Determining oxygen muscle saturation (SmO2) using near-infrared spectroscopy (NIRS) is an emerging technique that is increasingly used in sports science; therefore, it is necessary to know its results in different population groups. We analyzed it in a group of recreational participants in Nordic Walking. The purpose of this research was to analyze the SmO2 values obtained at various times from testing in a group of athletes over 45. Thirty athletes (18 males) with a mean age of 51.3 years completed a maximal exercise testing in treadmill according to a modified Bruce protocol on a ramp. The electrocardiogram was continuously monitored. We measured VO2max (Metalyzer 3B). In addition, we placed a Humon Hex device on the right thigh to measure quadriceps oxygenation. Heart rate, VO2, and SmO2 ratios were obtained based on the exercise intensity. We obtained a SmO2 at startup of 63.3%, standard deviation (SD) 9.2%; SmO2 declined 61.8%, SD 11.4%; SmO2 in VO2max 57.4% SD 10.2% and SmO2 5 minutes after starting recovery 72.5% SD 7.9%. There was a relationship between ventilatory thresholds and variations in SmO2. There were no significant differences between the sexes. We could conclude that the minimum values of SmO2 were related to the VO2 max. During the recovery phase, the values were higher than at rest. The information obtained could be used to control and plan the training.

KEY WORDS: nordic walking, muscle oxygenation, maximal exercise testing

Introduction

Haemoglobin is the oxygen transport protein from the lungs to the muscles. Oxygen intake is a key factor for muscle metabolism, maintaining physical activity and athletic performance (Hearris, Hammond, Fell, & Morton, 2018). In sports science, there are several methods used to evaluate muscle metabolism and plan training sessions, some of which are based on the measurement of lactic acid in capillary blood and others on the study of spirometric variables related to maximal oxygen uptake (VO2max) (Hawkins, Raven, Snell, Stray-Gundersen & Levine, 2007) and determining ventilatory thresholds (Lam & Ravussin, 2016). Recently, measurements of oxygen muscle saturation (SmO2) are also being used (Crum, O’Connor, Van Loo, Valckx, & Stannard, 2017). SmO2 is obtained non-invasively with Near-Infrared Spectroscopy (NIRS) via the placement of skin devices (Hamaoka & McCully, 2019). This technique allows obtaining immediately, on a screen, the percentage of muscle saturation of oxygen; the current devices comprise a small receiver that is placed with a belt surrounding the body segment to be assessed. The most commonly used location is in the thigh in order to measure the SmO2 of the quadriceps (vastus lateralis) (Grassi & Quaresima, 2016). The data are sent to a computer application that can be installed on a watch, smartphone, or tablet that can be consulted by the athlete or researcher. The information received enables adapting the intensity of the exercise according to a specific objective, similar to what is done with a heart rate monitor (Ferrari, Muthalib, & Quaresima, 2011).

NIRS technology for measuring the SmO2 is validated and has been used primarily by elite athletes (Chang et al., 2019), but there is little evidence of its use in older people who practice physical activity to improve their health (Gepner, Wells, & Gordon, 2019). For physical exercise to produce benefits, it is known that it is necessary to be
performed with adequate frequency and intensity (Murphy, Lahart, Carlin, & Murtagh, 2019). Therefore, the control of this intensity of physical activity and the possibility of regulating it according to the characteristics of each person is essential to increase the benefits of training (Wewege, Thom, Rye, & Parmenter, 2018).

The most recommended physical exercise for the elderly is walking for several hours, several days a week, with moderate intensity (Slaght, Sénéchal, Hrubeniuk, Mayo, & Bouchard, 2017). A modification of the usual walk is “Nordic walking” (NW), which is a specific sport discipline with its own rules and competitions (Padulo et al., 2018). In this sport, poles and a specific technique for walking are used, maintaining an upright posture and increasing the speed and intensity of effort (Mocera, Aquilino, & Somà, 2018). NW is increasingly recommended for older people because of its relative ease, accessibility and health effects (Tschentscher, Niederseer, & Niebauer, 2013). If NW practitioners monitor the pace of walking, depending on their specific abilities, they improve the effects of exercise (Takeshima et al., 2013).

