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Blood Oxygen Saturation (BO_2S) as a Parameter for Quantifying Training Load During Intermittent Exercise: Linear vs. Shuttle Runs

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Abstract: The aim of the present study is twofold: first, to investigate high-intensity intermittent exercises (10s-20s and 15s-30s work-rest ratios), and second, to shed light on the physiological impact specifically blood oxygen saturation (BO_2S) of directional changes during shuttle intermittent exercises. This was done by comparing two forms of intermittent exercise: a linear protocol and a shuttle protocol, both performed at two intensities (100% and 110% of maximal aerobic speed, MAS).The experimental study was conducted on two groups of 10 healthy male subjects, all students from the Department of Physical and Sports Activity Sciences at the University of Sétif 2. The participants were young athletes, including twelve football players and eight handball players, all with a similar fitness level and a minimum of six hours of training per week. The first group performed a high-intensity intermittent protocol with a 10s-20s work-rest ratio, while the second group followed the 15s-30s protocol.Throughout the experiment, several measurements were taken using the QUIRUMED OXYM4000 fingertip pulse oximeter. Statistical analysis of the collected BO_2S values revealed no significant differences between the physiological effects of high-intensity linear and shuttle intermittent protocols.

Keywords: Blood oxygen saturation; Maximal aerobic speed; High-intensity short intermittent linear exercise (LIT) ; High-intensity short shuttle intermittent exercise (SIT).

Article info

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1. Introduction

The primary objective of sports training is to develop physical capacities that provide athletes with an additional opportunity to enhance their performance and more easily reach elite levels of competition. Sports training is also recognized as a complex process that systematically and specifically affects athletic performance levels and the capacity to perform optimally under test and competition conditions (Weinek, J., 2001).

To date, physical preparation remains one of the components that coaches are best able to control and manage (Balsom, P.D., 1955). Consequently, the vast majority of technical staff include at least one strength and conditioning coach, based on the premise that an athlete in optimal physical condition will be better equipped to express their technical and tactical skills (Bangsbo, 1994, in Dellal, A., 2008).

Modern sports have evolved with a set of specific characteristics that exert a decisive influence on training management. These changes place increasingly complex demands on coaches and athletes alike (Mimouni, S., 2002), highlighting the necessity and relevance of implementing training load quantification models (Sedeaud et al., 2018), which are essential tools for managing training on an individual basis (Basset, F. & Chouinard, R., 2002).

One of the key challenges faced by coaches and performance staff is to apply a training load that is sufficiently demanding to improve targeted physical qualities, while simultaneously managing fatigue levels to avoid crossing the threshold that could lead to injury (Sedeaud et al., 2018).

Research into training load quantification has brought together two disciplinary perspectives. On one hand, physiologists have focused on metabolic and physiological foundations. Advances in wearable sensor technology have led to continuous improvements in physiological monitoring and load quantification through variables such as VO_2, heart rate, blood pressure, respiratory rate, and levels of metabolic byproducts (Schneider et al., 2018). On the other hand, psychologists have examined the emotional, motivational, and affective components of training load, relying on sensory and perceptual information (Basset & Chouinard, 2002).

In team sports, recent studies modeling physical demands during competition have led to significant advances in training content programming (Buchheit, M., 2005). Issues related to training load quantification and individualization of training programs and intensities are recurring concerns in team sports, aimed at improving athlete monitoring. The increasing professionalization of sports and the high frequency of matches throughout the season require strength and conditioning coaches to fully understand and manage all components of training load. This is essential not only to optimize player potential but also to preserve it over time—avoiding injuries and minimizing the risk of accumulating fatigue.

While numerous tools and devices now exist to measure physiological capacities, they are often expensive and not easily implemented in day-to-day practice. In this context, the use of perceptual responses appears to be a promising alternative that meets the needs of training professionals (Monnier-Benoît & Groslambert, 2014).

Training loads should be based on the specific demands of each sport. Accurately identifying these physical qualities requires in-depth knowledge of the sport and keen observational skills. Analyzing both

internal indicators (e.g., heart rate, blood lactate levels) and external indicators (e.g., effort durations, rest periods, running speeds, number of sprints, jumps) during competition allows for a more precise estimation of the energy systems and physical abilities involved in performance (Buchheit, M., 2003).

Handball is a fast-paced, dynamic, offensive, and aggressive sport, both in attack and defense, regardless of player position (Bayer, 1993, in Buchheit, M., 2003). This discipline is characterized by a high number of brief (2–7 seconds), high-intensity efforts, which are often decisive during a match (Chelly et al., 2011). Sprinting ability is a major component of performance. On average, a handball player performs over 20 sprints of around 3 seconds per match, 15 jumps, 20 duels and blocks, and roughly 60 movement sequences involving directional changes. Studies by Póvoas et al. (2012), Ravier & Bouzigon (2014), and Mangematin & Babault (2010) have shown that during a match, a handball player performs nearly 300 short, explosive actions, with recovery periods ranging from 25 to 30 seconds.

