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# Utility of INSCYD athletic performance software to determine Maximal Lactate Steady State and Maximal Oxygen Uptake in cyclists

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**Abstract:** Serious amateur and elite athletes regularly take part in structured physiological testing sessions so that their progress gets tracked and training loads in the training plan correctly prescribed. Commonly, athletes are tested for the maximal oxygen uptake ($\dot{V}O_2max$) and maximal lactate steady state intensity (MLSS). While for the former expensive laboratory equipment is required, the latter requires multiple exercise trials for accurate determination. INSCYD athletic performance software is designed to enable continuous monitoring of these two parameters throughout the season after undertaking a single visit exercise testing session involving blood lactate sampling and power output measurement. The purpose of the present study was to assess validity of the software's estimates of $\dot{V}O_2max$ and MLSS and compare them to gold standard laboratory measures. 11 trained participants ($\dot{V}O_2max$ 61.0 ± 7.9 $mL \cdot kg^{-1} \cdot min^{-1}$) took part in this study consisting of formal graded $\dot{V}O_2max$ test, multiple MLSS trials and a recommended test to obtain the data later fed the INSCYD athletic performance software. Both relative $\dot{V}O_2max$ (Δ=0.13 $ml.kg^{-1}.min^{-1}$, p=0.885) and MLSS calculated values (Δ=2 W, p=0.655) were within expected daily variation and thus the estimations considered valid. It can be concluded that INSCYD athletic performance software offers its users utility to accurately predict $\dot{V}O_2max$ and MLSS provided that the practitioner has a good idea of where the MLSS lies.

**Keywords:** endurance, testing, performance, $VO_2max$, maximal lactate steady state

1. **Introduction**

Physiological testing has numerous benefits when trying to optimise performance. The information gained can be used to better prescribe training intensity, track longitudinal changes in performance and determine an athlete's strengths and weaknesses (Jamnick, Pettitt, Granata, Pyne, & Bishop, 2020; Leo, Spragg, Podlogar, Lawley, & Mujika, 2021). However, a complete physiological assessment can be time consuming, and it usually requires expensive laboratory equipment (e.g., a metabolic cart). As a result, there have been numerous attempts to create testing protocols that would not require expensive laboratory grade equipment; and which could be undertaken in either a laboratory or field setting in a time efficient manner. One such testing battery that has gained popularity among cyclists and is believed to be used by some of the worlds' best cycling teams, is INSCYD athletic performance software (INSCYD GmbH, Oberfelben, Switzerland). The protocol requires access to a power meter and a lactate analyser and lasts approximately 3 hours. The protocol professes to be able to provide 'performance diagnostics to create a granular analysis of the physiology of an athlete' ("INSCYD," 2021). However, before any testing battery is endorsed for being utilised, it should be validated against gold standard testing procedures and proven to be sufficiently reliable (Halperin, Vigotsky, Foster, & Pyne, 2018).

INSCYD athletic performance software provides its users with numerous metrics; these include maximal oxygen uptake ($\dot{V}O_2$max) maximal lactate steady state (MLSS) and the intensity eliciting maximal fat oxidation (FatMax). Whereas gold standard measures are available for the two former measures (Beneke, 2003; Lundby et al., 2017), unfortunately a validation of the latter is difficult to perform due to the large day-to-day variability of the measure itself (Achten, Gleeson, & Jeukendrup, 2002; Chrzanowski-Smith et al., 2020).

