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Predicting the individual lactate minimum speed by T10 and T30 in swimming

Running Title: Aerobic capacity in swimming

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Abstract

BACKGROUND: This study investigated the relationship between the lactate minimum (LAC_{min}) and the 10- (T10) and 30-min (T30) continuous tests in swimmers.

METHODS: Twelve swimmers (78.1 ± 3.1% of world record) performed the LAC_{min} (hyperlactatemia: 2 x 50 m all-out 8-min apart, incremental part: n x 300 m 30-s apart), T30 and T10 using the front-crawl stroke. Blood samples were collected after each stage of LAC_{min} for lactate analysis. Swimmers were oriented to swim as fast and as constant as possible in T10 and T30.

RESULTS: Speeds in T10 (1.28 ± 0.10 m/s) and T30 (1.21 ± 0.09 m/s) were different from LAC_{min} (1.24 ± 0.09 m/s). T10 and T30 speeds presented a nearly perfect relationship with LAC_{min} and acceptable prediction errors (T10: $r = 0.938$, $p < 0.001$, 0.033 m/s; T30: $r = 0.927$, $p < 0.001$, 0.036 m/s, respectively).

CONCLUSIONS: T10 and T30 can be used as indirect tests for evaluating LAC_{min} in swimming.

Keywords: endurance, performance, testing, physiology

Introduction

The ability to generate a high propulsive force consistently from the beginning to the end of the race is critical for swimming performance and is predominantly supported by the aerobic pathways in several competitive events [1]. Coaches then devote a large part of the training to develop swimmers' aerobic capacity and may use the lactate threshold (LT) to determine and individualize the exercise intensity for the sets.

The LT may represent the highest exercise workload in which there is a balance between lactate production and removal from the blood (i.e., the maximum lactate steady state [2]). Above this point, there is a saturation of the clearance mechanisms and a rapid increase of blood lactate concentrations [3]. Monitoring the LT can be useful for performance prediction, training prescription and monitoring fitness profile of endurance athletes [2].

One of the protocols employed for determining the LT is the lactate minimum [4] (LAC_{min}), which involves the induction of the hyperlactatemia through high-intensity efforts, a recovery period, and then an incremental test. This procedure stands out because it allows the determination of individual anaerobic and aerobic parameters in a single testing session [5], and the results are consistent regardless of the muscle glycogen concentration [6]. A previous study has also demonstrated the sensitivity of the LAC_{min} for detecting the training-induced adaptations in competitive swimmers [7].

Although the assessment of the LT is useful to establish and individualize the exercise intensity, blood analysis can be costly, and time-consuming in a large swimming squad, and inaccessible for ordinary athletes. For this reason, more practical field-based indirect tests that requires the swimmer to perform the longest distance in a given time can be introduced regularly into athletes' routine, and have been proposed as surrogates of the LT. In swimming, the 10- (T10 [8]) and 30-min (T30 [9]) continuous tests have been proposed as alternatives for aerobic capacity evaluation because of their high relationship with the speed

corresponding to the lactate concentration of 4 mmol/l (T10: $r = 0.95$, $p < 0.05$ and T30: $r = 0.97$, $p < 0.001$). However, the results obtained with a fixed concentration (i.e., 4 mmol/l) may not represent the individual LT [10].

Considering the importance of aerobic capacity evaluation in swimming and that no previous study has examined the relationship between T10, T30 and the individual lactate threshold in swimming, the aim of this study was to analyse the association between these indirect tests and the LAC_{min}. We hypothesized that both tests correlate with LAC_{min} and can also be used to indirectly estimate aerobic capacity as represented by the LAC_{min}.

Materials and methods

Participants

Twelve state competitive swimmers (seven males and five females, age: 20.5 ± 1.6 years; body mass: 63.8 ± 10.4 kg; height: 1.70 ± 0.09 m; arm span: 1.74 ± 0.11 m) from the university squad volunteered for this study. The best competitive freestyle races of the participants ranged from 50 to 400 m freestyle, and they achieved 78.1 ± 3.1% of the short course World record. To be included, the participants must have reached the qualifying time for the state championship within one year prior to the beginning of the study and have five years of competitive experience (11.3 ± 2.5 years). They were informed about the risks and benefits of the investigation and provided verbal and written informed consent to participate. Procedures complied with the Declaration of Helsinki and were approved by the University's Ethics Committee for human investigation (Process number 101/2006).

