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Boris Clark & Paul W. Macdermid

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VLa_{max} Correlates Strongly With Glycolytic Performance

Boris Clark[a] and Paul W. Macdermid[b]

[a]Cycling New Zealand; [b]Massey University

ABSTRACT

$\dot{V}La_{max}$ estimates an athlete's maximal-glycolytic rate. This study aimed to determine the relationships between the $\dot{V}La_{max}$ and cycle ergometry efforts with a high-glycolytic energy contribution and the influence of $\dot{V}La_{max}$ and VO_{2max} on respiratory compensation point. Eleven national-international endurance cyclists ($VO_{2max} = 70.7 \pm 5.9$ ml·kg^{-1}·min^{-1}) completed a 15-s isokinetic-test with pre- and postlactate measurements to determine $\dot{V}La_{max}$, a 1-min maximal effort, and a ramp test to exhaustion in a single test session. The main findings showed strong relationships between $\dot{V}La_{max}$ and the mean absolute ($r = 0.83$, $p = .002$) and relative ($r = 0.88$, $p = .0004$) power during the lactic interval of the 15-s isokinetic-test. This relationship weakened when comparing $\dot{V}La_{max}$ with mean absolute ($r = 0.52$, $p = .098$) and relative ($r = 0.29$, $p = .393$) power during a 1-min maximal effort. Combining the $\dot{V}La_{max}$ and $\dot{V}O_{2\,max}$ data through multiple regression resulted in a positive effect on the estimation of respiratory compensation point. It was concluded that the $\dot{V}La_{max}$ is a relevant indicator of maximal glycolytic rate. However, this metric currently lacks scientific validation as an accurate estimate of glycolytic rate and provides minimal extra information over using the power output from the isokinetic test alone. Practitioners may simply measure power over glycolytically demanding efforts to understand the maximal glycolytic rate of their athletes.

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Elite cyclist; performance; testing

Physiological testing has long been a part of understanding the "engines" of athletes and tracking changes in fitness (Cintia et al., 2013). Tests to determine metabolic parameters such as maximal oxygen consumption ($\dot{V}O_{2\,max}$), lactate thresholds (LT), ventilatory thresholds (VT), and gross efficiency are commonplace in performance diagnostics of cyclists (Bell et al., 2017; Svendsen et al., 2018). Despite laboratory assessments historically being considered the gold standard in physiological testing, there has been a recent move to assess athletes using power-output-based performance estimates such as critical power (Podlogar, Leo, et al., 2022; Poole & Jones, 2023). This can be determined through relatively simple time-efficient protocols (Simpson & Kordi, 2017) or even from race data (Spragg & Leo, 2021). Furthermore, many training software applications now use day-to-day training and racing data to provide estimates of $\dot{V}O_{2\,max}$ or lactate threshold with sufficient accuracy, provided representative data is entered into the model (Ashfaq et al., 2022; Cooper & Shafer, 2019). This progress in performance analysis software and hardware has improved the logistics and time strain required to collect valid and reliable performance parameters in the field. Many practitioners now lean toward performance testing over physiological testing, even though the latter can remain an important part of assessing athlete's responses to training (Almquist et al., 2020; Bell et al., 2017; Gordon et al., 2017). One such laboratory protocol metric has attracted recent interest is maximum glycolytic rate ($\dot{V}La_{max}$) (Adam et al., 2015) and dates back to the work of Mader and Heck (1986). They proposed that the maximal lactate steady state (MLSS) occurs at the exercise intensity wherein the production and combustion of lactate are equal. The maximum combustion rate being related to the individuals $\dot{V}O_{2\,max}$, and the maximal production rate being related to the maximal glycolytic rate now termed $\dot{V}La_{max}$. These maximal rates being tied to all sub-maximal production and combustion rates.

The cycling-specific test to estimate $\dot{V}La_{max}$ is a 15-s isokinetic sprint on a cycle ergometer, with blood lactate measurements taken immediately prior ti and postsprint, and every 1 min thereafter until the peak lactate value is reached. The change in blood lactate concentration pre- and posttest is then calculated and divided across the test duration (15 s) minus the time taken for power to drop 3.5% from the peak output to provide the lactate production rate synonymous with $\dot{V}La_{max}$ (Adam et al., 2015; Hauser et al., 2014). The cycling specific test assumes maximal activation of the glycolytic system from the time power has dropped 3.5% from the peak until the conclusion of the test. However, as the $\dot{V}La_{max}$ is specific to the working muscles used, other tests have been developed to accommodate noncycling activities such as swimming (Mavroudi et al., 2023; Sengoku et al., 2024), running (Quittmann et al., 2020, 2021), strength exercise (Nitzsche, Baumgärtel, & Schulz, 2018, 2020), hand cycling (Quittmann et al., 2022), and canoe paddling (Zwingmann et al., 2020), all of which follow similar sport-specific protocols.