The INSCYD athletic performance software also provides some metrics which on their own lack scientific validity and could therefore not be validated as part of a validation study of the software itself. These include the maximum glycolytic power (VLamax) and maximum carbohydrate metabolism (CarbMax). VLamax is thought to represent maximal lactate production rate and is usually determined by assessing blood lactate responses after a 15-second maximal sprint (Thomas Hauser, Adam, & Schulz, 2014; Mader & Heck, 1986). While an attractive metric, VLamax is, to our knowledge, impossible to assess in vivo for various reasons. Firstly, lactate could be used within a muscle cell that produced it and hence part of the lactate produced would never appear the bloodstream (Brooks, 2018). Secondly, blood and muscle lactate concentrations differ (Tesch, Daniels, & Sharp, 1982). Thirdly, blood lactate concentrations merely represent the relationship between blood lactate removal and appearance, a concept also known as lactate shuttle theory (Brooks, 2018). CarbMax intensity is thought to represent an intensity at which carbohydrate utilisation rates exceeds the possible rate of oxidation of exogenous carbohydrates. Again, as there are numerous factors affecting maximal exogenous carbohydrate oxidation rates (Rowlands et al., 2015) it is unfortunately impossible to validate this concept.

The aim of the present study was to assess how valid are the estimates of $\dot{V}O_2$max and MLSS (i.e., the metrics that can be validated) produced by the INSCYD athletic performance software when crudely estimating the MLSS intensity (e.g., from a ramp test) by comparing these values to those obtained using gold standard measures.

2. Materials and Methods

Participants

Eleven healthy, endurance-trained males (age 35 ± 7 years, height 176 ± 4 cm, $\dot{V}O_2$max 61.0 ± 7.9 mL · kg$^{-1}$ · min$^{-1}$ (4.41 ± 0.46 L · min$^{-}$

[1], MLSS 268 ± 35 W (3.7 ± 0.6 W · $kg^{-1}$), body mass 73.0 ± 10.5 kg and body fat 13 ± 3 %) provided written informed consent and completed the study that was approved by the Committee of Republic of Slovenia for Medical Ethics (0120-3/2021/3) and conducted in accordance with the Declaration of Helsinki. The main inclusion criteria for enrolment in the study was regular endurance training (i.e., at least 3 times a week), being accustomed to indoor training on a stationary bicycle and having $\dot{V}O_2max$ higher than 50 $ml.kg^{-1}.min^{-1}$. Only male athletes were recruited to avoid menstrual cycle affecting the results due to multiple laboratory visits.

Experimental design

The study consisted of 3-8 laboratory visits. On the first occasion, the participants were tested for $\dot{V}O_2max$ and the exercise intensity corresponding to the respiratory compensation point (RCP). These metrics were determined in line with a previously described protocol (Iannetta, Inglis, Pogliaghi, Murias, & Keir, 2020). The power output corresponding to RCP was subsequently employed when setting the initial exercise intensities to determine maximal lactate steady state intensity (MLSS) and during an INSCYD test. As INSCYD athletic performance software is meant to be primarily used to continuously track athletes throughout the season, a training history and thus a crude estimate of MLSS known – hence RCP was used as a starting point. All other laboratory visits were conducted in a randomised order and were separated by 2-4 days. Participants visited the laboratory on each occasion at the same time of day (± 2 hrs). During all testing participants used their own bicycles mounted onto an electrically braked cycle ergometer (Kickr V5, Wahoo, Atlanta, Georgia, USA). Blood lactate concentrations were measured throughout from the earlobe via a handheld blood lactate monitor (Lactate Plus, Nova Biomedical, USA) that has been previously validated (Hart, Drevets, Alford, Salacinski, & Hunt, 2013).

Formal $\dot{V}O_2max$ testing

The formal $\dot{V}O_2max$ test consisted of a graded intensity cycling protocol that aimed to elicit maximal oxygen uptake in 8-12 minutes; as per recommendations for such a test (Iannetta et al., 2020; Jamnick, Botella, Pyne, & Bishop, 2018; Yoon, Kravitz, & Robergs, 2007). The testing protocol also allowed the determination of RCP.