Experimental procedures

During two weeks after the preparatory period (total of eight weeks, training volume: 13,750 ± 1,336 m/week, 5 sessions/week), swimmers individually performed (to avoid pacing

effect) three tests in the following order: lactate minimum (LAC_{min}, Monday 1), 30- (T30, Wednesday 1) and 10-min (T10, Monday 2) tests. Tests were conducted in a 25-m pool (water temperature: 26.0 ± 0.5 ºC) at the same time of the day (~2:00 PM). Swimmers used the front crawl stroke and started from a push-off. The warm-up was standardized in all testing sessions and consisted of a 10-min active stretching plus approximately 10 min of swimming in low to moderate intensity, subjectively determined by the swimmers.

The LAC_{min} used the protocol proposed by Ribeiro et al. [11]. The hyperlactatemia was induced by two successive 50 m maximal swimming 1-min apart. After 8 min of passive recovery, swimmers started the incremental part of the test, which comprised stages of 300 m with 30 s of interval in-between, when 25 μL of fingertip capillary blood samples were collected into a glass tube for lactate concentration analysis at the end of each stage. The initial speed ranged from 1.05 to 1.25 m/s and was individually chosen so that swimmers could accomplish at least four stages. Swimming speed increased 0.05 m/s every stage until voluntary exhaustion. A researcher with a chronometer walked alongside the pool and provided the correct pacing for the swimmer every 25 m. Speed and lactate data were fitted by a second-order polynomial regression and the lowest point of the curve represented the intensity of LAC_{min} [11,12].

During T10 and T30 swimmers were oriented to swim as fast and as constant as possible during each test duration. The beginning and the end of the tests were signalled by a whistle. Researchers individually monitored the total distance swum and registered the 50 m splits with a manual chronometer so the individual variation could be calculated. The average speed in each test was retained for analysis. Immediately before and after completion of each swim, 25 μL of fingertip capillary blood samples were collected into a glass tube for lactate concentration analysis.

Blood samples were mixed with 50 µl of sodium fluoride at 1% and stored in the liquid nitrogen (-190 ºC) until the transportation to the laboratory. Blood lactate concentrations were assayed using electroenzymatic methods using an automated analyser (YSI 1500 Sport, Yellow Spring Instruments, OH, USA) and expressed as mmol/l.

Statistical Analysis

Descriptive statistics of the variables were reported as means ± SD. Shapiro-Wilk test checked the assumptions of normally-distributed samples, whereas the presence of outliers was identified by the outlier labelling rule [13]. The swimming speed consistency during each indirect test was quantified by the coefficient of variation of the 50 m splits. Repeated measures analysis of variance (ANOVA) computed differences among tests. In case of violation of sphericity, the p values were adjusted by the epsilon Greenhouse-Geisser correction factor. Multiple pairwise comparisons were performed using the Bonferroni test. The effect size was calculated through partial eta squared and interpreted as following (when significant): >0.01-0.09: small; >0.09-0.25: medium; and large >0.25. The Bland-Altman analysis checked the agreement between LAC_{min} and T10 and T30 and adopted the limits of ± 1.96 SD of the difference. Pearson correlation coefficients assessed the relationships between variables and were interpreted as (when significant): <0.30: small, 0.31-0.49: moderate, 0.50-0.69: large, 0.70-0.89: very large, and 0.90-1.00: nearly perfect [14]. Linear regression models computed lactate minimum speed as dependent variables and the average speeds in T10 and T30 as independent variables (separately). The Durbin-Watson test verified the autocorrelation of the residuals (between 1.5 and 2.5). The regular coefficients of determination (R^2) were also obtained and interpreted as: <0.04: very weak, 0.04-0.16: weak, 0.16-0.49: moderate, 0.49-0.81: high, and 0.81-1.00: very high [15]. The standard error of estimate (SEE) tested the accuracy of the sample mean and models were validated by

comparing the LAC_{min} speed and the estimated speed results through the paired Student's t- (parametric) and through the effect size calculated by Cohen's d, which was interpreted as: < 0.2: trivial; >0.2-0.6: small; >0.6-1.2: moderate; 1.2-2.0: large; 2.0-4.0: very large [14]. The significance level was set at $p < 0.05$. Analyses were conducted using IBM SPSS for Windows (Version 25.0, Armonk, NY, USA).