Similarly, in football, qualitative analyses reveal that a player's activity can be described as a sequence of short, intense efforts interspersed with recovery phases (Kharoubi, M.F., 2016). A football player performs between 825 and 1,632 movements per match, including running at various intensities, lateral movements, jumps, tackles, backward runs, and more (Bangsbo, 1994a, in Dellal, A., 2008).

It appears that the activity of both handball and football players consists of a very high number of short, explosive actions. These efforts are key determinants of performance, as they often make the difference during a match for example, scoring a goal following a quicker start, or stopping an attacker thanks to a faster defensive reaction (Buchheit, M., 2003; Ravier & Bouzigon, 2014). These specific qualities should therefore be the primary focus of physical conditioning programs.

In conclusion, the activity of handball and football players can be described as intermittent in nature. During a match, players perform a variety of actions such as dribbling, sprinting, shooting, and directional changes at randomly fluctuating intensities, depending on the position played, level of play, experience, and the tactical role within the team.

It is now widely acknowledged that intermittent training is among the most utilized and effective training methods in team sports, particularly in handball and football (Dellal et al., 2010). Each training method involves exercises of varying forms and intensities, which must be carefully designed to ensure effective training load quantification. Accordingly, intermittent training has been the subject of numerous studies in recent years.

The structure of an intermittent training program typically involves work phases performed at target intensities, alternated with periods of active or passive recovery (Hervé & Cometti, 2007; Dellal et al., 2010). Individualized programming of these sessions allows for the simultaneous development of various physical qualities, depending on specific parameters such as the total duration of effort, the respective durations of work and rest periods, and the intensity of each. The duration of these efforts is directly related to intensity, but is also selected based on the demands of competitive activity (Buchheit, M., 2005; Ferré, J. & Leroux, P., 2009).

Several studies have reported that high-intensity intermittent training (HIIT) is associated with the development of maximal aerobic power (MAP) (Hervé & Cometti, 2007) and the optimization of maximal oxygen uptake (VO_2peak) in players (Dellal et al., 2010). This training method also allows athletes to train for longer durations compared to continuous exercise at the same intensity (Hervé &

Cometti, 2007). However, intermittent training does not result in the accumulation of large amounts of lactate due to the short duration of exercise bouts; moreover, the lactate produced is likely to be metabolized during recovery periods (Dellal, 2008).

The format of intermittent exercise serves as the foundation of the present study. Intermittent exercises may be performed either in linear fashion or with directional changes. These directional changes can involve 180° turns, known as shuttle-based intermittent exercises, or lateral movements (Dellal, 2008). Notably, based on analytical studies of handball and football activity profiles, shuttle-based intermittent formats appear more appropriate for these sports, as athletes frequently perform runs at varying intensities that involve directional changes during matches (Ravier & Bouzigon, 2014; Dellal et al., 2010).

The aim of the present study is to investigate the physiological response, specifically blood oxygen saturation (BO_2S), to directional changes, deceleration, and reacceleration during 10s-20s and 15s-30s high-intensity intermittent efforts, performed both linearly and as shuttle runs. This investigation holds significant relevance for intermittent training load quantification, a key issue in team sports for enhancing athlete monitoring and training individualization.

To address this aim, we sought to answer the following research question:

Does the impact of a high-intensity linear intermittent effort on blood oxygen saturation (BO_2S) match that of a shuttle-based intermittent effort?

2. Method

2.1 Participants

Our experimental study was conducted on a sample of two groups, each consisting of 10 healthy male participants. All participants were students from the Department of Physical and Sports Activity Sciences at Mohamed Lamine Debaghine University, Sétif 2. The subjects were young athletes, including football and handball players, with a homogeneous training level, each engaging in at least six hours of weekly practice.

The first group followed the high-intensity intermittent training protocol with a 10s-20s work-rest ratio, while the second group followed the high-intensity intermittent protocol with a 15s-30s ratio.

Table 1. Anthropometric, physical, and physiological characteristics of the participants are presented below:

	Age	Weight	Height	MHR	RHR	HRR	[La]	MAS	LTim
Group 10s-20s Values S±D	22.5 ± 1.15	76.3 ± 4.6	178.7 ± 2	185.60 ± 7.41	56.6 ± 2.22	129 ± 8.95	1.87 ± 0. 2	97% ± 1.69	17,75 ± 0.54
Group 15s-30s Values S±D	22.3 ± 1.15	72.09 ± 6.13	179.4 ± 5	185.80 ± 6.32	55.8 ± 1.93	130 ± 7.46	1.92 ± 0.19	97.6 % ± 1.17	19.5 ± 0.97

2.2 Measurement of Blood Oxygen Saturation (BO_2S)

Figure 1. Quirumed OXYM4000 fingertip pulse oximeter



The operating principle of this measuring device is based on the emission of two types of light-red and infrared and the measurement of their absorption by the pulsatile blood flow.

