Reliability of estimating maximal glycolytic power using the maximal lactate accumulation rate (VLamax): a systematic review

Fiabilidad de la estimación de la potencia glucolítica máxima mediante la tasa máxima de acumulación de lactato (VLamax): una revisión sistemática

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How to cite in APA

Fernandez-Jarillo, I., & Lomero-Arenas, T. (2025). Fiabilidad de la estimación de la potencia glucolítica máxima mediante la tasa máxima de acumulación de lactato (VLamax): una revisión sistemática. *Retos*, *66*, 448–455. https://doi.org/10.47197/retos.v66.110040

Abstract

Introduction: In recent years, maximal lactate accumulation rate (VLa_{max}) has received increasing attention as an estimator of maximal glycolytic power. The VLa_{max} could enhance physiological profiling by aiding in athlete assessment, training prescription, and talent identification.
Objective: This systematic review aims to synthesize and analyse studies that have assessed the reliability of the VLa_{max} as a representative parameter of maximal glycolytic power in healthy adult subjects.
Methodology: The proposed PICO question was: Is VLa_{max} a reliable metric for estimating maximal glycolytic power in healthy adults? Systematic literature searches on PubMed, Google Scholar, Scopus, SPORTDiscus and Web of Science were conducted. Five articles were included. The quality of the included articles was assessed using a modified Downs and Black Checklist.
Results: All articles were considered to be high quality (76,9-84,6%). The intraclass correlation coefficient (ICC) of VLa_{max} was 0.66-0.96.
Discussion: The reliability of VLa_{max} is influenced by factors that affect lactate accumulation and the estimation of alactic time. VLa_{max} strongly correlates with the power or speed of maximal efforts lasting 20-31 seconds, aligning with the glycolytic energy system's peak contribution range.
Conclusions: This systematic review shows that the VLa_{max} estimates maximal glycolytic power with moderate to excellent reliability, although further research is needed to better understand this metric: the most appropriate test to determine it in a practical way, its relationship with other markers of anaerobic performance, its response to certain training methods and its influence on maximal metabolic steady state, among others.

Keywords

Exercise; lactate; metabolism; performance; physiology.

Resumen

Introducción: En los últimos años, la tasa máxima de acumulación de lactato (VLa_{max}) ha recibido una atención creciente como estimador de la potencia glucolítica máxima. El VLa_{max} puede mejorar el análisis fisiológico al optimizar la evaluación del rendimiento de los atletas, la planificación de entrenamientos personalizados y la detección de talento.
Objetivo: Esta revisión sistemática tiene como objetivo sintetizar y analizar estudios que han evaluado la fiabilidad del VLa_{max} como un parámetro representativo de la potencia glucolítica máxima en sujetos adultos sanos.
Metodología: La pregunta PICO propuesta fue: ¿Es el VLa_{max} un parámetro fiable para estimar la potencia glucolítica máxima en adultos sanos? Se realizaron búsquedas bibliográficas sistemáticas en PubMed, Google Scholar, Scopus, SPORTDiscus y Web of Science. Se incluyeron cinco artículos. La calidad de los artículos incluidos se evaluó mediante una escala modificada de Downs y Black.
Resultados: Todos los artículos fueron considerados de alta calidad (76,9-84,6%). El coeficiente de correlación intraclase (ICC) del VLa_{max} fue de 0.66-0.96.
Discusión: La fiabilidad del VLa_{max} se ve influenciada por factores que afectan a la acumulación de lactato y el cálculo del tiempo aláctico. El VLa_{max} muestra una fuerte correlación con la potencia o velocidad de esfuerzos máximos de 20 a 31 segundos, coincidiendo con el rango de máxima contribución del sistema energético glucolítico.
Conclusiones: Esta revisión sistemática muestra que el VLa_{max} estima la potencia glucolítica máxima con una fiabilidad de moderada a excelente, aunque se necesita más investigación para comprender mejor esta métrica: la prueba más adecuada para determinarlo de manera práctica, su relación con otros marcadores del rendimiento anaeróbico, su respuesta a ciertos métodos de entrenamiento y su influencia en el estado metabólico estable máximo, entre otros.

