Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Oxygen saturation at the anterior muscle side of the lower limb during the 6-minute walk test in healthy people

Gheorghe Ionescu
University of Craiova
Denisa Piele
University of Craiova
Michi Mihail Geambeșa
University of Craiova
Robert Mihai Rusu
University of Craiova
Ligia Rusu
ligia.rusu@edu.ucv.ro
University of Craiova
Mara Marin
S.C. Poem Metaphore S.R.L.
Gabriel Buciu
Titu Maiorescu University

Short Report

Keywords: gait biomechanic, muscle behaviour, oxygen muscle saturation

Posted Date: September 20th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10779556/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Measurement of transporting oxygen could be assess by evaluating oxygen muscle saturation (SmO2). The *objective* was to analyse muscle SmO2 in the muscle groups quadriceps CV and tibialis anterior TA and its relationship with cardiac parameters (heart rate HR) during a 6-minute walking test (6Mwt). The research includes a group of 26 younger participants, average age 23.77 years. Evaluation of SmO2 was made using NIRS equipment. The *results* indicated SmO2 CV - TA: **19.78%** (the CV has an SmO2 19.78% higher than the TA), Right - Left: **3.35%** (the right leg has an SmO2 3.35% higher than the left), HR 106.46 bpm. There is no significant difference in the magnitude of asymmetry between the two muscle groups. The values obtained indicate greater symmetry in the CV muscle group, but no significant difference between the asymmetries of the two muscle groups analysed ($p = 0.470$). Moderate to strong positive correlation between SmO2 in the left and right anterior TA, indicating a symmetrical bilateral oxygenation pattern. We observed that SmO2 in the CV muscle during (6Mwt)test, which involves moderate, submaximal effort, was 66%. The use of this functional monitoring, correlated with cardiac parameters, allows for much more precise interventions after prolonged immobilisation.

Introduction

Muscle metabolism is fundamentally dependent on oxygen supply, both during daily activities and in sporting performance. Consequently, haemoglobin levels and the manner in which it transports oxygen are essential factors, as haemoglobin is the protein responsible for oxygen transport [1]. In this regard, there are studies that have focused on measurements of muscle oxygen saturation (SmO2) [2], utilising NIRS technology to measure SmO2, which is validated and has been used primarily in sports [3], but there is little evidence regarding its use in people who do not practice sport or engage in physical activity to improve their health, with the aim of monitoring muscle behaviour in the lower limbs [4].

Studies conducted to date have shown that, specifically, SmO2 reflects the balance between oxygen supply and consumption in the muscle and can be used indirectly to assess microvascular reactivity and muscle tissue haemodynamics [5, 6].

Most of these studies analyse endurance exercises, many of them using running and walking. In this biomechanical context, Rissanen et al. [7] reported a linear decrease in vastus lateralis (VL) oxygenation from a speed of 5 km/h (walking) to 15 km/h (running to exhaustion), whilst Hiroyuki et al. [8] found that, compared with the resting state, VL oxygenation increased during walking at 4 and 6 km/h, whilst in the lateral head of the gastrocnemius, it decreased.

Consequently, the aim of some studies, such as that by Stathopoulos et al. [9] was to compare muscle oxygenation and blood flow in the VL and medial gastrocnemius (GM), correlated with heart rate, respiratory gas exchange and blood lactate concentration, during walking at a comfortable speed.

On the other hand, the authors Tuesta et al. [10] observed in their meta-analysis that there are studies demonstrating that muscle oxygen saturation (SmO2) has a moderate correlation with heart rate. The

reliability of SmO2 was moderate to high at low exercise intensities, and decreased as the relative intensity of the exercise increased, suggesting a greater influence of muscle ischemia.

A recent study investigated the relationship between heart rate (HR) and SmO2 during self-paced walking, using NIRS technology on the gastrocnemius and biceps brachii muscles. The authors reported a weak negative correlation between HR and SmO2 in the left gastrocnemius, but not in the right gastrocnemius. In pathological conditions, SmO2 behaviour was analysed during the 6-minute walk test(6Mwt) for patients with interstitial lung diseases, and the observations revealed that changes in SmO2 and total haemoglobin (tHb) occur in the CV muscles and showed that, although at rest SmO2 values differ between muscles, the mean SmO2 does not change.