Despite the body of work involving $\dot{V}La_{max}$ and its continual growth, the test has yet to be validated or related to glycolytic performance. Indeed, in their original work, Mader

CONTACT Paul W. Macdermid p.w.macdermid@massey.ac.nz School of Sport, Exercise & Nutrition, Massey University, Private Bag 11-222, Palmerston North 4474, New Zealand.

and Heck (1986) state that "the rate of glycolysis cannot be measured directly in humans or animals." More recently, doubt of its validity and ability to be accurately determined has been presented (Podlogar, Cirnski, et al., 2022). Furthermore, $\dot{V}La_{max}$ has been referred to in the literature as the maximum lactate accumulation rate as opposed to the maximum glycolytic rate (Mavroudi et al., 2023; Quittmann et al., 2020) due to the measurement recording a change in blood lactate concentration rather than a direct measure of glycolysis. Despite this lack of measurement validity, $\dot{V}La_{max}$ shows promise in that it can be used in calculations alongside $\dot{V}O_{2max}$ to accurately predict the maximal lactate steady state in cyclists (Adam et al., 2015; Hauser et al., 2014) while also demonstrating test- retest reliability in isokinetic force tests and 15-s isokinetic cycle ergometer sprinting (Adam et al., 2015; Nitzsche, Baumgärtel, Maiwald, et al., 2018).

While a validation of $\dot{V}La_{max}$ does not exist and indeed may not be possible, $\dot{V}La_{max}$ may still be a useful indicator of maximal glycolytic rate. To our knowledge there is no evidence of $\dot{V}La_{max}$ correlating with a performance parameter known to involve a high glycolytic contribution such as 10- to 15-s sprint power output (Gastin, 2001). Additionally, there is no data investigating the relationship between {$\dot{V}La_{max}$ and more extended efforts that still involve a significant (though likely submaximal) glycolytic contribution, such as a 1-min maximum effort (Jeukendrup et al., 2000). If the relationship between short term sprint power and $\dot{V}La_{max}$ is large and significant, it may be possible to move the test out of the laboratory and into a more practical setting as has occurred with critical power (Karsten et al., 2014).

The aim of this study is to determine whether the $\dot{V}La_{max}$ is related to power output in a 15-s isokinetic sprint test, a 1-min maximum effort, and measurements of aerobic fitness, and, specifically, the interaction between $\dot{V}La_{max}$ and $\dot{V}O_{2\,max}$ on the power output associated with respiratory compensation point (RCP). It was hypothesized that significant correlations would only exist between $\dot{V}La_{max}$, mean test power (15s sprint power) and power over the lactic time interval (15s—time to peak power − 3.5%) of the 15s isokinetic test, while tests involving longer exercise duration and more contribution from the aerobic system would display significantly weaker correlations with $\dot{V}La_{max}$.

Methods

Eleven nationally-internationally competitive endurance cyclists —age = 25 ± 4.5 years; height = 179.9 ± 5.2 cm; weight = 70.5 ± 7.3 kg; $\dot{V}O_{2\,max}$ = 70.7 ± 5.9 ml·kg^{-1}·min^{-1}, 4.97 ± 0.46 L·min^{-1} — participated in a single laboratory testing session regularly used as part of their athlete monitoring. These sessions comprised a 15-s isokinetic sprint test, a 1-min maximum effort, and a ramp-style test to volitional exhaustion. The Massey University Human Ethics Committee approved the study, and all participants provided written consent prior to participating in the study. This sample size of 11 participants was determined was used based on an a priori power analysis (G*power V 3.1.9.7, Heinrich-Heine University, Dusseldorf, Germany). The analysis was conducted for a correlation, bivariate normal model with input parameters derived from previous studies examining the relationship between $\dot{V}La_{max}$ and 50-m sprint performance where $r = 0.839$, the α level = 0.05, power (1-ß err prob) = 0.95, and a sample size of 11 was required (Mavroudi et al., 2023). Using the same G*power inputs for a correlation between critical power and onset of blood lactate $r = 0.912$, a sample size of 7 was required. For the first aerobic threshold $r = 0.83$, the sample size was estimated at 12 (Valenzuela et al., 2021).

Laboratory testing

Participants were advised to avoid any intervals or rides over 4 h in duration two days prior to testing, no more than 1 h easy ($LT_{\Delta 1}$) the day prior to the testing, and no exercise prior to reporting to the laboratory on the day of the testing. Upon arriving at the laboratory participants were measured for height (SECA 213 stadiometer, Hamburg, GER) and body weight (SECA 876, Hamburg, GER) prior to commencing a standardized warm-up for the 15-s isokinetic test. After the 15-s isokinetic sprint test, participants completed a preapproved personalized warm-up and then the 1-min maximum effort test and ramp-style test to volitional exhaustion.