Oxyhemoglobin absorbs more infrared light and allows more red light to pass through, whereas deoxyhemoglobin absorbs more red light and allows more infrared light to pass.

The non-absorbed light is captured by a photoelectric sensor and then analyzed.

The analysis is based on the absorption values of oxyhemoglobin and deoxyhemoglobin, and the device outputs the oxygen saturation level (BO_2S) as a percentage (%).

2.3 Statistical Analysis

The data collected from the different sessions of the two experimental protocols were expressed as mean values ± standard deviation (SD).

Statistical processing was performed using SPSS for Windows (version 20; SPSS, Inc., Chicago, IL).

Before comparing the results obtained from the intermittent shuttle (SIT) and straight-line (LIT) exercise sessions, we first conducted a normality test of the distribution of variances using the Kolmogorov-Smirnov test, and homogeneity of variances was assessed using Hartley's test.

The paired Student's t-test was used for comparative analysis when the assumptions of normality and homogeneity of variances were met.

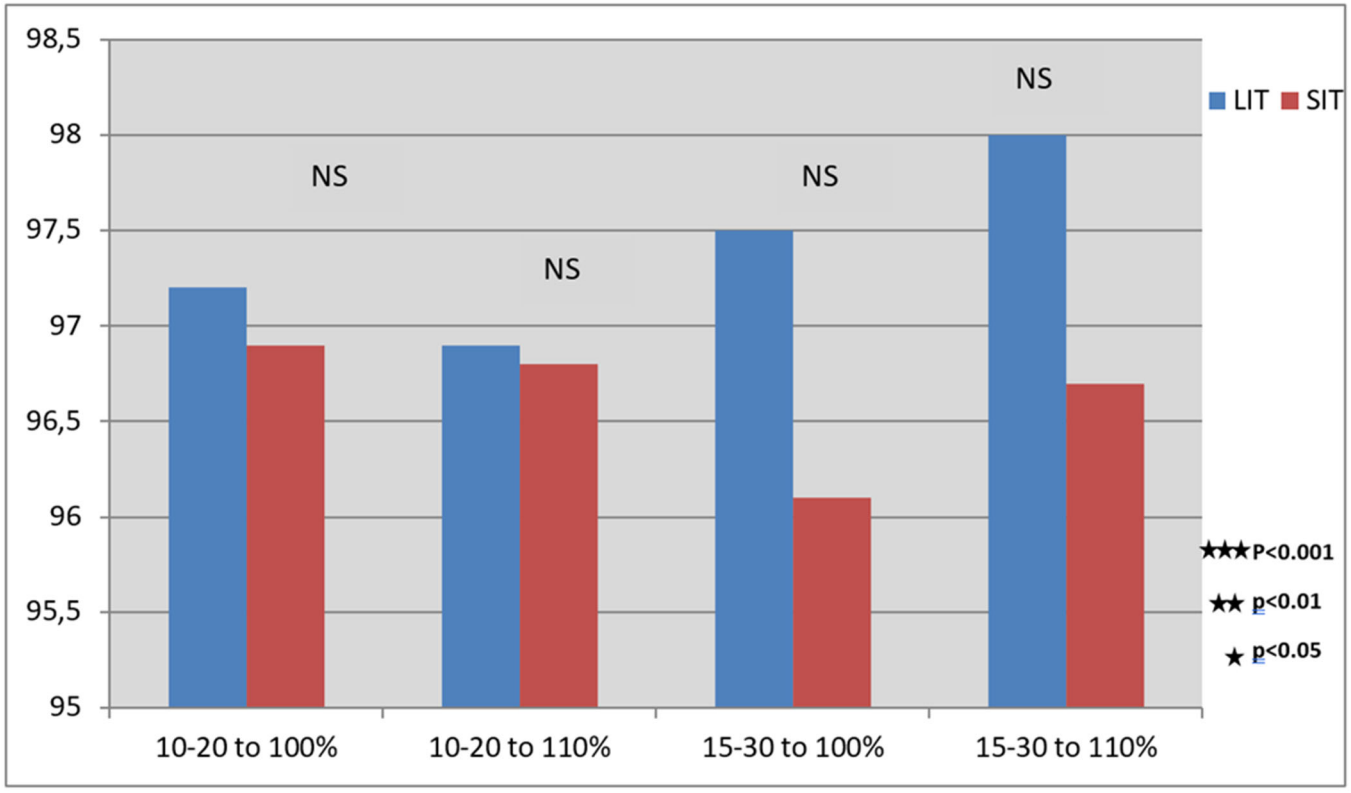
Blood oxygen saturation (BO_2S) was measured using the **Quirumed OXYM4000** fingertip pulse oximeter (Fig. 01). Measurements were taken before, during, and after each session of linear and shuttle-based intermittent exercise.