Correlations can be extended between the aforementioned parameters and HR. The study conducted by Zhang et al. (2017) [11] investigated the correlations between performance on the (6Mwt) test (6MWT) and various physiological measures. Feldmann et al. [12] mention that changes in the muscle oxygenation signal derived from NIRS are directly linked to changes in oxygen extraction and utilisation at the local muscular level [13] and, consequently, closely correlated with the arteriovenous difference at rest and during exercise [14]. For this reason, numerous studies have demonstrated a correlation between VO2 and changes in muscle oxygenation [15, 16, 17]. Taking into account the two corresponding Fick principles [18], this relationship is appropriate for investigating maximum oxygen extraction in terms of minimum SmO2.

The use of NIRS technology in relation to the functioning of cardiometabolic systems has also been explored by Porter et al. [19], who noted that SmO2 monitoring serves as an indicator of phosphocreatine (PCr) resynthesis [20].

Muscle oxygen dynamics was also the focus of Shirai et al. [21]. The studies to which he refers have focused on muscle oxygen dynamics as a response to energy metabolism in skeletal muscle [22, 23, 24]. Shirai et al. investigated two hypotheses regarding the lower limb muscles in children during walking: (1) the SmO2 response varies depending on the muscle and age, and (2) the energy metabolism of each muscle correlates with walking efficiency. The findings showed that energy metabolism during walking in children involves the calf muscles more than the thigh muscles, and the response of the calf muscles may vary depending on the age group. Furthermore, the oxygen dynamics of the TA (tibialis anterior) may influence walking efficiency. In addition, another landmark study investigated changes in lower leg muscle oxygenation during a (6Mwt) test in patients with peripheral arterial disease and the results indicated a significant decrease in SmO2 during the test, [21, 25].

However, the literature highlights a major gap: the lack of studies simultaneously investigating SmO2 dynamics and heart rate during the (6Mwt) test in healthy subjects, for the muscles of the lower limbs.

Based on the data in the literature, the aim of our study was to analyse muscle behaviour in the muscle groups of the anterior regions of the thigh and calf bilaterally (quadriceps and tibialis anterior muscles)

in terms of SmO2 and its relationship with cardiac parameters (heart rate, heart rate variability) during a 6-minute walking test.

Methods

Subjects

This study was carried out by the University of Craiova, Faculty of Physical Education and Sport (FEFS), Department of Kinesiotherapy and Sports Medicine, between October 2025 and January 2026. A sample of 26 participants (13 women and 13 men) with a mean age of 23.77 years (SD 7.60), average weight 65.38 kg (SD 14.20), average height 171.18 cm (SD 10.08), average body mass index (BMI) 22.17 (SD 3.32). All participants signed written informed consent and approval was obtained from the Ethics Committee of FEFS on 289/10.09.2025; the research was conducted in accordance with the principles of the Declaration of Helsinki, 2013 version. Participants were selected on a voluntary basis from among physiotherapy students at the University of Craiova.

The inclusion criteria were as follows:

- students aged between 19 and 24
- in good health as determined by medical history
- no musculoligamentous injuries in the last 6 months
- the ability to perform moderate physical activity
- have not taken part in any strength training programmes in the 48 hours prior to the assessments

Exclusion criteria:

- smokers
- post-traumatic sequelae affecting muscles and ligaments
- daily consumption of nutritional supplements
- BMI greater than 30

Experimental design

Assessment: evaluation of cardiovascular parameters (heart rate, heart rate variability), functional assessment via the (6Mwt) test [26], measurement of oxygen saturation (SmO2quadriceps(CV) and tibialis anterior(TA) using near-infrared spectroscopy (NIRS).

The protocol of the 6-Minute Walk Test (6MWT) was described as follows.

Testing was performed along a straight, flat, indoor corridor with minimal traffic, measuring 30 meters in length. The corridor was marked at both ends with reflective cones. The walking surface was smooth,

free of obstacles, and maintained under thermally comfortable conditions.

Participants were prepared by being informed about the purpose and procedures of the test.

Cardiac parameters were assessed using a Polar Heart Rate Sensor H10 telemetry device, which enabled the measurement of heart rate (HR) and heart rate variability (HRV).

To assess the degree of muscle oxygenation, the Moxy device, based on NIRS technology, was used. The device, via sensors placed in direct contact with the skin, measures at intervals of 2 or 0.5 seconds the percentage of oxygen-carrying haemoglobin (SmO2) and the total localised haemoglobin content (Thb), which are relevant indicators of the muscle oxygenation profile. In our study, we focused on SmO2 in the lower limbs, specifically the CV muscles (at the vastus lateralis muscle, 15 cm above the centre of the patella and 3 cm lateral to the vertical line of the CV) and the TA (in the area of maximum muscle prominence), where Moxy sensors (Muscle Oxygen Monitor -- one sensor per muscle group bilaterally) were placed (Fig. 1), with the aim of collecting SmO2 values during the (6Mwt) test. SmO2 was measured continuously during the test. SmO2 is a regional indicator, and the NIRS method allows the measurement of muscle oxygenation in the area beneath the sensor.

