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Article

Reliability of the Single-Visit Field Test of Critical Speed in Trained and Untrained Adolescents

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Abstract: Recent studies in adults have shown that the critical intensity during running and cycling estimated from three prediction trials interspersed by 30 min is valid and reliable. To establish the reliability of the single-visit field test to determine critical speed (CS) and the distance above critical speed (D′) in adolescents, 29 trained and 14 untrained participants (mean ± SD age: 17.5 ± 0.5 years) performed three tests on a 400-m outdoor track separated by 48 h. Each test consisted of three distances selected to result in finishing times between 2 and 15 min that must be completed as fast as possible. CS and D′ were modeled using the linear 1/time model (Speed = D′(1/t) + CS). While the coefficient of variation (CV) of CS was between 2.4% and 4.3%, the CV of D′ was 9.3% to 13.6%. Also the intraclass correlation coefficient ranged from 0.919 to 0.983 for CS and from 0.325 to 0.828 for D′. The results show that the single-visit field test provides reliable estimates of CS but not D′ in trained and untrained adolescents.

Keywords: critical power; field test; youth athletes; test-retest reliability

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1. Introduction

Critical power (CP), which represents the asymptote of a participant's power-duration curve, separates the boundaries of the heavy and very heavy intensity domains and has been broadly associated with maximal lactate steady state [1]. According to the theory of Monod and Scherrer [2], CP represents the maximal power that can be sustained indefinitely. While this has been shown not to be the case, CP has been proposed as an important parameter of aerobic function [3]. The two component CP model assumes that the CP is representative of the maximal rate at which ATP turnover is supplied aerobically, whilst the curvature constant of the hyperbolic curve, represents a finite anaerobic energy store within the muscle, signified as W′ (indicative of work that can be performed above CP) [4]. During an exercise period undertaken above CP, exhaustion will occur when the W′ is depleted, and the rate is determined by how much a participant is exercising above his or her CP, represented by the equation

$$\text{Time to exhaustion} = W'/(P - CP) \quad (1)$$

where P represents power.

To date most studies examining CP have been conducted using cycle ergometers but the CP concept is easily translated to running or swimming, termed critical velocity or critical speed, as a vector or scalar quantity, respectively. For clarity, critical speed (CS) will be used throughout the paper. Based on Equation (1), the time to exhaustion for an acquired speed can be predicted during exercise above CS. Furthermore, if the aim is to require a participant to complete a known amount of work or distance in a training session, the theoretical time to complete this work can be calculated from:

$$\text{Time to exhaustion} = (D - D')/CS \quad (2)$$

where D and D′ represent the distance and distance above CS, respectively.

CP or CS is strongly associated with $\dot{V}O_{2max}$ [5,6] and endurance performance [7,8] indicating the validity to measure aerobic function. In comparison with adults, where CP has been identified as the highest sustainable exercise intensity above which a loss of intramuscular metabolic (e.g., phosphocreatine, pH) and systemic (e.g., $\dot{V}O_2$, blood lactate) homeostasis occurs [9], physiological responses during exercise at CP in young people are limited [6,10]. Williams *et al.* [6] reported non steady-state responses in $\dot{V}O_2$ and blood lactate during cycling at CP and 10% above CP and concluded, that CP does not represent a sustainable exercise intensity in adolescents. In accordance, Barker *et al.* [10] showed increases in $\dot{V}O_2$ and blood lactate over time, accompanied by reduced time to exhaustion during cycling 10% above CP. At an intensity 10% below CP, all participants completed 30 min of exercise and a steady-state in $\dot{V}O_2$ and blood lactate profile was identified [10].

There is a useful and practical application of CS in the prediction and monitoring of young athletes' aerobic fitness and performances. Additionally, coaches would be able to manipulate the time or intensity of training in order to affect the stimulus of training. This practical application of CS can be observed most commonly in swimming, where the calculation of CS is frequently utilized for youth training and performance [7,11–13]. Application can also be found, although infrequent, in other sports e.g., running [14].

Before a wider uptake by coaches and sports science support staff for the CS method to assess aerobic function in a field setting can be undertaken, it is important to determine the reliability of the method.

