Lactate responses in high-intensity interval training sessions and their metabolic implications in different protocols: an integrative review

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Summary

Objective: To verify, through an integrative review, the behavior of lactate in the face of High-Intensity Interval Training (HIIT).
Material and method: Specific recommendations for the type of work were followed. Original studies that used HIIT in different populations were used. In order for the discussions to be broader, publication periods were not determined. The studies included in this review were carried out with healthy, trained individuals.
Results: Both types of protocol (short and long) result in a significant increase in lactate due to the high metabolic demand. Lactate can provide parameters for the aerobic and anaerobic contribution, as a more significant accumulation of this metabolite can lead to a greater anaerobic contribution. However, in HIIT, recovery time can interfere with lactate accumulation, which predicts the magnitude of the aerobic and/or anaerobic contribution. Shorter recovery times may require greater aerobic contributions, due to insufficient resynthesis of energy (ATP) via the glycolytic pathways. There is a tendency for lactate to accumulate more due to the high anaerobic effect (even with aerobic participation) and the lower removal capacity of this metabolite. On the other hand, a longer recovery time is more conducive to optimizing energy resynthesis via the glycolytic pathway, as there will be more time for this system to re-establish itself (totally or partially) in order to perform a high-intensity stimulus. With regard to lactate, the longer the recovery time, the lower the accumulation, as there is greater removal capacity and less intramuscular imbalance responsible for acidosis.
Conclusion: Despite some limitations, this review shows that we can use lactate to determine energy demand. However, it seems that the recovery time between stimuli is a determining factor in energy intake and, consequently, lactate accumulation. In this way, this metabolite can help us understand different HIIT protocols and, therefore, prescribe them for different objectives.

Key words:
Interval training. Lactate. Aerobic system. Anaerobic system. Training physiology.

Respuestas del lactato en sesiones de entrenamiento interválico de alta intensidad y sus implicaciones metabólicas en diferentes protocolos: una revisión integradora

Resumen

Objetivo: Verificar, a través de una revisión integradora, el comportamiento del lactato frente al Entrenamiento Interválico de Alta Intensidad *(HIIT)*.
Material y método: Se siguieron recomendaciones específicas para el tipo de trabajo. Se utilizaron estudios originales que utilizaron *HIIT* en diferentes poblaciones y no se determinaron los periodos de publicación. Los estudios incluidos en esta revisión se realizaron con individuos sanos y entrenados.
Resultados: Los protocolos cortos y largos dan lugar a un aumento significativo del lactato debido a la elevada demanda metabólica. El lactato puede proporcionar parámetros para la contribución aeróbica y anaeróbica, ya que una acumulación más significativa de este metabolito puede conducir a una mayor contribución anaeróbica. Sin embargo, en el *HIIT*, el tiempo de recuperación puede interferir con la acumulación de lactato, lo que predice la magnitud de la contribución aeróbica y/o anaeróbica. Los tiempos de recuperación más cortos pueden requerir mayores contribuciones aeróbicas, debido a la insuficiente resíntesis de energía a través de las vías glucolíticas. Existe una tendencia a una mayor acumulación de lactato debido al elevado efecto anaeróbico y a la menor capacidad de eliminación de este metabolito. Por otro lado, un mayor tiempo de recuperación es más propicio para optimizar la resíntesis energética a través de la vía glucolítica, ya que habrá más tiempo para que este sistema se restablezca para realizar un estímulo de alta intensidad. Al lactato, cuanto mayor sea el tiempo de recuperación, menor será la acumulación, ya que existe una mayor capacidad de eliminación y un menor desequilibrio intramuscular responsable de la acidosis.
Conclusiones: Esta revisión muestra que podemos utilizar el lactato para determinar la demanda energética. Parece que el tiempo de recuperación entre estímulos es un factor determinante en el consumo energético y, en consecuencia, en la acumulación de lactato. Este metabolito puede ayudarnos a comprender diferentes protocolos *HIIT*.

Palabras clave:
Entrenamiento por intervalos. Lactato. Sistema aeróbico. Sistema anaeróbico. Fisiología del entrenamiento.

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Introduction

High-Intensity Interval Training (HIIT) has become popular in the fitness and training market and is among the latest trends in activities to be practiced worldwide[1]. Regarding scientific research, studies related to HIIT have shown constant growth[2]. HIIT, first and foremost, is not a method but a variation of interval training (which is the method)[3]. Physiologically, HIIT causes necessary adaptations, central (e.g., maximum oxygen consumption, cardiac efficiency, etc.) and peripheral (e.g., molecular responses, mitochondrial density, etc.)[4] and metabolic (e.g., muscle glycolytic and oxidative capacity)[5].