15-s isokinetic sprint test ($\dot{V}La_{max}$ test)

A standardized warm-up was performed including 12 minutes of cycling at a power output corresponding to 1.5 times body weight (kg), followed by a 5 s of all out isokinetic sprint at 130 rpm and then 10 min of cycling at 50 W (Adam et al., 2015; Hauser et al., 2014). After the warm-up, two capillary lactate samples were taken (Table 1) from a sterilized earlobe with a lactate scout 4 analyzer (EKF Diagnostic, GmbH, Barleben, Germany) and averaged to establish the pretest lactate concentration (La_{Pre}). The ergometer (Cyclus 2 ergometer, Avantronic, Leipzig, Germany) was then set to isokinetic mode (130 rpm) and participants were given a countdown of 5 s preceding the 15 s test (t_{test}) for which power output was recorded at 8 hz. Mean power was defined as the mean power output over the complete 15-s period, while the lactic power interval was the mean power output for the period from test start to the time point at which power output had dropped

Table 1. Mean ± *SD* and number of participants (*n* =) blood lactate values (mmol·L^{-1}) following the warm-up period preceding the 15-s isokinetic test, immediately following, and every 1-min period thereafter until peak lactate was determined.

	Time (mins) following 15-s Isokinetic Sprint Test ($\dot{V}La_{max}$)								
Post-Warm-up	0	1	2	3	4	5	6	7	Peak La
1.2 ± 0.2 n = 11	2.3 ± 0.3 n = 11	6.1 ± 1.0 n = 11	7.1 ± 1.1 n = 11	7.5 ± 1.2 n = 11	7.8 ± 2.0 n = 9	10.5 ± 0.8 n = 3	10.9 ± 0.8 n = 2	11.4 n = 1	1.2 ± 0.2 n = 11

3.5% from peak power. After the 15 s, sprint participants were instructed to stop pedaling and remain stationary. A lactate sample was taken immediately posttest (<30s), and every minute thereafter until a decline occurred (Table 1) and, therefore, the maximum lactate concentration ($La_{max\ post}$) had been determined. $\dot{V}La_{max}$ was calculated according to Equation 1.

$$\dot{V}La_{max} = (La_{maxPost} - La_{Pre})/(t_{test} - t_{alac}) \quad (1)$$

where $La_{max\ post}$ = maximal posttest blood lactate; La_{pre} = blood lactate post-warm-p and pre-15-s sprint; t_{test} = 15, which is the test duration (s); t_{alac} = alactic time interval. which is the time from the test start to the point at which power output has decreased by 3.5%.

1-min maximum effort test

After completion of the isokinetic sprint test, participants had a 15-min rest period during which blood lactates were taken (Table 1) and their bikes were transferred to a smart trainer (Wahoo KICKR, Wahoo Fitness, Atlanta, GA, USA). They then commenced a preapproved, personalized warm-up of their choice prior to the 1-min maximum effort test. This test was used to assess an intermediary duration between the 15-s isokinetic sprint and the aerobic performance of participants and justified by the estimated energy contribution from the relevant energy systems (Jeukendrup et al., 2000). Prior to commencing this test, participants were advised to remain seated on the bicycle throughout and pace the test to achieve the highest power output they could for the 1-min effort using a self-selected cadence. A 10-s countdown was given prior to commencement. Data were logged using a Garmin Edge 530 (Garmin, Schaffhausen, Switzerland).

Ramp test

Upon completion of the 1-min maximum effort test, participants undertook 5 min of active recovery (<150 W), followed by 20 min of passive recovery. Schneider and Berwick (1997) showed reductions of, but no uncoupling of $\dot{V}_E$ from $\dot{V}CO_2$ following 1-min maximal exercise, where determination of power output at the RCP was not significantly different. As such it was felt that 25 min of recovery between tests was appropriate. They then commenced a ramp test starting at 150 W, increasing 30 W per minute until volitional exhaustion. Cadence was self-selected. Gas exchange (ParvoMedics Trueone 2400, ParvoMedics, Salt Lake City, UT, USA) and power output were measured throughout the test. Gas-exchange data were averaged every 15 s and used to determine ventilatory threshold (VT), respiratory compensation point (RCP), and $\dot{V}O_{2\,max}$. VT was defined at the $\dot{V}O_2$ and corresponding power output where there was an increase in the ventilatory equivalent for oxygen ($VE{\cdot}VO_2^{-1}$) and partial pressure of end-tidal oxygen ($P_{ET}O_2$) with no corresponding increase in the ventilatory equivalent for carbon dioxide ($VE{\cdot}V_CO_2^{-1}$). RCP was defined as the VO_2^{-1} and corresponding power output where there was an increase in $VE{\cdot}VO_2^{-1}$ and $VE{\cdot}V_CO_2^{-1}$ with a corresponding decrease in partial pressure of end-tidal carbon dioxide $P_{ET}CO_2$ (Lucía et al., 2000). $\dot{V}O_{2\,max}$ was determined as the highest 1-min epoch of the test, with the finish 1-min power output being identified as W_{max}.