While the critical speed estimated from the single-visit field test has been shown to be reliable and valid in adults [15,16], the reliability in children and adolescents remains to be shown. Therefore, the aim of this study was to establish the reliability of CS and D′ obtained from the single-visit field test in trained and untrained adolescents.

2. Method

2.1. Participants

A total number of 43 adolescents (19 males) volunteered to participate in this study. According to an interview with the participants and their parents, the group was divided into trained and untrained subjects. Twenty nine participants (15 males) (mean ± SD age: 17.7 ± 0.5 years; stature: 170.7 ± 6.1 cm; body mass: 63.4 ± 8.9 kg) had a training volume of at least 6 $h \cdot week^{-1}$ (range: 6–18 $h \cdot week^{-1}$) and were classified as trained. All were members of local sport clubs and participated in a variety of sports (football (seven), gymnastics (five), triathlon and tennis (four), volleyball (three), swimming and judo (two), dancing and climbing (one)). The remaining 14 participants (four males) (mean ± SD age: 17.4 ± 0.6 years; stature: 169.9 ± 6.1 cm; body mass: 63.3 ± 14.8 kg) participated in less than 3 $h \cdot week^{-1}$ of physical activity (school sports), and therefore were classified as untrained. After being briefed as to the risks of the research, informed written parental consent and the participants' assent were provided before entering the study, which was conducted in accordance with the ethical principles of the Declaration of Helsinki and approved by the University's institutional review board.

2.2. Study Design

At the first visit body mass and stature were measured using an electronic scale and stadiometer (Seca 813 and 213, Seca, Hamburg, Germany). The study involved three testing sessions, separated by 48 h, for each participant on a 400 m outdoor track. During each session, the participants were asked to complete three fixed distances in the shortest possible time (*i.e.*, as fast as possible) using a 30 min recovery between the runs [15,16]. All sessions were performed at sea level, at approximately the same time of the day (±2 h) and the temperature and humidity were 22–25° C and 40%–45%, respectively. The wind speed was less than 2.0 $m \cdot s^{-1}$ during all tests [17]. Prior to each session, a standardized warm-up of 5 min jogging followed by a series of five 30 s runs with increasing speed, was completed. The participants were asked to refrain from strenuous exercise in the 24 h before the tests.

2.3. Determination of Critical Speed

The three fixed-distance runs were conducted in the following order: 500 m, 1200 m and 2000 m for the trained and 400 m, 1000 m and 1600 m for the untrained participants. These distances were estimated to result in finishing times between 2 and 15 min [4] and based on previous experience. The participants started in 30 s intervals and were strongly verbally encouraged throughout the tests. All runs were hand-timed and recorded to the nearest second and no information on elapsed time was provided. Linear regression was used to calculate CS and D′ using the 1/time model (Speed = D′(1/t) + CS). The model was chosen as it provides the better parameter estimates of CS compared with the linear distance-time model (standard error: 0.12 ± 0.09 m·s^{-1}, 95% confidence interval: 0.09 to 0.13 m·s^{-1}; r^2 = 0.96 ± 0.06; 95% CI: 0.95 to 0.97).

2.4. Statistical Analyses

The parameter estimates of the linear 1/time model were resolved with the software Graph Pad Prism 6.0 (Graph Pad, La Jolla, CA, USA). Statistical analyses were performed with the software package SPSS Statistics 22 (IBM Corporation, Armonk, NY, USA). Descriptive data are summarized as mean ± standard deviation (SD). The assumption of normality was verified using the Shapiro-Wilk statistic. A two-way analysis of variance was used to compare CS and D′ across the three tests and between the groups (trained *vs.* untrained). Significant main effects were followed up with pairwise comparisons employing the Bonferroni procedure for multiple testing [18]. The reliability of CS and D′ was assessed with the 95% limits of agreement (LoA) [19] and the intraclass correlation coefficient (ICC). In addition, the within-subject variation was calculated as a coefficient of variation (CV) derived from log-transformed data [20]. All measures of reliability are reported with 95% confidence intervals (95% CI). The level of significance was set at $p < 0.05$.