Tissue oxygenation measurements were performed using Near-Infrared Spectroscopy (NIRS), a non-invasive technique that allowed dynamic assessment of muscle oxygenation during functional activities. Prior to sensor placement on the participants, the skin was cleaned with alcohol to ensure optimal signal quality. In addition, local hair was removed when necessary to ensure optimal contact between the sensor and the skin surface. Control of subcutaneous adipose tissue thickness: to limit the influence of subcutaneous adipose tissue on near-infrared light penetration and NIRS signal quality, sensors were positioned on anatomically standardized muscle regions with minimal adipose tissue thickness. Management of motion artifacts- following data acquisition, the collected data were visually inspected, and segments affected by evident motion artifacts were excluded from the analysis using standard signal-processing procedures.

Statistical Analysis

A two-way repeated-measures ANOVA (2 x 2: Laterality x Muscle Group) was performed to examine the effects of laterality (left vs. right leg) and muscle group (quadriceps vs. tibialis anterior) on mean SmO2 values. The within-subject factors were: (1) Laterality with two levels (left, right), and (2) Muscle group with two levels (quadriceps, tibialis anterior). Follow-up paired t-tests were conducted for specific comparisons. Bilateral asymmetry was quantified using the Asymmetry Index: AI(%) = |Right - Left| / ((Right + Left)/2) x 100. Effect sizes were reported as partial eta-squared (η^2p). Statistical significance was set at $\alpha = 0.05$. All analyses were performed using XLStat software.

Results

The assessment of cardiovascular parameters relating to HR and HRV during the (6Mwt) test is presented in Tables 1 and 2 as mean values for the entire group of subjects.

Table 1
Heart rate (HR) during the 6-minute walk test

HR	Minimum	Maximum	Mean	Standard deviation
Minimum	75	96	85.34	2.27
Maximum	132	152	141.70	5.99
1st Quartile	85.50	103.50	95.85	2.95
Median	93.50	118.50	106.87	3.99
3rd quartile	103	125	114.56	4.47
Mean	95.85	116.42	106.46	3.79
Standard deviation	12.96	15.24	14.37	0.98

Table 2
Heart rate variability (HRV) during the 6-minute walk test

HRV	Minimum	Maximum	Mean	Standard deviation
Minimum	0.0	25.5	22.6	5.6
Maximum	0.0	98.5	69.9	5.6
1st Quartile	0.0	46.1	40.0	5.6
Median	0.0	54.6	45.2	5.6
3rd quartile	0.0	63.6	54.4	5.6
Mean	0.0	56.4	46.7	5.6
Standard deviation	0.0	15.9	11.9	0.0

We observe an average value of HR 106.46 bpm (Table 1).

HRV recorded an average value of 46.7 bpm (Table 2).

The results of oxygen saturation (SmO2) are shown in Table 3.

Table 3
Average SmO2 values (%) by muscle group

Muscle group	Mean	SD	SE	Min	Max
CV Left	66.18	16.56	3.25	31.93	93.36
Right CV	66.85	23.44	4.60	0.14	98.38
Left TA	43.72	12.11	2.38	25.80	81.98
Right TA	49.75	13.47	2.64	25.34	93.55

Main differences

CV - TA: 19.78% (the CV has an SmO2 19.78% higher than the TA)

Right - Left: 3.35% (the right leg has an SmO2 3.35% higher than the left)

With regard to SmO2, we carried out a detailed statistical analysis using the ANOVA test, which examined the following aspects: whether there were significant differences in SmO2 between the right and left sides, whether there were significant differences between muscle groups, and whether there was an interaction effect, specifically the degree of left-right asymmetry.

The results obtained by applying the ANOVA test showed the following:

Analysing the behaviour of the two muscle groups (CV vs TA), the results show:

SS = 10168.83 → Very large difference between CV and TA

MS = 10168.83 → (df = 1, so MS = SS)

$p < 0.001$

$\eta^2p = 0.541$ (LARGE effect -- 54% of the variation)

The conclusion is that there is a very significant difference between the CV and the TA in terms of SmO2. The CV exhibits a significantly higher SmO2 (66.51%) compared to the TA (46.73%), with an average difference of 19.78%. Consequently, the CV has better vascularization, more intense activation during walking, and higher metabolic demands in maintaining posture and propulsion whilst walking.

