



ORIGINAL ARTICLE

Functional Speed Reserve as a Proxy for the Anaerobic Speed Reserve Using the Critical Speed Concept

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ABSTRACT

Background. Although maximal sprint speed (MSS) and the anaerobic speed reserve (ASR) provides valuable information about an athletes' speed profile, these parameters fall short of providing important information about sub-maximal metabolic thresholds. The only field test that can offer an estimate of a sub-maximal metabolic threshold is the 3-minute all-out test for running (3MT), which delivers three parameters of interest: the critical speed (CS), fatigability constant (D'), and 3MT-specific maximal running speed (MS_{3MT}). **Objectives.** We offer an alternative to the ASR, termed the 'functional' speed reserve (FSR). Therefore, this study's purpose was two-fold: firstly, to compare MSS to MS_{3MT} and FSR to ASR, and secondly, to determine the correlations between ASR, FSR, and D'. **Methods.** Thirty-two participants volunteered for the study (age: 22.50 ± 4.32 years; height: 1.67 ± 0.78 m; body mass: 66.58 ± 11.30 kg) and completed a graded exercise test (GXT), 3MT, and 40-m sprint test following familiarization bouts for each test. **Results.** MSS and MS_{3MT} were strongly correlated (r = 0.93, p < 0.001). The ASR and FSR were also strongly correlated (r = 0.77, p < 0.05), with the FSR also showing a strong correlation with D' (r = 0.77, P < 0.05). **Conclusion.** The 3MT provides a viable, arguably more ecological alternative to the ASR (i.e., FSR) and provides additional parameters such as CS, D', and MS_{3MT}. Field testing based on the 3MT can offer coaches and athletes unique performance insights and tools to program and effectively prescribe training interventions.

KEYWORDS: *Critical Speed, Maximal Speed, Speed Reserve, Thresholds.*

INTRODUCTION

The training prescription framework is most often based on the utilization of specific physiological anchor points to elicit favorable outcomes in cardiorespiratory and neuromuscular conditioning (1). More specifically, the practitioner typically needs to know three key anchors: (i) a maximal threshold (e.g., maximal oxygen uptake [$\dot{V}O_{2max}$], maximal heart rate [HR_{max}]), (ii) a submaximal threshold (e.g. lactate threshold [LT], gas exchange threshold [GET]), and (iii) maximal strength and/or speed (1,2). These parameters are usually derived from extensive testing batteries that are either

laboratory-based (e.g., graded exercise test [GXT]) or field-based (e.g., 2km time trial), with the outcome parameters, then being used to more formally construct training programs targeting aerobic, anaerobic and/or neuromuscular bioenergetics pathways (2, 3).

Most field sports rely on field-based assessments to derive these outcome parameters of interest, coupled with various logistical constraints (4-7). Although several field tests exist to estimate $\dot{V}O_{2max}$ (e.g. University of Montreal track test, Vam-Eval, 20-m shuttle test, 30-15 test) (2, 8), presently the only single-

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session field test, to the knowledge of the authors, that is not only applicable to both field-sport athletes and moderately trained individuals, but that is also able to provide an estimate of a submaximal threshold that can separate sustainable from non-sustainable running speeds, is the linear 3-minute all-out test for running (3MT) (9-11). The 3MT yields three key variables of interest, namely: (i) critical speed (CS), which represents a critical metabolic threshold that separates sustainable from non-sustainable running speeds, (ii) D', which is a fatigability constant representing a finite energy reserve for running at speeds exceeding CS, and (iii) 3MT-specific maximal running speed (MS_{3MT}) which is the maximum speed attained during the all-out linear run (9, 12, 13). Furthermore, the 3MT-derived variables have shown exceptional utility for customized and predictable high-intensity exercise prescription and performance prediction (11, 14-16). With such parameters in hand, the practitioner is in a favorable position to know the athletes' metabolic response across the spectrum of running speeds, except the athletes' maximal sprinting speed (MSS).