Palabras clave

Ejercicio; fisiología; lactato; metabolismo; rendimiento.

Introduction

Physical performance, when explained in terms of metabolism, results from the transformation of metabolic power into mechanical power with a certain metabolic efficiency (Rodriguez & Mader, 2011). Metabolic power, in turn, arises from the interaction between different energy systems, including the phosphagen system, glycolytic system, and aerobic system.

Performance in competition remains the ultimate goal, but relying solely on this outcome does not provide a full understanding of the factors that enable an athlete to achieve it. It is common to find athletes with similar performance levels but markedly different physiological characteristics. These individual profiles indicate that each athlete requires a distinct training approach to maximize progress in their sporting career (Kozina et al., 2015).

The evolution of physiological assessments over time facilitates the understanding of an athlete's individual physiological profile. Since the discovery of maximal oxygen consumption (VO2max) between 1923 and 1925 by Archibald Vivian Hill, researchers have focused on this parameter. By the mid-20th century, VO2max assessments had become standardized (Taylor et al., 1955). Simultaneously, studies on lactate kinetics during exercise emerged. Initially, steps were taken in the wrong direction, and it was believed that lactate was the waste product of glycolysis and was formed when less oxygen than necessary reached the muscles during exercise (Hill et al., 1924). However, current knowledge establishes that lactate functions as an energy substrate, a gluconeogenic precursor, and a signaling molecule (Brooks et al., 2022). Additionally, there is now a clear understanding that lactate constantly shuttles between glycolytic-producing and oxidative-consuming cells (Brooks, 2018).

In endurance sports, aerobic metabolism remains the primary focus of performance assessments, often neglecting the contribution of the glycolytic system to energy generation for muscle contraction. VLamax is thought to represent the maximal rate of lactate production, but it seems impossible to assess in vivo for several reasons. Firstly, lactate may be used within the same muscle fiber that produced it, preventing its appearance in the blood (Brooks, 2018). Secondly, lactate concentrations in muscle and blood differ (Tesch et al., 1982). Thirdly, lactate concentrations reflect the balance between production and clearance, a concept known as the "Lactate Shuttle Theory" (Brooks, 2018). Given these challenges, VLamax should be defined as the maximal rate of lactate accumulation rather than lactate production, since differentiating between production and clearance is not feasible. Research confirms that different combinations of VO2max and VLamax can produce identical lactate curves with equal lactate thresholds (Mader & Heck, 1986).

VLamax has the potential to significantly enhance the physiological profiling of athletes, offering potential applications in assessment, training prescription, and talent identification. However, its practical implementation remains contentious due to limitations associated with lactate measurement, including the effects of prior nutritional status, exercise timing, and post-exercise sampling protocols, all of which may influence the reliability of VLamax (Buchheit & Laursen, 2013).

This systematic review aims to synthesize and analyse studies that have assessed the reliability of VLamax as a representative parameter of maximal glycolytic power in healthy adult subjects. Establishing the reliability of this parameter is crucial for determining its validity in performance evaluation, training optimization, and metabolic profiling.

