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Are the swimming velocities at the lactate and glucose thresholds similar and well-related?

KEYWORDS:
Swimming. Evaluation. Aerobic metabolism. Lactate. Glucose.

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ABSTRACT

This study aimed to compare the swimming velocities at lactate and glucose thresholds, as well as to analyse their relationships. Eight trained swimmers performed in front crawl a 200m steps intermittent incremental test and a lactate minimum test. Lactate and glucose concentrations were identified at rest, during the intervals and at the end of the tests to compute the lactate/velocity and glucose/ velocity curves, and asses the corresponding lactate and glucose thresholds swimming velocities. Paired Student's *t*-test, Cohen's *d*, Pearson correlation and linear regression were applied for a $p < 0.05$. Lactate and glucose thresholds swimming velocities obtained in intermittent incremental and lactate minimum tests were different (1.46 ± 0.16 vs. 1.41 ± 0.15 $m \cdot s^{-1}$ and 1.42 ± 0.17 vs. 1.37 ± 0.17 $m \cdot s^{-1}$, respectively; $p < .05$), with large and moderate effect size values (respectively). However, lactate and glu-cose thresholds swimming velocities were highly related in both tests ($r = .96$; $p < .05$). Since current data indicate that lactate and glucose thresholds swimming velocities are not coin-cident, eventually not representing the same physiological boundary, further studies should be warranted to better understand their relations considering their application in swimmers' evaluation and training control.

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As velocidades de natação dos limiares de lactato e glicose são semelhantes e estão bem relacionadas?

RESUMO

Este estudo teve como objetivo comparar e relacionar as velocidades de nado crol correspondentes aos limiares de lactato e glicose. Oito nadadores treinados realizaram um teste incremental intermitente com patamares de 200 m e um teste de lactato mínimo (ambos na técnica de crol e separados por 48 h de intervalo). As concentrações de lactato e glicose foram identificadas em repouso, durante os intervalos e no final dos testes para calcular as curvas de lactato/velocidade e glicose/velocidade e, desta forma, identificar os limiares de lactato e glicose. Foram aplicados os testes *t* de Student pareado, *d* de Cohen, correlação de Pearson e a regressão linear para um $p < .05$. A velocidade ao limiar de lactato foi superior à do limiar de glicose (1.46 ± 0.16 vs. 1.41 ± 0.15 $m \cdot s^{-1}$ no protocolo incremental e 1.42 ± 0.17 vs. 1.37 ± 0.17 $m \cdot s^{-1}$ no teste de lactato mínimo; $p < .05$), com valores de tamanho de efeito grande e moderado (respetivamente). No entanto, essas velocidades de nado foram altamente relacionadas entre si em ambos os testes ($r = .96$; $p < .05$). Como os presentes dados indicaram que as velocidades de nado correspondentes aos limiares de lactato e glicose não são coincidentes, eventualmente não representando o mesmo limite fisiológico, novos estudos devem ser realizados para melhor compreensão das relações entre estes indicadores e sua aplicação na avaliação e controlo do treinamento de natação.

PALAVRAS-CHAVE:
Natação. Avaliação. Metabolismo aeróbio. Lactato. Glicose.

INTRODUCTION

The energy requirements for optimal performance depend on the race duration and intensity, with blood lactate concentrations ([La-]) measurements being frequently used for exercise intensity control and performance prediction (Billat, 1996; Gladen, 2004; Carvalho et al., 2020). Specifically in swimming, it is consensual that the relationship between [La-] and velocity is very useful for performance assessment (Fernandes, Sousa, Machado & Vilas-Boas, 2011; Olbrecht, Madsen, Mader, Liesen & Hollmann, 1985; Simon, 1997). In fact, the anaerobic threshold was defined more than 30 years ago as the highest exercise intensity allowing a balance between lactate production and its removal (Heck et al., 1985; Simon, 1997; Wasserman et al., 1963), corresponding to the upper limit of the moderate intensity domain (de Jesus et al., 2016; Ribeiro et al., 2017). Fixed values of 3.5 and 4 mM of [La-] (Fernandes et al., 2010; Heck et al., 1985; Mader, Heck, Hollmann, 1978), determined by interpolating the [La-]/velocity curve, have been accepted as standard for anaerobic threshold assessment in swimming and, since this threshold is determined using [La-], it is also known as lactate threshold (Colantonio & Kiss, 2007; Denadai, Greco & Teixeira, 2000).

