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ACUTE EFFECTS OF MUSCLE STRENGTH ON HEMOGLOBIN CONCENTRATION AND MUSCLE OXYGEN SATURATION BEHAVIOR IN HEALTHY ADULTS.

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ÍNDICE

ACUTE EFFECTS OF MUSCLE STRENGTH ON MUSCLE OXYGEN SATURATION BEHAVIOR IN HEALTHY ADULTS.

Indya del Cuerpo Rodríguez.

Abstract: The purpose of this study was to describe hemoglobin concentration (HbC) and muscle oxygen saturation (SmO_2) behavior in different maximum strength determination protocols using a functional electromechanical dynamometer (Dynasystem®). Measurements of SmO_2 and HbC were collected from 16 healthy males (36.13 ± 6.40 years, 80.38 ± 10.03 kg and 173.56 ± 6.52 cm) during two sessions. After 10 minutes rest, participants performed 10 minutes of low-load cyclo ergometer warm-up. Then they performed 8 seconds of isometric knee maximum extension for 3 times (ISO) with sixty seconds of rest between series. After that, the following two protocols were counterbalanced and participants performed maximum dynamic knee extensions with increments of 2 kg in each repetition until muscle failure starting, with an initial load of 40% of the mean isometric strength (P1) and 40% of the peak isometric strength (P2). The main findings of this study suggest that during all protocols and rest the HbC curve behaves differently than the SmO_2 one. Furthermore, there are significant differences between protocols in HbC ($p = 0.003$, $\omega^2 = 0.055$), but, in terms of SmO_2 ($p = 0.135$; $\omega^2 = 0.011$), there are not. In conclusion, during isometric and dynamic exercise the HbC curve follows almost the same pattern, but the SmO_2 one follows different patterns. We also found that HbC behaves statistically differently as long as the measure is taken during ISO exercise or P2. In the case of SmO_2, we found similarities between all protocols and rest.

Resumen: El propósito de este estudio fue describir la concentración de hemoglobina (HbC) y el comportamiento de la saturación de oxígeno muscular (SmO_2) en diferentes protocolos de fuerza máxima utilizando un dinamómetro electromecánico funcional (Dynasystem®). Las medidas de HbC y SmO_2 se tomaron a 16 adultos sanos (36.13 ± 6.40 años, 80.38 ± 10.03 kg y 173.56 ± 6.52 cm) durante dos sesiones. Tras 10 minutos de reposo, los participantes realizaron un calentamiento de 10 minutos en cicloergómetro a baja carga. Tras ello, realizaron 3 series de 8 segundos de extensión máxima de rodilla isométrica (ISO) con 60 segundos de descanso entre series. Finalmente, los dos siguientes protocolos se contrabalancearon y consistían en la realización de extensiones de rodilla dinámicas máximas con incrementos de 2 kg en cada repetición hasta el fallo muscular, comenzando con una carga inicial del 40% de la fuerza isométrica media (P1) y del 40% de la fuerza isométrica pico (P2). Los principales hallazgos de este estudio sugieren que, durante la extensión isométrica y dinámica de la rodilla, la curva de HbC se comporta de manera diferente a la curva de SmO_2. Además, hay diferencias significativas en la curva de HbC ($p = 0.003$, $\omega^2 = 0.055$), pero, en cuanto a la de SmO_2 ($p = 0.135$; $\omega^2 = 0.011$), no las hay. En conclusión, durante la extensión isométrica y dinámica de rodilla, la curva de HbC se comporta casi siempre de la misma manera, pero la de SmO_2 sigue patrones diferentes de comportamiento. También se observa que la HbC presenta un comportamiento diferente en función de los diferentes protocolos de fuerza evaluados, sobre todo en ISO y P2. En el caso de la SmO_2, se encontraron similitudes durante todos los protocolos y el reposo.

Key words: NIRS, knee extension, resistance training, vastus lateralis, isometric strength, dynamic, strength.