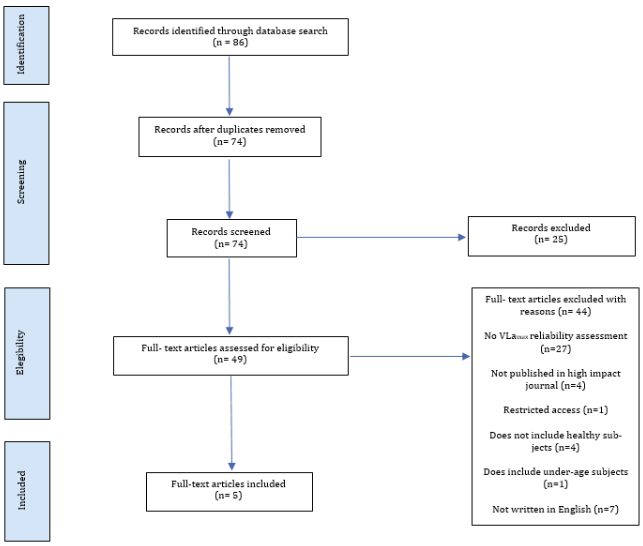
Method

We conducted a systematic literature search following the PRISMA guidelines. The search was performed between January and March 2024 across the electronic databases PubMed, Scopus, Google Scholar, SPORTDiscus, and Web of Science. The search strategy used the keywords "VLamax", "VLa max", "reliability" and "maximal lactate accumulation rate" with Boolean operators (OR and AND). The exact search syntax was: "VLamax" OR "VLa max" OR "maximal lactate accumulation rate" AND "reliability". All results were extracted and imported into a reference manager (Mendeley).

We used the following inclusion criteria: (1) only full articles published in English by high impact journals; (2) only quantitative, observational and experimental studies were considered; (3) only studies with healthy adult subjects were included. We used the following exclusion criteria: (1) studies published in a language other than English were excluded; (2) studies that could not be accessed due to lack of access to the full text were also excluded. The search had no date restriction. Screening was performed following the inclusion and exclusion criteria outlined above and duplicate articles were removed. The articles obtained from the screening were read in full. The finally selected articles were then assessed by I.F. and T.L. using the Downs and Black Checklist (Downs & Black, 1998). A modified Downs and Black Checklist was used because several items of the original checklist did not apply to the selected studies. For this review, studies were considered as high, medium or low quality if the score obtained was respectively >75%, 60-75% and <60% (Bonetti et al., 2019).

An Excel document was used for data extraction. From each manuscript selected for review, the following information was considered: authors, date of publication, sport, sample size, participant characteristics, VLamax assessment protocol, VLamax equation, equation for the alactic time (Talac), results and conclusions.

Figure 1. PRISMA flow chart of study identification and eligibility for the systematic review.



Results

After removal of duplicates, 74 records were identified, which were reduced to 49 after screening titles, abstracts and keywords for eligibility (Fig 1). After full-text evaluation, 5 studies matched the selection criteria. These studies underwent a quality assessment (Table 1) and were subsequently summarized (Table 2). The publication dates of the included articles ranged from 2020 to 2024. While the concept of VLamax has been present in literature since the 1980s (Mader & Heck, 1986), studies evaluating its reliability have only emerged in recent years.

A total of 99 subjects (31 women and 68 men) participated across the included studies. Moreover, athletes from various sports were included (rowing, running, cycling and hand cycling).

The quality of the included articles was assessed using a modified Downs and Black Checklist (Table 1). All articles were considered to be high quality (76,9-84,6%).

Table 1. Assessment of quality with a modified Downs and Black Checklist (Downs & Black, 1998).

	Held et al., 2024	Quittmann et al., 2020	Quittmann et al., 2021	Harnish et al., 2023	Quittmann et al., 2021
Q.1	1	1	1	1	1
Q.2	1	1	1	1	1
Q.3	1	1	1	1	1
Q.5	0	0	0	0	0
Q.6	1	1	1	1	1
Q.7	1	1	1	1	1
Q.10	1	1	1	1	1
Q.11	1	1	1	1	1
Q.12	1	1	1	0	0
Q.16	1	1	1	1	1
Q.18	1	1	1	1	1
Q.20	1	1	1	1	1
Q.25	0	0	0	0	0
Points	11	11	11	10	10
Score (%)	84,6%	84,6%	84,6%	76,9%	76,9%

Table 2. Studies analyzing VLa_{max} reliability included in the present systematic review.

