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Abstract

Purpose: To assess the concurrent and predictive validity of the 3-min all-out test (3MT) against conventional methods (CM) of determining critical speed (CS) and curvature constant (D′), and to examine the test-retest reliability of the 3MT in highly-trained swimmers.

Methods: Thirteen highly-trained swimmers (age: 16 ± 2 y, weight: 64.7 ± 8.5 kg, height: 1.76 ± 0.07 m) completed four time trials, and two 3MT over 2 weeks. The distance-time (DT) and speed-1/time (1/T) models were used to determine CS and D′ from four time trials. CS_{3MT} and D'_{3MT} were determined as the mean speed in the final 30 seconds of 3MT and as the speed-time integral above CS, respectively.

Results: CS_{3MT} (1.33 ± 0.06 $m.s^{-1}$) did not differ from the CS_{CM} (1.33 ± 0.06 $m.s^{-1}$, $p>0.05$) and correlated nearly perfectly with CS_{CM} ($r=0.95$, $p<0.0001$). D'_{3MT} (19.50 ± 3.52 m) was lower compared to D'_{DT} (23.30 ± 6.24 m, $p<0.05$) and $D'_{1/T}$ (22.15 ± 5.75 m, $p=0.09$). Correlations between D'_{3MT} and D'_{CM} were very large ($r=0.79$, $p=0.002$). CS and D′ between the two 3MT trials were not different (CS mean change = -0.009 $m.s^{-1}$, p=0.102; D′ mean change= 0.82 m, p=0.221). Correlations between two 3MT trials were nearly perfect and very large for CS ($r=0.97$) and D′ ($r=0.87$, $p<0.05$), respectively, with coefficient of variation of 0.9% for CS and 9.1% for D′.

Conclusion: 3MT is a valid protocol for the estimation of CS and produces high test-retest reliability for CS and D′ in highly-trained swimmers.

Key words: critical speed, 3-minute all-out, testing, monitoring, swimming

Introduction

The critical speed (CS) model describes the capacity of an individual to sustain particular work rates as a function of time, via the demarcation of two physiological parameters; critical speed (CS) and the curvature constant (D′) [1-5]. The CS represents the highest speed that can be sustained for an extended period of time (~ 30 min), whilst D′ represents the finite capacity available for work above the CS threshold [1-5]. Given that CS represents a boundary between steady and non-steady state exercise intensity domains, the CS concept could arguably be a more meaningful parameter for optimising training and performance processes than lactate threshold or $\dot{V}O_{2max}$ [1].

Originally, testing protocols for the determination of CS and D′ required the completion of 3-5 time-to-exhaustion (TTE) or time-trials (TT) [1-3]. However, performing multiple tests in this manner is cumbersome and time-consuming, which may have precluded the wider implementation of the CS concept in applied practice [1-5]. To overcome this limitation, a 3-min all-out test (3MT) has been developed by Burnley, Doust and Vanhatalo [4], which enables the calculation of CS and D′ within a single exercise bout. Whilst the 3MT has been validated and applied in multiple sports such as cycling [6], running [7], rowing [8], and team sports [9], only two attempts have been made to validate the 3MT in free swimming [10, 29]. Tsai and Thomas [10] assessed the validity of the 3MT in recreational swimmers and found that D'_{3MT} was lower compared to D'_{CM}, whilst CS_{3MT} was not different compared to CS_{DT} but was different compared to $CS_{1/T}$. Mitchell et al. [29] examined the validity of a modified 3MT (12 x 25 m) in elite swimmers, and found that CS derived from the modified 3MT was significantly higher compare to the CS derived from two TT. Whilst there was no significant difference between D′ values derived from the modified 3MT and TT, the result for D′ did not display a sufficient level of agreement. However, both of these studies were subject to a number of potential limitations: Tsai and Thomas [10] used a recreational and heterogeneous sample of athletes; combined primary (time trials using a push-off start) and secondary (race results using a dive start) data for derivation of CS and D′ in the conventional methods; used an inconsistent and high-intensity warm-up; and failed to include a 3MT familiarisation. Mitchell et al. [29] only used two TT (100 and 200 m), both with a duration < ~2.5 min; excluded turns from the 3MT; and allowed ~ 5 s rest between each 25 m. The aforementioned factors may have impacted on the results, given previous research demonstrating the impact of these variables on CS and D′ [1].

Therefore, the aim of the current study was to assess the concurrent and predictive validity of the 3MT in a squad of national and international swimmers. We hypothesised that CS_{3MT} and D'_{3MT} values derived from the 3MT will not differ significantly from the CS_{CM} and D'_{CM} derived via the conventional testing methods (CM). The secondary aim of the current study was to assess the test-retest reliability of the 3MT in this setting.

Methods

Participants

Thirteen healthy swimmers (6 males, 7 females, age 16 ± 2 y, weight 64.7 ± 8.5 kg, height 176 ± 7 cm) volunteered to participate in this study, which received approval from the Research Ethics Approval Committee for Health at the University of Bath and was undertaken in accordance with the Declaration of Helsinki. All participants regularly competed in one or more national or international events per year and had personal best times for their primary stroke of 70-80% in relation to the world records. The swimmers completed a training volume of ~ 45 km/week, (~8-9 swimming session, 2-3 land sessions /week) and had training histories of 7.5 ± 2.8 y. One swimmer was excluded from the validation analyses and two swimmers were excluded from the reliability analyses, due to either not following the instructions of the procedures or health issues.