If we analyze the same effect in a left-right comparison, it was observed that

SS = 292.28 → Small difference between the left and right sides

MS = 292.28 → (df = 1, so MS = SS)

$p = 0.070$

$\eta^2p = 0.126$ (MEDIUM effect)

This means that there is no statistically significant difference between the left and right lower limbs overall ($p = 0.070$), although the trend is marginally significant. The right lower limb shows an SmO2 saturation level 3.35% higher than the left. Therefore, it can be said that there is minimal lateral asymmetry overall, possibly an effect of slight lateral dominance (the majority of subjects being right-dominant). The medium-sized effect (12.6%) suggests practical relevance even if it does not reach the statistical threshold ($p = 0.070$).

Analyzing the behavior of the muscle groups in relation to each of the lower limbs, right and left, using the ANOVA test, we observed

SS = 186.89 → Very small difference between the left and right limbs, for both CV and TA.

MS = 186.89 → (df = 1, therefore MS = SS)

p = 0.519

$\eta^2p = 0.017$ (INSIGNIFICANT effect – 1.7%), therefore there is no significant interaction between location (left/right) and muscle group. This means that the pattern of lateral asymmetry is similar for both muscle groups, which indicates that there is a constant left-right asymmetry between CV and TA; the difference between CV and TA is the same in both lower limbs. This finding can be interpreted as the existence of a common bilateral motor control mechanism, the absence of compensation, and the existence of a symmetrical pattern of muscle recruitment during walking.

Asymmetry index for SmO2 values

Continuing the analysis of SmO2, we considered it useful to calculate the asymmetry index for SmO2 values using the formula Asymmetry Index (%) = |Right - Left| / ((Right + Left) / 2) x 100, with the mean values presented in Table 4 for the CV and Table 5 for the TA, and a summary of the results is provided in Table 6.

Table 4
Asymmetry Index (AI) values for the quadriceps (CV)

Value	Mean CVR	Mean CVStg	IA Quadriceps [%]
Mean	66.85	66.18	23.60
SD	23.4447	16.6	41.2341

Table 5
Asymmetry Index (AI) values for the tibialis anterior (TA)

Value	Mean TADr	Mean TAStg	Anterior Tibial IA [%]
Mean	49.75	43.72	16.83
SD	13.46642	12.1103	17.47911

Table 6
Summary of the asymmetry index (AI) results

Muscle Group	Mean AI	SD	Range	Interpretation
Quadriceps	23.60%	41.23%	0.00% – 199.03%	HIGH asymmetry
Anterior Tibial	16.83%	17.48%	1.86% – 67.08%	HIGH asymmetry

Comparison of AI_CV vs AI_TA:

t(25) = 0.734, p = 0.470 (NOT significant). There is no significant difference in the magnitude of asymmetry, between the two muscle groups analysed (p = 0.470). The asymmetry index was interpreted in correlation with data from the literature, which classifies asymmetry as follows: < 10% = Low asymmetry (normal), 10–15% = Moderate asymmetry, > 15% = High asymmetry [27]. Given the absence of validated thresholds specific to NIRS (SmO2) parameters, we used the thresholds presented above as a reference, noting that the validity of these thresholds for muscle oxygenation requires further investigation.

We performed a post-hoc analysis of the SmO2 recording results because the ANOVA test revealed significant findings, so we wanted to see exactly where the differences lay. Thus, the application of this post-hoc analysis demonstrated that the results obtained via the ANOVA test are not random, and again highlighted the existence of real differences between the two muscle groups. The summary results of the post-hoc analysis regarding the SmO2 differences between the two muscle groups are presented in Table 7.

Table 7
Post-hoc paired comparisons

Comparison	t(25)	p	Mean Diff	Significance
CV Left vs Right	-0.173	0.864	0.67	ns
TA Left vs Right	-2.724	0.012 *	6.03	Significant
CV Left vs TA Left	6.489	< 0.001 ***	22.46	Very significant
CV Right vs TA Right	3.994	0.001 **	17.10	Highly significant

Post-hoc interpretation:

Left vs Right CV (p = 0.864): There is NO significant asymmetry in the CV

Left TA vs Right TA (p = 0.012): There is significant asymmetry in the TA (6.03%)

CV vs TA (both sides): VERY significant differences, confirming the main effect

The TA shows significant lateral asymmetry (p = 0.012), whilst the CV does not. However, the overall interaction remains non-significant (p = 0.519), suggesting that this difference is not strong enough to create a distinct interaction pattern.

Correlations of cardiac parameters and SmO2

The Pearson correlation matrix is presented in Table 8.