1. INTRODUCTION.

SmO_2 and HbC are essential for understanding how muscles respond to physical exercise (Farzam et al., 2018). During exercise, the majority of the oxygen uptake takes part in muscles. The respiratory gas analysis provides a complete measure of oxygen consumption which allows to the quantification of aerobic power (Colier et al., 1995). Also, other measurements such as heart rate, blood lactate concentration, or maximum oxygen uptake (VO_2max) are used to decide the power levels at which competitors ought to endeavor to amplify athletic execution (Farzam et al., 2018). But these methods do not provide concrete information about the working muscles.

In order to solve that problem, Hartling et al. used an invasive method to assess regional SmO_2, but this technique did not allow measuring on a continuous basis during exercise. To solve that problem, other methods have been developed, such as near-infrared spectroscopy (NIRS), an affordable and portable non-invasive technique that allows the evaluation of skeletal muscle oxygenation through relative concentrations of oxygenated and deoxygenated hemoglobin during exercise (Lucero et al., 2018). Interest in examining SmO_2 and HbC using NIRS has been growing thanks to all these benefits aforementioned (Alvares et al., 2020; Azuma et al., 2000; Biazon et al., 2019; Elcadi et al., 2013; Feldmann et al., 2019; Ferri et al., 2007; Kawaguchi et al., 2006; Ogata et al., 2002; Olivier et al., 2016; Paradis-Deschênes et al., 2016; Szczyglowski et al., 2017; Tew et al., 2010; Ufland et al., 2012; Wakasugi et al., 2018; Watanabe et al., 2005).

NIRS is a substantial tool to monitor changes in muscle oxygenation and blood volume in human tissue and represents the dynamic harmony between oxygen conveyance and oxygen utilization (Ferrari et al., 2004; Mancini et al., 1994). It works by conveying light (in the 650–900 nm wavelength range) into the tissue and estimating the diffused light to

gauge the properties of the absorption and scattering deliberate tissue volume (Yodh & Chacen, 1995).

NIRS estimation depends on the relative tissue straightforwardness for light in the NIRS and on the O_2 subordinate retention changes of hemoglobin (Hb) and myoglobin (Mb). Due to tremendously indistinguishable qualities, it is absurd expecting to recognize the overall pieces of Hb and Mb. In any case, it has been accounted for that the significant sign from NIRS (about 90%) originates from Hb (Costes et al., 2001; Mancini et al., 1994). SmO_2 measurements reflect the balance between oxygen consumption and oxygen supply and the HbC ones are obtained by commuting all oxy Hb, deoxy Hb and Mb in the muscle in question (Miura et al., 2000)

Despite the large number of existing studies examining SmO_2 and HbC on vastus lateralis, the most of them have been measuring aerobic exercise on cyclo ergometers (Calaine Inglis et al., 2017; Hopker et al., 2017; Kawaguchi et al., 2006; Ogata et al., 2002) and patients with different pathologies (de Paiva Azevedo et al., 2016; Moalla et al., 2012; Olivier et al., 2016) but there are no studies about muscle strength on healthy adults or during isometric exercise.

In this study, we determined muscle oxygen behavior during an isometric force protocol recorded by NIRS. The main purpose of this study was to describe hemoglobin concentration and muscle oxygen saturation behavior in different maximum strength determination protocols using a functional electromechanical dynamometer (Dynasystem®).

2. METHODS.

2.1. Participants.

Sixteen students from Andrés Bello University in Chile aged 24 to 51 volunteered to participate in the present study (Table 1). The inclusion criteria of the study included healthy adult men without acute altered health conditions. Exclusion criteria included subjects with a body mass index (BMI) higher than 30 kg/m^2, with medical comorbidities, those whose adipose tissue thickness was higher than the NIRS light penetration depth and those whose skeletal muscle condition impeded conducting the test. The participants were informed of the procedures before starting the study and they signed a written informed consent before starting the investigation.