Measuring SmO2 can be a good way of controlling the intensity of exercise and adapting it to the needs of the person (Wilkinson et al., 2019). To accomplish this, it would be interesting to have studies that confirm the usefulness of SmO2, relating it to the data obtained with traditional techniques of performance assessment, assuming the peculiar responses of these subjects. Thus, the objective of our work is to analyse the values of SmO2 obtained at various times in a maximal exercise stress test in a group of recreational athletes over 45 years old who practice NW.

Methods
The study population was 30 adults over 45 years old, recreational athletes of the clubs “Nordic Walking Murcia” and “Marcha Nórdica Costa Blanca Elx” (Spain), with at least two years of experience in NW (mean 2.9±1.0 years). Participants walked three days a week, about 10 km each day.

All participants provided written, informed consent for their participation in the study. The inclusion criteria were to have a minimum of one year of experience, excluding those suffering from illnesses, injuries, or deficiencies that prevented them from taking the stress test. The study was conducted according to the principles of the Declaration of Helsinki and was approved by the Research Ethics Commission of the University of Murcia.

First, cardiovascular examinations at rest were performed with the athletes in supine decubitus, assessing cardiac auscultation, blood pressure, and electrocardiogram (EKG). The electrodes were maintained to collect the EKG trace throughout the stress test. Heart rate (HR) and EKG recording were obtained with a Cube® cardioline electrocardiograph. Subsequently, a Humon Hex® device was placed on the thigh of the dominant side, on the vastus lateralis (Figure 1). To display the information of the SmO2, exercise time and heart rate (HR), the Humon Hex® was synchronized with a tablet with the Humon app.

The stress test was performed on a treadmill (model run7411*) with a modified Bruce ramp protocol. The test ended when the subject could no longer run and gestured with his hand and began the recovery phase by slowing down (3 minutes to 4 km/hour). The tests were considered to be maximum and valid when 85% of the theoretical maximum heart rate (220-age) was exceeded, and the respiratory ratio (RER) was greater than 1.15 (Howley 1995).

During the stress test, the subjects breathed through a mask connected to the gas analyser (Metalyzer 3b®, Cortex). All gas exchange parameters were measured during breathing and averaged every 30 seconds. The method used for determining VO2 max was to reach the plateau of oxygen consumption (Fletcher 2009). All
tests were carried out under similar environmental conditions.

The values of SmO2 were obtained from the curves SmO2/exercise time (Figure 2) provided by the Humon Hex app®, selecting the data for the following phases: 1) prior to the exercise; (2) decline phase: at the time of the sharp decline or descent of the SmO2 (Humon Hex® indicates this situation with a change in colour (orange); 3) the maximum descent that coincides with the maximum exercise intensity and with the VO2 max); and 4) recovery phase: after the exercise, when the normal values are retrieved (indicated by another colour change on the graph, from blue to green).

All statistical analyses were conducted using SPSS software version 24.0 (Chicago, IL, USA). Quantitative variables have been described with mean, standard deviation (SD) and coefficient of variation (CV=SD/mean ×100) and qualitative by absolute frequency and percentage. The normal distribution of the variables was checked by the Shapiro-Wilk test, and the equal variances using the Levene test. Comparison of means of independent variables and intergroups (men and women) was performed using the t-student test; a paired samples t-test was used to compare the means of related variables. The relationship between variables was studied using Pearson’s correlation analysis. A level of significance of p<0.05 was considered.

Results

In Table 1, the characteristics of the population separated by sex (18 male and 12 females) are shown; only differences between men and women in size, weight, and VO2 max are noted. Coefficients of variation indicate that the population is homogeneous.

| Gender | Mean | Standard deviation | Variation Coefficient (%) | Significance (p value) |
|--------|------|--------------------|--------------------------|------------------------|
| Age (years) | Males | 50.06 | 6.64 | 13.3 | 0.074 |
| Male | 1.78 | 0.05 | 2.8 |
| Female | 1.65 | 0.04 | 2.4 |
| 81.08 | 8.99 | 11.1 |
| Female | 71.31 | 7.16 | 10.6 |
| Male | 25.52 | 2.71 | 10.6 |
| Female | 24.72 | 2.54 | 10.3 |
| Male | 99.19 | 7.93 | 8.0 |
| Female | 96.79 | 10.29 | 10.6 |
| Male | 33.50 | 8.54 | 25.5 |
| Female | 27.08 | 4.52 | 16.7 |

Note. HR: Heart rate; SmO2 muscle oxygen saturation; VO2: oxygen consumption.
The comparison between groups by gender of SmO$_2$ and heart rate in each of the four stages in which the evolution of SmO$_2$ has been divided during the effort shows no differences between males and females (Table 2). Likewise, the percentage of HR at the time of the decline from the maximum reached also shows no differences between sexes. Males show slightly higher values at the onset of decline; there are also no differences between the sexes in the SmO$_2$ in maximum effort and recovery.