Table 8
Pearson correlation matrix

Variables	SmO2 Mean CVStg	SmO2 Mean TAStg	SmO2 Mean CVDr	SmO2 Mean TADr	HR Mean	HRV Mean
SmO2 Mean CVStg	1	0.273	0.554	0.264	-0.293	-0.148
SmO2 Mean TAStg		1	0.287	0.615	-0.147	0.291
SmO2 Mean CVDr			1	0.403	0.010	-0.026
SmO2 Mean TADr				1	0.247	0.268
HR Minimum					0.960	0.361
Maximum HR					0.974	0.393
Mean HR					1	0.431
Maximum HRV						0.934
HRV Mean						1

Interpretation of Pearson correlations:

SmO2 TAleft ↔ SmO2 TAright: r = + 0.615* ** (|r| > 0.5)

Moderate to strong positive correlation between SmO2 in the left and right anterior tibial arteries, indicating a symmetrical bilateral oxygenation pattern. This correlation indicates the presence of symmetrical motor control and synchronisation of gait patterns.

SmO2 CVleft ↔ SmO2 CVright: r = + 0.554** (|r| > 0.5)

Moderate positive correlation between oxygen saturation in the left and right CV, reflecting bilateral symmetry in the oxygenation of this muscle group. There is also bilateral motor control and symmetry within the CV, but the correlation is weaker than in the case of the TA, likely due to greater variability in recruitment patterns on the one hand, and on the other hand due to the specific role of the TA in controlling the leg during the phases of walking, particularly the propulsion phase.

Discussion

This study analysed, for the first time, the differences in muscle oxygenation and blood supply within the two muscle groups located on the anterior side of the lower limb during a (6Mwt) test in a group of young, healthy individuals. Compared with whole-body oxygen consumption kinetics, the study of local oxygen utilisation (i.e. in active muscles via changes in SmO2) during walking offers the advantage of a more detailed and focused examination of muscle behaviour in the lower limb. Both muscle groups exhibit high asymmetries (> 15%); consequently, there is very high variability between subjects in CV and more homogeneous variability in TA, but there is no significant difference between the asymmetries of the two muscles (p = 0.470). The high variability in CV (SD = 41.23%) suggests significant individual factors, likely explained by lateral dominance, fitness level, and individual movement patterns. There are no reference values for SmO2, but existing studies mention that in the CV muscle, at rest, the recorded values indicate a saturation of approximately 58–70% [28] of approximately 30–60% during submaximal exercise [29].

In the TA muscle, SmO2 is, according to Sanni et al. [30], 55–75% at rest, and 40–60% during submaximal exercise (walking).

Our results are consistent with the data in the literature, in that at the level of the CV, SmO2 values remain within resting ranges without any decrease during the exertion of the (6Mwt), whilst at the level of the TA, a decrease is observed during exertion, with values falling within those reported in the literature.

Regarding the relationship between the two muscle groups, during walking the CV muscle is much more actively involved compared to the TA. In our study, we observed that SmO2 in the CV muscle during the (6Mwt) test, which involves moderate, submaximal effort, was 66%, i.e. moderate deoxygenation, a finding also noted by Mavridis et al. [31]. With regard to TA, the reduction in oxygenation is more pronounced than in CV, which implies a decrease in oxygen extraction compared to the proximal muscle group, a finding also highlighted by Paternoster et al. [32]. These findings are explained by the fact that SmO2 can vary substantially depending on the biomechanical role of the muscle group, within the same gait pattern and at the same walking speed [9], such that whilst the CV muscle works eccentrically during the stance phase under high load, the TA muscle experiences a lower load, a finding supported by the SmO2 values. Regarding the relationship between HR and SmO2, HR increases gradually with exercise intensity, whilst SmO2 decreases, indicating increased oxygen extraction at the muscular level;

thus, a negative, non-significant correlation was found in the results of our study and also mentioned by Osmani et al. [33].

The study by Sperandio et al. [34], conducted on 86 participants aged between 40 and 74, showed that the (6Mwt) test corresponds to moderate to high-intensity exercise in middle-aged and older adults, with the maximum heart rate (HR) achieved during the test representing approximately 80 ± 23% of the maximum HR measured in a cardiopulmonary exercise test. This finding suggests that the (6Mwt) test is not merely a low-intensity functional test, but can place a significant demand on the cardiovascular system, making it useful for assessing SmO2 in relation to HR.

Although this study did not use NIRS / SmO2 with Moxy, its significance for data interpretation indicates that HR in the (6Mwt) test corresponds (as a percentage of HRmax) to moderate-to-vigorous exercise. Thus, if SmO2 decreases significantly towards the values observed during moderate exercise, one would expect a significant correlation with HR, particularly during the demanding phases of the test.