The graded intensity protocol commenced with a 2-min warm-up at 60W followed by 6-min of cycling at 120W (i.e., moderate intensity exercise domain). This was proceeded by a ramp incremental protocol increasing the exercise intensity by 30 W · $min^{-1}$ until task failure. A plateau in $\dot{V}O_2$ was confirmed in all participants. Breath by breath gas exchange measurements were performed using an automated online gas analysis system (MetaLyzer 3B-R3, Cortex, Lepizig, Germany. $\dot{V}O_2max$ was considered to represent the highest 30-s average of $O_2$ uptake. 30-minutes following the task failure during the first part of the test, the second part commenced, and it involved cycling for 2-min at 120W followed by 10-min of cycling ~55-65% of maximal intensity achieved during the first part of the test (i.e., heavy intensity exercise domain). RCP (i.e., boundary between heavy and severe exercise intensity domain) was determined as previously described (Iannetta et al., 2020). In brief, ramp test respiratory data was analysed by two experienced researchers that independently determined oxygen uptake associated with RCP ($\dot{V}O_2$ at which end-tidal $PCO_2$ began to fall after a period of isocapnia). Subsequently a spreadsheet supplementing the original article describing the protocol (http://links.lww.com/MSS/B957) was used to determine exercise intensities relating to RCP.

Prior to each trial gas analysers were calibrated with a known gas mixture (15.10% $O_2$, 5.06% $CO_2$; Linde Gas, Prague, Czech Republic) and the volume transducer was calibrated with a 3-litre calibration syringe (Cortex, Leipzig, Germany). During this and all the subsequent tests, laboratory conditions were comparable at 20 ± 3 °C and 30 ± 5 % relative humidity and two fans were pointing towards the participants (Vacmaster Air Mover, Cleva, Newcastle upon Tyne, UK) to improve air circulation.

Maximal Lactate Steady State Testing

MLSS intensity was determined using multiple constant-workload tests as per prior recommendations (Beneke, 2003). The test started with a 5 min long warm at 100-150W (individually determined based on the RCP) followed by 30 minutes of cycling at the intensity corresponding to the RCP intensity determined during the first laboratory visit. Blood lactate was determined at 10th and 30th minute and the MLSS was accepted if the difference between both values was not higher than 1 $mmol.L^{-1}$. Had this occurred, the next MLSS testing trial was conducted at a 5 W higher intensity and the trials were repeated until the blood lactate concentration rose by more than 1 $mmol.L^{-1}$ from 10th to the 30th minute. Conversely, if the first trial elicited a higher blood lactate change than 1 $mmol.L^{-1}$, the exercise intensity on the subsequent trial was reduced by 5 W. Thus, MLSS intensity was accurately determined to a value of ±2.5W. Up-to 5 trials per participant were required to establish a MLSS in all 11 participants.

INSCYD test

The INSCYD test followed the requirements obtained from the INSCYD athletic performance software developer (INSCYD GmbH, Switzerland; personal communication). Upon arrival at the laboratory, body composition of the participants was estimated using the bioelectrical impedance methodology (Tanita BC-601, Tanita Europe BV, The Netherlands). Then, an exercise bout was started. After an initial warm up there were 6 intervals performed at various intensities for various durations. The first interval lasted 2 minutes and was performed at the intensity corresponding to RCP. Upon its completion, blood lactate concentration was determined and had the concentration been higher than 4 $mmol.L^{-1}$, the intensity of the subsequent interval was reduced and increased if the concentration was below 2 $mmol.L^{-1}$. Modification of the intensity was based on the subjective assessment made by the experienced physiologist. The next interval was 8 minutes long and was performed at the intensity agreed by the researcher after conducting the initial 2-minute-long interval and was followed by 8 minutes and 4 minutes at 110% of this intensity. Lastly, 2-min all-out and 3-min all out efforts were carried out. Intervals at the constant load were interspersed with at least 12 minutes (ended up being approximately 15 minutes) of easy cycling (i.e., 50-120W) and the next interval was initiated once blood lactate concentration dropped to <2 $mmol.L^{-1}$, whereas during both all-out intervals participants rested and/or cycled at a very low intensity until blood lactate dropped to <2 $mmol.L^{-1}$or 60 minutes had passed which should suffice for complete reconstitution of anaerobic capacity (W') (Skiba, Chidnok, Vanhatalo, & Jones, 2012). During this time participants were allowed to consume carbohydrates in the form of gummy figures (Haribo, Bonn, Germany) in an ad libitum quantity. At the end of each interval a blood sample was obtained from the earlobe and analysed for blood lactate. This procedure was repeated each minute to obtain the highest blood lactate concentration as per the requirement of the INSCYD athletic performance software until the blood lactate concentration started to decline. The cycle ergometer was set into ERG mode during constant load cycling and to a simulated incline of 6% when doing all-out efforts and participants were free to choose the preferred cadence and gearing ratio (Wahoo App, Wahoo, US).