Maximal, or near maximal, running speeds provide some insights about an individual's athletic "flexibility" in terms of the range of speeds they are capable of especially the upper echelons of running speed. This is the premise of the anaerobic speed reserve (ASR), which constitutes the difference between the maximal aerobic speed (denoted by the speed evoking $\dot{V}O_{2max}$ [$s\dot{V}O_{2max}$]) and the MSS, where the ASR has been associated with elite running performances (2, 17). It is worth noting, however, that, within sport-specific contexts such as soccer, rugby, and hockey, the number of near-maximal speed occurrences (i.e., > 90% of MSS) are deficient (18-21). Interestingly, Kramer et al. (13) postulated that the 3MT may provide information relating to a 'functional' speed reserve (FSR), which is the difference between CS and MS_{3MT} , which may in principle be similar to the ASR; although this has never been tested. Given the relative importance of both MSS and ASR and the diverse utility of the 3MT, more research is required regarding the interaction between the multitude of parameters from these tests and how they relate and interact.

Therefore, the objectives of this study were two-fold, namely, to determine: (i) the relationship between MSS and MS_{3MT} , and (ii) the

correlation between ASR, FSR, and D'. Based on the theoretical underpinnings, we hypothesized that there would be a significant, positive relationship between MSS and MS_{3MT} and that ASR, FSR, and D' would exhibit at least a moderate correlation.

MATERIALS AND METHODS

Study Design. We utilized a *one-group post-test only* design as the purpose of the study was to investigate the relationship between dependent variables within a single cohort.

Participants. A total of 32 participants volunteered for this study (age: 22.50 ± 4.32 years; height: 1.67 ± 0.78 m; body mass: 66.58 ± 11.30 kg). The a priori sample size was calculated to be 30 participants (assuming: $H_0: r = 0$; $H_1: r = 0.49$, $\alpha = 0.05$, power = 0.80) (G*Power, version 3.1.9.4). For eligibility into the study, participants had to: (i) be classified as moderately active based on their score on the international physical activity questionnaire (IPAQ), (ii) be between the ages of 18-30 years, and (iii) be free of injury before and during testing, and (iv) sign the informed consent form. The following eligibility into the study, participants were then informed: (i) of any potential risks and discomforts associated with testing, (ii) to avoid strenuous exercise 24 hours before testing, and (iii) to arrive for testing in a well hydrated and post-prandial state. The study was approved by the university research ethics committee and complied with the declaration of Helsinki (ethics code: H18-HEA-HMS-008).

Experimental Protocol. Participants visited the laboratory on four distinct occasions, each separated by 48-72 hours. The first visit was used to complete the informed consent forms and obtain baseline anthropometric data such as height (measured to the nearest 0.01 m) and weight (measured to the nearest 0.01 kg). The second visit was utilized for test familiarization for both the GXT as well as the 3MT. The third assessment required participants to complete the square-wave GXT consisting of a custom starting speed coupled with $0.8 \text{ km}\cdot\text{hr}^{-1}\cdot\text{min}^{-1}$ speed increments until volitional exhaustion (22). The fourth visit required participants to complete a 40-m sprint test and the 3MT, with the tests being separated by 15-20 minutes of recovery and dynamic stretching. Adequate, dynamic warm-up protocols preceded all testing and were followed by a 30-minute cool-down session.

The Graded Exercise Test. All equipment was calibrated per the manufacturer's instructions. Gas sensors were calibrated using gases of known concentrations (15% O_2 , 5% CO_2), and the turbine volume transducer was calibrated using a 3L syringe (Type M 9474-C, Cortex Biophysik, Leipzig, Germany). Participants were fitted with a heart rate (HR) belt (Polar H7, Kempele, Finland) and facemask for breath-by-breath sampling of pulmonary gas exchange (Metamax 3B, Cortex GmbH, Leipzig, Germany). The GXT was completed on a motorized treadmill (4Front, Woodway, Waukesha, USA) inclined at 1% (23). A custom protocol was used, which implemented ramp increments of $0.22 \text{ m}\cdot\text{s}^{-1}\cdot\text{min}^{-1}$ coupled with a participant-specific starting speed such that exhaustion, and thus $\dot{V}O_{2max}$, would be achieved in approximately 10-minutes (see Strom et al. for full details (22)). Effort was considered maximal if at least two of the following three criteria were met: (i) maximal respiratory exchange ratio > 1.10 , (ii) maximal HR within 15 beats of age-predicted HR_{max} (where HR_{max} was calculated as $208-0.7\cdot\text{age}$ (24)), and (iii) leveling off of $\dot{V}O_2$ despite an increase in workload (25).