These adaptations are relevant to the functional improvement of essential variables for increasing health levels[6–8]. These components are significantly altered because, in HIIT, high-intensity stimuli provide a high and rapid physiological demand[4], which can consequently interfere with chronic conditional responses. On the metabolism behavior, in HIIT, independent of the level of contribution of the energy pathway[9,10], there is a high lactate production. This is because there is a high metabolic demand due to the high intensity of the stimuli[11].

In general, one of the reactions to physical exercise is the behavior of lactate, a component resulting from glycolytic metabolism, independent of its magnitude of contribution to the exercise performed[12], widely used to delineate intensities starting from the anaerobic threshold[13,14] and is also considered one of the primary markers of fatigue and physiological stress[15,16]. In HIIT, we can better understand the stimuli applied through the accumulation of lactate, which is an important parameter for metabolic analysis[17] and, therefore, performance[18].

HIIT has been widely used in different training fields with different objectives. However, there is a gap in knowing more about its repercussions on the behavior of lactate, one of the components responsive to high-intensity effort. In this way, it will be even more possible to have a more significant interpretation of the metabolic reactions in different protocols of this training variation, thus making it possible to apply it with greater precision to different physiological objectives. In addition, despite knowing about the participation of lactate during a physiological integration in different organic metabolisms[19], we don't know for sure about the possible positive response of HIIT against lactate.

Another issue is that we know that lactate will be produced significantly as a result of high-intensity stimuli. In HIIT, little is known about lactate production and its significance in metabolism in different protocols. Could it be that the level of production can direct energy behavior in HIIT? Therefore, through an integrative review, this study aimed to describe lactate responses in HIIT sessions and their interpretations of metabolic behavior in different protocols.

Material and method

This integrative review was developed following specific scientific recommendations for this type of research[20,21]. Therefore, this research was conducted after determining some didactic parameters, such as problem formulation, bibliographic research, data evaluation and analysis (of the selected studies), and finally, data interpretation and presentation[22,23]. As this is an integrative review, it was not necessary to determine a minimum or maximum publication period for the articles selected for this discussion. However, only studies directly related to this research's subject were used. The studies selected for this integrative review were found in Pubmed and Web of Science scientific databases. For this search, strategies using combinations of keywords related to the theme of the work were used[24]. Moreover, the personal archives of the researchers involved in the work were consulted to identify possible studies to be included in this work.

A brief explanation of HIIT: Types of protocols, terminology, and methodological aspects

HIIT can be applied in different types of protocols characterized by the stimulus time, which is more directly short (<60 s) and long (≥60 s)[25]. HIIT with short stimuli is generally conducted in sprints, called Repeated Sprint Training (RST) or Sprint Interval Training (SIT). But, even more categorically, in HIIT, stimuli of less than or equal to 10 seconds (RST) and 10-30 seconds (SIT) were considered to be short, 30 to 2 minutes as medium, and greater than or equal to 2 minutes as long[6].

In methodological terms, the literature on HIIT is based on physiological (e.g., maximum oxygen consumption and heart rate) and mechanical (e.g., maximum aerobic speed) thresholds to define this variation of IT application[26,27]. In general, HIIT is applied at submaximal (close to the determined threshold: 90-95%), maximal (at the determined threshold: 100%), and supramaximal (above the determined threshold: greater than 100%) stimulus intensities related to some physiological or mechanical parameter[25,28]. However, due to its different methodological variations, HIIT can interfere with understanding its applicability[25,28] for different objectives and sampling characteristics.

A brief explanation of lactate in response to exercise

The lactate is well known for its role in protecting and preserving the cellular environment (though for a limited time) in a situation of acidosis being established due to heavy exertion[15]. However, this component also participates in critical metabolic functions in different systems of the human organism. In addition, lactate is an essential component (despite some misinterpretations) in cellular metabolism, through oxidation not only by the well-known Cori cycle but also by mitochondria[29]. Another important role of lactate is in the heart, where this organ participates directly in the transport function of the metabolite[30] and also has a demand for consumption of this chemical component through myocardial metabolism[31].

Still on the importance of lactate in physiological behavior, this component is also a direct agent in the efficiency of brain function in terms of the energy process[32] and the performance of executive functions, which are essential and necessary for human beings[33]. Finally, mediated by the anaerobic threshold, lactate is also present in a broad physiological integration, which allows for better responses in different states (rest and/or exertion)[19]. All this behavior in different systems will be decisive in times of effort, especially at high intensity.

HIIT, its repercussions on lactate, and interpretations of energy metabolism

In HIIT, high-intensity stimuli cause a significant increase in lactate in response to the high metabolic demand[34]. This is due to the demand for anaerobic metabolism during stimuli[9,28], but it's important to note that even with this anaerobic demand, HIIT is predominantly aerobic[10,25], including critical intramuscular responses to increased oxidative metabolism through mitochondrial density (greater efficiency) and biogenesis (reproduction)[35].