Results

Swimming speeds in the LAC_{min}, T10 and T30 are in Table 1. The average distances covered were 766 ± 59 and 2,183 ± 156 m for T10 and T30, respectively. Average and individual pacing patterns are available in Figure 1 and the coefficient of variation of the 50 m partials in T10 and T30 was 3.3 ± 1.0% (minimum: 2.3% and maximum: 6.1%) and 2.4 ± 1.0% (minimum: 4.4% and maximum: 1.0%), respectively, confirming the high consistency of swimming speed during these tests. The average speeds in T10 and T30 were different from LAC_{min} (Table 1). No differences were detected among the lactate concentrations prior to the tests (Table 1), whereas in post T10 differed from LAC_{min} and T30.

[Figure 1 near here]

[Table 1 near here]

The LAC_{min} speed is nearly perfect associated with both T10 ($r = 0.938$, $p < 0.001$) and T30 ($r = 0.927$, $p < 0.001$). The final regression models were significant for T10 ($F = 73.762$, $p < 0.001$) and T30 ($F = 60.972$, $p < 0.001$) and are presented in Figure 2. No autocorrelations of the residuals were found (Durbin-Watson = 1.723 and 1.739 for T10 and T30, respectively), whereas the paired Student's t-test did not detect significant differences between the official and the estimated results (T10: $p = 0.974$, Cohen's $d = 0.00$, trivial; T30: $p = 0.975$, Cohen's $d = 0.00$, trivial). Bland-Altmann plots are shown in Figure 3. Bias

between T10 and LAC_{min}, and T30 and LAC_{min} were 0.034 (95% limits of agreement: -0.03 to 0.10) and -0.030 m/s (95% limits of agreement: -0.10 to 0.04), respectively.

[Figure 2 near here]

[Figure 3 near here]

Discussion

This study analysed the association between T10 and T30 and the LAC_{min}. Our results demonstrated that T10 and T30 speeds were 2.7% higher and 2.4% lower than LAC_{min}, respectively, presenting a nearly perfect relationship and acceptable prediction errors, and, therefore, can be used as practical tests for evaluating swimming aerobic fitness profile and designing training prescription.

The LAC_{min} was proposed by Tegtbur et al. [4] as a surrogate to the maximal lactate steady state intensity. In swimming, Ribeiro et al. [16] indicated that the LAC_{min} overestimates the maximal lactate steady state when using stages lengths of 200 m (1.29 m/s vs. 1.23 m/s, respectively), whereas Ribeiro et al. [11] indicated that 300-m stages (as used herein) provide a more accurate estimation. Despite some disagreement [11], the LAC_{min} speed has been accepted as the maximum lactate steady state intensity (i.e. the threshold between heavy and severe domains) in studies comprising both animal [17,18] and humans [19,20] which, according to our results, can be estimated by T10 and T30.

Although popular among coaches, the T10 and T30 were proposed based on the fixed lactate concentration [8,9], which can be influenced by nutrition [21], glycogen stores [22], training level [23] and "may frequently underestimate (particularly in anaerobically trained subjects) or overestimate (in aerobically trained athletes) real endurance capacity" [10]. Herein, the T10 and T30 regression models explained 88 and 86% of the total LAC_{min} speed variance, respectively, both interpreted as very high [15], whereas the Bland-Altman analysis revealed

acceptable bias and residues distribution. Estimating the individual LAC_{min} with a reasonable level of error (standard error of estimation of 0.033 and 0.036 m/s for T10 and T30, respectively) and with no statistical difference between true and estimated values, may be of practical relevance for coaches to monitor aerobic fitness accurately and orienteer training prescription. The standardization of the diet prior the testing sessions is a critical factor since the muscle glycogen stores may influence these indirect test performances.