Increased production and utilization of La- represent the response to enhanced glycolytic flux elicited by a rise in work rate and, when [La-] starts accumulating exponentially in the arterial blood, the lactate threshold takes place. It is well-recognized that elevated [La-] indicates that the rate of lactate production or appearance has exceeded the values of disposal or disappearance (Poole, Rossiter, Brooks & Gladen, 2020). Lactate constitute an important energetic substrate via oxidation in multiple tissues, including contracting skeletal muscles (75-80%) and heart (Bergman et al., 1999), as well as serving as a gluconeogenic precursor (Bergman et al., 2000). Subsequently, concepts of anaerobic, lactate and ventilatory thresholds are pervasive in the literature, representing key concepts in basic and applied physiology, sports and pulmonary medicine (Brooks et al., 2021).

The metabolic threshold has been identified using other physiological indicators through blood glucose threshold tests, comparing and relating lactate and glucose thresholds in running (Simões, Campbell, Kokubun, Denadai & Baldissera, 1999) and resistance exercise (Moreira et al., 2008). Even if glucose threshold related studies are significantly fewer than those focusing on lactate threshold determination, modifications in its values were observed during military training (Rocha, Canellas, Monteiro, Antoniazzi & Azevedo, 2010) and in young adults running (Motoyama et al., 2014). However, it is still unclear whether swimming intensity at lactate and glucose thresholds is similar, with one study concluding that the lowest blood glucose concentration [Gluc] is a good predictor of the swimming metabolic threshold (Ribeiro, Baldissera, Balakian & Soares, 2004) and the other describing a lactate threshold improvement after 10 weeks of swimming training with a stable [Gluc] response (Sengoku, Nakamura, Takeda, Nabekura & Tsubakimoto, 2011).

Swimming velocity is a coach friendly variable to be used for intensity control (Olbrecht, Madsen, Mader, Liesen & Hollmann, 1985; Pelarigo et al., 2018), meaning that the velocities corresponding to lactate and glucose thresholds (vLT and vGT) could be interesting tools for monitoring swimmers and controlling the training process. Trying to overcome the above-referred literature gap, the current study aimed to compare and relate vLT and vGT obtained through previously validated and currently used intermittent incremental and lactate minimum tests. It was hypothesized that vLT and vGT represent a similar swimming intensity and are positively related indicating the same physiological boundary.

MATERIAL AND METHODS

PARTICIPANTS

Eight aerobically trained swimmers (six males and two females) participated in the current study. Their main physical and training level characteristics were 25.0 ± 7.5 years old, 66.9 ± 7.3kg, 174.0 ± 10.0cm, 6.0 ± 2.8% of body fat, 125.8 ± 14.3s at 200m freestyle best time, 16.0 ± 6.7 and 13.0 ± 5.0 years of swimming and competitive practice, 10.0 ± 2.7 competitions per year, 7.1 ± 2.0 training session per week and 202.5 ± 119.7min and 10.5 ± 5.5km per training session. The inclusion criteria were having ≥ four years of competitive swimming experience and to be involved in a systematic training program of five-six weekly sessions.

INSTRUMENTS AND PROCEDURES

All participants were informed about the experimental procedures and signed a free and informed consent form. This study was approved by Research Ethics Committee of the Federal University of São Paulo (Nº 52850816.5.0000.5505) conforming to the Code of Ethics of the World Medical Association (Declaration of Helsinki). The swimmers' diet was controlled by asking them to maintain a similar nutritional content the day before each testing session. On the testing day swimmers did not train and use any type of supplementary food.

Tests were performed at the swimmers' usual 25m outdoor training pool (27.1 ± 1.0° and 23.6 ± 1.6°C of water and air temperatures), at the same time of day, in a three weeks period. After assessing height, body mass and skinfolds (subscapular, triceps, pectoral, supra iliac, thigh and abdominal), body mass index and body composition were determined by estimating the body fat percentage (Gordon, Chumlea, & Roche, 1988). After warming-up at low-moderate intensity, swimmers performed in front crawl and using in-water starts and flip turns (with a 48h rest period in-between): (a) an intermittent incremental test with 200m steps, 0.05 $m \cdot s^{-1}$ velocity increments and 60s intervals, with the initial velocity corresponding to each swimmer individual performance at the 200m front crawl minus seven increments (Fernandes et al., 2010; Fernandes, Sousa, Machado, & Vilas-Boas, 2011; de Jesus et al., 2016); and (b) a lactate minimum test, comprising 2 x 50m all-out bouts (with a 60s interval) plus 5 x 200m at 80, 84, 88, 92 and 96% of each swimmer individual performance at the 200m front crawl (adapted from Mezzaroba & Machado, 2013). Swimmers individual pace was controlled by visual and audible signals.