Considering that lactate is an essential component in the intramuscular energy process[12,15], as well as in other important organs (e.g. heart and brain)[31,32], HIIT can be a positive intervention in the sense of enabling production/removal (by different pathways, e.g. liver and heart) and thus promoting more significant interaction of this metabolite with the physiological environment.

HIIT and lactate responses in some studies with short model protocols

In general, HIIT with short stimuli is methodologically conducted at maximum or supramaximum intensities[25,28], and therefore, there is a high lactate response[36] due to its high metabolic demand. For example, some studies have shown the repercussions of protocols with the same (short) characteristics on this important metabolite. Bogdanis *et al.*[37] used a protocol with only two stimuli, 30 seconds (75g.Kg^{-1}), plus a third 6-second stimulus (11 minutes after the second 30-second sprint). A 4-minute recovery period (active and passive) was used. Between the conditions (type of recovery), they observed no differences in lactate responses, but there was an approximate increase of 1.0 mmol. l^{-1} to 12.0 mmol. l^{-1}.

Among the control variables of HIIT, it is discussed that the type of recovery (active or passive) can influence the accumulation of lactate[38]. But, controversially, protocols with six 15-second stimuli (all out) with 3-minute active (80 rpm - 1kg) and passive recovery showed no difference in lactate (active rec: 9.09 ± 2.37 mmol. l^{-1}; passive rec: 10.05 ± 2.84 mmol. l^{-1}) after the protocol[39]. Furthermore, both active and passive recovery showed no differences in lactate (*P* >.05) after a short protocol containing two 15-second stimuli (120% maximum aerobic speed: MAS) with 15 seconds of recovery (the active one with 50% MAS), with values of 10.7 ± 2.0 mmol. l^{-1} for active recovery and 11.7 ± 2.1 mmol. l^{-1} for passive recovery[40]. In addition, 2 stimuli of 15 or 30 seconds (conditions carried out on different days) with three types of recovery (also carried out on different days) with 15 seconds, being active (20 and 40% maximum aerobic power) and passively generated a peak in lactate accumulation of 14.5 ± 2.8 mmol. l^{-1}, with all conditions having values close without significant differences (*P* >.05)[41].

Protocols with a progressive stimulus volume (every 2 weeks), starting with 6 (1st and 2nd week) and ending with 8 (5th and 6th week) of 30 seconds (120% MAS) with 3 to 5 minutes of active recovery (50w), did not alter the average lactate results (post-effort) in groups that performed 1 HIIT session per week (9.5 ±1.7 mmol. l^{-1}) to those that performed 2 weekly sessions (9.8 ± 2.9 mmol. l^{-1})[34].

HIIT and lactate responses in some studies with long-model protocols

Long protocols usually work with submaximal stimuli (close to thresholds)[9,10]. However, they also cause high responses in lactate production. Acala *et al.* (2020), using a protocol with 4 stimuli of 4 minutes (85-95% HR_{max}) with 3 minutes of active recovery (25% peak power output - PPO), showed discreet results in intra (9.3 ± 2.4 mmol. l^{-1}) and post (8.1 ± 2.2 mmol. l^{-1}) lactate. In another study with progressive stimulus volume (3 sessions per week), from 8 (1st week) to 10 (3rd week) of 1 minute (130% of ventilatory threshold = 70% PPO) with only 15 seconds of active recovery (10% PPO) they observed no differences (*P* >.05) in lactate between the first (10.5 ±2.2 mmol. l-^{1}) and ninth session (10.3 ± 2.2 mmol. l^{-1})[43].

Agnol *et al.* (2021) used four protocols with stimuli conducted at self-selected intensities (maximum possible levels): 1) 4 stimuli of 4 minutes for 1 minute of recovery, 2) 4 stimuli of 4 minutes for 2 minutes of recovery, 3) 4 stimuli of 8 minutes for 2 minutes of recovery and, 4) 4 stimuli of 8 minutes for 4 minutes of recovery. All protocols had active recovery at an intensity of between 80 and 100 w. Lactate was measured before and after the session (1, 3, 5, and 9 minutes). No differences (*P* >.05) were found between the mean and peak values, respectively, for protocols 1 (8.8 ± 4.1 mmol. l^{-1} and 11.3 ± 5.0 mmol. l^{-1}), 2 (9.0 ± 2.8 mmol. l^{-1} and 11.9 ± 3.4 mmol. l^{-1}), 3 (7.0 ± 2.8 mmol. l^{-1} and 8.6 ± 3.3 mmol. l^{-1}) and 4 (8.1 ± 3.4 mmol. l^{-1} and 9.6 ± 4.3 mmol. l^{-1}).

