Eur J Appl Physiol (2015) 115:2593–2598
DOI 10.1007/s00421-015-3233-6

ORIGINAL ARTICLE

Predicting maximal aerobic speed through set distance time-trials

Clint R. Bellenger[1] · Joel T. Fuller[1] · Maximillian J. Nelson[1] · Micheal Hartland[1] · Jonathan D. Buckley[1] · Thomas A. Debenedictis[1,2]

Received: 1 March 2015 / Accepted: 1 August 2015 / Published online: 5 August 2015

Abstract

Purpose Knowledge of aerobic performance capacity allows for the optimisation of training programs in aerobically dominant sports. Maximal aerobic speed (MAS) is a measure of aerobic performance; however, the time and personnel demands of establishing MAS are considerable. This study aimed to determine whether time-trials (TT), which are shorter and less onerous than traditional MAS protocols, may be used to predict MAS.

Methods 28 Australian Rules football players completed a test of MAS, followed by TTs of six different distances in random order, each separated by at least 48 h. Half of the participants completed TT distances of 1200, 1600 and 2000 m, and the others completed distances of 1400, 1800 and 2200 m.

Results Average speed for the 1200 and 1400 m TTs were greater than MAS ($P < 0.01$). Average speed for 1600, 1800, 2000 and 2200 m TTs were not different from MAS ($P > 0.08$). Average speed for all TT distances correlated with MAS ($r = 0.69$–0.84; $P < 0.02$), but there was a negative association between the difference in average TT speed and MAS with increasing TT distance ($r = -0.79$; $P < 0.01$). Average TT speed over the 2000 m distance exhibited the best agreement with MAS.

Conclusions MAS may be predicted from the average speed during a TT for any distance between 1200 and 2200 m, with 2000 m being optimal. Performance of a TT may provide a simple alternative to traditional MAS testing.

Keywords Maximal aerobic speed · Velocity at maximal oxygen consumption · Training intensity · Time trial · Agreement · Australian rules football

Abbreviations

GXT	Graded exercise test
MAS	Maximal aerobic speed
TT	Time trial
UM-TT	Université de Montréal Track Test
$\dot{V}O_{2max}$	Maximal oxygen consumption

Introduction

Performance tests are undertaken regularly by athletes to assess changes in physical fitness in response to changes in training load, and to inform the prescription of future training loads and intensities (Gore 2000). Laboratory-based performance tests may be utilised in this context, but are often time-consuming, only permitting the testing of one athlete at a time, and often requiring expensive and sometimes invasive equipment (Paradisis et al. 2014). Field-based performance assessments in comparison are generally time-efficient (allowing for frequent monitoring), inexpensive and have the greatest external validity, and thus may be considered more practical (Gore 2000; Paradisis et al. 2014). Commonly used field tests such as the Multistage Fitness Test and the Yo–Yo Intermittent Recovery Test have been shown to be valid measures of performance

Communicated by Peter Krustrup.

✉ Clint R. Bellenger
clint.bellenger@mymail.unisa.edu.au

1 Alliance for Research in Exercise, Nutrition and Activity (ARENA), Sansom Institute for Health Research, University of South Australia, GPO Box 2471, Adelaide, SA 5001, Australia

2 South Adelaide Football Club, Adelaide, Australia

(Gore 2000), but are not typically used to prescribe future training loads since their outcome measure is recorded as stage or level completed rather than speed, pace or power output (Dupont et al. 2010). In contrast, measurement of maximal aerobic speed (MAS), defined as the minimum speed required to elicit maximal oxygen consumption ($\dot{V}O_{2max}$) during a graded exercise test (GXT) (Dupont et al. 2004), has also been validated outside of the laboratory as a field test (Leger and Boucher 1980), and utilised as a measure of change in physical fitness (Buchheit et al. 2008, 2010, 2012) that can be used to prescribe future training loads (Dupont et al. 2002).

The practical application of MAS for prescribing training intensities was demonstrated by Dupont et al. (2002), who showed that interval training (15 s of running interspersed with 15 s of passive rest) at 120 % of MAS allowed participants to spend a greater amount of time at $\dot{V}O_{2max}$ than continuous exercise at 100 % of MAS, and interval training at 110, 130 and 140 % of MAS. Since training methods allowing for the greatest volume of time to be spent at $\dot{V}O_{2max}$ result in the largest improvements in $\dot{V}O_{2max}$ (Bompa 1999), training prescribed by MAS was hypothesised to result in improvements in endurance performance. Indeed, Dupont et al. (2004) and Wong et al. (2010) showed that periods of MAS-based interval training improved the physical fitness of soccer players during the course of a competitive season.