Blood samples for [La-] and [Gluc] determination were collected at rest, during the intervals and at the end of the tests through a finger puncture using Accutrend Plus® (Roche Diagnostics, Mannheim, Germany) and Breeze 2 Bayer® (Bayer AG, Leverkusen, Germany) electrochemical analyzers. The lactate and glucose thresholds determination (and the corresponding vLT abd vGT assessment) took place through visual inspection of the [La-] and [Gluc] curves by two independent and experienced evaluators. The intensity at which there was a loss of linearity with an abrupt and exponential increase of the lactatemia curve was considered to be the lactate threshold and the intensity at which the blood [Gluc] curve showed the lowest point was considered the glucose threshold (Simões, Campbell, Kokubun, Denadai, & Baldissera, 1999; Tegtbur, Busse & Braumann, 1993) independently blood lactate response. In Figures 1 and 2 it is possible to see some individual examples of vLT and vGT determination in both experimental tests.

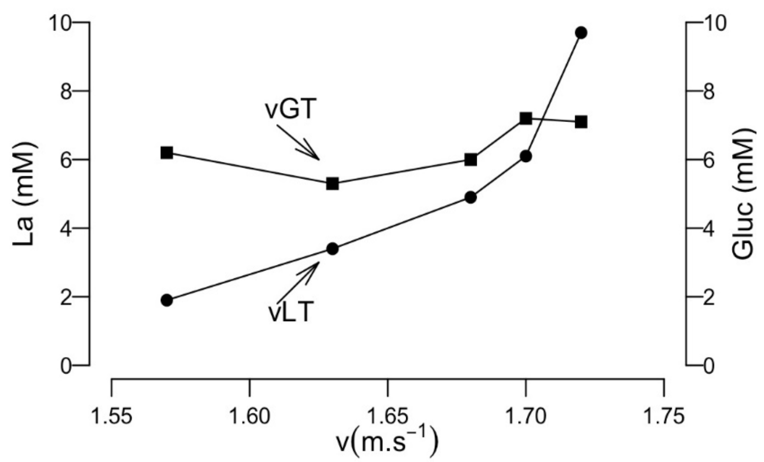

FIGURE 1. Example of individual [La-]/velocity and [Gluc]/velocity curves in the intermittent incremental test for anaerobic threshold assessment (represented by the interception of a linear and an exponential line).

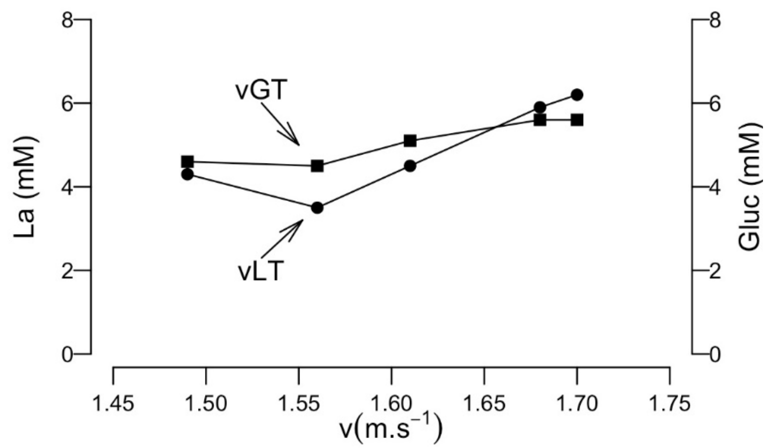

FIGURE 2. Example of individual [La-]/velocity and [Gluc]/velocity curves in the lactate minimum test protocol for anaerobic threshold assessment (represented by the lowest glucose point).

DATA ANALYSIS

Data normal Gaussian distributions were verified by the Shapiro-Wilk test and results were expressed as mean values ± standard deviations (*SD*) and 95% of the mean confidence intervals (95%CI). Paired Student *t*-test was used to compare vLT and vGT in each test. Effects sizes were identified with the Cohen *d* for paired data and were interpreted with the following criteria (Hopkins, 2002): 0–0.19 trivial, 0.2–0.59 small, 0.6–1.19 moderate, 1.2–1.99 large, 2.0–3.99 very large and > 4.0 nearly perfect. The relation between the vLT and vGT was tested with the Pearson correlation test and a linear regression between vLT and vGT was also applied. Statistical significance was set at $p < .05$.