Another study carried out the interventions on a natural road (outdoors) with an equalized volume of 4800 meters: 1) 12 stimuli of 400 meters (with 15 seconds of passive recovery), 2) 6 stimuli of 800 meters (with 30 seconds of passive recovery) and 3) 3 stimuli of 1600 meters (with 60 seconds of passive recovery). This study was conducted with two groups: runners (R) and multi-sport athletes (MT: triathletes, mountain bikers, and skiers). After the sessions, the lactate values did not differ (*P* >.05) between the groups for protocols 1 (R: 16.7 mmol. l^{-1} and MT: 15.3 mmol. l^{-1}), 2 (R: 15.1 mmol. l^{-1} and MT: 14.6 mmol. l^{-1}) and 3 (R: 15.9 mmol. l^{-1} and MT: 16.5 mmol. l^{-1})[45]. Billat *et al.* (1999) observed a maximum lactate value of 8.4 ± 2.3 mmol with a training program with different stimuli. l^{-1}. The intensities of the programmed stimuli were related to speed related to VO_{2max} (vVO_{2max}) and speed related to the onset of blood lactate accumulation (vOBLA) and with active recovery at 60% vVO_{2max}.

Metabolic implications and interpretations of lactate behavior in different HIIT protocols

Despite some confusion, it is now well established that HIIT (and its sub-variations: SIT and RST) is aerobic[9,10,25]. Perhaps the reason for some confusion is that the stimulus is considered in isolation (which can have an anaerobic characteristic), whereas, when it comes to HIIT, the session as a whole is considered in terms of its metabolic power[36,46].

However, lactate can provide parameters for aerobic and anaerobic contribution[47,48]. However, in terms of types of protocols, in HIIT, one of the variables that can significantly define the energy contribution is the length of the recovery period[49], not being so restricted to its type, active or passive[38–40]. To this end, shorter recoveries increase the demand for aerobic input[9]. This is because the recovery time is insufficient to promote the resynthesis of energy (ATP) via glycolytic pathways, leading to a greater aerobic contribution[36,46,49]. These protocols tend to have a greater lactate accumulation because they promote a greater reduction in blood pH and H^+ ions[50]. Lactate, to a certain extent, tries to contain intramuscular acidosis using a mechanism called buffering, and also that in short recovery times, the ability to remove this lactate becomes more complex through different physiological pathways[12,15,16].

On the other hand, in HIIT, stimuli with a longer recovery time are more likely to optimize energy resynthesis via the glycolytic pathway, as there will be more time for this system to re-establish itself (wholly or partially) to perform high-intensity stimuli (mainly short stimuli: short HIIT)[9]. In this case, regarding the behavior of lactate, it tends to be the case that the longer the recovery time, the lower the accumulation of lactate[44]. Another issue is that HIIT can also promote greater anaerobic capacity, and this makes the system more efficient, providing more work for less energy expenditure, resulting in less lactate accumulation[47] and consequently improving the lactate threshold[34].

Finally, HIIT also improves intramuscular oxidative capacity[48,51], making the aerobic contribution efficient (in this case, regardless of the type of protocol) through cellular mechanisms, such as improved mitochondrial density[4,5,52], so less lactate will also be accumulated. However, a significant increase in lactate during maximal/supra-maximal stimuli can also occur because the lactate produced is being reused for intramuscular energy resynthesis, but this is a particular case in severe exercise in terms of intensity[36,46].

Study limitations

This study has some limitations, and perhaps the main one, even knowing that HIIT is predominantly aerobic[46], is the fact that there are no studies that have evaluated the energy contribution (aerobic and anaerobic) of high-intensity interval training sessions. Studies on this topic are scarce. Studies on this subject are scarce[47,48], making it more challenging to discuss and even assume specific explanations related to the metabolic mechanism of lactate responses in HIIT. Therefore, we believe that, even without being able to extrapolate or even expose more information, this review is composed of the necessary information for the understanding of this physiological phenomenon between HIIT and lactate to be absorbed. However, further studies on this subject are of the utmost importance to make the whole context of this essential mechanism even more solid, and it deserves attention at the time of prescription (coach) and training (coach and/or practitioner/athlete).

Conclusion

Based on an integrative review, this study aimed to discuss the behavior of lactate in different HIIT protocols and the state of energy metabolism. However, even though it is constrained (as not all studies have assessed levels of aerobic or anaerobic contribution), we can use lactate to guide energy demand as long as this interpretation is coherent and without extrapolation. In this way, this metabolite can help understand different HIIT protocols and thus help prescribe this type of training to achieve different objectives. Similarly, using lactate (for the same HIIT intervention), we can suggest an improvement in metabolic performance, for example, a lower accumulation of post-exercise lactate compared to previous interventions. This parameter is fundamental for assessing physiological and mechanical performance.

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Conflict of interest

The authors declare that they have no conflict of interest with this research.

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