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Effects of Gender on Oxygen Saturation of Thigh Muscles during Maximal Treadmill Exercise Testing

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Abstract

Currently, muscle activity can be assessed by oxygen muscle saturation (SmO_2) measured with near-infrared spectroscopy (NIRS), which is a non-invasive technique that can be used in training planning and control, but more needs to be known about it. To analyse gender differences in the SmO_2 of quadriceps and hamstrings, in several phases of a maximum stress test. A total of 20 subjects, with an average age of 21 years (10 males and 10 females), were the subjects of maximal treadmill exercise testing. We obtained maximum oxygen consumption (Metalyzer 3B) and monitored the electrocardiogram continuously. In addition, we measured the SmO_2 of quadriceps and hamstrings in rest (R), start decline (D) and maximum effort (M), with two Humon Hex devices, one placed on the anterior side of the thigh and another on the back. Quadriceps SmO_2 in males: R=59.4±11.5%; D=48.3±19.1%; M=52.5±13%. Quadriceps SmO_2 in women: R=51±11.5%; D=48.5±9.4%; M=43.1±6.9%. Hamstrings SmO_2 in males: R=56.2±13.1%; D=62.9±9.1%; M=57.5±13.9%. Hamstrings SmO_2 in women R=56.9±18.9%; D=49.7±7.4%; M=38.2±14.6%. There are no significant differences between muscles. There are only significant differences in M in hamstrings (p-0.009). SmO_2 during treadmill exercise is similar in both sexes, but the overall decrease with maximum exercise is greater in women's hamstrings.

Keywords: *near-infrared spectrometry, quadriceps, oxygen consumption, exercise*

Introduction

Muscle oxygen saturation (SmO_2) is a specific measure used to determine the percentage of oxygen that is captured by muscle tissue in oxidative metabolism, in order to obtain energy (Inglis, Iannetta, & Murias, 2019). Currently, SmO_2 can be determined thanks to near-infrared spectrometry (NIRS) (Farzam, Starkweather, & Franceschini, 2018).

NIRS devices have a safe and non-invasive mechanism that report the degree of participation of a specific muscle during activity. This device provides information about the muscular activity through an APP, which can be used to plan a muscular activity and training control (Grassi & Quaresima, 2016). Its management in sports practice is simple since it has a wireless design and is easy to apply in any field (Koga et al., 2015).

Furthermore, in much of the bibliography regarding the NIRS, differences in SmO_2 between men and women during physical exercise have not been studied. Generally, they have focused on the adult male sports population, and there are hardly any studies on women (Louvaris et al., 2018; Jones & Cooper, 2018; Baláš, Kodejška, & Krupková, 2018).

In contrast, various studies have related the SmO_2 of different muscles, but without considering the relationship between antagonists. Contreras-Briceño et al. (2019) observed the different levels of oxygenation of the intercostal musculature and the large lateral muscle. Others have studied the erector muscles of the lumbar spine and soleus (Chambers, Haney, Huppert, & Redfern, 2019). Another

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comparison was between the twins and the superficial flexor of the fingers (Lagerwaard, Keijer, McCully, de Boer, & Nieuwenhuizen, 2019).

Most studies have used a single device, generally arranged in quadriceps (Saito, Goda, Yamagishi, & Kawakami, 2018; McLean, Kerhervé, Lovell, Gorman, & Solomon, 2016; Spencer, Amano, Kondo, Kowalchuk, & Koga, 2014). Therefore, it is interesting to know how the antagonistic muscles respond to the same activity.

Other authors have compared SmO_2, paying attention to different groups according to their sports activity, for example, between athletes and non-athletes (Clark et al., 2019; Jones & Cooper, 2018) or cyclists and non-cyclists (Crum, O'Connor, Van Loo, Valckx, & Stannard, 2017; Saito et al., 2018). Other works have been carried out to analyse the influence of obesity versus overweight (Vasquez-Bonilla et al., 2017; Soares, Reimer, Alenezi, Doyle-Baker, & Murias, 2018).

Given the scarcity of existing scientific literature on the NIRS, our study arises from the need to provide basic data on muscle oxygenation, taking into account the influence of gender and its impact on antagonist muscles.

To analyse gender differences in SmO_2 of quadriceps and hamstrings, in several phases of a maximum stress test.

Methods

A total of 20 students from the University of Murcia, with an average age of 21.9±1.6 years old were included in our work: 10 males and 10 females. The inclusive criteria were to be between 20 and 30 years old and not presenting injuries or defects that prevent the exercise test from being carried out.

The study was carried out in accordance with the Declaration of Helsinki and was approved by the Research Ethics Commission of the University of Murcia. All the participants signed the corresponding informed consent document.