RESULTS

The obtained vLT and vGT values are presented in table 1. It can be observed that, independently of the experimental conditions, the first was higher than the latter variable, with large and moderate effect sizes being observed for the intermittent incremental and the lactate minimum tests (respectively). The scattergrams between vLT and vGT in both testing situations are displayed in figure 3, with strong direct relationships being displayed. A positive vLT-vGT linear behavior is also possible to be observed in both tests.

TABLE 1. Mean ± *SD*, 95% of the mean confidence intervals (95% CI), mean difference (diff) and effects sizes (ES) of the vLT and vGT at both experimental conditions

	INTERMITTENT INCREMENTAL TEST				LACTATE MINIMUM TEST			
	vLT ($M \cdot S^{-1}$)	vGT ($M \cdot S^{-1}$)	DIFF ($M \cdot S^{-1}$)	ES	vLT ($M \cdot S^{-1}$)	vGT ($M \cdot S^{-1}$)	DIFF ($M \cdot S^{-1}$)	ES
Mean ± SD	1.46 ± 0.16	1.41 ± 0.15	0.04 ± 0.02*	2.0	1.42 ± 0.17	1.37 ± 0.17	0.05 ± 0.04**	0.9
95% CI	1.32 - 1.60	1.28 - 1.55	0.02 - 0.06	large	1.27 - 1.56	1.22 - 1.51	0.009 -0.09	moderate

* $t_7 = 5.49$; $p = .001$; ** $t_7 = 2.82$; $p = .026$

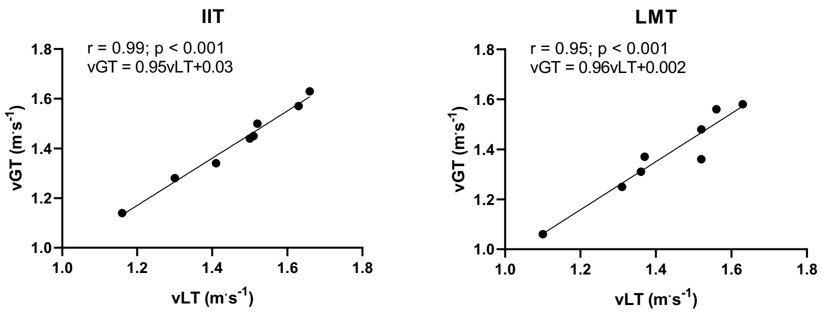

FIGURE 3. Scattergram between vLT and vGT in intermittent incremental and lactate minimum tests (*n* = 8).

DISCUSSION

The current study aimed to compare swimmers vLT and vGT through frequently used monitoring protocols. vLT was higher than vGT for the intermittent incremental and lactate minimum tests (with large and moderate effects sizes, respectively), but these variables were highly and directly related. The fact that the tests indicated different velocities corresponding to lactate and glucose thresholds might limit their indiscriminate use to identify swimmer's anaerobic threshold contrary to previous results (Ribeiro, Baldissera, Balakian, & Soares, 2004; Simões, Campbell, Kokubun, Denadai, & Baldissera, 1999). The use of the swimming intermittent incremental test (Anderson, Hopkins, Roberts, & Pyne, 2006: Costa et al., 2013; Fernandes et al., 2010) and the lactate minimum test (Kalva-Filho et al., 2018; Mezzaroba & Machado, 2013) for the assessment of the anaerobic threshold is a valid procedure for diagnostic purposes, being considered reliable and valid methodologies (Kalva-Filho et al., 2018).

A previous study conducted with national and international level swimmers performing a graded sub-maximal test indicated that [Gluc] profiles and the identification of the glucose threshold were not linked to the lactate threshold (Swanwick & Matthews, 2017). In fact, glucose threshold may be an effective tool for the observation of the exercise intensity that is independent of the mechanisms underlying anaerobic threshold and might be used more frequently since is obtained by a low cost and practical test. The current study presented very high correlation values ($r > .95$; $p < .001$) between vLT vs vGT for the intermittent incremental and lactate minimum tests, although their values were statistically different.