The fact that the T10 and T30 speeds were higher and lower than the LAC_{min}, respectively, is likely related to the duration of the protocols. Swimmers must manage their energetic reserves differently in these test durations to avoid premature fatigue [24] and, consequently, adopt distinct speeds to reach the greatest distance possible. The lactate concentrations were considerably greater in T10 than in T30 (13.8 vs. 7.5 mmol/l) and confirm that these endurance tests do not represent the same intensity. Considering that the standard errors of estimation were 0.033 and 0.036 m/s for T10 and T30, respectively, it is conceivable that a test duration between 10 and 30 min (e.g., 20 min) would predict the individual LAC_{min} speed more accurately. In cycling, for example, the 20-min continuous test has also been proposed as a functional way to estimate the upper limit of the heavy domain [25,26]. However, the anaerobic threshold power is estimated as 95% of the average power obtained in the functional 20-min test [26], suggesting that even the 20-min duration test may overestimate the heavy domain. The use of shorter tests may be a topic for future studies in swimming.

The lactate concentrations after the T30 were higher than the values reported previously (4.01 ± 0.75 [9], 3.68 ± 1.58 [27] and 4.41 ± 1.27 mmol/l [16], respectively), indicating a greater contribution of the glycolytic pathway. High-intensity training increases the activity of glycolytic enzymes, such as phosphofructokinase, lactate dehydrogenase and glycogen phosphorylase [28], which favours higher blood lactate concentrations. The group of swimmers

assessed herein competed in college competitions which largely comprised sprint races (50 and 100 m) so their training loads were organized accordingly (i.e., with a relevant part of the volume dedicated to high-intensity sets). These training characteristics combined with a relatively low weekly volume (~13 km/week) likely induced important adaptations of the glycolytic pathway and may explain higher lactate concentrations even in predominantly aerobic efforts like T30 (and also T10). The current results corroborate the findings of Itoh and Ohkuwa [29] that showed that sprinters have a higher peak blood lactate than long-distance athletes during 10-min continuous submaximal efforts (50% of the maximum heart rate).

Although test results are typically presented as speed [11,16], coaches are interested in pace and can organize the test outcomes as the required time to cover the 100-m distance, as previously reported by Pyne et al [2]. For this, one should divide 100 by the final T10 or T30 equations' speed results. For instance, a swimmer who achieves 1.30 m/s as the estimated LAC_{min} speed should perform every 100 m in 76.9 s when the training set goal is to swim in the transition between heavy and severe domains. In practical terms, every increase of ~10 and 28 m in T10 and T30, respectively, represents a reduction of 1 s in every 100 m in a training set aiming the LAC_{min} intensity.

This study is not without limitations. The validity of our predictive equations remains to be confirmed for other athletes of the same and other competitive levels. Also, we did not determine whether long-term changes in T10 and T30 are associated with modifications in the LAC_{min}. Therefore, future investigations should confirm the sensitivity of these indirect tests to detect training-induced adaptations throughout the season. Finally, tests were conducted in a 25-m pool so that results obtained in long course pools may require adjustments.

Conclusion

We conclude that T10 and T30 can be used as indirect tests for evaluating individual lactate threshold in swimming and can be used as practical tests for evaluating swimming

aerobic fitness. Despite the higher swimming intensity, the T10 may fit better in coaches' and practitioners' routines due to its shorter duration.

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NOTES

Conflicts of interest. The authors report no conflict of interest regarding the material discussed in the manuscript.

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Authors' contributions. All authors contributed equally to the manuscript and read and approved the final version of the manuscript.

Table 1. Swimming speed and blood lactate concentration before (LAC_{Pre}) and after (LAC_{Post}) the LAC_{min}, T10 and T30.