Table 1: *Descriptive data of subjects' characteristics (n=16).*

n = 16	Mean ± SD			Minimum – Maximum		
Age (years)	36.13	±	6.40	24.00	-	51.00
Weight (kg)	80.38	±	10.03	63.40	-	100.80
Height (cm)	173.56	±	6.52	1.60	-	1.90
BMI (kg/m^2)	26.65	±	2.73	23.01	-	31.60
Fat mass (%)	23.46	±	4.85	14.60	-	34.70
Muscle mass (kg)	34.98	±	3.70	28.20	-	40.80
Extra-cellular Water (%)	36.81	±	1.38	32,00	-	38,00
Leg muscle mass (kg)	18.64	±	2.17	15.30	-	22.40
Waist circumference (cm)	92.16	±	7.22	82.00	-	108.00
Thigh circumference (cm)	60.69	±	7,85	54.00	-	86.00
Thigh thickness (mm)	20.94	±	4.33	14.00	-	26.00
SBP (mmHg)	122.56	±	7.03	110.00	-	135.00
DBP (mmHg)	70.06	±	7.03	59.00	-	82.00
RHR (bpm)	64.00	±	11.87	51.00	-	87.00

Data expressed as mean ± standard deviation and minimum-maximum.
Abbreviations: SBP (systolic blood pressure), DBP (diastolic blood pressure) and RHR (resting heart rate).

The study was approved by the human research ethics committee of the respective local institutes (Andrés Bello University in Santiago, Chile and the University of Granada

in Granada, Spain). The study conformed to the standards set by the Declaration of Helsinki. All subjects were informed of the risks and procedures involved and signed the approved informed consent form before starting the measurement session.

2.2. Study design.

An experimental, retrospective and transversal design was performed using a non-probabilistic sample of convenience. It was used to describe the behavior of muscle oxygen and hemoglobin during an isometric strength protocol. The participants came to the laboratory to be tested on two separate times with 48 hours of rest between the sessions. Each session of the participant was allotted at the identical time of the day and under similar environmental conditions (22ºC; 60% of humidity; 738 m above sea level).

2.3. Materials.

Height, weight, fat mass and skeletal muscle mass were measured with Inbody (model 700, Seoul, Korea) which combinate a bioimpedance meter with a measuring row. Waist and thigh circumferences were evaluated with a Rosscraft (British Columbia, Canada) tape measure. Skinfold thickness was measured between the inguinal line and the patella's top edge with a Rosscraft caliper (Gaucho Pro, British Columbia, Canada) to assure that it would not impair light penetration. Systolic and diastolic blood pressure and heart rate were assessed with Carescape (model V100, Boston, USA) and Polar Electro T31 (Kempele, Finland), respectively. SmO_2 and HbC were measured just on the same point as skinfold thickness with Humon Beta, Dynometrics, Inc®. Finally, all strength protocols were measured with Dynasystem®.

2.4. Testing procedures.

Familiarization sessions started one week before the commencement of the experiments in order to explain testing procedures and minimize execution errors. All elements of the experimental protocol were explained to each subject during two sessions (48 to 72 hours apart) of 30 minutes long.

During testing procedures, volunteers were quoted at the laboratory at the same time each day with 4 hours fast and without physical exertion, alcohol and caffeine consumption during the 24 hours prior to evaluation to perform an isometric and dynamic exercise on the electromechanical dynamometer.

In the first session, before starting exercise, basic information was collected for each subject. This information included age, height, weight, fat mass, skeletal muscle mass, waist, tight circumferences and skinfold thickness. Firstly, age was asked during a short interview which also recorded personal background. For measuring height, the subject had to stand barefoot with his heels resting on the supports indicated on the equipment, the backside of the buttocks and the upper side of the back should be resting on the measuring row and the head located on Frankfort's plane. In order to measure weight and body composition, the subject had to wear light clothes and put his feet on the metal contact points indicated on the equipment. Dominant thigh circumference was measured one centimeter below the buttock crease, and waist circumference was evaluated on the midpoint between the last rib and the iliac crest. In both cases the subject had to stand with his legs slightly apart and the weight distributed equally between both legs. Thigh skinfold thickness was measured with the knee flexed on the midpoint between the inguinal line and the patella top edge.