The use of blood lactate measurements for exercise performance prediction and training control is widely spread, with its values being frequently used to determine training intensity (Anderson, Hopkins, Roberts & Pyne, 2006; Billat, 1996; Colantonio & Kiss, 2007; Heck et al., 1985; Pelarigo, Machado, Fernandes, Greco & Vilas-Boas, 2017). Even though the lactate production from glucose is also recognized, there is few scientific evidence showing that it can be directly connected with the body reaction to [Gluc] during varied intensities exercise. During exercise of low and medium intensity, [Gluc] usually remains stable, with a tendency to decrease during prolonged efforts. However, increasing intensity exercise > 90 min may cause a significant decrease in [Gluc], a process that is regulated by insulin that might inhibits glycogenolysis and gluconeogenesis (Bergman et al., 2000; Brooks et al., 2021; Maughan et al., 1997; Swanwick & Matthews, 2017).

Anaerobic threshold is the term used to express the exercise intensity when there is an abrupt increase in creatine phosphate hydrolysis and glycolysis, resulting in increased lactate production and decrease in muscle creatine phosphate (Robergs & Roberts, 1997). Stimulation of the glucose uptake may occur prior to the glucose threshold confirmed by the [Gluc] reduction driven by muscle contraction and followed an increased [Gluc] uptake by stimulating Glut4 carrier proteins to proliferate to the cell membrane (Cortright & Dohm, 1997). Therefore, it seems that the glucose threshold occurs before the lactate threshold, supporting the current study data, which can be due to these mechanisms: (a) uptake of blood glucose vs. muscle fibers type (Stanley, Wisneski, Gertz, Neese & Brooks, 1988); (b) exercise intensity vs. blood Gluc uptake (Howlett et al., 1998); (c) increased rate of glycolysis vs increased muscle glycogen usage (Green, Hughson, Orr & Ranney, 1983); and (d) [Gluc] rise vs greater glucose release from the liver due to increased catecholamines (Coggan et al., 1992).

One possible explanation for the [Gluc] and [La-] behavior at the intermittent incremental and lactate minimum tests was the adrenergic activity increase. Adrenaline and glucagon are responsible by blood [Gluc] enhancement during exercise, with the adrenaline activity promoting the most potent and rapid control of glycogenolysis during exercise according to its intensity. In fact, it was suggested long ago that there is a threshold intensity for high adrenergic activation and that adrenaline stimulates both glycogenolysis and lactate production during exercise (Stainsby, Brechue, & O'Drobinak, 1991).

Progressive incremental tests are commonly used to assess swimmers' physiological adaptations mainly by measuring [La-] and heart rate over a range of intensities and culminating in a maximal effort. Relationships between [La-] and velocity have been widely used to monitor swimmers training state of by identifying a velocity at a fixed blood [La-] or lactate threshold (Anderson, Hopkins, Roberts & Pyne, 2006). In the current study, the vLT and vGT mean values were very highly related when assessed using the intermittent incremental test achievement and its difference was of only 0.04 ± 0.02 m·s^{-1} (with a large effect size, *d* = 2).

Alternatively, lactate minimum test may be interesting to evaluate the aerobic fitness through the lactate minimum intensity (Dotan et al., 2011), since this velocity is estimated using only a single maximal swimming performance (Kalva-Filho et al., 2018; Mezzaroba & Machado, 2013; Ribeiro, Balikian, Malachias, & Baldissera, 2003). This approach is independent of muscular glycogen content and is a reliable procedure (Kalva-Filho et al., 2018). Previous studies evidenced that the minimum [Gluc] occurred at the same intensity as vLT in runners (Simões, Campbell, Kokubun, Denadai & Baldissera, 1999), type 2 diabetes subjects (Moreira et al., 2008), soldiers (Rocha, Canellas, Monteiro, Antoniazzi, & Azevedo, 2010) and active young adults (Motoyama et al., 2014). In the current study, when using the lactate minimum test, the vLT and vGT were not coincident (with a moderate effect size, *d* = 0.9) even if highly related in-between.

It was previously hypothesized that maximal lactate steady state could be predicted using two short-duration high-intensity efforts followed by an active recovery period and several submaximal workloads of progressively increasing intensity (Tegtbur, Busse, & Braumann, 1993). In this test, since the hyperlactatemia induction phase has a "U" shape, its lowest value theoretically represents the highest intensity of balance between appearance and removal of blood lactate (Ribeiro, Baldissera, Balikian, & Soares, 2004; Simões, Campbell, Kokubun, Denadai, & Baldissera, 1999). The vLT at lactate minimum test is the moment in which blood lactate reaches a minimal value (Ribeiro, Baldissera, Balikian, & Soares, 2004).