**TABLE 2.** Comparison, between genders (males n=18; females n=12), of SmO$_2$ and HR in each of the phases

| Gender                  | Mean  | Standard deviation | Variation Coefficient (%) | Significance (p-value) |
|-------------------------|-------|--------------------|---------------------------|------------------------|
| % SmO$_2$ Prior to the exercise |       |                    |                           |                        |
| Males                   | 62.73 | 7.42               | 11.8                      | 0.665                  |
| Females                 | 64.27 | 11.86              | 18.5                      |                        |
| % SmO$_2$ Decline phase |       |                    |                           |                        |
| Males                   | 63.11 | 9.10               | 14.4                      | 0.432                  |
| Females                 | 59.47 | 15.17              | 25.5                      |                        |
| % SmO$_2$ Maximum exercise |      |                    |                           |                        |
| Males                   | 59.51 | 9.27               | 15.6                      | 0.161                  |
| Females                 | 53.97 | 11.20              | 20.8                      |                        |
| % SmO$_2$ Recovery phase |       |                    |                           |                        |
| Males                   | 71.54 | 7.98               | 11.2                      | 0.413                  |
| Females                 | 74.01 | 7.93               | 10.7                      |                        |
| HR (lat/min) Prior to the exercise |       |                    |                           |                        |
| Males                   | 75.83 | 10.23              | 13.5                      | 0.328                  |
| Females                 | 72.33 | 8.05               | 11.1                      |                        |
| HR (lat/min) Decline phase |      |                    |                           |                        |
| Males                   | 143.11| 29.50              | 20.6                      | 0.445                  |
| Females                 | 134.60| 24.28              | 18.0                      |                        |
| HR (l/m) Maximum exercise |      |                    |                           |                        |
| Males                   | 169.20| 14.22              | 8.4                       | 0.180                  |
| Females                 | 160.8 | 18.35              | 12.1                      |                        |
| HR (l/m) Recovery phase |       |                    |                           |                        |
| Males                   | 120.11| 18.04              | 15.0                      | 0.174                  |
| Females                 | 111.00| 16.68              | 15.0                      |                        |
| % HR decline/HR maximum exercise |    |                    |                           | 0.740                  |
| Males                   | 83.83 | 13.51              | 16.1                      |                        |
| Females                 | 82.17 | 10.55              | 12.84                     |                        |
| Minutes to decline phase |       |                    |                           |                        |
| Males                   | 8.63  | 3.16               | 36.58                     | 0.072                  |
| Females                 | 6.56  | 1.98               | 30.21                     |                        |
| Minutes to maximum exercise |      |                    |                           |                        |
| Males                   | 11.62 | 2.97               | 25.54                     | 0.166                  |
| Females                 | 10.04 | 1.98               | 19.72                     |                        |
| Minutes to recovery phase |      |                    |                           |                        |
| Males                   | 5.31  | 3.06               | 57.61                     | 0.321                  |
| Females                 | 4.12  | 2.13               | 51.73                     |                        |

Note. HR: Heart ratio; SmO$_2$: muscle oxygen saturation; VO$_2$: Oxygen consumption.

Figure 3 shows the evolution of the SmO$_2$, VO$_2$, and HR throughout the stress test. VO$_2$ and HR increase in the early stages and decrease during the recovery phase; the situation is reversed with SmO$_2$.  

![Figure 3. Evolution of SmO$_2$, Rate Heart (RH) and Oxygen consumption (VO$_2$)](image-url)
When the SmO₂ with RER, HR, and VO₂ is correlated in each of the phases, only a significant correlation is observed between all of them in the recovery phase. With the maximum effort, SmO₂ is correlated with the RER; higher RER correlates with lower SmO₂ (Table 3).

| TABLE 3. Correlations between SmO₂ and ergometry values |
|--------------------------------------------------------|
|            | SmO₂ Decline | SmO₂ maximum exercise | SmO₂ Recovery phase |
| RER        | Pearson correlation | -0.360 | -0.454 | -0.789 |
|            | Significance (p value) | 0.065 | 0.039* | 0.000* |
| HR         | Pearson correlation | -0.125 | -0.021 | -0.391 |
|            | Significance (p value) | 0.533 | 0.913 | 0.033* |
| VO₂        | Pearson correlation | -0.266 | -0.193 | -0.486 |
|            | Significance (p value) | 0.180 | 0.315 | 0.006* |

Note. RER: Respiratory Exchange Ratio (Respiratory Quotient); HR: Heart rate; SmO₂, muscle oxygen saturation; VO₂: oxygen consumption; * p<0.05.