40-m Sprint Test. Three pairs of photocells (TCI system, Brower Timing Systems, Utah, USA) were set up at 0-m, 10-m, and 40-m marks along a straight path on a tartan sprinting track. Participants started 1-m behind the first set of photocells and were instructed to sprint as fast as possible to a set of cones placed at the 45-m mark to ensure maximal effort over the full 40-m. The sprint was recorded at 100 Hz using a high-speed camera (Sony Cyber-shot DSC-RX10 MK III, Sony, New York, America) placed 20-m perpendicular to the line of travel, and digitized (Tracker, Version 4.11.0, Open Source Physics, Boston, USA). The displacement data were numerically differentiated and then filtered using a fourth-order zero-lag Butterworth filter with a cut-off frequency of 2-6 Hz to obtain the MSS from the sprint. The filtered data were then modeled and fitted using least-squares procedures (11).

3-Minute All-Out Test for Running (3MT). The 3MT was completed on a 400-m outdoor track (environmental temperature: $18-21^\circ\text{C}$; relative humidity: 45-55%). Participants were fitted with an HR monitor (Polar H7, Kempele, Finland) and a foot pod (Stryd, Boulder, USA) to record HR and speed data at 1 Hz, respectively. Participants were instructed to run all-out and to

maintain their maximum possible speed throughout the test. Strong verbal encouragement was provided throughout the test to minimize the likelihood of pacing, and no information relating to elapsed time nor time remaining was provided. The foot pod's speed-time data were exported and modeled in OriginPro (2020b, version 9.7.5.184, OriginLab, USA) using the model from Kramer et al. (9) to obtain CS, D' and MS3MT.

Statistical Analysis. All data are presented as mean \pm SD unless otherwise stated. The first objective was evaluated using regression analysis and the Pearson correlation coefficient to substantiate the magnitude and direction of the relationship between MSS and MS3MT. The magnitude of the correlation coefficient was interpreted using the following thresholds: trivial: < 0.10 , small: < 0.30 , moderate: < 0.50 , large: < 0.70 , very large: < 0.90 , almost perfect: ≤ 1.00 (26). The paired t-test was used to assess whether the mean MSS and MS3MT were significantly different. The second objective was evaluated using the Pearson correlation coefficient, with ASR, FSR, and D' as the input parameters. The correlation coefficient was interpreted in the same manner as for the first objective. Statistical significance was accepted at $p < 0.05$. All statistics were conducted using Jamovi (The Jamovi Project, v1.1, Computer Software; retrieved from <http://www.jamovi.org>).

RESULTS

The descriptive results of all test parameters are presented in Table 1.

Table 1. Descriptive Results from All tests of Participants

Variable	Mean	SD
Age (years)	22.50	4.32
Height (m)	1.67	0.08
Weight (kg)	66.58	11.30
$\dot{V}O_{2max}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	46.79	6.06
$s\dot{V}O_{2max}$ ($\text{m}\cdot\text{s}^{-1}$)	4.07	0.69
CS ($\text{m}\cdot\text{s}^{-1}$)	3.29	0.60
D' (m)	196.21	56.23
CS as % of $s\dot{V}O_{2max}$	81.45	11.57
MS _{3MT} ($\text{m}\cdot\text{s}^{-1}$)	7.49	1.04
MSS ($\text{m}\cdot\text{s}^{-1}$)	8.26	1.25
MS _{3MT} as % of MSS	91.15	5.00
40-m sprint time (sec)	5.82	0.75
ASR ($\text{m}\cdot\text{s}^{-1}$)	4.19	0.82
FSR ($\text{m}\cdot\text{s}^{-1}$)	4.21	0.95

Where $\dot{V}O_{2max}$ is maximal oxygen uptake; $s\dot{V}O_{2max}$ is speed evoking $\dot{V}O_{2max}$; CS is critical speed; D' is the fatigability constant; MS_{3MT} is the maximal speed during the 3MT, MSS is maximal sprint speed during the 40-m sprint; ASR is the anaerobic speed reserve; FSR is the functional speed reserve.