Once all these data were taken, we started blood pressure, heart rate, SmO_2 and HbC measurements. The test was carried out using Humon Beta®, which had two light sources in the NIRS window and three photodetectors to quantify the power of the light that has engendered through the tissue. The sources and indicators are placed behind individual polycarbonate windows, which interact with the skin of the subject. The photodetectors are situated at distances of 1.2, 1.8, and 2.4 cm from the light sources. The rate is set to 4 Hz. The Humon Beta® is 6.0 × 5.7 × 1.4 cm in size and it was placed on the midpoint of the vastus lateralis of the dominant leg. The device was fixed with a strap that is linked to its edges and can be secured around the thigh with a velcro fastening. The Humon Beta® is connected to a smartphone via Bluetooth, and a custom application shows the workout progress in real-time. In both sessions SmO_2, HbC, blood pressure and heart rate measurements were taken while participants were lying down on a litter for ten minutes.

Before starting the test, subjects performed a a warm-up consisting on 10 minutes of low-load cyclo ergometer, at 60 revolutions per minute. When base protocol (ISO) began, the subject was sat on a chair with his back resting on the seatback, his feet were suspended and his arms were crossed in front of the chest. The participants were secured to the chair by two side straps at the hip and knee which were placed at 90º flexion. The gaze was directed to the front, observing at a fixed point (Frankfurt plane) previously established. They performed 8 seconds of isometric knee maximum extension for 3 times with sixty seconds of rest between series. The pulley with the resistance provided by DEMF was placed in the leg distal end, over the tibial and peroneal malleolus. Mean isometric strength (MIS) and peak isometric strength (PIS) were collected from all series.

Then, the following two protocols were randomized and counterbalanced, so after 5 minutes rest, first (P1) or second protocol (P2) was performed. P1 corresponds to the

maximum dynamic strength (MDS) with an initial load of 40% of the MIS. For this evaluation protocol, the subject's knee extension range was first measured until reaching 180º and 40% of the MIS was calculated to be the initial load. The subjects were told to perform knee extensions with increments of 2 kg in each repetition until muscle failure. The second force protocol (P2) corresponds to the same P1 procedure but the initial load was 40% of the PIS.

In the second session for re-test evaluation, which took place at the same time of day as the first one, only baseline parameter evaluations, warming and muscle strength protocols were repeated.

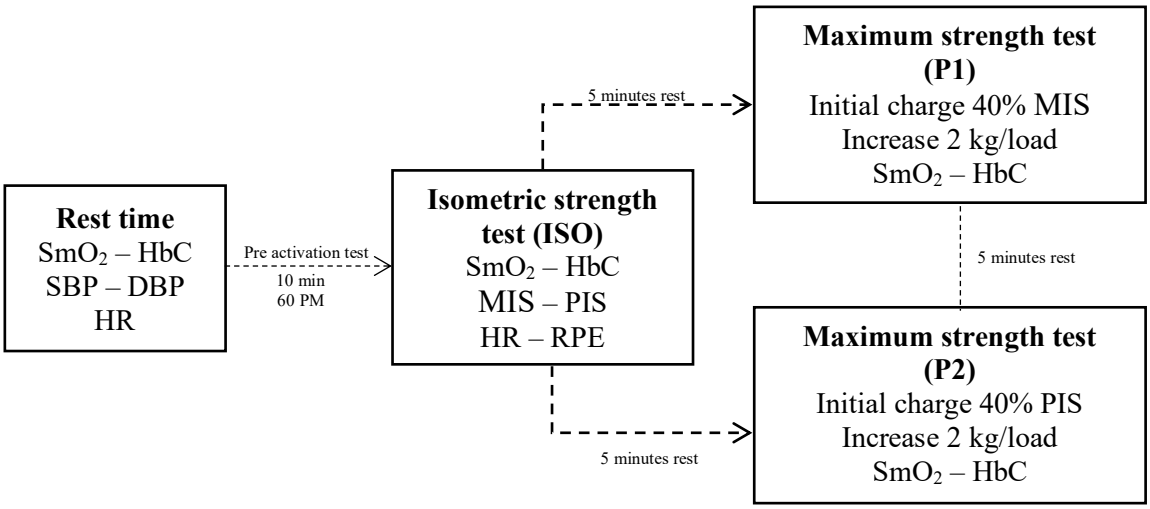

Figure 1. Strength muscle protocols (ISO, P1 and P2). Abbreviatures: SmO_2 (muscle oxygen saturation), HbC (hemoglobin concentration) SBP (systolic blood pressure), DBP (diastolic blood pressure), HR (heart rate) ISO (base protocol), P1 (protocol 1), P2 (protocol 2), MIS (mean isometric strength), PIS (peak isometric strength).