Experimental design

The protocol consisted of seven visits to the swimming pool. First, the subjects performed a 3MT familiarization trial. On the following visits and on separate days, subjects performed four TT and two 3MT to determine CS and D′. Each test was preceded by 5 min warm-up at low-intensity to minimize an impact of prior exercise on D′ [11] and was followed by 5 min rest. The front crawl technique was adopted in all TT and 3MT. All trials were completed in a 50 m pool with a push off start, flip turns and at the same time of the day (± 1 h) in order to minimize an impact circadian variation on performance. All swimmers were encouraged to come to the testing rested, fully hydrated and having eaten sufficiently.

Conventional protocol

The subjects completed a 200, 400, 600 and 800 m front crawl TT in the fastest possible time. Linear regression was used to calculate CS and D′ using the distance-time model (DT) and the speed-1/time model (1/T) that were obtained from the swimming time trials [10].

Three-min all-out test

Subjects were asked to swim at an “all out” swimming speed i.e. “as fast as you possible can at any given time during the test” to avoid pacing that could confound results in this test [1]. Time splits were recorded using a stopwatch (Finis Inc., 3x100 m, California, USA) at every 10 m as the swimmer’s head was visualized passing fluorescent cones that were placed parallel to the swimmer’s lane at every 5 m along the pool deck. As a swimmer was approaching 150 and 180 s, a 10 s countdown was given to the researcher that walked with a cone alongside the swimmer and a cone was placed at 150 and 180 s at the furthest point reached (i.e., hand). Subjects were filmed from an elevated area at the opposite side of the pool using a camera mounted on a tripod that was used to double check the displacement and velocity at each cone as well as to analyse stroke rate (SR). The SR was determined using the following equation:

$$\mathrm{SR}\ (\mathrm{cycles.min^{-1}}) = (60/\ \text{the time it takes to do three full stroke cycles}) \times 3$$

Distance at 150 s (D_{150}) and 180 s (D_{180}) were recorded using a 50 m tape measure placed parallel to the swimming lane and were used for the calculation of CS and D′ using the following formulas [12]:

$$\mathrm{CS}\ (\mathrm{m.s^{-1}}) = (D_{180}-D_{150})/30$$

$$D'\ (\mathrm{m}) = [(D_{150}/150)-\mathrm{CS}] \times 150$$

Mean 3MT speed-time and SR-time profile was calculated at 15 s intervals assuming a linear regression within the closest distance intervals that cross each of the 15 s interval, excluding turns [10]. Strong verbal encouragement was provided throughout the tests and subjects were not informed of the elapsed time or their performance to prevent pacing. The first 3MT trial was used for the validation analyses, mean 3MT speed-time and SR-time profile.

Statistical Analysis

A one-way repeated measures analysis of variance (ANOVA) was used to test for differences in CS and D′ estimates established from the 3MT and conventional models. A Bonferronni correction was applied for post-hoc comparisons in the presence of a significant *F* value. A Pearson correlation coefficient and a Bland-Altman analysis was used to assess the relationship and the limits of agreement (LOA) between CS and D′ estimated from the conventional methods and 3MT. The acceptable limits of agreement of differences was defined as 5% of mean CS [10] and as 10% of mean D′. Predicted times for TT were calculated using the following equation [5]:

$$t = (\text{distance} - D'_{3MT})/CS_{3MT}$$

The intra-class correlation coefficient, raw and standardised typical error of measurement and coefficient of variation were used to assess test-retest reliability of the 3MT. Default magnitude thresholds for the standardised typical error of measurement were 0.2, 0.6, 1.2, 2.0, 4.0 for small, moderate, large, very large and extremely large, respectively [13]. Paired-sample t-test and 95% confidence intervals (CI) of the mean differences were used to compare the responses between the two 3MT tests. The SPSS software package (version 24, SPSS, Chicago, IL) was used for statistical analysis. Statistical significance was accepted at $p < 0.05$ level, with data presented as means ± SD. Where DT and 1/T models provided identical results compared to 3MT, the 'CM' abbreviation was used for succinctness.

Results

The mean 3MT profile is shown in figure 1. When speed data were reduced to 15 s averages and compared, significant differences were observed between time bins (F=83.76, p<0.0001). Comparing one time interval to the previous, there was a significant decrease in speed across the first 60 s before the speed stabilised in the last 120 s. Figure 2 demonstrates the derivation of the CS and D′ parameters using the DT, 1/T models and the 3MT in a representative subject.

Validity

Table 1 provides a summary of CS and D′ estimated from the DT, 1/T models and 3MT. There was no significant difference between CS_{3MT}, CS_{DT} or $CS_{1/T}$ (F=1.89, p=0.193). CS_{3MT} correlated significantly with CS_{CM} (r=0.95, p<0.0001). There was a significant difference between three estimates of D′ (F=7.77, p=0.003). D'_{DT} was significantly higher (p=0.024) compared to D'_{3MT} and there was a trend for significantly higher $D'_{1/T}$ (p=0.09) when compared to D'_{3MT}. There was very large positive correlation between D'_{3MT} and D'_{CM} (r=0.79, p=0.002).