The approach in our study, in which we analysed muscle behaviour in terms of SmO2 during exertion, is also supported by the results of the study by Bradley et al. (2023) [35], conducted on healthy participants. It was observed that SmO2 measured with the Moxy Monitor during the (6Mwt) test in healthy subjects is reliable and correlated with physiological parameters such as heart rate (HR) and distance covered. These results are supported by previous research investigating the relationship between SmO2 and functional capacity in various populations.

The variation in SmO2 values during the (6Mwt) test is 4% for the quadriceps muscle, and in the TA muscle it is very high, with a 30% decrease, means a reduction in oxygenation; this indicates, as mentioned previously, better oxygen extraction in the CV muscle compared to the TA, explained by higher mechanical and metabolic load, a finding also reported by Gephine et al. [36].

Variations in SmO2 are also mentioned in the (6Mwt) test by Crispin [37] who notes that SmO2 assessment is an indicator of muscle functional capacity and response to the intensity of muscular effort during the test.

Conclusions

The difference in SmO2 between the CV and the TA is statistically significant ($p < 0.001$); the CV exhibits high oxygen saturation during walking. However, the pattern of asymmetry is similar in both muscle groups ($p = 0.519$), indicating a lack of compensation. The existence of this difference in SmO2 between the two muscle groups indicates distinct metabolic demands, which must be taken into account in the process of functional rehabilitation following lower limb surgery and bilateral motor control. On the other hand, there is considerable individual variability and the development of personalised patterns, which highlights the need for a personalised approach in gait assessment. SmO2 is an indicator of metabolic threshold and endurance.

The use of this functional monitoring, correlated with cardiac parameters, allows for much more precise interventions in subjects who have undergone lower limb surgery requiring prolonged immobilisation.

Limitations

The subjects studied were healthy and had no history of injury, which raises the question of whether the observed SmO2 asymmetries reflect normal variability or functional imbalances with potential pathological significance.

Abbreviations

SmO2
Muscle oxygen saturation
NIRS
Near-infrared spectroscopy
HR
Heart rate
HRV
Heart rate variability
6MWT
6-minute walk test
CV
Quadriceps femoris (vastus lateralis) muscle group
TA
Tibialis anterior muscle
BMI
Body mass index
AI
Asymmetry index
ANOVA
Analysis of variance
SD
Standard deviation
SE
Standard error
THb
Total haemoglobin
VO2
Oxygen consumption
FEFS
Faculty of Physical Education and Sport

SS
Sum of squares
MS
Mean square
η^2p
Partial eta-squared

Declarations

Ethics approval and consent to participate

Institutional Review Board Statement and approval number for studies involving humans or animals 289/2025. The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of FEFS on 289/10.09.2025 of the University of Craiova, FEFS. Informed consent was obtained from all subjects involved in the study.

Consent for publication

Written informed consent has been obtained from the participant(s) to publish this paper.

Competing interests

The authors declare that they have no competing interests.

Funding

This research received no external funding.

Author Contribution

G.I. investigation, data curation; D.P. formal analysis, resources; M.M.G. data curation; M.R.R. visualization, formal analysis; L.R. conceptualization, methodology; M.M. formal analysis; G.B. data curation, writing.

Acknowledgements

The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Data Availability

The dataset supporting the conclusions of this article is available on request from the corresponding author.