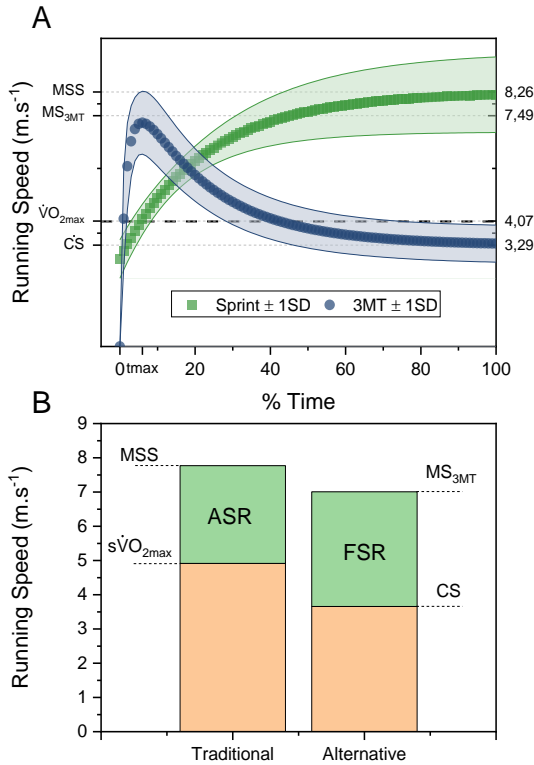


Figure 1. Maximal sprint speed, 3-min all-out test for running, and speed reserves. Panel A shows the mean \pm SD for the 40-m sprint test as well as the 3MT for all participants as a function of the total completion time. Panel B shows the speed reserves as determined from the traditional methods (termed ASR), and the proposed alternative (termed FSR) for a representative participant. *MSS* (maximal sprint speed); *sVO_{2max}* (maximal aerobic speed); *MS_{3MT}* (maximal sprint speed from the 3MT); *CS* (critical speed); *ASR* (anaerobic speed reserve); *FSR* (functional speed reserve).

The full speed profile as a function of the completion time for both the 3MT and 40-m sprint is presented in Figure 1 (panel A). The composition of the traditional speed reserve profile (i.e., ASR), in comparison to the proposed FSR, is shown in Figure 1 panel B.

The relationship between *MSS* and *MS_{3MT}* is shown in Figure 2 (panel A). A very strong, positive relationship is observed between these two parameters ($r = 0.93$, $CI_{95\%} [0.86, 0.96]$, $P < 0.001$), with the *MSS* being significantly larger than *MS_{3MT}* ($P < 0.001$) (Figure 2, panel A inset). The correlations between *ASR*, *FSR*, and *D'* are shown in Figure 2 (panel B). Large to very large, positive correlations are observed between these parameters (all $P < 0.05$), indicating that the *FSR* may serve as a viable surrogate for the *ASR*.

DISCUSSION

The novel findings of the present study highlight (i) a very strong association between *MSS* and *MS_{3MT}*, which appears to be mediated by *D'* classification, and (ii) the strong correlations between *ASR*, *FSR*, and *D'*. Based on the findings of the present study, the utility of the 3MT should be clear. Not only does the test provide information on the critical metabolic threshold (i.e., *CS*) and fatigability constant (*D'*), but it also provides information related to an arguably more ecologically valid maximal sprinting speed (i.e., *MS_{3MT}*) as well as *FSR*. The latter statement appears to be justified by experimental evidence, which shows that field-sport athletes rarely reach speeds exceeding 90% of *MSS* (18). The present study has shown that *MS_{3MT}* is approximately 91% of *MSS* (Table 1), and when this is coupled with a robust correlation with *MSS* ($r = 0.93$, $P < 0.001$), then *MS_{3MT}* provides clear evidence of practically attainable maximal running speeds.