Study	Sport	Sample	Participants	VLa_{max} and T_{alac} equation	Protocol	Results	Conclusions
Held et al., 2024	Rowing	n=17	Trained women (n=8); age: 17.7±6.1 yrs; VO_{2max}: 46±15 ml·kg $^{-1}$·min $^{-1}$ and trained men (n=9); age: 21.3 ±6.7 yrs; VO_{2max}: 61±7 ml·kg $^{-1}$·min $^{-1}$	$VLa_{max} = (La_{max} - La(0)) / (t_{test} - t_{alac})$ T_{alac} = 4s as indicated for the test of 20s (Heck et al., 2003)	Two 20-second all-out rowing sprint tests separated by one week (T1 and T2). Standardized low-intensity warm-up of 10 minutes at a low intensity/heart rate (corresponding to a blood lactate concentration of 2 mmol/L) before the 20-second all-out tests, followed by five minutes of passive rest while seated. Blood lactate concentration was measured before and after the all-out exercise as well as every minute after exercise for 15 minutes.	The paired t-test revealed no significant difference (p ≥0.11; SMD≤0.25) between both testing days for VLa_{max}, ICC for VLa_{max} was 0.85 (0.65-0.94).	The VLa_{max} testing procedure in rowing revealed an excellent intraclass correlation and low standard error of measurement for between-day reliability of VLa_{max}. High correlations between VLamax and rowing power indicated that VLa_{max} might be a promising parameter of anaerobic lactic power testing.
Quittmann et al., 2020	Running	n=16	Middle distance competitive runners. Women (n=5) and men (n=11); age: 23.1±2.9 yrs, weekly total volume of 10.7±1.8 hours and training experience of 10±6 yrs.	$VLa_{max} = (La_{max} - La(0)) / (t_{test} - t_{alac})$ T_{alac} determined as the period when power output decreased by 3.5% ($t_{pmax-3.5\%}$) (Hauser et al., 2014).	Performed an all-out 100-m sprint test on each of the three testing sessions (T1, T2 and T3), which were separated by 48 hours. As a standardized warm-up, every session started with five minutes of low intensity jogging at a self-paced velocity. Afterwards, the participants performed five minutes of running drills. At the end of the warm-up, the participants performed three almost maximal starts for 10m to 15m starting every 90 seconds followed by five minutes of passive rest while seated. Blood lactate samples were collected before and after the all-out exercise as well as every minute after exercise for 10 minutes.	100m time was measured using a stopwatch (SW), a photoelectric light barrier (LB) and a laser velocity guard (LAVEG). ICC for VLa_{max} was different depending on the 100m measurement system. ICC VLa_{max-SW}: 0.89-0.96 ICC VLa_{max-LB}: 0.90-0.96 ICC $VLa_{max-LAVEG}$: 0.91-0.93	$\dot{V}La_{max}$ and sprint performance parameters can easily and highly reliably be measured using this sport-specific field test in running. Sprint performance parameters demonstrate a close relationship to measures of lactate response.
Quittmann et al., 2021	Running and cycling	n=18	Competitive triathletes. Women (n=3) and men (n=15); age: 25.1±2.8 yrs, weekly total volume of 11.6±4.3 hours and training experience of 6.7±4.7 yrs.	$VLa_{max} = (La_{max} - La(0)) / (t_{test} - t_{alac})$ T_{alac} determined as the period when power output decreased by 3.5% ($t_{pmax-3.5\%}$)	The participants performed two all-out exercise tests in each exercise modality (cycling and running) within a two-week period. To ensure full recovery between tests in cycling and running, exercise tests in cycling were performed on Mondays, whereas exercise tests in running were performed on Fridays. In cycling, 15-second all-out tests were performed. Standardized low-intensity warm-up of 10 minutes (at 100 W), including three acceleration bursts of ten seconds (linearly up to 500W). After the warm-up, participants performed a passive rest for 5 minutes in seated position. The participants performed a 100-m sprint test on an indoor track, including a standardized warm-up of 15 minutes (Quittmann et al., 2020). Blood lactate samples were collected before and after the all-out exercise as well as every minute after exercise for 10 minutes.	$\dot{V}La_{max}$ demonstrated good reliability in cycling and running. The mean difference between trials of $\dot{V}La_{max}$ in cycling was -0.003 mmol·l $^{-1}$·s $^{-1}$ with limits of agreement ranging from -0.149 to + 0.143 mmol·l $^{-1}$·s $^{-1}$. In running, the mean difference between trials was -0.022 mmol·l $^{-1}$·s $^{-1}$ with limits of agreement ranging from -0.181 to + 0.137 mmol·l $^{-1}$·s $^{-1}$.	$\dot{V}La_{max}$ is highly reliable in both exercise modalities and higher in running compared to cycling.