Data analysis

Power data was analysed using WKO5 software (TrainingPeaks, LLC; Colorado, United States). Study participants' characteristics (i.e., body mass, body height, age, and body composition) together with power data and blood lactate values were analysed via the INSCYD athletic performance software by an independent person not familiar with values from the formal MLSS or $\dot{V}O_2max$ tests.

Statistical Analysis

All data are descriptively represented as mean ± standard deviation (SD), mean difference (Δ) and 95% confidence intervals (Δ95% CI). Normality of all data was assessed using Shapiro-Wilk test.

Absolute and relative $\dot{V}O_2max$ values as well as power output at MLSS were compared between the laboratory and INSCYD athletic performance software output using paired samples t-tests. Reliability was assessed using Pearson product correlation coefficient (r), coefficient of variation (CV), typical error, intraclass correlation coefficient (ICC) and Bland Altman plots with 95% limits of agreement (LoA). Level of statistical significance was set at *alpha* ≤ 0.05 - two tailed. Statistical analyses and graphical representation were processed with a commercially available software package (Prism 8, Graphpad Software Inc, San Diego, USA) and Microsoft Excel (Microsoft 365, Microsoft Corporation, Redmond, USA).

## 3. Results

*Maximal Oxygen Uptake*

No significant differences were found between laboratory and INSCYD athletic performance software derived $\dot{V}O_2max$ values for absolute (Δ=5.1 $ml.min^{-1}$, Δ95% CI = -145.5 to 155.9 $ml.min^{-1}$, p=0.940) and relative (Δ=0.13 $ml.kg^{-1}.min^{-1}$, Δ95% CI = -1.91 to 2.18 $ml.kg^{-1}.min^{-1}$, p=0.885). Reliability measures for absolute and relative $\dot{V}O_2max$ are represented in Table 1 and Table 2. Correlation between laboratory and INSCYD athletic performance software derived $\dot{V}O_2max$ was very strong for both absolute (r=0.945 p<0.001) and relative (r=0.954 p<0.01) values (Figure 1A and 1B). Bland Altman plots between laboratory and INSCYD athletic performance software derived $\dot{V}O_2max$ are presented in Figure 1C and Figure 1D.

**Table 1.** Reliability measures between absolute $\dot{V}O_2max$ estimates.

| Absolute $\dot{V}O_2max$ | Laboratory | INSCYD |
|---|---|---|
| Mean Difference ($ml.min^{-1}$) | 5.18 | |
| 95% CI Mean Difference ($ml.min^{-1}$) | -155 to 146 | |
| CV (%) | 11.1 | 14.6 |
| Typical Error ($ml.min^{-1}$) | 159 | |
| 95% CI Typical Error ($ml.min^{-1}$) | 110 to 278 | |
| ICC (p ≤ 0,001) | 0.945 | |

*CV – Coefficient of variation. CI – Confidence interval. ICC - intraclass correlation coefficient*

**Table 2.** Reliability measures between relative $\dot{V}O_2max$ estimates.

| Relative $\dot{V}O_2max$ | Laboratory | INSCYD |
|---|---|---|
| Mean Difference ($ml.kg^{-1}min^{-1}$) | -0.08 | |
| 95% CI Mean Difference($ml.kg^{-1}min^{-1}$) | 2.12 to 1.96 | |
| CV (%) | 13.6 | 16.5 |
| Typical Error ($ml.kg^{-1}min^{-1}$) | 2.15 | |
| 95% CI Typical Error ($ml.kg^{-1}min^{-1}$) | 1.50 to 3.77 | |
| ICC (p ≤ 0,001) | 0.954 | |

CV – Coefficient of variation. CI – Confidence interval. ICC - intraclass correlation coefficient.