Insert figure 1 here

Insert figure 2 here

Insert table 1 here

Figures 3 and 4 demonstrate the relationship and bias ± 95% LOA between estimates derived from the 3MT and from conventional methods. Mean bias between CS_{3MT} and CS_{DT} was 0.01±0.02 $m.s^{-1}$ (0.7±1.5%, 95% CI: -0.0031 to 0.02 $m.s^{-1}$) and between CS_{3MT} and $CS_{1/T}$ was 0.01±0.02 $m.s^{-1}$ (0.4±1.5%, 95% CI: -0.01 to 0.02 $m.s^{-1}$). Bland-Altman plots of CS between 3MT and conventional methods evidenced that the 95% LOA ranged from -0.03 to 0.05 $m.s^{-1}$ (DT: -0.03 to 0.05 $m.s^{-1}$, 1/T: -0.03 to 0.04 $m.s^{-1}$), which is within the value of 5% CS defined *a priori* as acceptable. The mean bias between D'_{3MT} and D'_{DT} was -3.8 ± 4.07 m (-13.8 ± 18.8 %, CI: -6.39 to -1.21 m) and between D'_{3MT} and $D'_{1/T}$ was -2.65 ± 3.68 m (-9.7 ± 22.2%, CI: -4.99 to -0.31 m), suggesting consistently lower D'_{3MT} values when compared to D'_{DT} and $D'_{1/T}$. Bland-Altman plots of D′ between 3MT and conventional methods with the 95% LOA ranged from -11.77 to 4.56 m (D-T: -11.77 to 4.18, 1/T: -9.86 to 4.56 m), which is not within the value of 10% D′ defined *a priori* as acceptable. The standard error of the estimate (SEE) between CS_{3MT} and CS_{CM} was 0.02 $m.s^{-1}$ (95% CI: 0.01 to 0.04 $m.s^{-1}$, ~1.5% of the mean CS_{3MT}). The SEE between D'_{3MT} and D'_{DT} was 4.01 m (95% CI: 2.80 to 7.03 m, ~20.6% of the mean D'_{3MT}) and was 3.71 m (95% CI: 2.60 to 6.52 m, ~19% of the mean D'_{3MT}) between D'_{3MT} and $D'_{1/T}$.

When calculation of predictive TT times were modelled with CS_{3MT} and D'_{3MT}, the calculation yielded times consistent with those actually performed and nearly perfect correlation was found between actual and predicted TT times (see Table 2).

Insert figure 3 here

Insert figure 4 here

Insert table 2 here

There were significant differences in SR between 3MT and TT (F=53.87, p<0.0001). SR was significantly higher in 3MT (40.62 ± 3.37 cycles.min^{-1}) compared to 400 m (37.70 ± 4.05 cycles.min^{-1}, p=0.005), 600 m (36.78 ± 4.01 cycles.min^{-1}, p<0.0001) and 800 m TT (36.59 ± 4.20 cycles.min^{-1}, p<0.0001). There was no significant difference between SR in 3MT and in 200 m TT (42.43 ± 4.58 cycles.min^{-1}, p=0.312). There was a negative correlation between SR in 3MT and D'_{3MT} (r= -0.56, p=0.056), D'_{DT} (r= -0.26, p>0.05) and $D'_{1/T}$ (r= -0.21, p>0.05). During the 3MT, the SR in the first 30 s was significantly higher compared to the SR in the last 30 s and decline in SR coincided with the decline in speed (see figure 5).

Insert figure 5 here

Test-retest reliability

Test-retest reliability for CS, D′, SR, and speed for 150 s and 180 s were high between the two 3MT trials (see table 3). There were no significant differences in CS between two 3MT trials (mean change=-0.009, 95% CI: -0.02 to 0.002, $t_{(10)}$= -1.80, p=0.102). There was a nearly perfect and significant positive ICC in CS between two 3MT trials (r=0.97, 95% CI: 0.89 to 0.99, p<0.0001). Similarly, there were no significant differences in D′ between two 3MT trials (mean change=0.82, 95% CI: -0.58 to 2.22, $t_{(10)}$= 1.31, p=0.221). There was a very large and significant positive ICC in D′ between two 3MT trials (r=0.87, 95% CI: 0.58 to 0.96, p=0.001). The coefficient of variation (CV) between the two 3MT trials was 0.9% for CS (95% CI: 0.6-1.6%) and 9.1% for D′ (95% CI: 6.3-16.5%). The raw and standardised TE of the CS between the two 3MT trials was 0.01 m.s^{-1} (95% CI: 0.01-0.02 m.s^{-1}) and 0.20 (small) (95% CI: 0.14-0.35), respectively. The raw and standardised TE of the D′ between the two tests was 1.47 m (95% CI: 1.03-2.59 m) and 0.45 (small) (95% CI: 0.31-0.78), respectively.

Insert table 3 here

Discussion

The principal finding of this study is that the CS derived from the 3MT is comparable to the CS derived from conventional models, supporting our first hypothesis. D′ values from 3MT were lower compared to the conventional methods, which is contrary to our second hypothesis. Additionally, the 3MT method showed high test-retest reliability in both CS and D′. To our knowledge, this is the first study that has assessed concurrent and predictive validity and examined the test-retest reliability of the 3MT in highly-trained swimmers.

The mean end-speed in the 3MT test (1.33 ± 0.06 m.s^{-1}) was almost identical and strongly correlated with the CS_{CM} (1.33 ± 0.06 m.s^{-1}), extending findings from previous studies conducted in cycling [6], running [7], rowing [8] and swimming [10]. The SEE in our study (0.02 m.s^{-1} or 1.5% of mean CS_{3MT}) was lower in comparison to SEE previously reported in swimmers (0.11 m.s^{-1} or 12%) [10], cyclists (6-11 W, 2-5%) [6, 14] and rowers (24 W, 9%) [8]. The lower SEE in CS compared to the Tsai and Thomas study [10] could be related to recruitment of more homogenous group of highly-trained swimmers as well as the implementation of familiarisation trial and consistent low-intensity warm-up used in this study [1].