2.5. Statistical analysis.

Descriptive data is presented as mean and standard deviation (SD). The normal distribution of the data (Shapiro–Wilk test) and the homogeneity of variances (Levene test) were confirmed ($P > 0.05$). For the main analysis, a repeated-measures analysis of variance (ANOVA) was conducted with Bonferroni Post-Hoc analysis. The Greenhouse-

Geisser correction was used when the Mauchly sphericity test was violated. Omega square (ω^2) was calculated for the ANOVA where the values of the effect size 0.01, 0.06 and above 0.14 were considered small, medium, and large, respectively (Cohen, 1988). Statistical significance was accepted at $p < 0.05$ level. The JASP statistics package (version 0.11.1) was used for statistical analyses.

3. RESULTS.

Descriptive characteristics of SmO_2, HbC during all protocols and rest and of MIS and PIS during all protocols are shown in Table 2.

Table 2: *SmO_2 and HbC behavior during all protocols and rest and MIS and PIS behavior during all protocols (media ± standard deviation).*

n = 16	Rest			ISO			P1			P2		
SmO_2 (%)	66,728	±	12,067	69,453	±	6,965	66,318	±	9,384	69,051	±	9,952
HbC (g/dl)	12,032	±	0,375	12,365	±	0,567	12,221	±	0,555	12,368	±	0,589
MIS (kg)	-	-	-	49,670	±	9,134	27,006	±	6,776	29,151	±	7,158
PIS (kg)	-	-	-	56,316	±	9,907	47,394	±	7,410	50,006	±	7,614

Data expressed as mean ± standard deviation. Abbreviations: ISO (base protocol); P1 (protocol 1); P2 (protocol 3).

HbC behavior during all strength protocols and rest are shown in figure 2 and table 3. The results in muscle HbC differed significantly between rest and ISO and between rest and P2: $F(1.988, 29.814) = 7.353$; $p = 0.003$, $\omega^2 = 0.055$. Table 3 shows that the post hoc analysis using Bonferroni correction revealed that hemoglobin concentration levels increased significantly between rest and ISO (mean difference = 0.334, $p = 0.011$) and between rest and P2 (mean difference = 0.336; $p = 0.023$).

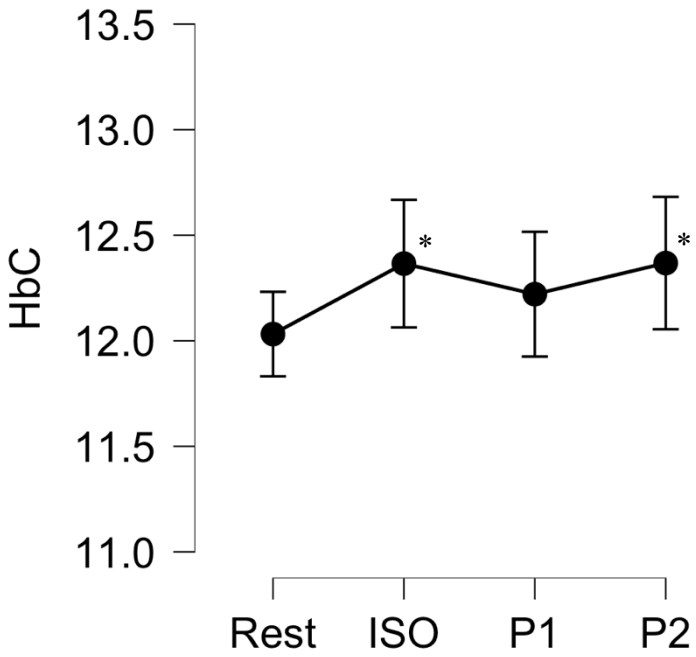

Figure 2. HbC (g/dl) characteristics during all protocols and rest. Abbreviatures: HbC (hemoglobin concentration), ISO (base protocol), P1 (protocol 1), P2 (protocol 2). *: significant differences respect to rest.