*Maximum Lactate Steady State*

While the difference between the estimate of MLSS from the RCP intensity and laboratory MLSS was not significant (Δ= -12 W, Δ95% CI = -24 to 1 W, p=0.051), it was greatly improved by INSCYD athletic performance software (Δ=2 W, Δ95% CI = -6 to 9 W, p=0.655). Reliability measures for the power output at the MLSS are represented in Table 3.

Correlations between power output at the MLSS derived from laboratory and INSCYD athletic performance software was very strong (r=0.95 p<0.001). Correlations and Bland Altman plots between power output at the MLSS derived from laboratory and INSCYD athletic performance software are presented in Figure 2.

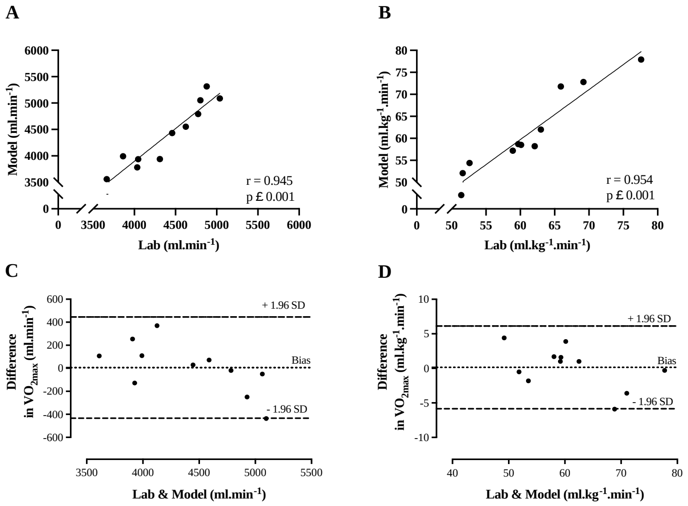


**Figure 1.** Correlations (A and B) and Bland Altman plots (C and D) between laboratory and INSCYD athletic performance software derived V̇O2max

**Table 3.** Reliability measures between MLSS estimates

| MLSS | Laboratory | INSCYD |
|---|---|---|
| Mean Difference (W) | 2 | |
| 95% CI Mean Difference (W) | -6 to 9 | |
| CV (%) | 14.4 | 14.0 |
| Typical Error (W) | 8 | |
| 95% CI Typical Error (W) | 6 to 14 | |
| ICC (p ≤ 0,001) | 0.976 | |

CV – Coefficient of variation. CI – Confidence interval. ICC - intraclass correlation coefficient.

## 4. Discussion

The aim of the present study was to assess the utility of the INSCYD athletic performance software to accurately estimate V̇O2max and MLSS after having a crude idea of where the MLSS could be (e.g., RCP intensity) by

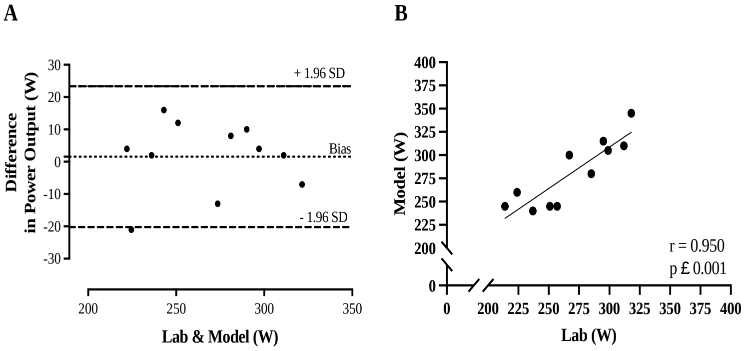


**Figure 2.** Correlations and Bland Altman plots between laboratory and INSCYD athletic performance software derived MLSS values

comparing the output values with the values obtained during formal gold-standard laboratory tests. The data shows that INSCYD athletic performance software was able to provide V̇O2max and MLSS estimates that were within the typical daily variation of these estimates when obtained from gold standard testing protocols and can thus be considered valid.