3. Results

3.1. Critical Speed

The CS was significantly higher in the trained than the untrained participants ($F_{1,41}$ = 18.9; $p < 0.001$). There was a significant difference in CS across the three tests in the untrained participants (2.47 ± 0.37 m·s^{-1}, 2.60 ± 0.37 m·s^{-1} and 2.43 ± 0.37 m·s^{-1}; $F_{2,12}$ = 47.5; $p < 0.001$). The post-hoc test revealed that CS estimated from the second test was significantly higher compared to the first test (p = 0.02) and the third test ($p < 0.001$). No significant differences in CS across the three tests were observed in the trained participants (3.20 ± 0.48 m·s^{-1}, 3.15 ± 0.55 m·s^{-1} and 3.17 ± 0.54 m·s^{-1}; $F_{2,27}$ = 1.4; p = 0.27).

The bias in the trained participants was -0.04 ± 0.14 m·s^{-1} (−1.6% ± 4.4%; 95% LoA −0.32 to 0.23 m·s^{-1}) for tests 2-1 and 0.01 ± 0.10 m·s^{-1} (0.5% ± 3.3%; −0.19 to 0.22 m·s^{-1}) for tests 3-2 (Figure 1). In the untrained participants the bias was 0.13 ± 0.15 m·s^{-1} (5.3% ± 6.0%; −0.17 to 0.43 m·s^{-1}) and −0.18 ± 0.08 m·s^{-1} (−7.2% ± 3.3%; −0.34 to −0.01 m·s^{-1}) for tests 2-1 and for tests 3-2, respectively (Figure 1). The ICC was 0.963 (95% CI 0.923 to 0.983) for tests 2-1 and 0.982 (0.962 to 0.992) for tests 3-2 in the trained and 0.919 (0.758 to 0.974) for tests 2-1 and 0.960 (0.874 to 0.987) for tests 3-2 in the untrained participants. The within-subject variation, expressed as a coefficient of variation, was 3.2% (2.6% to 4.4%) for tests 2-1 and 2.4% (1.9% to 3.3%) for tests 3-2 in the trained and 4.3% (3.1% to 7.1%) for tests 2-1 and 2.6% (1.9% to 4.3%) for tests 3-2 in the untrained participants.