Note: VO_{2max} = maximal oxygen consumption, VLa_{max} = maximal lactate accumulation rate, La_{max} = maximum lactate, t_{alac} = alactic time, t_{test} = test time, $t_{pmax-3.5\%}$ = time until power output decreased by 3.5% from peak power, La (0): pre-test blood lactate.

Q.1: Is the hypothesis of the study clearly described?

Q.2: Are the main outcomes to be measured clearly described in the introduction or in the methods section?

Q.3: Are the characteristics of the subjects included in the study clearly described?

Q.5: Are the distributions of the main confounding factors in each group of subjects to be compared clearly described?

Q.6: Are the main findings of the study clearly described?

Q.7: Does the study provide estimates of random variability in the data for the main outcomes?

Q.10: Have the actual probability values been reported for the main outcomes except where the probability value is less than 0.001?

Q.11: Were the subjects asked to participate in the study representative of the entire population from which they were recruited?

Q.12: Were the subjects willing to participate representative of the entire population from which were recruited?

Q.16: If any of the study results were based on "data dredging" was this made clear?

Q.18: Were the statistical tests used to assess the main results adequate?

Q.20: Were the main outcome measures used accurate (valid and reliable)?

Q.25: Was there adequate adjustment for confounding factors in the analyses from which the main findings were drawn?

Table 2 (continuation). Studies analyzing VLa_{max} reliability included in the present systematic review.

Study	Sport	Sample	Participants	VLa_{max} and T_{alac} equation	Protocol	Results	Conclusions
Harnish et al., 2023	Cycling	n=30	18 men and 12 women. Age: 29.9 ± 9.8 yrs, men mean 15s (W): 846.4± 147.7 and women mean 15s (W): 434.9± 91.4.	VLa_{max} = (La_{max} – La (0) / (t_{test} – t_{alac}) T_{alac} determined as the period when power output decreased by 3.5% ($t_{pmax-3.5\%}$)	Two sprint sessions to measure VLa_{max} over a period of 1 week. Warm up consisted of 10 minutes easy cycling, followed by 1 minute rest where a blood lactate sample was taken. Then the 15-second sprint was performed and after that, lactate samples starting at 1 minute post 15-second sprint and every 2 minutes until blood lactate concentration peaked and then dropped 1 mmol·l $^{-1}$.	VLa_{max} was moderately reliable across the trials with CV, ICC and r values of 18.6%, 0.66 and 0.67 respectively.	15-second VLa_{max} cycling test offers only moderate reliability when used within a one-week test period for both men and women. Overall reliability is impacted both by the lactate measurements (pre and peak) as well as the variability and inherent problems in determining t_{alac}.
Quittmann et al., 2021	Handcycling (HC) and cycling (C)	n=18	Competitive triathletes. Women (n=3) and men (n=15); age: 25.1±2.8 yrs, weekly total volume of 11.6±4.3 hours and training experience of 6.7±4.7 yrs.	VLa_{max} = (La_{max} – La (0) / (t_{test} – t_{pmax}) t_{pmax} determined as the time until peak power was reached.	The participants performed a standardized low-intensity warm-up of ten minutes including three acceleration bursts. The basic load of the warm-up for HC and C was 30 W and 100 W, respectively. The acceleration bursts were applied for ten seconds each and power output was increased up to five times the basic load. After the warm-up, the participants rested for five minutes in a sitting position. Blood lactate samples were collected before and after the all-out exercise as well as every minute after exercise for 10 minutes	VLa_{max} demonstrated good to excellent reliability for C and HC. C: ICC = 0.87 (0.69-0.95). HC: ICC = 0.83 (0.60-0.93). However, the reliability of t_{pmax} was poor.	VLa_{max} attained in 15-second all out sprint demonstrate good to excellent reliability in HC and C.