V̇O2max is considered as the gold standard measure of aerobic fitness (Martin-Rincon & Calbet, 2020) despite requiring special equipment for its accurate determination. In a standard laboratory practice, it is computed by assessing the volume and fractional utilisation of oxygen from the expired air in each time frame. As is the case with most measures, it is also prone to daily variability. Early research showed daily variability to be as high as ±5.6% which is a result of both biological variability and a measurement error (Katch, Sady, & Freedson, 1982). A meta-analysis found that average standard test-retest measurement error is 2.58 $ml.kg^{-1}.min^{-1}$ (Vickers, 2003), while some individual studies using more up-to-date measurement equipment report an even smaller daily variability (Blagrove, Howatson, & Hayes, 2017). The calculated typical error between V̇O2max estimates in the present study was 2.15 $ml.kg^{-1}.min^{-1}$ with an ICC of 0.954 (CI 0.826-0.988). This is within acceptable and previously reported day-to-day variability limits (Blagrove et al., 2017). It can therefore be concluded that INSCYD software provides users with a valid $\dot{V}O_2max$ estimate.

Likewise, the typical error for MLSS estimates derived by the INSCYD athletic performance software was 8W, which is smaller than the 3% typical day to day variability of MLSS values (T. Hauser, Bartsch, Baumgärtel, & Schulz, 2013). From an applied perspective, while the typical error might seem high, this is still within a difference between certain estimation methods for critical power or MLSS (Iannetta, Ingram, Keir, & Murias, 2022) which are both thought to represent the boundary between heavy and severe exercise intensity domains. Thus, this allows the authors to conclude that INSCYD athletic performance software can provide users with a valid MLSS estimate.

While the data suggests that the INSCYD athletic performance software provides its users with valid estimates of both $\dot{V}O_2max$ and MLSS, there are some important limitations of the INSCYD athletic performance software. In addition to those discussed in the introduction, notably that some of the measures provided by the INSCYD software cannot be validated, the present study also highlighted some considerations for potential users. Furthermore, future studies are required to assess daily variability in the values obtained by INSCYD athletic performance software.

Firstly, to collect the data required by the INSCYD athletic performance software to accurately estimate $\dot{V}O_2max$ and MLSS, one needs to first estimate the MLSS intensity as this is used to determine the intensity at which the intervals within the protocol are performed. In the present study the RCP intensity obtained from the initial $\dot{V}O_2max$ test was used. While this provides the software an idea of where the MLSS actually lies, the INSCYD athletic performance software improved the estimation of MLSS intensity, which is what the software would be primarily used in the field as well. However, one cannot, based on the results of the present study, say that the INSCYD athletic performance software has an utility to accurately predict MLSS without prior crude estimation of MLSS. However, provided that this condition is met, INSCYD athletic performance software can accurately determine the MLSS intensity. This is useful especially for continuous tracking of athletes rather than their initial assessment.

The gold standard protocol for MLSS determination requires at least two exercise trials; performed on separate days. Therefore, its utility in an elite athlete population may be limited due to the amount of time out of training and or competition that would be required. This is arguably where the INSCYD athletic performance software has great utility, i.e., is a relatively time efficient way to estimate both $\dot{V}O_2max$ and MLSS, at least compared with gold standard measures. However, in practice, MLSS is typically estimated from graded exercise tests during in which lactate is sampled at the end of stage (Heck et al., 1985; Jamnick et al., 2018), commonly these measurements are combined with $\dot{V}O_2max$ measurement. It should be noted that when combining both $\dot{V}O_2max$ and MLSS determination in a single graded exercise test there is potential for underestimation/overestimation of either of the parameters (Jamnick et al., 2018). However, utilising the INSYCD athletic performance software is not the only way to derive MLSS estimates in a time efficient way, in fact a single session test to estimate MLSS has been validated (Hering, Hennig, Riehle, & Stepan, 2018), although this would still require a separate laboratory visit for the assessment of $\dot{V}O_2max$.