Statistical analysis

Descriptive data (mean, standard deviation) were calculated for all data recorded in the 15-s isokinetic test, 1-min maximum effort, and ramp test. Normality of data for dependent variables was assessed using the Shapiro-Wilk test.

Relationships between all variables were analyzed using Pearson correlations and multiple regressions analysis, graphed with 95% confidence intervals, where data were presented as the *r*-value or *r*-squared and corresponding *p*-value, respectively. Fischer's transformation using Matlab R2022b was used to test whether key correlations significantly differed. Multiple regression analyses were performed to estimate dependent variables using specific independent variables, where partial *F*-tests were conducted to assess the significance of adding predictors to the models. All statistical analyses, except for Fischer's transformation, were performed using Graphpad Prism (V8.4.3). Correlation sizes were reported according to the guidelines set out by Gignac and Szodorai (2016).

Results

Normality testing using the Shapiro-Wilk indicated that performance data for anaerobic power (W = 0.910, p = .243) and relative $\dot{V}O_{2\,max}$ (W = 0.956, p = .721) was normally distributed.

15-s isokinetic sprint test ($\dot{V}La_{max}$ test)

Mean ± *SD* peak power in the 15-s isokinetic sprint test was 1288 ± 298 W or 18.13 ± 2.58 $W{\cdot}kg^{-1}$. Time to peak power −3.5% was 1.57 ± 0.26 s. Mean test power output was 896 ± 197 W or 12.63 ± 1.74 $W{\cdot}kg^{-1}$, while power output over the lactic interval of the test was 922 ± 198 W or 13.01 ± 1.75 $W{\cdot}kg^{-1}$. Pre-test lactate was 1.2 ± 0.2 mmol/L while peak lactate was 8.2 ± 1.9 mmol/L, resulting in $\dot{V}La_{max}$ of 0.52 ± 0.13 $mmol{\cdot}L^{-1}{\cdot}s^{-1}$.

Pearson's correlations revealed large significant correlations between $\dot{V}La_{max}$ and mean isokinetic absolute power output (r = 0.83, p = .002) and relative power output (r = 0.88, p = .0004, Figure 1b) but not significantly different (z = 0.492, p = .623, Figure 1). There were also large significant correlations between $\dot{V}La_{max}$ and peak power output for the same 15-s isokinetic test for absolute power output (*0.75*, p = .007) and relative power output $W{\cdot}kg^{-1}$ (r = *0.80*, p = .003).

1-min maximum effort test

Mean ± *SD* power output was 589 ± 83 W or 8.34 ± 0.71 $W{\cdot}kg^{-1}$. Correlations were not significant between $\dot{V}La_{max}$ and absolute 1-minmaximum effort test mean power (r = 0.52, p = .098 Figure 2a) and between $\dot{V}La_{max}$ and 1-min maximum effort test power $W{\cdot}kg^{-1}$ (r = 0.29, p = .393), and there were no differences between these correlations (Z = 0.731, p = .465).

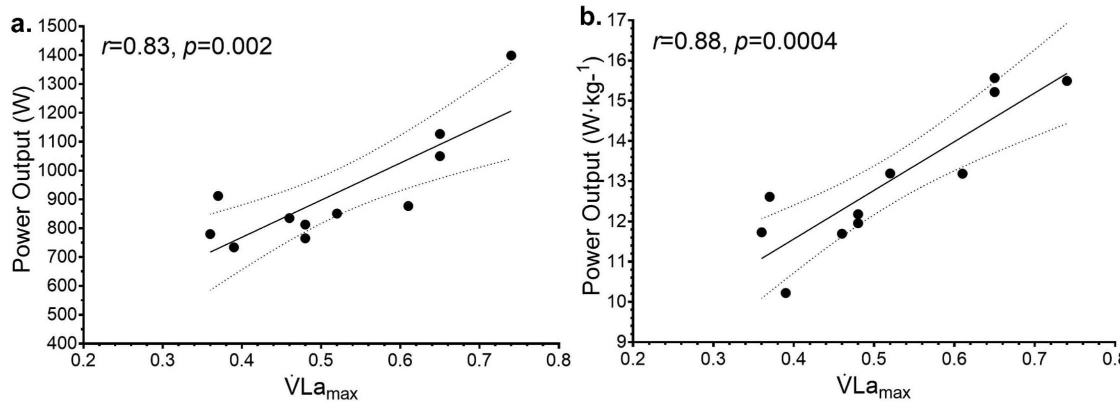

Figure 1. Pearson's correlation (n=11) between the $\dot{V}La_{max}$ and the power output over the lactic interval of the 15-s isokinetic test with 95% confidence intervals for (a) absolute power output, and (b) relative power ($W{\cdot}kg^{-1}$) *where,* $\dot{V}La_{max}$ *is the estimation of maximal glycolytic rate as Eq.1.*