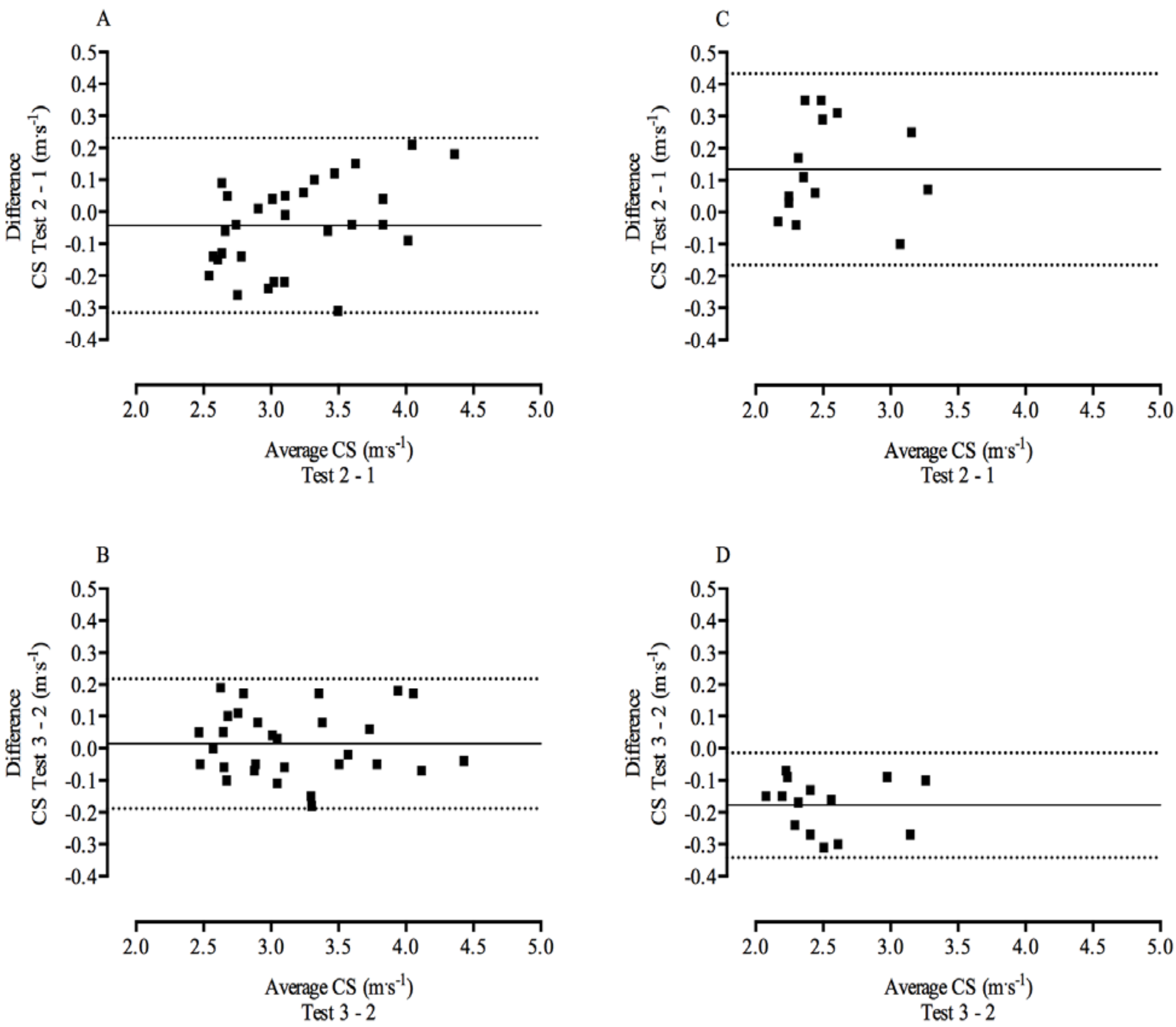

Figure 1. Bland-Altman plots of the mean differences in critical speed between tests 2-1 (**A**) and 3-2 (**B**) for the trained and the untrained adolescents (**C**,**D**). Solid and dotted lines represent the bias and 95% limits of agreement, respectively.

3.2. Distance above Critical Speed

No significant differences between the trained than the untrained participants were found for D′ ($F_{1,41}$ = 1.2; p = 0.28). There was a significant difference in D′ across all three tests in the untrained participants (163 ± 22 m, 134 ± 23 m and 148 ± 20 m; $F_{2,12}$ = 11.4; p = 0.002). No significant differences in D′ across the three tests were observed in the trained participants (135 ± 27 m, 139 ± 28 m and 143 ± 35 m; $F_{2,27}$ = 1.9; p = 0.17).

The bias in the trained participants was 4.3 ± 16.8 m (3.1 ± 12.5%; 95% LoA −28.6 to 37.2 m) for tests 2-1 and 4.4 ± 20.5 m (2.2 ± 15.2%; −35.8 to 44.5 m) for tests 3-2 (Figure 2). In the untrained participants the bias was −29.2 ± 22.3 m (−20.1 ± 17.7%; −73.0 to 14.6 m) and 14.3 ± 19.6 m (10.8% ± 15.0%; −24.1 to 52.7 m) for tests 2-1 and for tests 3-2, respectively (Figure 2). The ICC was 0.818 (95% CI 0.645 to 0.911) for tests 2-1 and 0.796 (0.606 to 0.900) for tests 3-2 in the trained and 0.325 (−0.248 to 0.730) for tests 2-1 and 0.565 (0.050 to 0.843) for tests 3-2 in the untrained participants. The CV was 9.3% (7.7% to 13.4%) for tests 2-1 and 11.4% (9.5% to 16.7%) for tests 3-2 in the trained and 13.6% (10.4% to 24.6%) for tests 2-1 and 11.3% (8.5% to 19.9%) for tests 3-2 in the untrained participants.