Table 3*: HbC (g/dl) Bonferroni post hoc comparisons (n=16).*

n = 16		Mean difference	SE	t	Cohens'd	p_{bonf}
ISO	P1	0.145	0.064	2.253	0.563	0.238
	P2	-0.002	0.054	-0.047	-0.012	1.000
	Rest	0.334	0.088	3.790	0.948	0.011*
P1	P2	-0.147	0.066	-2.242	-0.560	0.243
	Rest	0.189	0.112	1.692	0.423	0.667
P2	Rest	0.336	0.098	3.422	0.855	0.023*

Abbreviations: P1 (protocol 1); P2 (protocol 2); P3 (protocol 3). *: significant differences.

SmO_2 behavior during all strength protocols and rest is shown in figure 3 and table 2. There are no significant differences between means of the different protocols for SmO_2: $F(1.637, 24.548) = 2.246$; $p = 0.135$; $\omega^2 = 0.011$.

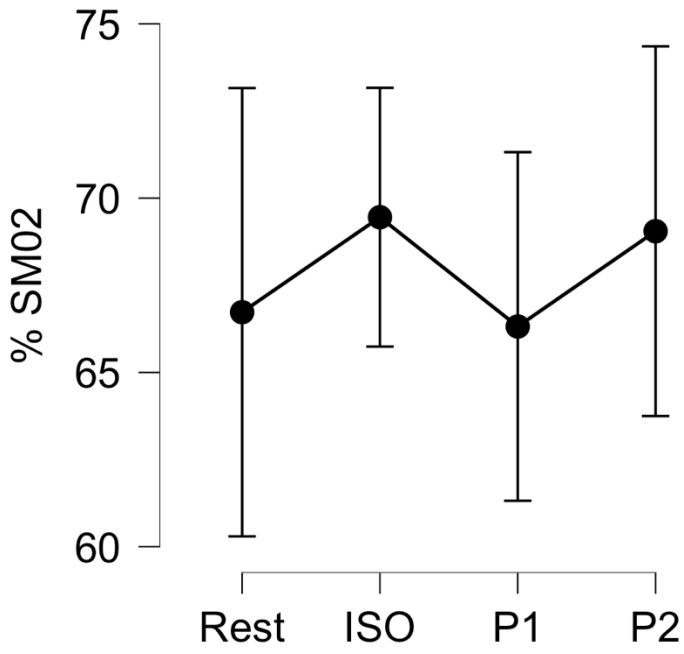

Figure 3. SmO_2 (%) characteristics during all protocols and rest. Abbreviatures: SmO_2 (hemoglobin concentration), ISO (base protocol), P1 (protocol 1), P2 (protocol 2).

4. DISCUSSION.

The purpose of this study was to describe HbC and SmO_2 behavior in different maximum strength determination protocols (ISO, P1 and P2) using a functional electromechanical dynamometer (Dynasystem ®). The main findings of this study suggest that during all protocols and rest the HbC curve behaves differently than the SmO_2 one. Furthermore, there are significant differences between protocols in HbC, but, in terms of SmO_2, there are not.

Exercising with different strength protocols (ISO, P1 and P2) induced different changes in HbC behavior. HbC is often considered as an indirect measure of blood flow within the photon path (Cardinale et al., 2007) and reflects the blood volume in small vessels, including arterioles, capillaries and venules (Watanabe et al., 2005). So, the obtained data suggest that local blood flow was higher during ISO and P2.

Although, to our knowledge, there is little literature studying NIRS measurements during knee extension on vastus lateralis, our results are pretty similar to the studies carried out by Koga et al. (2019), Lucero et al. (2018) and Szczyglowski et al. (2017), who demonstrated that the HbC curve during isometric and dynamic knee extension suffers a slight increase during the time that the subject is performing the exercise (figure 4a). This is because of the increased metabolic demand due to the increase in exercise intensity that evokes a growth in capillary hematocrit with elevated perfusion (Poole et al., 1997). It is known that muscle contractions, by increasing local liberation of ions and metabolites as well as reducing sympathetic nervous stimulation in the active muscles, contribute to raising vasodilatation in the exercised muscles (Bangsbo & Hellsten, 1998; Silveira Alvares et al., 2020).