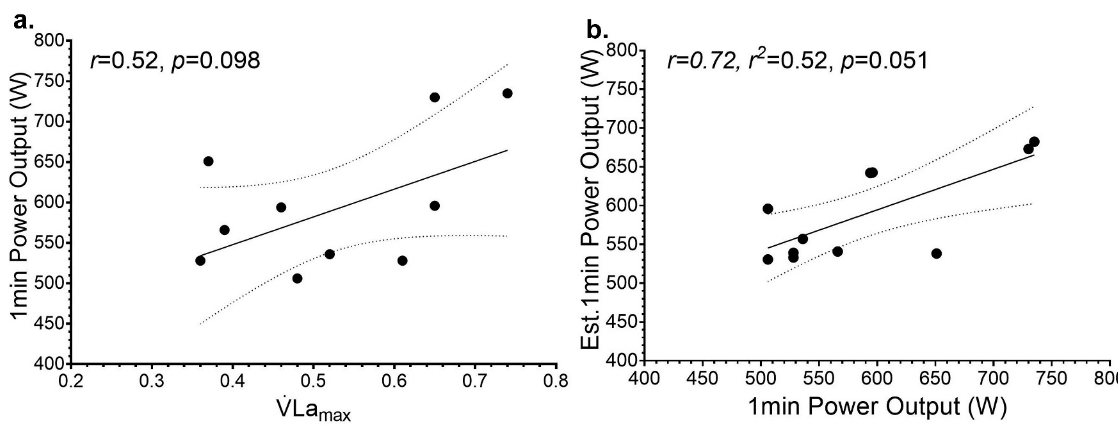

Figure 2. Pearson's correlation (n = 11) with 95% confidence intervals between (a) $\dot{V}La_{max}$, and absolute 1-min maximum effort test mean power output (W) and between (b) the 1-min maximum effort test mean power output, and the estimated 1-min power output through use of multiple regression. *Where, 1-min maximum effort test power output is the maximal mean power output held for a period of 1-min, Est. 1min power output was calculated using Eq. 2.*

Multiple regression (Equation 2) to estimate the dependent variable (Est. 1-min power output) used independent variables $\dot{V}O_{2\,max}$ ($L{\cdot}min^{-1}$) and $\dot{V}La_{max}$. The use of $\dot{V}O_{2\,max}$ ($L{\cdot}min^{-1}$) and $\dot{V}La_{max}$ to estimate1-minpower output revealed a moderate relationship ($r^2 = 0.524$, $p = .052$, $SE = 64$ W, Figure 2b).

The regression coefficients were $ß_0 = {}^{-}11.71$ ($p = .960$), $\dot{V}La_{max}$ ($ß_1$) = 223.4 ($p = .226$), and $\dot{V}O_{2\,max}$ ($ß_2$) = 97.56 ($p = .075$). Although $\dot{V}O_{2\,max}$ did not reach conventional significance levels, the overall model fit improved with its inclusion ($F_{(2,8)} = 4.398$, $p = .052$).

$$\text{Est.1} - \text{min power output} = -11.71 + (\dot{V}La_{max} * 223.4) + (\dot{V}O_{2\,max}(L \cdot min^{-1}) * 0.098) \tag{2}$$

Ramp test

Mean ± SD absolute and relative power output values for VT, RCP, and W_{max}, were 270 ± 33 W, 3.85 ± 0.48 $W{\cdot}kg^{-1}$, 335 ± 38 W, 4.78 ± 0.56 $W{\cdot}kg^{-1}$, and 426 ± 61 W, 6.05 ± 0.73 $W{\cdot}kg^{-1}$, respectively.

Correlations between $\dot{V}La_{max}$ and ramp-test variables ranged from insubstantial to moderate, with none reaching significance and no differences between absolute or relative ($\dot{V}O_{2\,max}$ ($L{\cdot}min^{-1}$), $r = 0.34$, $p = .30$; $\dot{V}O_{2\,max}$($ml{\cdot}kg^{-1}{\cdot}min^{-1}$) $r = {}^{-}0.16$, $p = .64$; $Z = 1.325$, $p = .185$, VT (W), $r = 0.01$, $p = .98$; VT ($W{\cdot}kg^{-1}$), $r = {}^{-}0.29$, $p = .32$; $Z = 0.778$, $p = .437$; RCP (W), $r = {}^{-}0.19$, $p = .57$; RCP ($W{\cdot}kg^{-1}$), $r = {}^{-}0.53$, $p = .086$; $Z = 1.019$, $p = .308$). Correlations between ramp-test variables $\dot{V}O_{2\,max}$ and RCP produced significant and strong positive relationships for absolute data ($r = 0.77$, $p = .006$; see Figure 3a) and relative data ($r = 0.81$, $p = .003$; see Figure 3b) but not different from one another ($Z = 0.788$, $p = .269$).