A second consideration when performing data collection test for the INSCYD athletic performance software is the large number of lactate samples required (usually 20 or more per test). This could be both cost prohibitive and may lead to some discomfort for participants. A final consideration is that the INSCYD athletic performance software does not calculate the boundary between moderate and heavy intensity exercise domain. This boundary has been shown to have utility when defining training zones for the prescription of training intensity (Jamnick et al., 2020).

## 5. Practical Applications.

The INSCYD athletic performance software using the data collection protocol described within the present study provides valid $\dot{V}O_2max$ and MLSS estimates and can therefore be used as a tool for practitioners. However, as with any testing protocol, practitioners need to acknowledge the potential drawbacks; namely, some provided metrics are unvalidated, the initial intensity for the intervals within the protocol needs to be estimated, no estimate of the boundary between the moderate and heavy exercise intensity domains is provided, and finally the large number of lactate samples required may be cost prohibitive in some circumstances.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## References

Achten, J., Gleeson, M., & Jeukendrup, A. E. (2002). Determination of the exercise intensity that elicits maximal fat oxidation. *Medicine and Science in Sports and Exercise*, *34*(1), 92–97. https://doi.org/10.1097/00005768-200201000-00015

Beneke, R. (2003). Methodological aspects of maximal lactate steady state-implications for performance testing. *European Journal of Applied Physiology*, *89*(1), 95–99. https://doi.org/10.1007/s00421-002-0783-1

Blagrove, R. C., Howatson, G., & Hayes, P. R. (2017). Test–retest reliability of physiological parameters in elite junior distance runners following allometric scaling. *European Journal of Sport Science*, *17*(10), 1231–1240. https://doi.org/10.1080/17461391.2017.1364301

Brooks, G. A. (2018). The Science and Translation of Lactate Shuttle Theory. *Cell Metabolism*, *27*(4), 757–785. https://doi.org/10.1016/j.cmet.2018.03.008

Chrzanowski-Smith, O. J., Edinburgh, R. M., Thomas, M. P., Haralabidis, N., Williams, S., Betts, J. A., & Gonzalez, J. T. (2020). The day-to-day reliability of peak fat oxidation and FATMAX. *European Journal of Applied Physiology*, *120*(8), 1745–1759. https://doi.org/10.1007/s00421-020-04397-3

Halperin, I., Vigotsky, A. D., Foster, C., & Pyne, D. B. (2018, February 1). Strengthening the practice of exercise and sport-science research. *International Journal of Sports Physiology and Performance*, Vol. 13, pp. 127–134. Human Kinetics Publishers Inc. https://doi.org/10.1123/ijspp.2017-0322

Hart, S., Drevets, K., Alford, M., Salacinski, A., & Hunt, B. E. (2013). A method-comparison study regarding the validity and reliability of the Lactate Plus analyzer. *BMJ Open*, *3*, 1899. https://doi.org/10.1136/bmjopen-2012

Hauser, T., Bartsch, D., Baumgärtel, L., & Schulz, H. (2013). Reliability of maximal lactate-steady-state. *International Journal of Sports Medicine*, *34*(3), 196–199. https://doi.org/10.1055/s-0032-1321719

Hauser, Thomas, Adam, J., & Schulz, H. (2014). *Comparison of calculated and experimental power in maximal lactate-steady state during cycling*. Retrieved from http://www.tbiomed.com/content/11/1/25

Heck, H., Mader, A., Hess, G., Mücke, S., Müller, R., & Hollmann, W. (1985). Justification of the 4-mmol/l Lactate Threshold. *International Journal of Sports Medicine*, *06*(03), 117–130. https://doi.org/10.1055/s-2008-1025824