An additional important finding from the present study was that D'_{3MT} was ~14% lower in comparison to D'_{CM}. This is consistent with previous studies in swimming [10], cycling [6] and running [7], but is in contrast with Cheng et al. [8], who reported higher D'_{3MT} compared to D'_{CM} in highly trained rowers. We found a very large correlation between D'_{3MT} and D'_{CM} (r=0.79) and SEE of 4.01 m between D'_{3MT} and D'_{DT} (~20.6% of the mean D'_{3MT}) and 3.71 m between D'_{3MT} and $D'_{1/T}$ (~19% of the mean D'_{3MT}). This is similar to the findings of Vanhatalo et al. [6], who observed a very large correlation between work done above the end power (WEP) and W′ (r=0.84) and an SEE value of 2.8 kJ or ~18.7% of the mean WEP. This is however contrary to studies in rowing [8] and swimming [10], which reported a weak relationship between D'_{3MT} and D'_{CM}.

Whether the D'_{CM} and D'_{3MT} represent the same physiological quantity is still under debate [6, 15]. Indeed, D′/W′ may not be a simple "anaerobic capacity" parameter as originally thought [1, 16]. Green and Dawson [17] suggested that "anaerobic capacity" is a theoretical construct and measuring it in units of work may be prone to measurement errors, making it difficult to investigate. Current research suggests D′ as a more variable measure compared to CS [5, 15, 16]. Previous research has noted the sensitivity of D′ to nutrition [18], cadence [19], prior high-intensity exercise [11], interval duration [20], choice of TT or TTE method [21], and even to mental fatigue [22]. Whether, the conventional methods represents the gold standard method for the estimation of D′ in swimming is questionable. Indeed, the original method for deriving CS and D′ from the DT model is based on the assumption that the energy cost of transport is constant as speed increases [23]. Considering the exponential relationship that exists between speed and energy expenditure in swimming due to the drag swimmers encounter [23], defining parameters of the CS concept using this method might be problematic in swimming. Indeed, Tsai and Thomas [10] attributed the lower values of D'_{3MT} to the exponential increase in energetic cost with speed that translated to a quicker decline in speed and shorter time in reaching asymptotic speed that led to a smaller D′. Similarly to Tsai and Thomas [10], we observed a significant short but rapid decrease in speed in the first 60 s which could indeed be a plausible explanation for lower D'_{3MT} values in our study.

Alternatively, although participants in this study were encouraged to come to the TT prepared and the intensity of the warm-up was low to minimise any impact of prior exercise on D′, day-to-day variability associated with TT, could have had an impact on D'_{CM}. Johnson et al. [15] suggested that the conventional methods of determining W′ is more prone to high variability due to the extension of trials over multiple days, therefore the authors suggested the 3MT as more reliable method of assessing D′. Indeed, there were no significant differences in the tested parameters between two 3MT trials and high test-retest reliability was observed, in agreement with Johnson et al. [15], Cheng et al. [8] and Mitchell et al. [29]. In the present study, the coefficients of variation for D′ was higher when compared to CS. Considering the factors that D′ is sensitive to, and their relationship to preparedness of athletes to perform, D′ could be utilised for monitoring and optimising the prescription of training in the future work.

Furthermore, potential factors that could have contributed to discrepancies between D'_{3MT} and D'_{CM} could be related to stroke mechanics. The SR during the 3MT was higher compared to the SR in 400 m, 600 m, and 800 m TT. Thus, the lower D'_{3MT} values could be related to the higher SR observed in 3MT. Indeed, Vanhatalo et al. [19], examined the impact of cadence on W′ values in trained subjects and found that the W′ was significantly higher in the low cadence trials and lower in the high cadence trials. This is somewhat in agreement with previous studies that examined the influence of stroke mechanics on energy cost in swimming [24] and found that whilst SR might increase propulsion, it also leads to a disproportionate increase in energy expenditure and oxygen consumption [24]. In the present study, a rapid speed decline in the first

60 s coincided with decreases in SR, and could therefore contribute to a plausible explanation for differences in D′ derived from the two methods.

Finally, although D'_{3MT} was lower compared to D'_{CM}, when the calculation for predictive TT times was modelled with CS_{3MT}, the predicted times were similar to those actually performed. On average, the time difference between actual and predicted TT was 1.23 ± 2.06, 2.06 ± 3.30, 1.06 ± 6.67 and 1.33 ± 6.47 s for 200, 400, 600 and 800 m TT, respectively.

Practical application

One of the main practical advantages of the 3MT is its ability to accurately demarcate CS in a single test. Although the 3MT represents physiological phenomenon, this concept is fundamentally based on performance and requires minimal time, data analysis, expertise and resources, making it accessible to applied practice. Indeed, these factors have recently been identified by coaches as the primary issues preventing the translation of science into practice [25]. The applications of 3MT include assessment of physical fitness and technical components, the prediction of performances, athlete selection, as well as informing warming-up, pacing and racing strategies [5]. Additionally, parameters derived from 3MT enable coaches to prescribe training sessions with quantitative goals that are challenging yet attainable, thereby minimising the likelihood of overtraining, as well as serving as a useful motivational tool for athletes. Indeed, the 3MT method allows complex assessment of parameters related directly to performance that have functional meaning and have real-world use in a short space of time [5]. More recently, power-duration-based intensity zones have been demarcated using critical power from 3MT in cycling, emphasising the potential of this test to demarcate three physiological domains of exercise intensity in a single test [26]. Given that this approach can now be applied to swimming, future swimming research and practice should explore these methods as a means of providing enhanced prescription and testing methods compared to those currently used in swimming practice. Additionally, based on the results of Courtright et al. [12], the 3MT has the potential to facilitate a shift in the perception that high training volumes are a requirement for success in swimming. High volumes of training have been identified as a cause for a wide array of overuse injuries [27] and burnout [28] in swimming, and so the 3MT has the potential to improve these training practices in swimming.