Multiple regression (Equation 3) to estimate the dependent variable (absolute power output associated with RCP) used dependent variables $\dot{V}La_{max}$ and $\dot{V}O_{2\,max}$ ($L{\cdot}min^{-1}$). The use of these independent variables to estimate absolute power output associated with RCP revealed a strong relationship ($r^2 = 0.83$, $p = .0008$, $SE = 17$ W; see Figure 3c).

The regression coefficients were $ß_0 = 26.67$ ($p = .668$), $\dot{V}La_{max}$ ($ß_1$)=${}^{-}153.2$ ($p = .010$), and $\dot{V}O_{2\,max}$ ($ß_2$) = 78.2 ($p < .001$), indicating a strong and significant relationship for both predictors ($F_{(2,8)} = 19.62$, $p = .0008$).

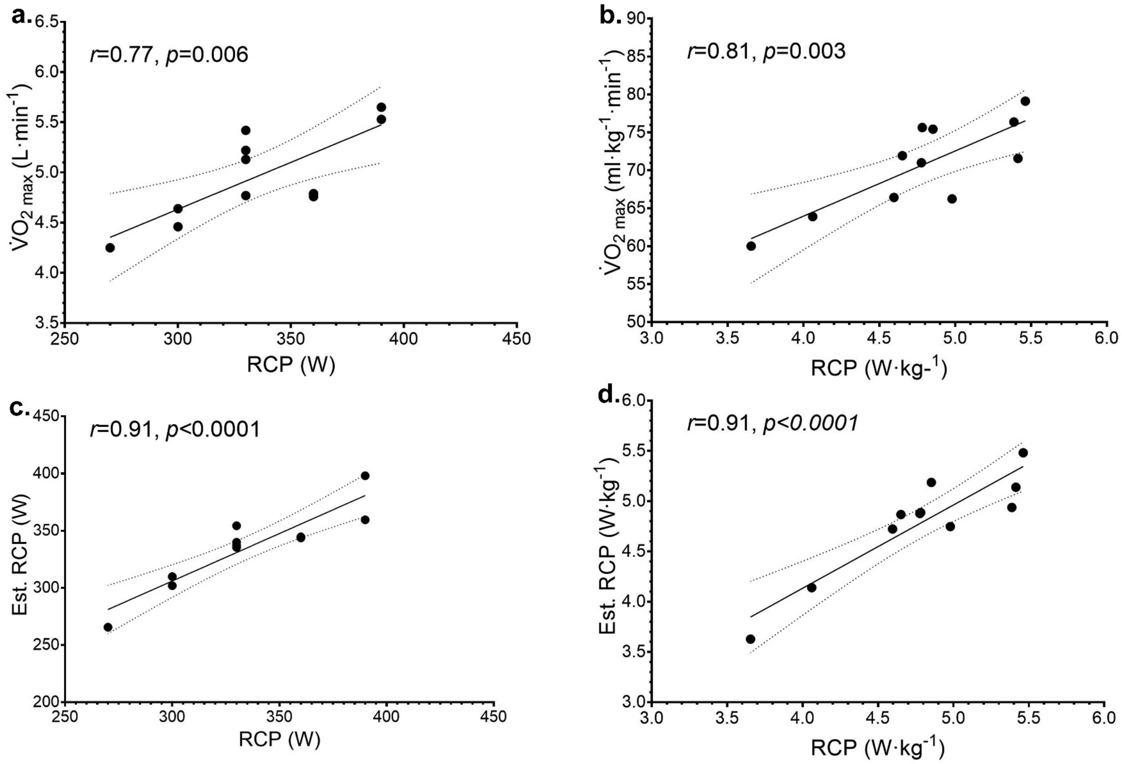

Figure 3. Pearson's correlation (n = 11) with 95% confidence intervals between the respiratory compensation points and (a) absolute $\dot{V}O_{2max}$ ($L{\cdot}min^{-1}$), (b) relative $\dot{V}O_{2max}$ ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$), and the correlations between the estimated RCP and actual RCP for (c) absolute power output using Equation 3, and (d) relative power output using Eq. 4. *where RCP is respiratory compensation point, and* $\dot{V}O_{2max}$ *is the maximal oxygen uptake.*

$$\mathrm{RCP(W)}= 26.67 + \left(\dot{V}La_{max}* \; - 153.17\right) + \left(\dot{} VO_{2\,max}\left(\mathrm{Lmin}^{-1}\right)^{*}0.0078\right) \quad (3)$$

Multiple regression (Equation 4) to estimate the dependent variable (relative power output associated with RCP) used dependent variables $\dot{V}La_{max}$ and $\dot{V}O_{2\,max}$ ($ml{\cdot}min^{-1}{\cdot}kg^{-1}$). The use of these independent variables to estimate relative power output associated with RCP revealed a strong relationship (r^2 = 0.83, p = .0009, SE = 0.26 $W{\cdot}kg^{-1}$; see Figure 3d).