All of them performed a maximum stress test on the treadmill (model run7411) with a continuous and progressive ramp protocol (1% slope). Testing started at 7 km/h with increments of 0.1 km/h every 6 seconds, with a warm-up phase of 2 minutes at 6 km/h. From it, the maximum oxygen consumption was obtained (Metalyzer 3b).

Prior to the start of the stress test, a cardiovascular examination was performed at rest. With the patient in a supine position, cardiac auscultation, blood pressure, and electrocardiogram were performed. Subsequently, the electrodes kept recording throughout the stress test. In addition, two Humon Hex® devices were placed, one on the anterior aspect of the right thigh (quadriceps) and the other on the posterior aspect of the left side (hamstrings). Each was synchronized with a Samsung Tablet connected to the corresponding APP, to visualize the information of the SmO_2, the exercise time and the heart rate. The SmO_2 of quadriceps and hamstrings at rest (R); at the beginning decline (D) and in maximum effort (M) were obtained by the SmO_2 / time graphs.

The test ends when the subject is exhausted and gestures with his hand to start the recovery phase at 3 km/h for 3 minutes and at rest for another 2 minutes. The tests were considered to be maximum and valid when they exceeded 85% of the theoretical maximum heart rate (220-age), and the respiratory quotient was greater than 1.15 (Howley, Bassett, & Welch, 1995). Finally, an active recovery period of 4 minutes at 4 km/h was carried out.

The data were analysed with the Statistical Package for Social Science (SPSS v.24). The quantitative variables have been described with the mean and standard deviation, and the qualitative ones with the absolute frequency and relative frequency. Comparison of the means of independent inter-group variables (men and women) was performed using the t-student test, and the comparison of the means of related variables was made with the t-paired test. The relationship between variables was studied using the Pearson Test. A minimum level of significance of $p<0.05$ was established.

Results

In Table 1, the basic characteristics of the population sorted by gender and the significance of their differences are shown.

Table 1. Anthropometric characteristics, according to gender

Characteristics	Gender	M±SD	p
Age (years)	Male	21.90±1.60	0.142
	Female	21.00±0.94	
Height (cm)	Male	173.51±5.68	0.000
	Female	160.30±4.80	
Weight (kg)	Male	67.52±8.42	0.018
	Female	58.48±7.06	
BMI (kg/m²)	Male	22.37±2.05	0.712
	Female	22.80±2.92	
Girth of the thigh (cm)	Male	48.00±3.50	0.952
	Female	48.10±3.81	
Fold of the thigh (mm)	Male	20.90±7.02	0.000
	Female	33.80±6.30	

The saturation of both muscles in the three phases of exercise, separated by gender, is shown in Table 2. It is observed that there are only significant differences between men and women in the hamstring values in maximum exercise.

Table 2. Muscle saturation in each situation, muscle and gender

SmO_2	Muscle	Gender	N	M±SD	p
In rest (R)	Quadriceps	Males	10	59.40±11.58	0.121
		Females	10	51.00±11.51	
	Hamstrings	Males	10	56.20±13.15	0.925
		Females	10	56.90±18.96	
The beginning decline (D)	Quadriceps	Males	8	48.39±19.11	0.982
		Females	8	48.56±9.48	
	Hamstrings	Males	7	62.99±9.13	0.060
		Females	7	49.77±7.46	
In maximum effort (M)	Quadriceps	Males	9	52.56±13.00	0.193
		Females	10	43.10±16.91	
	Hamstrings	Males	9	57.56±13.94	0.009
		Females	10	38.20±14.61	

When the population is analysed as a whole, it is observed that there are no significant differences in the SmO_2 in the quadriceps versus the hamstrings in any of the three situations studied (Table 3).

The correlations between SmO_2 values and anthropometric variables show that the fold of the thigh is negatively correlated with the saturations of both muscles at the time of maximum effort; likewise, the girth of the thigh also does it with the SmO_2 of the hamstrings (Table 4).

Table 3. Differences in the SmO_2 between muscles in the population as a whole

SmO_2	Muscle	N	M±SD	p
In rest (R)	Quadriceps	20.00	55.20±12.03	0.774
	Hamstring	20.00	56.55±15.88	
The beginning decline (D)	Quadriceps	9.00	45.31±16.70	0.098
	Hamstring	9.00	57.89±10.39	
In maximum effort (M)	Quadriceps	19.00	47.58±15.54	0.966
	Hamstring	19.00	47.37±17.08	