Pulse oximetry (also referred to as pulsed oximetry or oxygen saturation monitoring) is a non-invasive method used to measure the oxygen saturation of hemoglobin in the capillary blood. The biometric variable recorded is BO_2S, which is displayed by the device as a percentage value.

If these assumptions were not satisfied, the Wilcoxon Signed-Rank Test was applied.

The significance level was set at 5% ($p \leqslant 0.05$) for all comparative analyses.

Figure 2. Comparison of arterial oxygen saturation (BO_2S) values recorded during the different straight-line and shuttle intermittent exercise sessions.



4. Discussion

The results of the present study show no significant difference in BO_2S responses between straight-line (LIT) and shuttle intermittent (SIT) exercise protocols. In both conditions, oxygen saturation remained stable, with fluctuations not exceeding 2%. This stability suggests that the two exercise modalities, despite their different mechanical and metabolic demands, do not generate sufficient physiological stress to induce a measurable decline in peripheral oxygen saturation in recreationally trained individuals.

A first layer of interpretation relates to the physiological robustness of oxygen transport mechanisms during submaximal to high-intensity exercise. As reported by Benoît et al. (2006), increases in oxygen demand during exercise are compensated through elevated cardiac output and enhanced muscular oxygen extraction. In healthy subjects, this adaptive response preserves arterial oxygen saturation even when metabolic requirements rise substantially (Noury & Mucci, 2004). The absence of desaturation in both protocols therefore aligns with classical physiological expectations.

Another interpretative consideration concerns the population studied. Desaturation during exercise is generally associated with pathological conditions such as interstitial lung disease or pulmonary hypertension (Rassouli & Robert, 2015). Outside of these conditions, exercise-induced hypoxemia (EIH) is mainly observed in highly trained endurance athletes with very high aerobic capacities ($VO_2peak > 60$ $ml \cdot min^{-1} \cdot kg^{-1}$) (Dempsey et al., 1999). These athletes can reach pulmonary diffusion and ventilatory limitations that lead to a ≥4% drop in BO_2S during intense exercise (Legrand et al., 2005). The participants in the present study, who do not belong to such a population, do not appear to reach the ventilatory thresholds necessary to induce EIH. This may partially explain the negligible changes in BO_2S across both exercise modalities.

From a methodological perspective, the absence of significant variation also raises questions about the sensitivity of BO_2S as a monitoring tool. Pulse oximetry provides an accessible and non-invasive measure of hemoglobin saturation, yet its responsiveness during short intermittent bouts may be limited. Factors such as peripheral perfusion, motion artifacts, and device response time can dampen the detection of rapid physiological fluctuations. Therefore, BO_2S may not be sufficiently sensitive to discriminate between exercise modalities that differ more in biomechanical pattern than in global metabolic load.

From an applied standpoint, these findings indicate that BO_2S alone is unlikely to be a relevant marker for evaluating internal load or physiological strain during SIT and LIT sessions in non-elite populations. Coaches and practitioners should therefore prioritize more sensitive indicators such as heart rate dynamics, lactate responses, perceived exertion, or ventilatory markers when seeking to distinguish between intermittent exercise formats.

Perspectives and Recommendations

- **Broader physiological monitoring**

Future studies should integrate complementary biomarkers—such as HR variability, VO_2 kinetics, or lactate dynamics—to determine whether subtle physiological differences between SIT and LIT appear in parameters other than oxygen saturation.

- **Longer or more intense protocols**

Since short bouts did not elicit significant saturation changes, extending the duration or increasing the intensity may help determine whether BO_2S becomes more informative under higher physiological strain.

Population-specific investigation

Considering the relevance of EIH among elite endurance athletes, replicating the protocols with high-level athletes could reveal different patterns of oxygen desaturation and provide valuable insights for sports performance monitoring.

- **Technological refinement**

Advanced oximetry devices with higher sampling frequency and motion-artifact correction may improve the ability to detect micro-variations in saturation during intermittent locomotor tasks such as shuttles.

Conclusion

Overall, the absence of differences between SIT and LIT highlights the limited utility of BO_2S as an isolated monitoring tool in intermittent training contexts for recreational subjects. Rather than reflecting a lack of physiological response, the stable saturation suggests a robust adaptive capacity of the oxygen

transport system and underscores the need for integrating more sensitive physiological markers to fully capture the internal load associated with different exercise modalities.

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