While MAS might be useful for prescribing training, the traditional protocol for its assessment requires performance of a GXT that is quite onerous; requiring numerous staff and testing equipment, and demanding up to 30 min of exercise time. These factors can become barriers for assessment of MAS, and thus a shorter and less onerous assessment may be favourable.

Prediction of MAS based on short distance time-trial (TT) performance is plausible since these TTs require maximal efforts demanding a high contribution of aerobic power, which MAS is purported to measure (Leger and Boucher 1980). TTs are also performed regularly in athletic training programs and are generally shorter and easier to administer than a GXT, and thus may be considered preferable. Consequently, the primary aim of this study was to determine the TT distance that would elicit an average speed that most closely approximated a GXT-derived measure of MAS, such that a TT could be used to assess MAS on a regular basis to identify changes in physical fitness and prescribe future training loads. It was hypothesised that a GXT-derived measure of MAS would be closely approximated by the average speed elicited during an optimal distance TT, but that TT distances shorter or longer than this optimal distance would elicit average speeds that over-predicted or under-predicted MAS, respectively.

Methods

Twenty-eight Australian rules football players (age 19.8 ± 2.6 years, height 187.3 ± 7.0 cm, mass 84.5 ± 8.2 kg) competing at South Australian National Football League level participated in this study, which was approved by the Human Research Ethics Committee of the University of South Australia.

Testing took place across four sessions (temperature 16.8–32.5 °C, humidity 12–73 %) throughout a 10-day period during pre-season training and all tests were performed on a 400 m grass track. During the initial session, all participants completed the Université de Montréal Track Test (UM-TT) (Leger and Boucher 1980) in order to determine MAS. Participants were then randomly allocated into two balanced groups (n = 14 per group) via a process of minimisation (Altman and Bland 2005), using MAS values as the minimisation variable. During the three subsequent sessions, participants from each group completed one of three different TT distances in a randomised and balanced order (Fig. 1). TT distances for one group were 1200, 1600 and 2000 m, and 1400, 1800 and 2200 m for the other

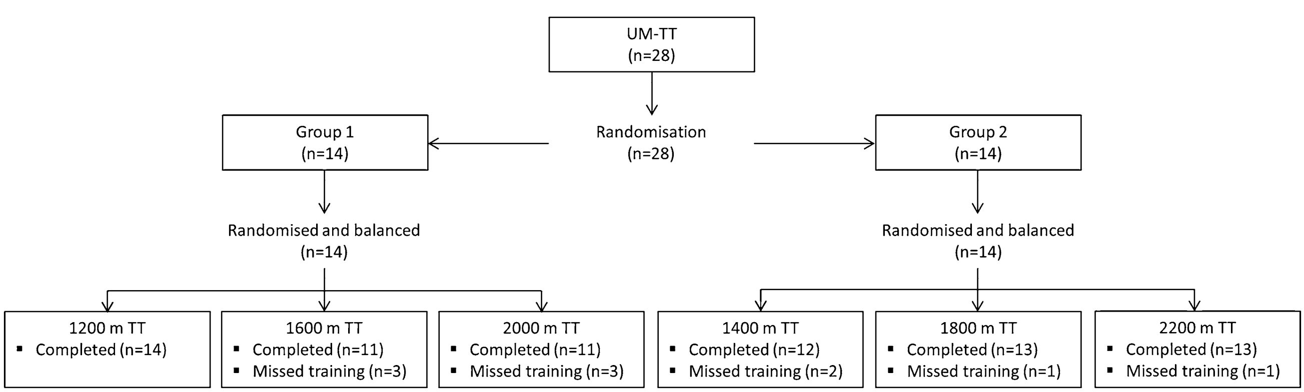

Fig. 1 Study design. *TT* time trial, *n* number of participants, *UM-TT* Université de Montréal Track Test

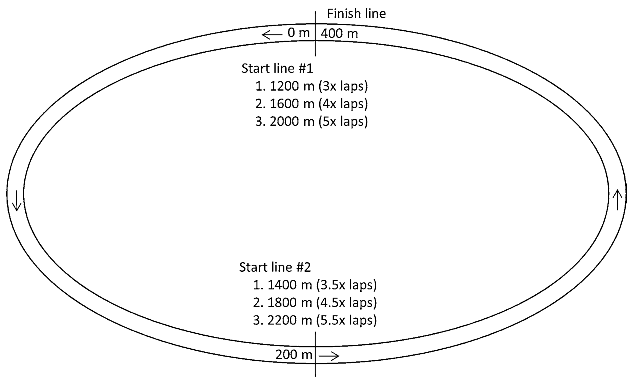

Fig. 2 Schematic of set distance time-trial set-up

group. Each testing session was separated by a minimum of 48 h and was undertaken at the same time of day. Participants completed a standardised warm up prior to each test and were encouraged to maintain their normal daily routine throughout the testing period.