As far as we know, there is only one study that uses Humon Beta® as a NIRS device (Farzam et al., 2018). We know that they study HbC during the incremental cycle ergometer test, but, it does not provide detailed information about HbC behavior. So, unfortunately, we could not compare their results with ours.

Regarding to SmO_2 behavior, previous studies which investigated SmO_2 with NIRS placed on the vastus lateralis during maximum dynamic knee extension exercise (Azuma et al., 2000; Feldmann et al., 2019; Okushima et al., 2020; Tew et al., 2010) are in line with our results (figure 4b) and have demonstrated that knee extension exercise evoked a slight increase and then a great decrease in SmO_2 in all participants in all protocols carried out in their studies. As well as in our study, the higher the training load, the higher the percentage the SmO_2, but the curve follows the same pattern.

As it is said before, there is only one study that uses Humon Beta® as a NIRS device. In this case, we do can contrast our information because it provides a figure where shows

how SmO_2 behaves. It is measured during an endurance training while subjects performed an incremental test on a stationary cycle ergometer (Farzam et al., 2018). Although the protocols are pretty different between that study and ours (figure 4b), we found that, at the beginning SmO_2 slightly increases, but as soon as the power and training load increases and the subject goes through high exertion levels, a decrease in SmO_2 occurs.

All this behavior is due to the fact that muscle contraction generates movement, and energy is required to perform it, so skeletal muscle motor units must be recruited and they are fueled by ATP, so aerobic generation of ATP by the mitochondria is critical and requires oxygen. That is the reason why, in order to provide oxygen to the working muscles, blood flow increases (Dempsey, 1986; Joyner & Casey, 2015; Yu et al., 2005). So, at the beginning of the exercise, an overcompensation of blood occurs accompanied by an increase in SmO_2 (figure 4b). As, during contractions, subjects start getting fatigated, oxygen consumption in the muscle exceeds the oxygen supply and, as a result, a decrease in SmO_2 occurs (Gorczynski et al., 1978; Marshall & Tandon, 1984).

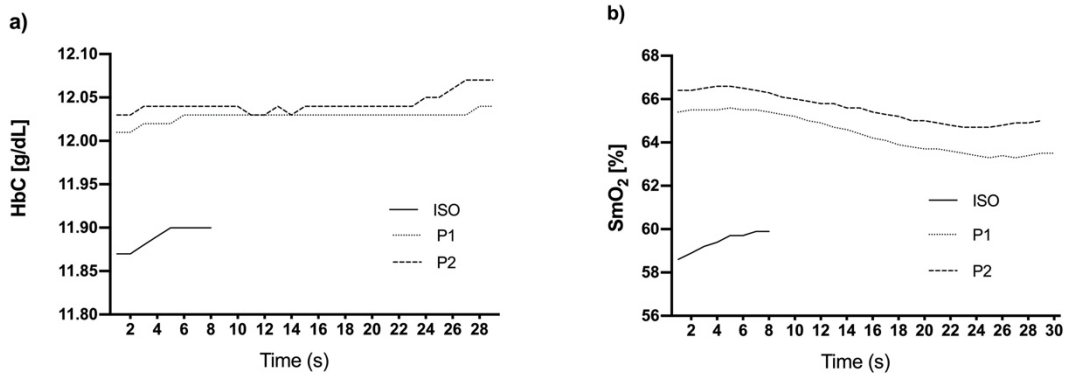

Figure 4. HbC (a) and SmO_2 (b) behavior from subject 15 during ISO, P1 and P2 protocols.