Conclusion

In conclusion, this is the first study to demonstrate that the three-minute all-out test is a valid and reliable alternative protocol to estimate critical speed in highly-trained swimmers. It is recommended that future studies examine the relationship between the curvature constant derived from both methods, and the factors influencing this complex parameter. The demonstrated concurrent and predictive validity of the three-minute all-out test in swimming represents a potential for the more widespread use of the critical speed concept, as its application in swimming has not been fully maximised to date. This could therefore represent a very fruitful area of interest for researchers as well as athletes, coaches and sports practitioners working in swimming.

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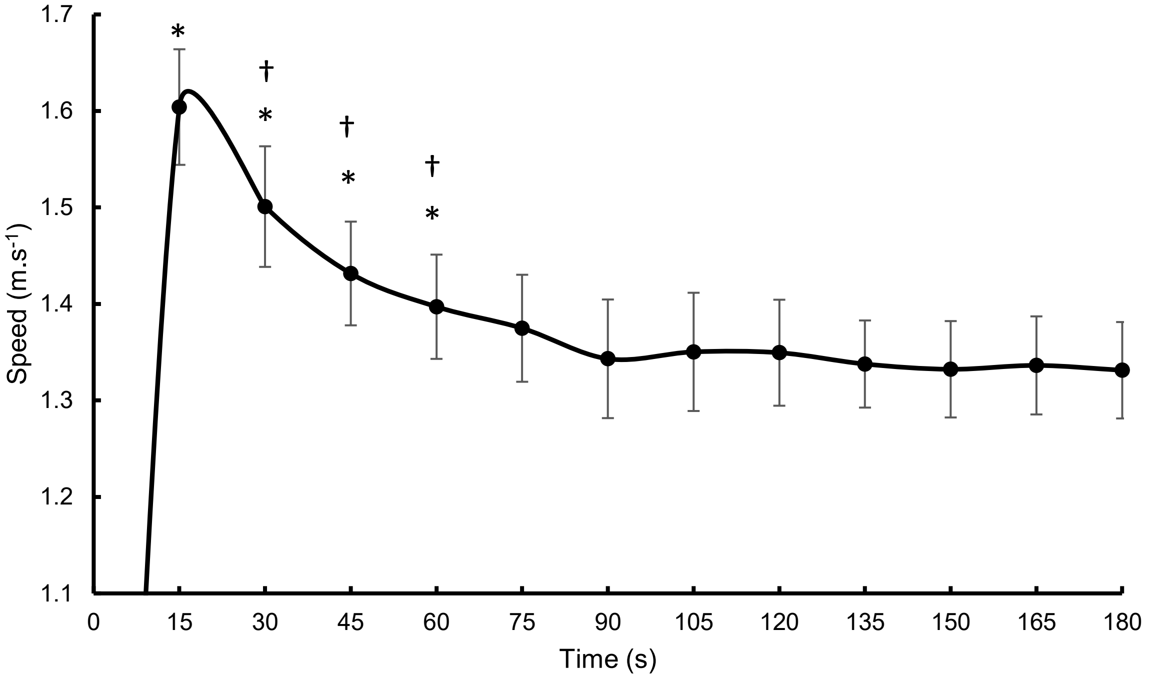

Figure 1. The group mean speed profile of the 3-min all-out test. **p*<0.05 compared to CS_{3MT}, † *p*<0.05 compared to the previous 15 s speed interval, n=12