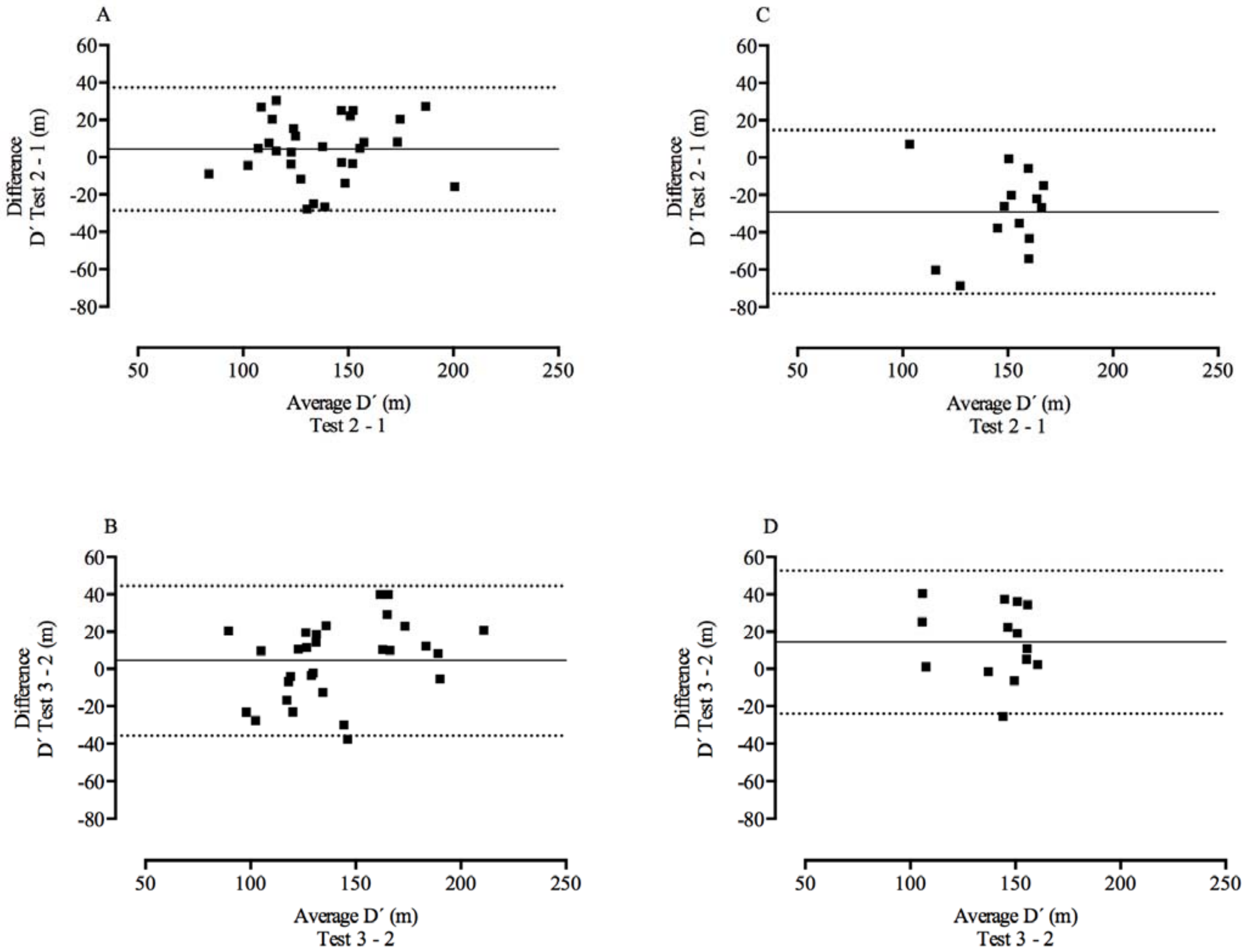

Figure 2. Bland-Altman plots of the mean differences in the distance above critical speed between tests 2-1 (**A**) and 3-2 (**B**) for the trained and the untrained adolescents (**C**,**D**). Solid and dotted lines represent the bias and 95% limits of agreement, respectively.