On the other hand, our actual results differ substantially from the general results obtained in other studies that measured SmO_2 with NIRS placed on the vastus lateralis during maximum isometric knee extension exercise (McManus et al., 2018; Moalla et al.,

2006; Pereira et al., 2009) where an instantaneous decrease in SmO_2 at the start of isometric contraction was observed. It is important to highlight that all these isometric contractions were maintained for 30 seconds, until exhaustion and about 20 seconds, respectively. According to what was said before about the SmO_2 behavior during MDS exercise, this increase is due to the isometric contraction being pretty short, and in our study, it was maintained during just 8 seconds and that is a very short time for the muscle to get fatigued. Despite this, it should be noticed that our results are consistent with the ones of one subject in Pereira et al. (2009), where SmO_2 increases for the first seconds of the exercise.

Now, trying to compare behaviors and determining whether hemoglobin concentration and muscle oxygen saturation are able to discriminate training load, in the present study we found that exercising with maximum isometric strength and with MDS starting with a load of 40% of the PIS induced a significant increase in HbC compared to rest and to MDS with an initial load of 40% of the MIS (figure 3). In regard to SmO_2, it does not allow us to discriminate between protocols.

So, focusing on HbC, it can be seen that the behavior of the curve is almost constant, but it is higher or lower on the Y-axis (HbC [g/dL]) depending on the exercise intensity or training load. These results are in line with the ones obtained by Lucero et al. (2018) from the control group during progressive intensity 90-degree rhythmic isotonic knee extension exercise. Which also found significant differences between protocols.

It should be considered that there are some methodological barriers that have to be taken into consideration when interpreting the findings of this study. Firstly, the sample size of 16 subjects was a small, convenient and heterogeneous sample, so further studies should increase such variability by getting a larger sample size to increase statistical

power. Secondly, the global COVID-19 pandemic did not allow us to take these data. Despite we are indeed grateful to the Chilean group that provided it to us, we consider this a weakness in our study, since we have less control over the data. Finally, the study used continuous-wave NIRS to measure HbC and SmO_2 signals and adipose tissue thickness is one of the greatest staggers for the NIRS measurements (Ferrari et al., 2011). So, using PortaMon, Artinis Medical Syste BV®, the NIRS gold standard, could have minimized the adipose tissue thickness influence (Jones et al., 2014). Other limitation that we found, in order to compare different NIRS measurements and to obtain more accurate results, is the triangulation of three NIRS mobile devices. To our knowledge it is something that had not been tested yet. McManus et al. (2018), compared Moxy® and PortaMon® and found that both devices produce acceptable measures during supine rest and demonstrate a similar trend during dynamic exercise under appropriately controlled conditions in specific subject groups. So, it would be interesting to compare these two with a cheaper device such as Humon Beta®.

5. CONCLUSIONS.

In summary, this study shows the behavior of NIRS measurements during different strength protocols. The main findings of this study suggest that during isometric and dynamic knee extension, the HbC curve follows almost the same pattern but the SmO_2 one follows different patterns.

Finally, we found that HbC behaves statistically differently as long as the measure is taken during isometric exercise or MDS with an initial load based on PIS. In the case of SmO_2, we found similarities between all protocols and rest. Focusing on HbC during isometric and dynamic exercise and SmO_2 during dynamic exercise, the behavior of the

curve is almost the same, but it is higher or lower on the Y-axis (HbC [g/dL]) depending on the exercise intensity or training load.

To further studies which investigate NIRS measurements behavior and try to discriminate different training load with NIRS, all these considerations should be taken in account.

6. APPLICATIONS.

Humon Beta® has been designed to be used by athletes in different types of sports practices. There have been some proposals as to how NIRS could be useful on individual sports in order to optimize training (Belardinelli et al., 1995; Bhambhani et al., 1997). But, currently, no one has yet been able to indicate a concrete benefit in muscle NIRS to increase strength training performance. So, this study is useful to start monitoring strength training by NIRS focusing, mainly, on HbC which could indicate a variation on training load, as well as knowing how HbC and SmO_2 behave during different strength protocols.

But our objective is to have a thorough internal control of strength training by using a NIRS device, so our short-term goal is to determine whether Humon Beta® is a good indicator of training load. In order to achieve that, as it is said before, our intention is doing a triangulation between three NIRS devices, something that, to our knowledge, is until undone.

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