The regression coefficients were $ß_0$ = 0.802 (p = .486), $\dot{V}La_{max}$ ($ß_1$)=$^{-}$1.851 (p = .022), and $\dot{V}O_{2\,max}$ ($ß_2$) = 0.070 (p = .001), indicating a strong and significant relationship for both predictors ($F_{(2,8)}$ = 19.35, p = .0009).

$$\mathrm{RCP}\left(\mathrm{W}\cdot\mathrm{kg}^{-1}\right) = 0.8+ \left(\dot{V}\mathrm{La}_{max}* -1.85\right) + \left(\dot{V}\,\mathrm{O}_{2max}\left(\mathrm{ml}\cdot\mathrm{min}^{-1}\cdot\mathrm{kg}^{-1}\right)^{*}0.007\right) \quad (4)$$

Discussion

The main aim of this study was to determine relationships between $\dot{V}La_{max}$ and performance in glycolytically demanding efforts. This was achieved through determining the size and significance of the relationships between $\dot{V}La_{max}$ and power in a 15-s isokinetic sprint test, a 1-min maximal effort test, and markers of aerobic performance. The main findings show that (a) $\dot{V}La_{max}$ displays large and significant relationships with power in a 15-s isokinetic sprint test; (b) $\dot{V}La_{max}$ is significantly correlated with power in a 1-minmaximal effort test when accounting for $\dot{V}O_{2max}$; (c) $\dot{V}La_{max}$ and aerobic variables display no correlation of note or significance; however, when $\dot{V}La_{max}$ and $\dot{V}O_{2max}$ are used in multiple regression they provided a large and significant ability to accurately predict respiratory compensation point, with $\dot{V}O_{2max}$ (both absolute and relative) being positively related to the magnitude of respiratory compensation point while $\dot{V}La_{max}$ was negatively related, thus, aligning with the results of previous work (Hauser et al., 2014).

15-s isokinetic sprint test is the primary form of assessment of $\dot{V}La_{max}$ in cyclists (Hauser et al., 2014, Nitzsche, Baumgärtel, and Schulz, 2018; Wahl et al., 2017); however, to our knowledge no study has yet compared the $\dot{V}La_{max}$ with the power output from this 15-s isokinetic sprint test. Logically if the $\dot{V}La_{max}$ is to be a useful estimate of glycolytic performance it will relate to power outputs with significant glycolytic contributions. The data presented compared the $\dot{V}La_{max}$ with the mean power in this test, as well as power during the "lactic interval," which occurs in the time period during which power output is primarily derived from anaerobic glycolysis (Gastin, 2001). Our findings support $\dot{V}La_{max}$ as a strong predictor of power output in efforts demanding high levels of glycolysis given the strong and significant relationships between $\dot{V}La_{max}$, mean test power, and power over the lactic interval. This finding should provide practitioners using $\dot{V}La_{max}$ confidence that the metric does indeed provide an indication of the maximal glycolytic rate. Further supporting this, is the relationship between $\dot{V}La_{max}$ and power output in the 1-min maximal effort test. Efforts of 1 min contain a significant glycolytic energy contribution; however, the contribution is relatively less than that observed in a 15-s sprint (Gastin, 2001; Jeukendrup et al., 2000). Therefore, it would be expected that $\dot{V}La_{max}$ is related to 1-min maximal effort test power output but to a lesser degree than power output over the lactic interval of the 15-s test. These findings are exactly what were observed, with $\dot{V}La_{max}$ displaying a large correlation with power in the 1-minmaximum effort test when presented as absolute power.

In addition to the fact that $\dot{V}La_{max}$ displays stronger relationships with efforts requiring a greater reliance on energy derived from glycolysis is the observation that $\dot{V}La_{max}$ displayed no relationships of note with any aerobic variables. While glycolytic and aerobic systems are linked, as some of the lactate produced is being shuttled to specific mitochondria and utilized as fuel (Brooks, 2020), and the pyruvate generated from glycolysis serves as a fuel source (Hauser et al., 2014; Mader & Heck, 1986), inference to maximum capacities is kept independent (Mader & Heck, 1986). The data presented therefore suggests that the power-time relationship with $\dot{V}La_{max}$ closely resembles that of the glycolytic system (Gastin, 2001). During this period, glycolysis is the primary contributor to power output over maximal efforts of 10–15 s and approaching 50% contribution to a 1-min effort (Jeukendrup et al., 2000). Durations greater than 1 min observe significant decreases in power output and increases in aerobic energy provision (Gastin, 2001; Jeukendrup et al., 2000). These findings further strengthen the evidence that $\dot{V}La_{max}$ is a useful marker of maximal glycolytic rate and power production. Given that there is no universally accepted method to measure the maximal glycolytic rate, the data presented supports $\dot{V}La_{max}$ as a practical estimate. Combined with previous work (Adam et al., 2015) that has demonstrated the reliability of the $\dot{V}La_{max}$, observing the delta of $\dot{V}La_{max}$ over time may assist in understanding the performance of athletes and the adaptation to training despite its limitations.