Table 4. Correlations between anthropometric variables and SmO_2

		In Rest		Beginning of Decline		In Maximum Effort	
		Q	H	Q	H	Q	H
Age (years)	Pearson	0.091	-0.237	-0.589	0.243	0.367	0.222
	Sig.	0.703	0.315	0.016	0.500	0.122	0.362
	N	20	20	16	10	19	19
Height (cm)	Pearson	0.474	-0.005	0.126	0.380	0.409	0.230
	Sig.	0.035	0.985	0.641	0.278	0.082	0.344
	N	20	20	16	10	19	19
Weight (kg)	Pearson	0.219	-0.155	0.079	-0.140	0.289	-0.209
	Sig.	0.354	0.514	0.772	0.700	0.229	0.390
	N	20	20	16	10	19	19
BMI (kg/m^2)	Pearson	-0.197	-0.198	-0.019	-0.559	-0.015	-0.457
	Sig.	0.405	0.402	0.945	0.093	0.951	0.049
	N	20	20	16	10	19	19
Girth of the thigh (cm)	Pearson	-0.086	-0.170	0.071	-0.439	0.141	-0.479
	Sig.	0.717	0.474	0.795	0.204	0.563	0.038
	N	20	20	16	10	19	19
Fold of the thigh (cm)	Pearson	-0.213	-0.033	0.199	-0.479	-0.638	-0.525
	Sig.	0.366	0.891	0.460	0.161	0.003	0.021
	N	20	20	16	10	19	19

Discussion

The objective of the present study was to analyse the differences between the genders of the SmO_2 of the quadriceps and hamstring muscles in various phases of a maximal stress test, in a total of 20 subjects. Other authors, such as Vitorio et al. (2018) and Born, Stöggl, Swarén and Björklund (2017) used a similar number to determine if there are effects of rhythmic auditory signals during gait on cortical activation and cognitive function or whether heart rate or tissue saturation is affected by the continuous change of intensity in the exercise.

We have focused this work on the analysis of the main antagonist muscles present in the race, comparing SmO_2 between the quadriceps and hamstrings of the subjects as a whole, in which no significant differences were obtained in any of the three phases. Therefore, we cannot compare these results with other works, since we did not find in the available literature any study involving these muscle; most studies are focused on the quadriceps (e.g. Saito et al., 2018; McLean et al., 2016).

The results obtained indicated that men have higher SmO_2 values in the hamstrings than women during the maximum exercise phase. In contrast, most of the consulted papers (Contreras-Briceño et al., 2019; Louvaris et al., 2018; Jones, & Cooper, 2018) only evaluated SmO_2 in men. Therefore, it is difficult to determine if there are differences in relation to gender.

We evaluated SmO_2 analysis during three different phases: rest, the onset of decline, and the highest point of exercise. In contrast, different studies evaluated SmO_2 at the maximum peak of exercise intensity (Koga et al., 2015; Contreras-Briceño et al., 2019) or, to a lesser extent, this is combined with the measurements at rest (Inglis et al., 2019; Louvaris et al., 2018).

Furthermore, a relationship between anthropometric measurements and oxygen saturation has been sought. Both the fold and the girth of the thigh have shown a negative relationship with SmO_2 at the moment of maximum effort, that is people with a higher fat content have lower SmO_2 values. In previous studies (Quaresima et al., 2003; Vasquez-Bonilla et al., 2017) it was seen that women generally have a greater layer of subcutaneous fat, which can cause interference in the receptor signal and decrease the reliability.

The stress test was carried out on a treadmill with an incremental ramp protocol; because it is one of the most widely used protocols and allows reaching the maximum effort of the athlete in a relatively short time (Boone & Bourgois, 2012). Despite this, most of the works related to the NIRS have used the cyclo-algometer, using an incremental cycling test in a laboratory (Koga et al., 2015; Saito et al., 2018). Therefore, because they are two different evaluation tests with opposite sports gestures, it is not appropriate to make comparisons.

Regarding the limitations of this study, our subjects are amateur athletes who present a very similar physical condition; therefore, since we do not have highly trained subjects, we cannot assure that our SmO_2 values are representative of other populations. Despite this, the values obtained can serve as a basis for the study of this sort of population.

NIRS-based technology could be used to improve athlete performance in a non-invasive and safe manner, aiding in planning the training according to the physiological characteristics and physical condition of each subject. Also, it is a way of keeping track of muscle oxygenation and helping to set short and medium-term goals aimed at improving performance in physical exercise.

We conclude that the oxygen saturation of the hamstrings at maximum effort is different between men and women, while there are no differences in the other phases of exercise. Likewise, there are no differences in oxygenation between both muscles. However, a negative correlation appears with the anthropometric measurements of the thigh, that is, the higher the percentage of subcutaneous fat in the thigh, the lower SmO2.

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Conflict of Interest
The authors declare the absence of conflict of interest.

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