References

1. Hearris MA, Hammond KM, Fell JM, Morton JP. Regulation of muscle glycogen metabolism during exercise: implications for endurance performance and training adaptations. Nutrients. 2018;10(3):298. 10.3390/nu10030298.
2. Crum EM, O'Connor WJ, Van Loo L, Valckx M, Stannard SR. Validity and reliability of the Moxy oxygen monitor during incremental cycling exercise. Eur J Sport Sci. 2017;17(8):1037–43. 10.1080/17461391.2017.1330899.
3. Chang SC, Adami A, Lin HC, Lin YC, Chen CP, Fu TC et al. Relationship between maximal incremental and high-intensity interval exercise performance in elite athletes. bioRxiv. 2019:856237. Available from: https://www.biorxiv.org/content/10.1101/856237v1
4. Gepner Y, Wells AJ, Gordon JA, Arroyo E, Varanoske AN, Coker NA, et al. Differences in muscle oxygenation between young and middle-aged recreationally active men during high-volume resistance exercise. Kinesiology. 2019;51(1):3–11. 10.26582/k.51.1.4.
5. Rodriguez RF, Townsend NE, Aughey RJ, Billaut F. Influence of averaging method on muscle deoxygenation interpretation during repeated-sprint exercise. Scand J Med Sci Sports. 2018;28(11):2263–71. 10.1111/sms.13238.
6. Koutlas A, Smilios I, Kokkinou EM, Myrkos A, Kounoupis A, Dipla K et al. NIRS-derived muscle deoxygenation and microvascular reactivity during occlusion-reperfusion at rest are associated with whole-body aerobic fitness. Res Q Exerc Sport. 2023:1–13.
7. Rissanen APE, Tikkanen HO, Koponen AS, Aho JM, Hagglund H, Lindholm H, et al. Alveolar gas exchange and tissue oxygenation during incremental treadmill exercise, and their associations with blood O2 carrying capacity. Front Physiol. 2012;3:265.
8. Hiroyuki H, Hamaoka T, Sako T, et al. Oxygenation in vastus lateralis and lateral head of gastrocnemius during treadmill walking and running in humans. Eur J Appl Physiol. 2002;87:343–9. 10.1007/s00421-002-0644-y.
9. Stathopoulos A, Petridou A, Kantouris N, Mougios V. A comparison of leg muscle oxygenation, cardiorespiratory responses, and blood lactate between walking and running at the same speed. Sports (Basel). 2024;12(2):48. 10.3390/sports12020048.
10. Tuesta M, Yáñez-Sepúlveda R, Verdugo-Marchese H, Mateluna C, Alvear-Ordenes I. Near-infrared spectroscopy used to assess physiological muscle adaptations in exercise clinical trials: a systematic review. Biology (Basel). 2022;11(7):1073. 10.3390/biology11071073.
11. Zhang Q, Lu H, Pan S, Lin Y, Zhou K, Wang L. 6MWT performance and its correlations with VO2 and handgrip strength in home-dwelling mid-aged and older Chinese. Int J Environ Res Public Health.

2017;14(5):473. 10.3390/ijerph14050473.

12. Feldmann A, Ammann L, Gächter F, Zibung M, Erlacher D. Muscle oxygen saturation breakpoints reflect ventilatory thresholds in both cycling and running. J Hum Kinet. 2022;83:87–97. 10.2478/hukin-2022-0054.
13. Grassi B, Quaresima V, Marconi C, Ferrari M, Cerretelli P. Blood lactate accumulation and muscle deoxygenation during incremental exercise. J Appl Physiol. 1999;87(1):348–55. 10.1152/jappl.1999.87.1.348.
14. Ferreira LF, Townsend DK, Lutjemeier BJ, Barstow TJ. Muscle capillary blood flow kinetics estimated from pulmonary O2 uptake and near-infrared spectroscopy. J Appl Physiol. 2005;98(5):1820–8. 10.1152/japplphysiol.00907.2004.
15. Hiroyuki H, Hamaoka T, Sako T, Nishio S, Kime R, Murakami M, et al. Oxygenation in vastus lateralis and lateral head of gastrocnemius during treadmill walking and running in humans. Eur J Appl Physiol. 2002;87(4–5):343–9. 10.1007/s00421-002-0644-y.
16. Okushima D, Poole DC, Barstow TJ, Rossiter HB, Kondo N, Bowen TS, et al. Greater VO2peak is correlated with greater skeletal muscle deoxygenation amplitude and haemoglobin concentration within individual muscles during ramp-incremental cycle exercise. Physiol Rep. 2016;4(23):e13065. 10.14814/phy2.13065.
17. Wang B, Xu G, Tian Q, Sun J, Sun B, Zhang L, et al. Differences between the vastus lateralis and gastrocnemius lateralis in the assessment ability of breakpoints of muscle oxygenation for aerobic capacity indices during an incremental cycling exercise. J Sports Sci Med. 2012;11(4):606–13.
18. Wagner PD. Modelling O2 transport as an integrated system limiting VO2max. Comput Methods Programs Biomed. 2011;101(2):109–14. 10.1016/j.cmpb.2010.03.013.
19. Porter M, Langley J. The relationship between muscle oxygen saturation kinetics and maximal blood lactate accumulation rate across varying sprint cycle durations. Eur J Sport Sci. 2025;25(3):e12242. 10.1002/ejsc.12242.
20. Van Hooren B, Souren T, Bongers B. Accuracy of respiratory gas variables, substrate, and energy use from 15 CPET systems during simulated and human exercise. Scand J Med Sci Sports. 2023;34(1). 10.1111/sms.14490.
21. Shirai Y, Ito T, Ito Y, Matsunaga N, Noritake K, Ochi N, et al. Evaluation of muscle oxygen dynamics in children's gait and its relationship with the physiological cost index. Healthc (Basel). 2023;11(2):221. 10.3390/healthcare11020221.
22. Bassett DR Jr, Howley ET. Limiting factors for maximum oxygen uptake and determinants of endurance performance. Med Sci Sports Exerc. 2000;32(1):70–84. 10.1097/00005768-200001000-00012.
23. Takagi S, Murase N, Kime R, Niwayama M, Osada T, Katsumura T. Skeletal muscle deoxygenation abnormalities in early post-myocardial infarction. Med Sci Sports Exerc. 2014;46(11):2062–9. 10.1249/MSS.0000000000000334.