	LAC_{min}	T10	T30	*F* value	*p*	Partial eta^2	Interpretation
Speed (m/s)	1.24 ± 0.09	1.28 ± 0.10 *	1.21 ± 0.09 * #	22.132	>0.0001	0.668	Large
LAC_{Pre} (mmol/l)	2.6 ± 0.8	2.0 ± 0.5	2.2 ± 0.9	1.780	0.192	0.139	-
LAC_{Post} (mmol/l)	8.1 ± 2.3	13.8 ± 3.1 **	7.5 ± 2.1 #	31.700	>0.0001	0.742	Large

* $p < 0.05$ from LAC_{min}; ** $p < 0.0001$ from LAC_{min}; # $p < 0.0001$ from T1

FIGURES

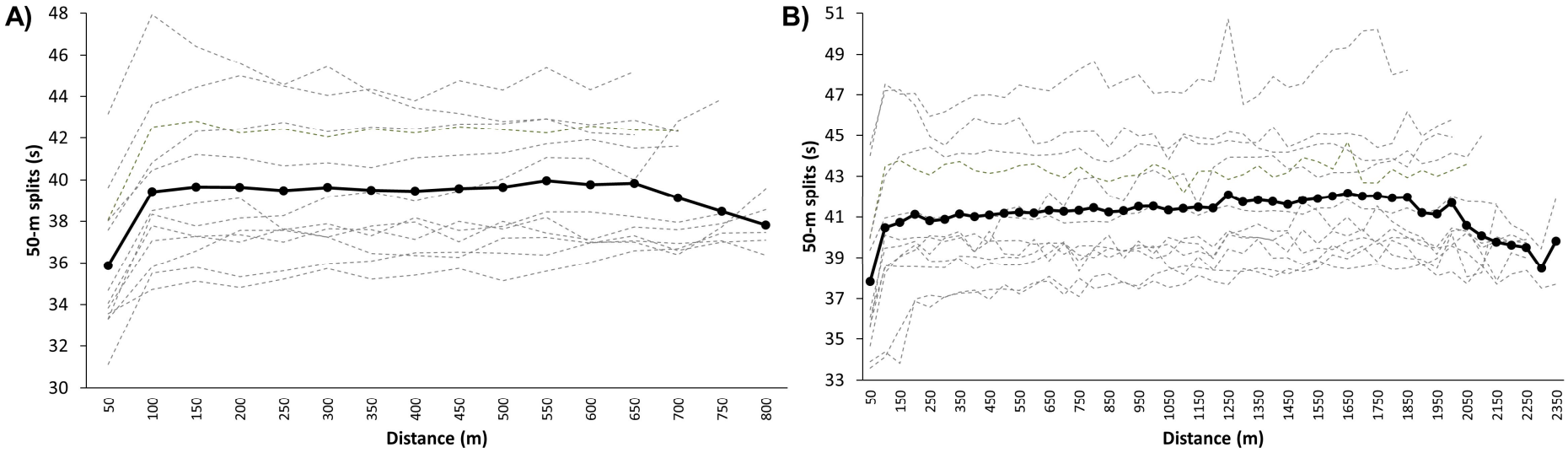

Figure 1. Average (continuous line) and individual 50-m splits during T10 (A) and T30 (B).