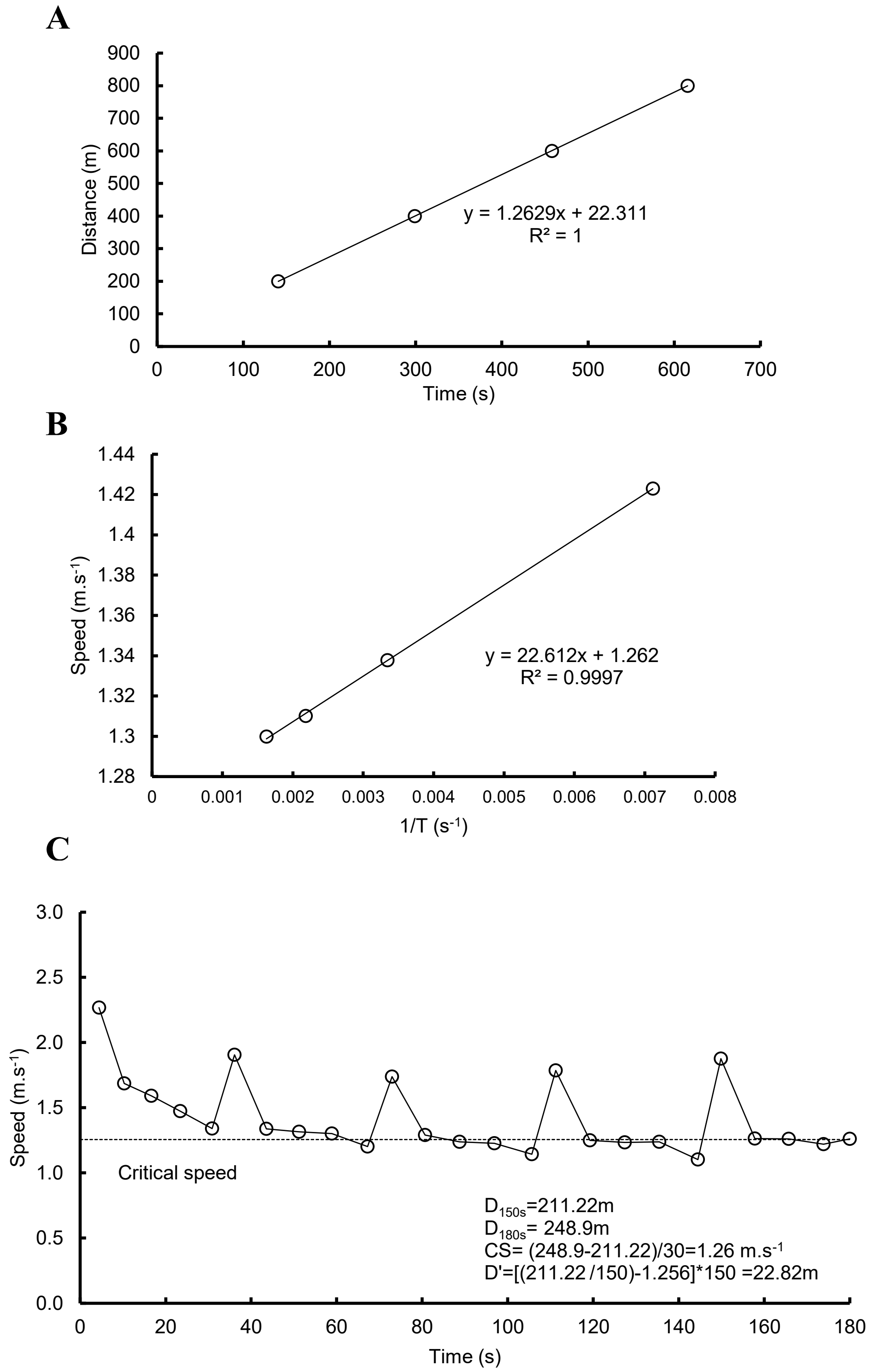

Figure 2. The derivation of the critical speed (CS) and the curvature constant (D′) estimates from the linear distance-time (A), speed-1/time (B) models and a 3-min all-out test speed profile (C) in a representative subject. Panel C illustrates the 3MT profile including turns that represent "spikes" in the profile. These were removed from the mean 3MT speed-time and SR-time profiles by using a linear regression within the closest distance intervals that cross each of the 15 s interval, excluding turns.

Table 1. Comparison of the critical speed and D′ derived from the 3-min all-out and conventional models.

	CS estimates (m.s^{-1})			**D′ estimates (m)**			**SEE**	
Subject	**3MT**	**D-T**	**1/T**	**3MT**	**D-T**	**1/T**	**D′**	**CS**
1	1.33	1.29	1.30	21.60	27.55	26.42	7.99	0.02
2	1.25	1.25	1.25	22.40	23.41	23.49	0.80	0.002
3	1.26	1.26	1.26	22.82	22.31	22.61	0.61	0.001
4	1.29	1.26	1.26	23.30	32.44	32.25	1.32	0.004
5	1.29	1.29	1.29	15.70	16.03	16.64	1.63	0.003
6	1.42	1.42	1.43	18.35	20.81	17.30	4.26	0.01
7	1.37	1.35	1.35	16.20	22.49	23.58	3.98	0.01
8	1.36	1.32	1.33	21.51	27.64	25.85	3.75	0.01
9	1.36	1.39	1.39	14.10	17.36	17.98	3.25	0.01
10	1.30	1.30	1.30	21.50	21.80	21.39	2.32	0.01
11	1.39	1.38	1.40	22.20	34.08	27.40	6.54	0.02
12	1.39	1.39	1.40	14.30	13.67	10.88	2.59	0.01
Mean	**1.33**	**1.33**	**1.33**	**19.50**	**23.30***	**22.15**	**3.26**	**0.01**
SD	**0.06**	**0.06**	**0.06**	**3.52**	**6.24**	**5.75**	**2.25**	**0.01**

CS, critical speed; D′, distance covered above critical speed; 3MT, the 3-min all-out test; D-T, the distance-time model; 1/T, the speed-1/time model, SEE = standard error of the estimate for the conventional method.

