaned by using materials such as razor blades and depilatories. In addition to this, the dead skin on the skin was also removed to some extent during this application. After cleaning the bristles, the dead skin remaining on the skin was removed from the surface using sandpaper or special pastes. After the dead skin was cleaned, the skin was cleaned with alcohol, the last remaining substances on the skin surface were removed and the skin surface was made suitable for moxy monitor bonding. Incremental cycle test was performed with Monark LC4. LC4 set up as closely as possible to the subject's own bike. Following, the pre-exercise measures, the subjects mounted the ergometer and finished a 5-minute warm-up at 50 Watts (W). Subsequently, they completed a step-wise protocol, which began at 75 W and increased by 25 W every minute until exhaustion. Incremental cycling protocol was chosen to allow assessment of the Smo2 and THb in different loading intensities. During the test with incremental tests, heart rate (HR) counts were taken from the subjects continuously. HR and Moxy data were recorded constantly throughout the test, with the average values from the of each stage being used for analysis.

Statistical Analyses

The Statistical Package for the Social Sciences version 25.0 (IBM Corp, Chicago, IL, USA) was used to analyze the obtained datas. Normality and sphericity tests were done using Kolmogorov-Smirnov and Mauchly's test, respectively. Outliers were determined using boxplots. Descriptive statistics include mean (M) and SDs. To see differences among intensities, Repeated Measure Anova test was used. We analyzed relationship between body composition variables and Smo2 & THb by Pearson correlation test. In all analyzes of the data, the significance level was accepted as $p<0,05$.

RESULTS

Table 1: The subject descriptive characteristics

	N	Minimum	Maximum	Mean	Std. Dev.
Age (year)	44	18,00	26,00	20,18	2,11
Height (cm)	44	163,00	195,00	180,00	8,03
Body Fat (%)	44	6,90	24,40	14,05	4,51
Weight (kg)	44	53,90	109,97	73,02	12,20
BMI (kg/m^2)	44	16,64	33,20	22,49	3,16

Table 2: Smo2 and THb parameters in Different Loading İntensies

		N	Mean	Std. Deviation
Smo2	Rest	44	64,01$^{\alpha}$	13,67
	Warm-Up	44	67,70$^{\alpha}$	12,65
	AeT	44	54,77$^{\alpha}$	14,46
	AnT	44	46,06$^{\alpha}$	15,02
	Max	44	40,49$^{\alpha}$	15,40
THb	Rest	44	12,13†	0,517
	Warm-Up	44	12,16†	0,492
	AeT	44	12,233‡	0,551
	AnT	44	12,294‡	0,565
	Max	44	12,365‡	0,577

α: There is significantly difference among intensities, $p<0.05$. †: There is no significantly difference, $p>0.05$. ‡: There is significantly difference from rest and warm-up, $p<0.05$.

Table 3: Correlation of Smo2 & THb and Body Composition Parameters

			Weight	BMI	Body Fat
Smo2	Rest	r	,254	,014	,139
		p	,097	,928	,368
	Warm-Up	r	,378*	,135	,245
		p	,011	,383	,108
	AeT	r	,332*	,136	,194
		p	,028	,378	,206
	AnT	r	,324*	,194	,249
		p	,032	,207	,103
	Max	r	,249	,119	,168
		p	,104	,441	,276

THb	Rest	r	-,690**	-,453**	-,483**
		p	,000	,002	,001
	Warm Up	r	-,714**	-,477**	-,487**
		p	,000	,001	,001
	AeT	r	-,656**	-,431**	-,462**
		p	,000	,004	,002
	AnT	r	-,607**	-,400**	-,428**
		p	,000	,007	,004
	Max	r	-,619**	-,411**	-,422**
		p	,000	,006	,004
		N	44	44	44

*: It showed that there are significantly correlation among variables, $p<0.05$.

DISCUSSION

This study conducted to evaluate SmO2 and THb levels in different load intensities. Each variable was evaluated five intenties, rest, after warm-up, aerobic threshold, anaerobic threshold and maximal. SmO2 values for intensities, rest, warm-up, AeT, AnT and Max were 64.01±13.67, 67.70±12.65, 54.77±14.46, 46.06±15.02, 40.49±15.40, respectively. SmO2 values has significantly difference by intensities. Warm-up Smo2 value was the highest. Smo2 values decreased gradually for AeT, AnT and Max. THb values increased gradually for all intensities, respectively. On the other hand, THb values for intensities were 12.13±0.51, 12.16±0.49, 12.23±0.55, 12.29±0.56, 12.36±0.57, respectively. Also, THb values had moderate correlation with body weight, body mass index and body fat, negatively, while Smo2 values had just low correlation body weight, positively.