4. Discussion

The present study investigated the reliability of the single-visit field test of critical speed (CS) in trained and untrained adolescents. The main findings were that the estimates of CS but not the distance above CS (D′) were reproducible in both groups. Specifically, the coefficients of variation (CV) were between 2.4% and 4.3% and the ICC ranged from 0.919 to 0.982 for CS indicating that this test can be used reliably to estimate CS. This was however not found for D′ where the CV was above 9% and the ICC was lower than 0.818.

It was also observed that trained adolescents were more stable than their untrained counterparts when performing maximal-effort trials as requested in the present study. Unsurprisingly, the young trained athletes had significantly higher estimates of CS (mean difference 0.67 $m \cdot s^{-1}$; $p < 0.001$), but more importantly there was no significant difference across the three tests ($p = 0.27$). In contrast, the untrained participants performed significantly better during the second compared with the first ($p = 0.02$) and the third test ($p < 0.001$). These results suggest, that at least one familiarization session appeared to be required for the attainment of a stable estimate of CS [21]. In addition, the Bland-Altman plots revealed mean differences between the second and the first test (0.13 $m \cdot s^{-1}$ or 5.3%) as well as between the second and the third test (0.18 $m \cdot s^{-1}$ or 7.2%), indicating that although the untrained subjects were able to perform significantly better in the second test compared to the first test, performance dropped back in the third test. We do not believe environmental conditions such as temperature or wind had affected our findings as these were controlled. It is more likely that motivational factors such as goal-orientation, self-perception and willpower could explain the inconsistency in untrained adolescents [22]. It has been shown that males are more ego-oriented than females in outperforming each other [23] and therefore there might also be a gender bias as the trained athletes consisted of 15 boys and 14 girls while the group of untrained participants consisted of four boys and 10 girls. An additional explanation for the inconsistency found in untrained athletes might be the order of the prediction trials. While some studies started with the longest trial [15,16], others started with the shortest trial or randomly applied the trials [24,25]. Starting with the shortest trial in the present study, could have affected the untrained athletes due to inexperience with maximal efforts and this in turn might impact consistency.

The Bland-Altman plots also showed smaller ranges of the 95% LoA (*i.e.*, 1.96 × SD of the bias) between the third and second test compared with the second and first test in both groups, indicating that both groups had a higher consistency after the familiarization trial. This effect was however, much larger in the untrained athletes where the 95% LoA changed from ±0.29 $m \cdot s^{-1}$ (±11.8%) to ±0.16 $m \cdot s^{-1}$ (±6.5%) compared with the trained participants (±0.27 $m \cdot s^{-1}$ or ±8.6% to ±0.19 $m \cdot s^{-1}$ or ±6.5%). Assuming a negligible bias in the trained participants this shows that CS may not differ by more than 6.5% between any two tests due to measurement error. This small measurement error in both groups was corroborated by ICCs > 0.960 between the second and third test. With 95% CI between 0.758 and 0.992, the CS demonstrated a good to excellent degree of reproducibility [26]. This was also reflected by the CV, which was ~2.5% in both groups.

Our results are in accordance with previous studies that investigated the reliability of the single-visit protocol during running [15] and cycling [24] in trained adults. For example, Galbraith *et al.* [15] reported CVs of 2.0% (1.4% to 3.8%) and 1.3% (0.9% to 2.4%) for tests 2-1 and 3-2, respectively. In addition, the 95% LoA improved from ±0.27 $m \cdot s^{-1}$ or ±5.7% to ±0.18 $m \cdot s^{-1}$ or ±3.8%. These observations show that even highly trained distance runners ($\dot{V}O_{2max}$ 69.1 ± 4.2 $mL \cdot min^{-1} \cdot kg^{-1}$) should use a familiarization trial to improve the reliability of the single-visit field test before its use to monitor performance.