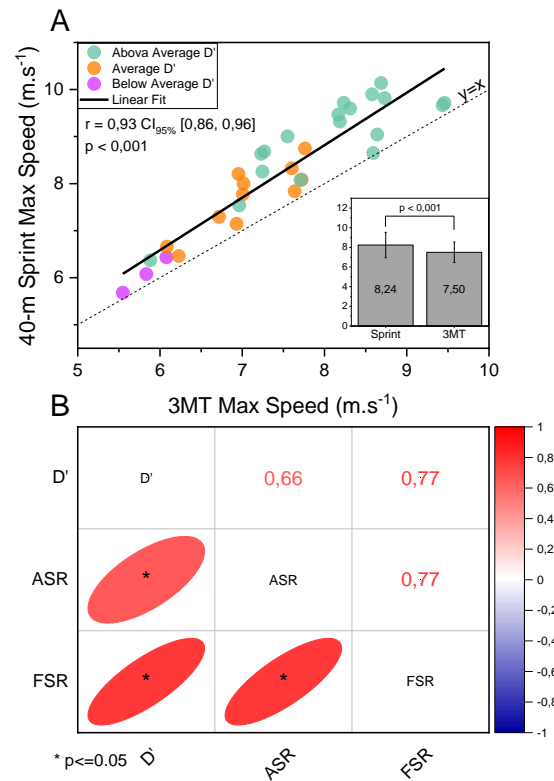


Figure 2. Relationship between *MSS*, *MS_{3MT}*, and *D'*. Panel A shows the linear relationship between *MSS* and *MS_{3MT}* with data highlighted according to *D'* classification; the inset shows the mean \pm SD for *MSS* and *MS_{3MT}*. Panel B shows the magnitude (top right section), direction (bottom left section), and statistical significance (indicated by Asterisk in the bottom left section) of the correlation coefficients between *ASR*, *FSR*, and *D'*. *ASR* (anaerobic speed reserve); *FSR* (operating speed reserve).

Knowledge of maximal speeds (e.g., MSS) and speed reserves (e.g., ASR) is undoubtedly useful, as evidenced by the fact that time to exhaustion at intensities above $s\dot{V}O_{2max}$ is better related to MSS/ASR than to $s\dot{V}O_{2max}$. (27, 28) However, the determination of ASR requires two anchor points, namely $s\dot{V}O_{2max}$ from some form of GXT (laboratory- or field-based), as well as MSS from a 40-m sprint test. A recent review by Jamnick *et al.* (1) highlighted the methodological variability of obtaining $s\dot{V}O_{2max}$ which is ultimately dependent on stage gradation and duration. Furthermore, exercise programming using $s\dot{V}O_{2max}$, or some percentage thereof, is often flawed as it does not account for metabolic response variability between participants even at the same relative intensities (1, 29). The 3MT, on the other hand, is (i) not subject to such methodological inconsistencies, (ii) has high test-retest reliability especially when familiarization is utilized (30), (iii) is substantially more efficient (i.e., the test is only 3-minutes in duration), and (iv) is arguably more informative as a data collection procedure. Moreover, the CS provides an estimate of the speed boundary beyond which prolonged exercise becomes predictably unsustainable because it partitions the heavy-from the severe-intensity domains (31, 32). It is here that the FSR reveals its utility on the basis that it provides valuable information on the range of speeds attainable above CS, and given the strong correlation with D' ($r = 77, P < 0.05$), its use for performance classification (9-11). Furthermore, from various intervention studies, the parameters from the 3MT have been readily and easily implemented in the design of individualized high-intensity interval training programs that elicited significant improvements in CS (11, 14, 16) and $\dot{V}O_{2max}$ (11) within a 4-6 week timeframe.

The extent to which various interventions change ASR or the context of the present study, the FSR, is presently unknown. Based on the findings of the present study, the FSR is closely related to

both ASR ($r = 0.77, P < 0.05$), and D' ($r = 77, P < 0.05$). Since FSR is bounded by CS and MS_{3MT} , both of which encapsulate the speed range within the severe-intensity domain, it is not surprising to see the strong affinity between D' and FSR, which by definition share similar constraints (9). This relationship may hint at similar underlying physiological and neuromuscular mechanisms for their improvement, which is an aspect that has remained elusive for the predictable improvement of D' (33, 34). Future research should investigate match-specific parameters from field-sports and their associations to the 3MT variables discussed in the present study.

A limitation of the present study relates to the sample's relative homogeneity (i.e., level of activity, age-range, and geographic location). Therefore, future research should be expanded to include additional participants of varying fitness levels, age ranges, geographic locations, and more varied sporting backgrounds.

CONCLUSION

Knowledge of MSS and ASR is useful for building intuitions related to the speed profile of individuals but falls short of providing arguably more important information related to metabolic thresholds for standardizing exercise prescription. Furthermore, within context-specific domains, individuals rarely reach speeds exceeding 90% of MSS. The 3MT may be a viable, more holistic alternative in that it not only offers similar parameters (e.g., MS_{3MT} and FSR) but extends beyond this by providing knowledge of the critical metabolic threshold as well as the fatigability constant.

APPLICABLE REMARKS

- Parameters from the 3MT provide viable surrogates for MSS and ASR but more importantly, also provide valuable information regarding the critical metabolic threshold and fatigability constant in a much more time-efficient manner (i.e. a relatively straightforward 3-minute test).

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