In contrast, the correlations between pre-exercise SmO₂ and the other saturation measures show significant values, with SmO₂ decline phase (r=0.875; p<0.000); with SmO₂ in the maximum effort (r=0.851; p<0.000) and with SmO₂ in the recovery phase (r=0.816; p<0.000).

There are significant differences between SmO₂ prior to the test and that obtained in the maximum effort (t=6.061; p<0.000), also with the SmO₂ of the recovery phase (t=9.350; p<0.000); but there are differences with the SmO₂ obtained at the beginning of the decline (t=1.995; p=0.056).

The SmO₂ at the time of decline does not maintain a correlation with the percentage of the maximum HR reached (r= -0.34; p=0.868), nor with the exercise time to that point (r=0.048; p=0.813).

Discussion

Measuring SmO₂ using NIRS devices is a recently used technique in the assessment of physical condition. For this reason, we have done this work to provide new knowledge about its use and its results. We used a Humon Hex® device in a population of subjects over 45 years of age, practitioners of Nordic Walking, to measure the SmO₂ of the quadriceps while performing a stress test on a treadmill, the validity of this device has been previously verified by Farzam, Starkweather, and Franceschini (2018). We have divided the stress test into four phases and compared the values of men and women without entering differences between the sexes.

The stress test has been performed with a modified Bruce ramp protocol because it manages to reach the exhaustion of the subject without having to run. Furthermore, this test is more similar to NW than the protocols based on speed increase (Pellegrini, 2018).

Most studies with NIRS have been done with young male athletes, while we have studied middle-aged adults, comparing both sexes, allowing us to increase the information available on SmO₂ (Seshadri, et al., 2019). Our results indicate, as in the study of Wilkinson et al. (2019), that as exercise intensity increases, a decrease in SmO₂ occurs, to a point at which an inflection appears. This is shown in the tablet graphics with a colour change (Humon, 2020). Other authors relate this inflection to the ventilatory threshold (Karatzano et al., 2010), although they indicate that there is a great individual variability due to fat percentage, age, and physical activity (Zwaard et al., 2016).

We have also found that the exercise time in which this change occurs is different among subjects, showing a medium coefficient of variation (30-36%), but without significant differences between the sexes; this could be related to the physical condition of each person (Takaishi et al., 2002).

From the tipping point, the SmO₂ continues to decrease, as the intensity of the exercise progresses, reaching exhaustion. We have seen that the minimum value of SmO₂ also appears at the time when the VO₂ max is achieved. Inglis, Iannetta & Murias (2017) state that this situation would not indicate the upper limit of O₂ extraction and that there could be a reserve area. With the maximum exercise, our subjects had values higher than those cited by Yamamoto et al. (2014).

At the beginning of recovery, after the point of maximum effort, the heart rate begins to drop, at which point it is observed that SmO₂ increases gradually, reaching values higher than the initial ones. This effect is similar to the “super-compensation principle” of training (Doering, Coxa, Aretac, & Coffey, 2019). Not all authors value this phase of recovery (Contreras Briceño et al., 2019); however, we think it may be interesting when using the Humon Hex® device to conduct training and schedule the return to calm.

One limitation of this work is that it has been done on a laboratory test in which participants were not able to use the poles and is, therefore, not fully comparable to the actual activity of the NW.

The usefulness of this study is the applicability of the use of the Humon Hex® device in the training of Nordic walking practitioners. They can adjust the intensity of their effort to the signals received and avoid depletion,
decreasing intensity when SmO₂ values reach the tipping point. The advantage of using the device instead of VO₂max is that there is no need to pre-perform a stress test to regulate exercise intensity.

We conclude that there are no differences between the sexes. The evolution of SmO₂ is opposite to that of heart rate and oxygen consumption, decreasing during exercise and increasing in recovery.

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