It has been hypothesized that there is a link between the glycolytic and aerobic systems with regard to the maximal lactate steady state (Mader & Heck, 1986). While we did not measure maximal lactate steady state, we did measure respiratory compensation point, which has been found to display large correlations with maximal lactate steady state (Pallarés et al., 2016). The results of our multiple regression with $\dot{V}O_{2max}$ and $\dot{V}La_{max}$ being positively and negatively related to respiratory compensation point, respectively, provides support for this theory and aligns with the theory set out in the equations of Hauser et al. (2014). Combing the $\dot{V}La_{max}$ and $\dot{V}O_{2max}$ in a multiple regression reduced the standard error of estimating respiratory compensation point from 25 W to 17 W and 0.35 W·kg^{-1} to 0.26 W·kg^{-1}. This finding is important, but the equation provided is only relevant to this participant pool. Considering the maximal glycolytic rate in threshold determination is an important factor when planning training and monitoring adaptation or developing training software. However, it is unknown how or if the $\dot{V}La_{max}$ relates to factors such as the repeatability of intense efforts or durability over the course of an event, both of which are often more important than fresh power output to performance outcomes (Maunder et al., 2021; Valenzuela et al., 2022).

While our results demonstrate that $\dot{V}La_{max}$ is a useful indicator of the maximal glycolytic rate in cycling, questions remain regarding the validity and usefulness of this metric. There are several reasons $\dot{V}La_{max}$ estimated via changes in blood lactate cannot be a true measure of the maximal lactate production. It is possible for lactate to be produced and utilized without ever reaching the blood (Brooks, 2018), which leads to a difference in lactate concentrations between blood and muscle (Jorfeldt et al., 1978; Medbø & Toska, 2001). Additionally, the total volume over which lactate is distributed is not taken into account (Mader & Heck, 1986). It is therefore implausible for the $\dot{V}La_{max}$ to provide an accurate estimate of the maximal rate of glycolysis. However, as our data show, this does not mean it cannot be used as a useful metric to confer with maximal glycolytic rate. However, as both mean and lactic interval power in the 15-s isokinetic sprint test display remarkably strong correlations with $\dot{V}La_{max}$, it seems unnecessary to add the additional blood lactate measurements when glycolytic performance can simply be estimated by the performance in the test itself. The estimation of $\dot{V}La_{max}$ may be useful when there is a desire to try to isolate the glycolytic and phosphagen systems' contribution to power output. For example, if a cyclist were to supplement with creatine, this may improve mean sprint power output due to increased phosphocreatine availability (Dawson et al., 1995), despite no change in maximal glycolytic rate. Nonetheless, in the absence of changes in phosphocreatine availability, it makes sense practically and logistically to simply use the lactic interval of the sprint test as a marker of maximal glycolytic rate. To further improve the ease of monitoring glycolytic performance future research should aim to determine whether power output from a nonisokinetic test would yield similar relationships with $\dot{V}La_{max}$. This would improve test accessibility as it removes the need for a special ergometer with an isokinetic setting or could possibility even allow testing on the road during regular training sessions. Further research would be needed to determine the effect of doing the sprint in a nonisokinetic capacity and among a much broader range of cyclist performance levels.

Conclusion

The primary aim of this study was to determine the relationship between $\dot{V}La_{max}$ and performance in glycolytically demanding efforts in cyclists. Strong and significant relationships were found between power output in a 15-s isokinetic sprint test and $\dot{V}La_{max}$. This relationship became weaker, but still significant, when considering the combined relationship of $\dot{V}La_{max}$ and $\dot{V}O_{2max}$ on power output in a longer 1-min maximal effort test, during which there is a similar level of energy contribution between glycolytic and aerobic systems. The results also supported prior work wherein the $\dot{V}La_{max}$ and $\dot{V}O_{2max}$ have been used in calculations to determine MLSS power, with $\dot{V}O_{2max}$ having a positive relationship on MLSS and a negative relationship for $\dot{V}La_{max}$. These results indicate that the $\dot{V}La_{max}$ can indeed be related to performance in glycolytically demanding efforts; however, the data also raises the question of the need for this test when we can simply monitor the performance itself with greater ease and relevance to practical application. While there is no harm in estimating $\dot{V}La_{max}$ via lactate, based on the available research coaches may simply wish to measure performance in glycolytically demanding efforts to estimate this performance parameter.

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ORCID

Paul W. Macdermid http://orcid.org/0000-0003-4163-2699

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