The results of the current study showed that while the smo2 level gradually increased until the steady-state state, it began to decrease in the ongoing process. Previous studies found similar results to our study. Shirai et al. (2023) stated that there was diffencence in smo2 in term of intensity. A study conducted on sprint kayakers reached the same finding which is smo2 decrease as the loading density and test time increase. Results of another study found that men have more decreases in SmO2 from sixty to one hundred percentage of the workload (Espinosa-Ramírez et al., 2021). They said that this is because the cross-sectional areas of the muscles are larger and the higher speed and more intense exercise tempo. Chin et al. (2011) stated that Smo2 values decrease as the load increases during incremental exercise. The results of this study were the same as our study. Klusiewicz et al. (2021) conducted study assessing the aerobic training loads of world-class rowers and they revealed negative relation between smo2 and lactic asid. That is, they said that as lactic acid level increases, smo2 can decrease. A study conducted in triathletes found the similar starting smo2 values in different exercise, but 2 min after starting, smo2 values started to drop (Olcina et al., 2019). (Vasquez-Bonilla et al., 2023) stated that maximum peak torque and average peak torque were associated with the decrease in SmO2. In a study investigating muscle oxygen saturation while walking, results similar to ours were obtained. Smo2 values tended to decrease as the walking time increased (Shriver et al., 2023). According to Grassi et al. (1999) Smo2 values decreased linearly during incremental exercises. Conducted study by Dykstra et al. (2020) which is similarly to present study found that smo2 values gradually decreased during continuous exercise. It has been shown that the main reason for this may be the decrease in the efficiency of contraction due to continuous contraction and the increase in muscle internal pressure due to the increase of metabolite waste materials in the muscles (Crenshaw et al., 2010). At the same time, the inability of the contractile elements of the muscle to perform their functions completely due to the decrease in muscle oxygen uptake due to the limitations in optimal oxygen transport and metabolism can be shown as the reason for this decrease (Vanhatalo et al., 2011). Hoffman et al. (2003) stated that the total duration of maximal exercises may be more important than the relative intensity of exercise in influencing muscle oxygen saturation and recovery. Moreover, both volume and exercise intensity affect muscle oxygenation, but Timón et al. (2017) and Raeder et al. (2016) found more markers of fatigue and higher muscle reoxygenation time than the type of muscle contraction. That is, exercise intensity affected the oxygenation of the muscle. Luck et al. (2017) found in healthy and peripheral artery disease fallen down Smo2 during exercise. Kirby et al. (2021) found their study that Smo2 values decreased during the exercise, especially as the anaerobic threshold was approached and after the anaerobic threshold was passed. It also remained stable until steady state. As observed at quadriceps, average %SmO2 was highest during exercise in the moderate phase and the lowest during exercise in the severe phase. Finally, results of another study on muscle strength refers to the decrease in SmO2 during muscle strength exercises, compared before, during, and after exercise. Strength protocol which is applied more than 75% of the 1 RM had similarly significant difference Smo2 and THb, in contrary to moderate intensity. As stated in the literature, Reason for this result could be increased oxygen consumption of muscles during exercise and may increase during high-intensity training (Hamaoka et al., 2011). High-intensity differ from continously exercise. During high intensity exercises, intramuscular pH and phosphocreatine concentration decreases and blood lactate and intramuscular inorganic phosphate concentrations increases. As a result, oxygen uptake (VO2) persist until muscle fatigue, reflecting an ineffective muscle metabolic system over time (Hammer et al., 2020). It has been shown that increased intramuscular mechanical pressure during muscle strength exercise can lead to decreased blood flow, which can lead to temporary muscle hypoxia (Hug et al., 2005), which can lead to a feeling of fatigue and reduced physical performance. On the other hand, tissue thickness over skeletal muscle may also be shown to interfere with the outcomes provided by the NIRS. It can reduce the relative contribution of the underlying skeletal muscle to the overall NIRS response.

CONCLUCIONS

In summary, Our study had two important results. Smo2 values decreased in more intensity. Secondly Smo2 have positively correlation with body weight and THb have negativeliy correlation with body weight, body mass index and body fat.

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