* *p*<0.05 compared to the 3-min all-out test

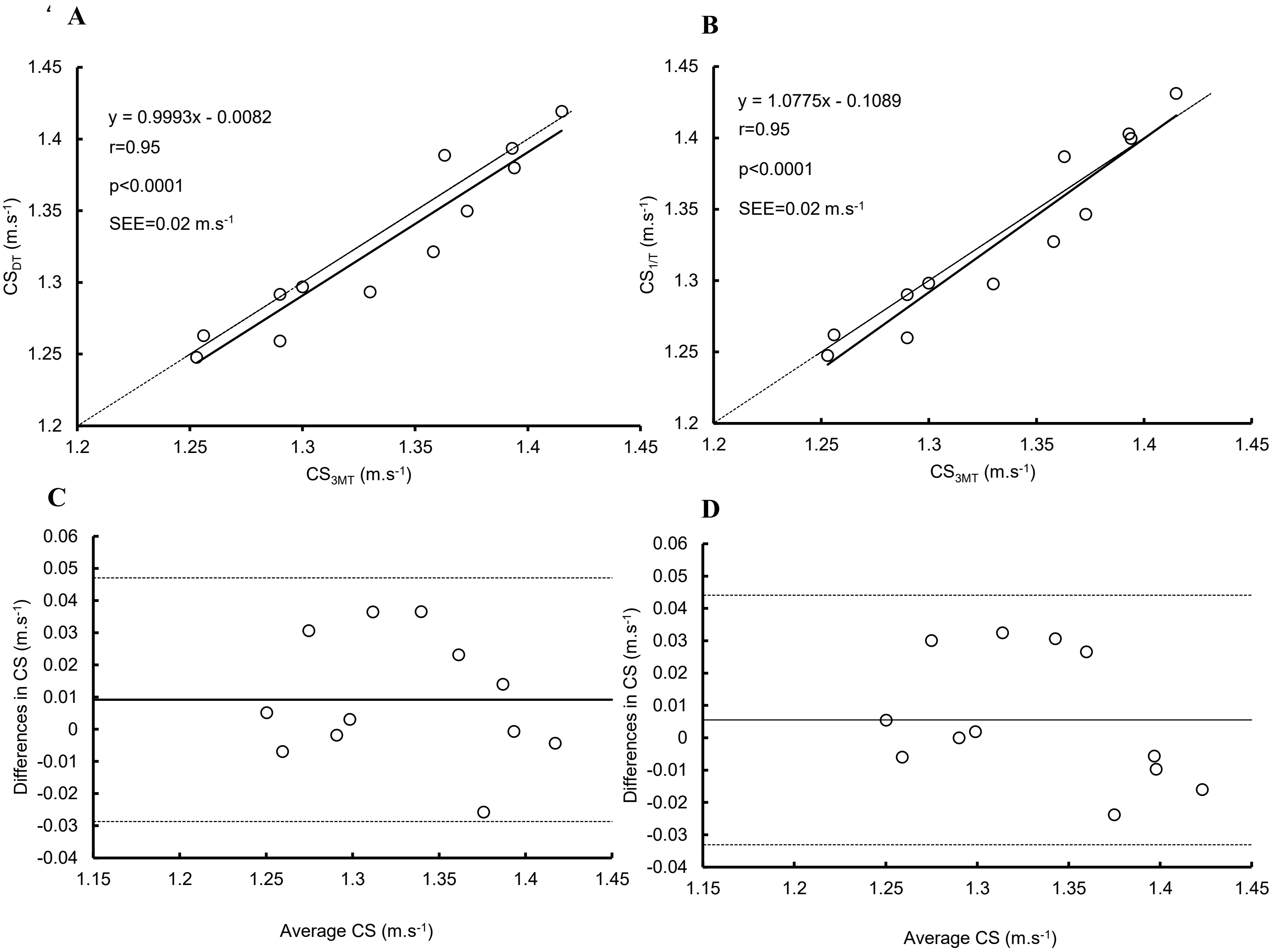

Figure 3. Correlation and Bland-Altman analyses for differences in CS between the 3MT and the distance-time model (A, C) and between the 3MT and the speed-1/time model (B, D). In the panels A and B, the *solid line* is the line of best-fit linear regression and the *dashed line* is the line of identity. In the panels C and D, the *solid horizontal lines* represent the mean difference between the CS_{3MT} and CS_{DT} and CS_{3MT} and $CS_{1/T}$, respectively, and the *dashed lines* represent the 95% limits of agreement; n=12