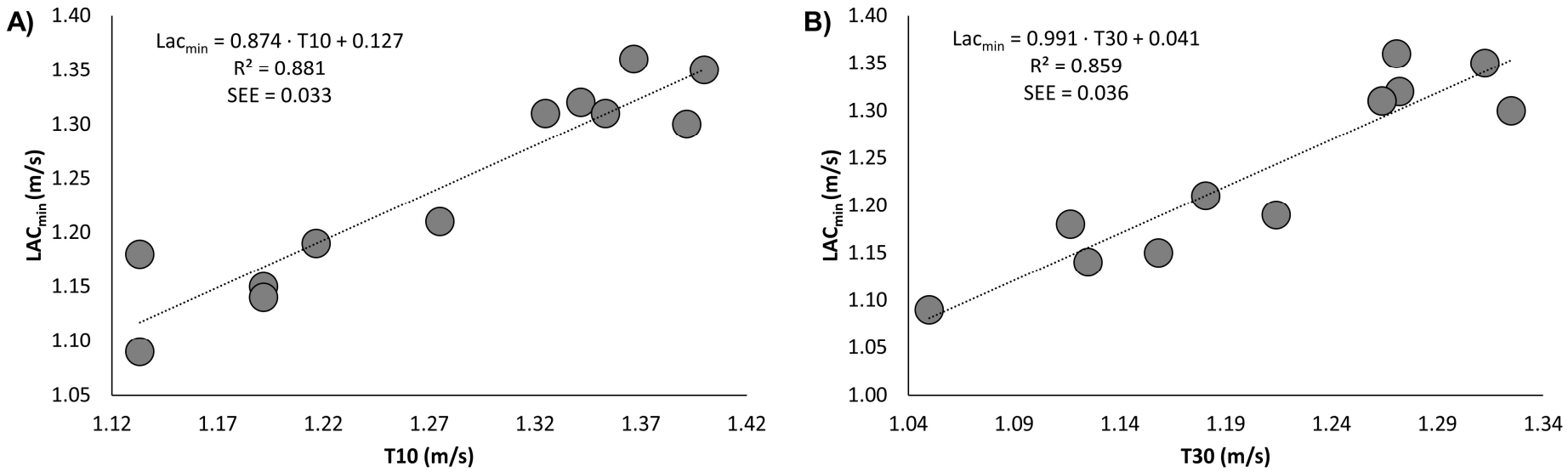

Figure 2. Regression models between LAC_{min} and T10 (A) and T30 (B, two subjects presented the exact same performance in T30 and LAC_{min}, so the points are superposed).

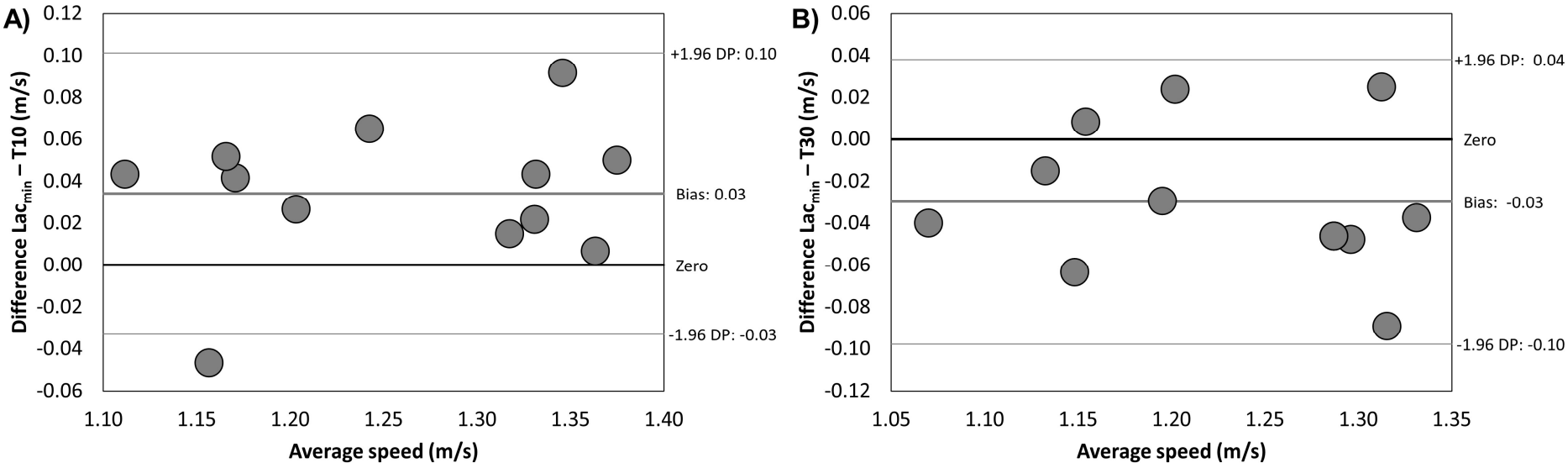

Figure 3. Bland-Altman of LAC_{min} and T10 (A), and LAC_{min} and T30 (B, two subjects presented the exact same performance in T30 and LAC_{min}, so the points are superposed).