It has been shown that, during an incremental exercise, [Gluc] decreases until lactate threshold is attained and increase thereafter (Kalva-Filho et al., 2018; Simões, Campbell, Kokubun, Denadai & Baldissera, 1999). This [Gluc] rise is attributed to higher sympathetic activity, leading to a greater rate of liver glycogenolysis. Therefore, the exercise intensity at which the [Gluc] begins to increase during the incremental test is called the individual glucose threshold and has been observed in other studies (Pyne, Lee & Swanwick, 2001; Ribeiro, Baldissera, Balikian & Soares, 2004; Rocha, Canellas, Monteiro, Antoniazzi & Azevedo, 2010). In the current study, it was verified a high relationship between vLT and vGT in both experimental protocols, supporting the idea of applying the lactate-glucose minimum test for identifying the swimmers' anaerobic threshold velocity.

The anaerobic threshold determination using [La-] has been frequently used for the aerobic capacity monitoring and to determine exercise intensities for training and scientific investigation (Pyne, Lee & Swanwick, 2001; Simões, Campbell, Kokubun, Denadai & Baldissera, 1999). The lactate threshold assessment requires expensive equipment, specialized staff, invasive procedures and calibration procedures before testing. On the other hand, glucose threshold testing could be used more often since it presents several benefits as it is a practical and inexpensive technique (which is relevant especially in contexts of unfavorable economic conditions). In addition, since the mechanisms associated with glycolysis and lactate accumulation seem to take place prior to observable increases in blood lactate (Green, Hughson, Orr, & Ranney, 1983; Swanwick & Matthews, 2017), the glucose threshold assessment could be a nice alternative for ensuring the correct prescription of swimming training intensities.

CONCLUSIONS

The vLT and vGT were not similar, presented large and moderate effects sizes (for intermittent incremental and lactate minimum tests, respectively) and were highly related in-between. Although these findings might be affected by swimmers' characteristics and conditions (such as prior feeding, training state and muscle fiber expression and recruitment pattern), it is expected that by setting up more stringent testing conditions this variation could be greatly diminished. Further studies should be warranted to better understand these physiological mechanisms in different exercise conditions and swimmers' groups.

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Implicações do estado maturacional no desempenho físico e tático de jovens futebolistas: Projeto INEX.

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RESUMO

O presente estudo teve como objetivo perceber as implicações dos diferentes estatutos maturacionais (Pré-PVC, PVC e Pós-PVC) no desempenho físico (i.e., velocidade 30 metros; agilidade; e salto horizontal) e tático ofensivo de jovens futebolistas. Participaram na investigação 84 jovens jogadores de futebol do sexo masculino (Pré-PVC, *M* = 12.81± 0.50; PVC, *M* = 13.95 ± 0.78; Pós-PVC, *M* = 14.67 ± 0.63), que foram avaliados por meio de uma bateria de testes físicos, e pelo Sistema de Avaliação Tática no Futebol (FUTSAT) em situação de jogo reduzido GR + 4 X 4+GR. Utilizou-se uma análise exploratória para verificar a normalidade dos dados (Kolmogorov-Smirnov), e recorreu-se ao teste estatístico ANOVA com Pós-Teste de Tukey (p <.05) para verificar as diferenças entre os grupos. Os resultados indicam que o desempenho físico na velocidade 30m e no salto horizontal é superior no grupo Pós-PVC em relação aos Pré-PVC, e nos jogadores PVC quando comparados com os Pré-PVC. Por sua vez, os três grupos relativos ao estatuto maturacional dos jogadores não evidenciaram diferenças estatisticamente significativas quanto ao desempenho tático. Os jogadores em estágios maturacionais avançados (PVC e Pós-PVC) são mais rápidos em 30 metros e apresentam resultados superiores no salto horizontal em relação aos Pré-PVC. Os jogadores que ainda não alcançaram o PVC parecem criar adaptações constantes na sua forma de jogar para equilibrarem o desempenho com os jogadores em estágios maturacionais avançados. Sugere-se que o planeamento do processo de treino se realize de forma coordenada em relação às necessidades individuais dos jogadores, em particular que os treinadores atendam ao efeito da maturação sobre o desempenho físico.

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