Note: VO_{2max} = maximal oxygen consumption, VLa_{max} = maximal lactate accumulation rate, La_{max} = maximum lactate, t_{alac} = alactic time, t_{test} = test time, $t_{pmax-3.5\%}$ = time until power output decreased by 3.5% from peak power, La (0): pre-test blood lactate.

Discussion

This systematic review aimed to assess whether VLamax is a reliable and representative parameter of maximal glycolytic power based on existing literature. To our knowledge, this is the first systematic review to explore the reliability of VLamax.

The included studies reported intraclass correlation coefficients (ICC) ranging from 0.66 to 0.96, indicating moderate to excellent reliability (Koo & Li, 2016). One study (Harnish et al., 2023) reported Pearson's r at 0.67, suggesting moderate reliability (Akoglu, 2018). However, the reliability of VLamax was affected by baseline lactate values (CV = 45.6%), peak lactate values (CV = 23.3%), and alactic time calculations (CV = 38.3%) (Harnish et al., 2023). Given that lactate values are influenced by multiple factors—including carbohydrate intake (Ivy et al., 1981), caffeine consumption (Costill et al., 1978), hydration status (Armstrong et al., 1985), environmental conditions (MacDougall et al., 1974), and psychosocial stress (Kubera et al., 2012)—it is crucial to minimize variability in these factors when using VLamax as a performance marker.

The alactic time, a critical component of the VLamax formula, represents the period during which the phosphagen energy system primarily supplies energy for muscle contraction. Studies included in this review determined alactic time either as the time to peak power (Quittmann et al., 2021) or as the time from peak power until a 3.5% drop (Quittmann et al., 2021; Harnish et al., 2023). The ICC values for alactic time ranged from -0.115 to 0.680, indicating poor to moderate reliability. Alternative methods, such as interpolating alactic time based on test duration (Quittmann et al., 2020) or assigning a fixed value based on total work time (Heck et al., 2003; Mavroudi et al., 2023), have demonstrated higher reliability. Using a fixed alactic time removes individual variability in phosphagen system contribution, although this may not be a major concern, given that VLamax primarily assesses glycolytic power. This limitation can be addressed by complementing VLamax with additional metrics that evaluate both aerobic and phosphagen energy systems.

VLamax exhibits a strong correlation with average power output in a 20-second rowing sprint (r = 0.81) (Held et al., 2024) and swimming speed in a 50m maximal test (r = 0.84) (Mavroudi et al., 2023). However, its correlation with swim speed in a 25m maximal test (r = 0.54) (Mavroudi et al., 2023) is only moderate. These findings support the hypothesis that VLamax is a representative marker of glycolytic power, as it aligns well with efforts lasting 20–31 seconds, where anaerobic metabolism contributes 73–82% of total energy output (Gastin, 2001). In contrast, for shorter efforts (5–15 seconds), energy production is primarily driven by the phosphagen system, reducing the relevance of VLamax.

There is considerable variability in VLamax assessment protocols, including differences in warm-up procedures, maximal test duration, and post-exercise lactate measurement methods (Table 2). Standardizing a practical, sport-adaptable protocol is essential to ensure consistency and applicability across different athletic settings. Additionally, the protocol should be feasible for coaches to implement in real-world scenarios, as some existing methods are overly complex and resource-intensive, limiting their use for routine assessments.

The primary limitation of this study is the small number of studies included in the systematic review (n = 5). Future research incorporating a larger number of studies could help to corroborate the findings presented here. Additionally, a certain degree of heterogeneity was observed among the included studies, particularly regarding the sports disciplines, fitness levels of the participants, and methods of Talac determination.

More research is needed to better understand this metric: the most appropriate test to determine it in a practical way, its relationship with other markers of anaerobic performance, its reaction to certain training methods and its influence on the maximum metabolic steady state, among others.

Conclusions

This systematic review shows that the VLa_{max} estimates maximal glycolytic power with moderate to excellent reliability. VLa_{max} could help to control fluctuations in an athlete's maximal glycolytic power over the season if all factors that could affect lactate values are controlled and a fixed value for alactic time (depending on the duration of the test implemented) is used.

Disclosure statement

The authors report there are no competing interests to declare.

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