24. Takagi S, Murase N, Kime R, Niwayama M, Osada T, Katsumura T. Aerobic training enhances muscle deoxygenation in early post-myocardial infarction. Eur J Appl Physiol. 2016;116(4):673–85. 10.1007/s00421-016-3326-x.
25. Andrade-Lima A, Cucato GG, Domingues WJR, Germano-Soares AH, Cavalcante BR, Correia MA, et al. Calf muscle oxygen saturation during 6-minute walk test and its relationship with walking impairment in symptomatic peripheral artery disease. Ann Vasc Surg. 2018;52:147–52. 10.1016/j.avsg.2018.03.038.
26. Kammin EJ. The 6-minute walk test: indications and guidelines for use in outpatient practices. J Nurse Pract. 2022;18(6):608–10. 10.1016/j.nurpra.2022.04.013.
27. Kyritsis P, Bahr R, Landreau P, Miladi R, Witvrouw E. Likelihood of ACL graft rupture: not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. Br J Sports Med. 2016;50(15):946–51. 10.1136/bjsports-2015-095908.
28. Miranda-Fuentes C, Chirosa-Ríos LJ, Guisado-Requena IM, Delgado-Floody P, Jerez-Mayorga D. Changes in muscle oxygen saturation measured using wireless near-infrared spectroscopy in resistance training: a systematic review. Int J Environ Res Public Health. 2021;18(8):4293. 10.3390/ijerph18084293.
29. Feldmann A, Schmitz R, Erlacher D. Near-infrared spectroscopy-derived muscle oxygen saturation on a 0% to 100% scale: reliability and validity of the Moxy Monitor. J Biomed Opt. 2019;24(11):1–11. 10.1117/1.JBO.24.11.115001.
30. Sanni AA, McCully KK. Interpretation of near-infrared spectroscopy (NIRS) signals in skeletal muscle. J Funct Morphol Kinesiol. 2019;4(2):28. 10.3390/jfmk4020028.
31. Mavridis K, Petridou A, Chatzinikolaou A, Mougios V. Oxygenation kinetics of three quadriceps muscles during squatting exercise in trained men. Sports (Basel). 2024;12(10):283. 10.3390/sports12100283.
32. Paternoster FK, Seiberl W. Comparison of different approaches to estimating skeletal muscle oxygen consumption using continuous-wave near-infrared spectroscopy at a submaximal contraction level - a comparative study. Appl Sci. 2022;12:2272. 10.3390/app12052272.
33. Osmani F, Lago-Fuentes C, Alemany-Iturriaga J, Barcala-Furelos M. The relationship of muscle oxygen saturation analyser with other monitoring and quantification tools in a maximal incremental treadmill test. Front Physiol. 2023;14:1155037. 10.3389/fphys.2023.1155037.
34. Sperandio EF, Arantes RL, Matheus AC, Silva RP, Lauria VT, Romiti M, et al. Intensity and physiological responses to the 6-minute walk test in middle-aged and older adults: a comparison with cardiopulmonary exercise testing. Braz J Med Biol Res. 2015;48(4):349–53. 10.1590/1414-431X20144235.
35. Bradley AP, Roehl AS, Smith J, McGrath R, Hackney KJ. Muscle-specific declines in oxygen saturation during acute ambulation with hands-free and conventional mobility devices. Front Sports Act Living. 2023;5:1210880. 10.3389/fspor.2023.1210880.

36. Gephine S, Mucci P, Bielmann M, Martin M, Bouyer L, Saey D, et al. Quadriceps physiological response during the 1-min sit-to-stand test in people with severe COPD and healthy controls. Sci Rep. 2022;12(1):794. 10.1038/s41598-022-04820-z.
37. Crispin P. Effect of anaemia on muscle oxygen saturation during submaximal exercise. Transfusion. 2020;60(1):36–44. 10.1111/trf.15588.

Figures



Figure 1

Positioning of Moxy sensors