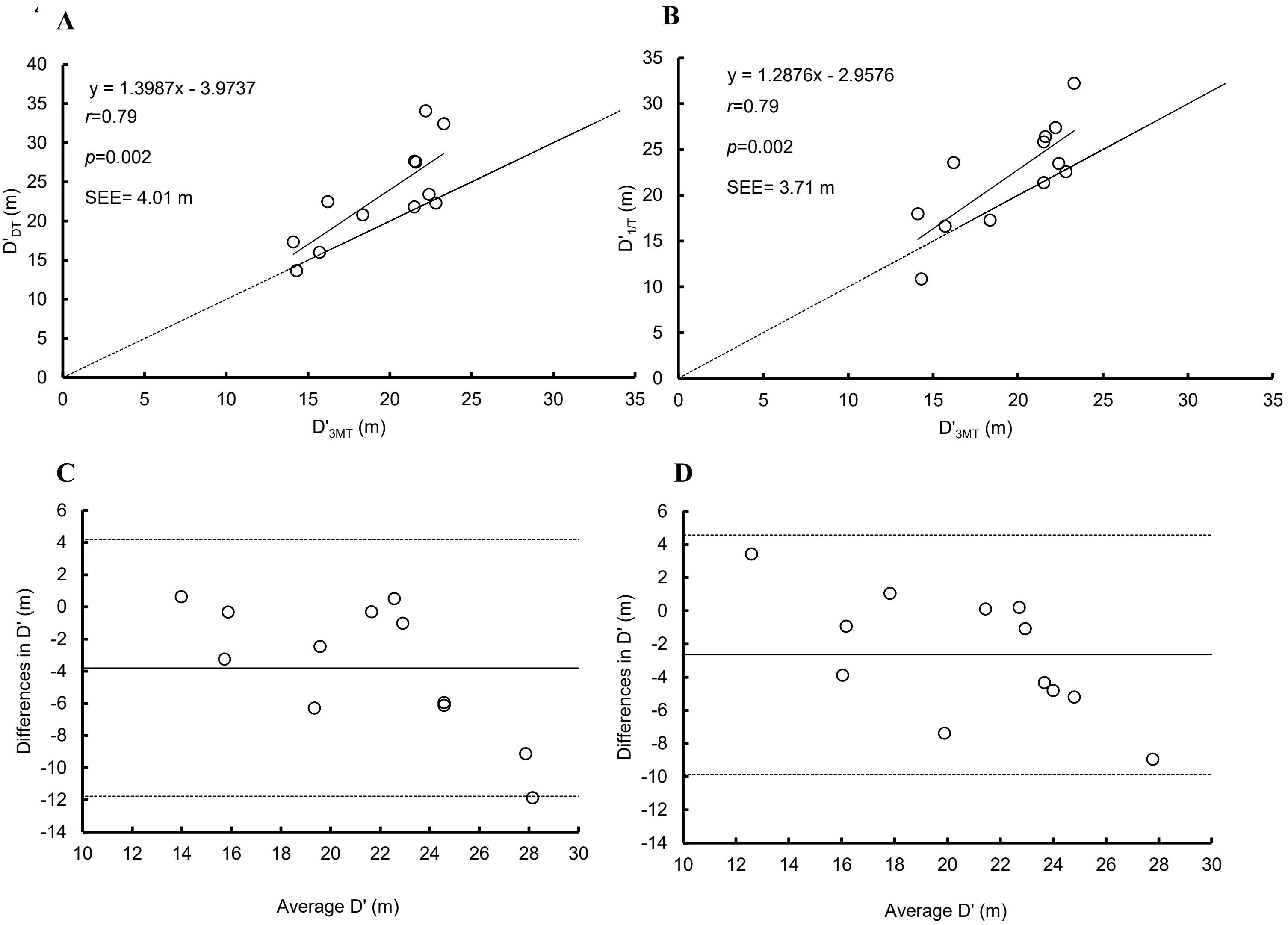

Figure 4. Correlation and Bland-Altman analyses for differences in D′ between the 3MT and the distance-time model (A, C) and between the 3MT and the speed-1/time model (B, D). In the panels A and B, the *solid line* is the line of best-fit linear regression and the *dashed line* is the line of identity. In the panels C and D, the *solid horizontal lines* represent the mean difference between the D'_{3MT} and D'_{DT} and D'_{3MT} and $D'_{1/T}$, respectively, and the *dashed lines* represent the 95% limits of agreement; n=12

Table 2. Comparison of the actual versus predicted time trial (TT) times.

	200 m (s)	**400 m (s)**	**600 m (s)**	**800 m (s)**
Actual TT	134.18±5.54	283.44±12.97	436.65±19.40	587.02±24.29
Predicted TT	135.41±4.95	285.50±10.95	435.59±17.17	585.69±23.46
r	0.93*	0.98*	0.94*	0.96*

*$p<0.0001$

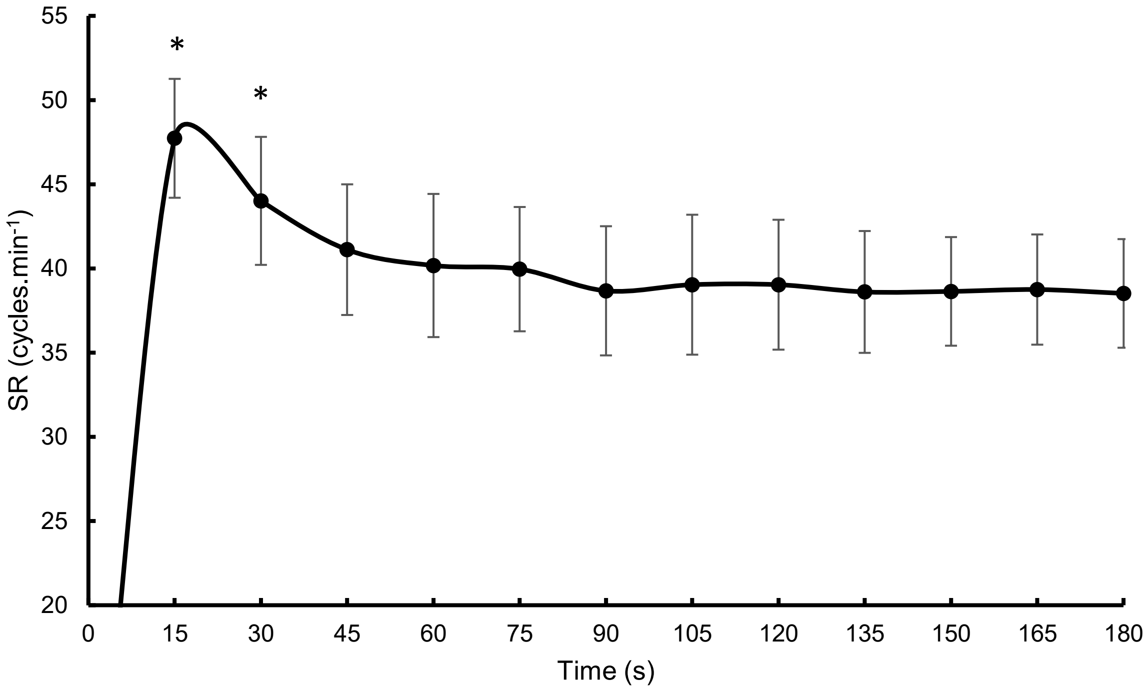

Figure 5. The group mean stroke rate profile of the 3-min all-out test. *$p<0.05$ compared to SR in the last 30 s, n=12

Table 3. Test-retest reliability of the 3-min all-out swimming tests.

	3MT$_1$	3MT$_2$	CV (%)	ICC (α)	Raw TE (Standardised)	95% CI
CS (m.s^{-1})	1.34±0.06	1.34±0.06	0.9	0.97*	0.01 (0.20)	-0.02 to 0.002
D′ (m)	18.36±4.07	17.54±3.11	9.1	0.87*	1.47 (0.45)	-0.58 to 2.22
Speed for 150 (m.s^{-1})	1.46±0.06	1.46±0.06	0.6	0.98*	0.01 (0.15)	-0.01 to 0.01
Speed for 180 (m.s^{-1})	1.44±0.06	1.44±0.06	0.6	0.98*	0.01 (0.15)	-0.02 to 0.004
SR (cycles.min^{-1})	41.20±2.87	41.13±3.58	2.6	0.91*	1.07 (0.35)	-0.95 to 1.08

CV, coefficient of variation; ICC, intra-class correlation coefficient; TE, typical error; CI, confidence interval; CS, critical speed; D′, distance covered above critical speed; SR, stroke rate; n=11; *$p<0.05$