To place the present study into context with other studies on reliability measures in children and adolescents, it appears that the single-visit field test is among those with the highest reliability. To assess the reliability of anaerobic power in 12 to 14 year old rowers, two modified 30-s Wingate anaerobic tests were completed interspersed by a 15-min active recovery period [27]. The authors reported CVs of 2.9% (2.6% to 3.4%) for mean power and 2.4% (2.1% to 2.8%) for peak power. These were accompanied by very high ICCs (0.994 to 0.996). In another study, the same authors investigated the same test in a more heterogeneous group of 12 to 18 year old rowers with the retest performed 5–7 days after the first test [28]. It was shown, that CVs for mean and peak power were 6.7% (5.8 to 7.9%) and

7.3% (6.3% to 8.6%), respectively and the ICCs ranged from 0.973 to 0.982. Dore *et al.* [21] compared the reliability of cycling peak power obtained from the Wingate anaerobic test between pre-pubertal children and young adults. Again the CV changed from 4.7% and 3.0% in children and adults, respectively to less than 3.0% in both groups.

Only a few studies have reported the reliability of field test measures of aerobic fitness in children and adolescents [29–31]. Castagna *et al.* [31] evaluated a popular field test for aerobic fitness in football in Italy. The peak speed during a progressive 45-s run with 15 s passive recovery was used as a reflection of aerobic fitness. In comparison with our results, the CV and ICC were 3.75% (2.85% to 5.62%) and 0.92 (0.78 to 0.97), respectively. The Yo-Yo Intermittent Recovery Test Level 1 is frequently used to assess aerobic fitness in football players [32]. Recently the reliability of the test was evaluated in young football players and it was found, that the test was less reliable in younger age groups (U13 and U15) with CVs of 17.3% (90% CI 14.5% to 21.7%) and 16.7% (13.9% to 21.2%), compared with the U17 category (7.9%; 5.8 to 12.6%) [30]. In a follow-up study, where a third familiarization trial was included, the same authors reported CVs of 7.1% (90% CI 5.6 to 9.5%), 3.1% (2.3 to 4.8%) and 3.0% (1.8% to 8.6%) between the second and third test across the age categories U15, U17 and U19, respectively [29].

From a practical perspective, the results of the present study are important for coaches and physical education teachers involved in the fitness evaluation of young people. First, the concept of critical speed is a non-invasive approach to determine the highest rate of oxygen utilisation matched by oxygen delivery (*i.e.*, “anaerobic threshold”) [33,34]. Second, the single-visit field test protocol allows the determination of CS independently from any laboratory equipment within a training session or physical education class. Third, based on the reliability data presented here, meaningful changes in performance could be detected. For example, in a young adolescent athlete with a CS of 3.17 $m \cdot s^{-1}$ and the reported CV of 2.4%, any change in performance of 0.08 $m \cdot s^{-1}$ (0.27 $km \cdot h^{-1}$) would be detected as meaningful. Using the upper limit of the 95% CI of 3.3 and 4.3% these meaningful changes are 0.10 $m \cdot s^{-1}$ (0.38 $km \cdot h^{-1}$) and 0.11 $m \cdot s^{-1}$ (0.39 $km \cdot h^{-1}$) in the trained and untrained participants, respectively.

Finally, our study revealed that the distance above critical speed (D′) is less reliable than CS, which is in agreement with previous studies [15,16,24,25]. On average, the CV ranged from 9.3% to 13.6% and the 95% CI from 7.7% to 24.6%, indicating a limited reliability and thus practical relevance. The reasons for this remain unclear but previous studies excluded residual fatigue, standing start during cycling, duration of the prediction trials and familiarization as possible factors [16,25].

5. Conclusions

In conclusion the present study showed that the single-visit field test to estimate critical speed is a reliable test for assessing physical fitness in trained and untrained adolescents. We also recommend planning at least one familiarization trial to use the estimated critical speed as a valid performance measure. The non-invasive and time saving protocol is of particular practical value for practitioners, such as coaches or physical education teachers and the test is sensitive enough to detect meaningful changes of ~0.3 to 0.4 $km \cdot h^{-1}$. It should also be noted that the distance above critical speed is currently not reliable enough to be used as a valid measure.

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Author Contributions

Alfred Nimmerichter and Mathias Steindl designed and conceived the study. Mathias Steindl collected the data. Alfred Nimmerichter, Mathias Steindl and Craig Anthony Williams analyzed the data. Alfred Nimmerichter and Craig Anthony Williams wrote the original draft of the paper. All authors reviewed and approved the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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