Hering, G. O., Hennig, E. M., Riehle, H. J., & Stepan, J. (2018). A lactate kinetics method for assessing the maximal lactate steady state workload. *Frontiers in Physiology*, *9*(MAR). https://doi.org/10.3389/fphys.2018.00310

Iannetta, D., Inglis, E. C., Pogliaghi, S., Murias, J. M., & Keir, D. A. (2020). A "Step-Ramp-Step" Protocol to Identify the Maximal Metabolic Steady State. *Medicine & Science in Sports & Exercise*, *Publish Ah*(9), 2011–2019. https://doi.org/10.1249/MSS.0000000000002343

Iannetta, D., Ingram, C. P., Keir, D. A., & Murias, J. M. (2022). Methodological Reconciliation of CP and MLSS and Their Agreement with the Maximal Metabolic Steady State. *Medicine and Science in Sports and Exercise*, *54*(4), 622–632. https://doi.org/10.1249/MSS.0000000000002831

INSCYD. (2021). Retrieved November 10, 2021, from https://inscyd.com

Jamnick, N. A., Botella, J., Pyne, D. B., & Bishop, D. J. (2018). Manipulating graded exercise test variables affects the validity of the lactate threshold and V˙O2peak. *PLOS ONE*, *13*(7), e0199794. https://doi.org/10.1371/journal.pone.0199794

Jamnick, N. A., Pettitt, R. W., Granata, C., Pyne, D. B., & Bishop, D. J. (2020). An Examination and Critique of Current Methods to Determine Exercise Intensity. *Sports Medicine*, (0123456789). https://doi.org/10.1007/s40279-020-01322-8

Katch, V. L., Sady, S. S., & Freedson, P. (1982). Biological variability in maximum aerobic power. *Medicine & Science in Sports & Exercise*, *14*(1), 21–25. https://doi.org/10.1249/00005768-198201000-00004

Leo, P., Spragg, J., Podlogar, T., Lawley, J. S., & Mujika, I. (2021). Power profiling and the power-duration relationship in cycling: a narrative review. *European Journal of Applied Physiology*. https://doi.org/10.1007/s00421-021-04833-y

Mader, A., & Heck, H. (1986). A Theory of the Metabolic Origin of "Anaerobic Threshold." *International Journal of Sports Medicine*, *07*(S 1). https://doi.org/10.1055/s-2008-1025802

Martin-Rincon, M., & Calbet, J. A. L. (2020). Progress Update and Challenges on VO2max Testing and Interpretation. *Frontiers in Physiology*, *11*(September), 1–8. https://doi.org/10.3389/fphys.2020.01070

Rowlands, D. S., Houltham, S., Musa-Veloso, K., Brown, F., Paulionis, L., & Bailey, D. (2015). Fructose–Glucose Composite Carbohydrates and Endurance Performance: Critical Review and Future Perspectives. *Sports Medicine*, *45*(11), 1561–1576. https://doi.org/10.1007/s40279-015-0381-0

Skiba, P. F., Chidnok, W., Vanhatalo, A., & Jones, A. M. (2012). Modeling the expenditure and reconstitution of work capacity above critical power. *Medicine and Science in Sports and Exercise*, *44*(8), 1526–1532. https://doi.org/10.1249/MSS.0b013e3182517a80

Tesch, P. A., Daniels, W. L., & Sharp, D. S. (1982). Lactate accumulation in muscle and blood during submaximal exercise. *Acta Physiol Scand*, *114*, 441–446.

Vickers, R. R. (2003). *Measurement Error in Maximal Oxygen Uptake Tests*.

Yoon, B. K., Kravitz, L., & Robergs, R. (2007). V̇O2max, protocol duration, and the V̇O2 plateau. *Medicine and Science in Sports and Exercise*, *39*(7), 1186–1192. https://doi.org/10.1249/mss.0b13e318054e304