According to the protocol of Leger and Boucher (1980) for determination of MAS, the initial running speed was set at 10 km h^{-1} and increased by 1 km h^{-1} every 2 min. Cones were positioned at 25 m intervals around the 400 m track, and running speed was dictated by the sound of a whistle, indicating when the participants were required to pass within 2 m of the next cone to maintain the required speed. Participants were encouraged to give a maximal effort and the test concluded when the participants were unable to maintain the required pace for three consecutive cones or were volitionally exhausted. MAS was calculated using the following formula:

$$\text{MAS} = S_f + ((t/120) \times i)$$

where S_f was the speed of the last completed stage in km h^{-1}, t was the time spent running (in s) during the uncompleted stage and i was the increment in km h^{-1} with each stage (in this case 1 km h^{-1}).

Each group completed their assigned TT distance simultaneously with the starting time staggered to avoid heavy congestion during the TTs. Two starting positions were used; however, all participants completed their TT at the same finishing position (Fig. 2). Participants assigned to the 1200, 1600 and 2000 m TT distances started and completed their TT at the same point after completing 3, 4 and 5 laps on the 400 m track, respectively. Participants assigned to the 1400, 1800 and 2200 m TT distances began their TT 200 m from the finishing position and completed 3.5, 4.5 and 5.5 laps on the 400 m track, respectively. Time to complete the assigned distances were measured manually using a stopwatch to the nearest s, and converted to the average speed in km h^{-1} held over the TT distance.

Statistical analysis was performed using SPSS (version 19, IBM, Chicago, USA) with statistical significance set at $P < 0.05$. Normality of data was checked using the Shapiro–Wilk test. All data were normally distributed. Paired sample t tests were used to compare running speeds for MAS and the various TTs using Bonferroni correction for multiple comparisons. Absolute agreement between tests was determined using limits of agreement analysis (Bland and Altman 2010). Linear regression and bivariate correlation analysis were used to determine relationships between variables.

Results

Maximal aerobic speed and average TT speeds are shown in Table 1. Average running speeds for the 1200 and 1400 m TT distances were greater than MAS ($P < 0.01$). There were no differences between average running speeds for the 1600, 1800, 2000 and 2200 m TT distances and MAS ($P > 0.08$). MAS correlated with average speed for all TT distances ($r = 0.69$–0.85; $P < 0.02$). Bias was least and limits of agreement narrowest for the comparison of MAS and average running speed for the 2000 m TT.

There was a negative association between the percentage bias in MAS and running speed at each TT distance ($r = -0.79$; $P < 0.01$; Fig. 3). Based on this relationship, MAS could be predicted from running speed for any TT distance between 1200 and 2200 m using the equation:

$$\text{MAS} = \text{TT}_s\ (0.766 + 0.117\ [\text{TT}_d])$$

where TT_s is the average time trial speed (km h^{-1}) and TT_d is the time trial distance (km).

Discussion

The present study aimed to determine the TT distance that would elicit an average speed that most closely approximated MAS derived from a GXT. As hypothesised, a GXT-derived measure of MAS was able to be closely approximated by the average speed elicited during an optimal distance TT, which was shown to be 2000 m. Additionally, the TT distances trialled in the present study that were shorter than this optimal distance (1200, 1400, 1600 and 1800 m) elicited average speeds that over-predicted MAS, while a TT distance longer than this optimal distance (2200 m) under-predicted MAS.

The average speed elicited during a 2000 m TT had the smallest bias and narrowest limits of agreement compared with MAS, suggesting that a GXT-derived measure of MAS (representative of $\dot{V}O_{2max}$) may be held for the

Table 1 Agreement between MAS and average time trial speed for each time trial distance

	Group 1				Group 2			
	MAS	1200 m	1600 m	2000 m	MAS	1400 m	1800 m	2200 m
Subjects (*n*)	14	14	11	11	14	12	13	13
Speed (km h^{-1})	16.35 ± 0.75	17.90 ± 0.74*	16.93 ± 0.66	16.48 ± 0.70	16.25 ± 0.86	17.45 ± 0.82*	16.50 ± 0.84	15.96 ± 0.92
r	–	0.70	0.69	0.79	–	0.85	0.81	0.82
Bias								
km h^{-1}	–	1.55*	0.45	<0.01	–	1.32*	0.33	−0.29
%	–	9.6	2.8	0.0	–	8.2	2.0	−1.7
LOA								
km h^{-1}	–	±1.11	±1.04	±0.89	–	±0.89	±0.99	±1.04
%	–	±7.1	±6.4	±5.3	–	±5.8	±6.2	±6.4

Values reported are mean ± standard deviation

MAS maximal aerobic speed, *n* number of subjects, *r* Pearson correlation coefficient, *LOA* limits of agreement

* Significantly different to MAS ($P < 0.05$)

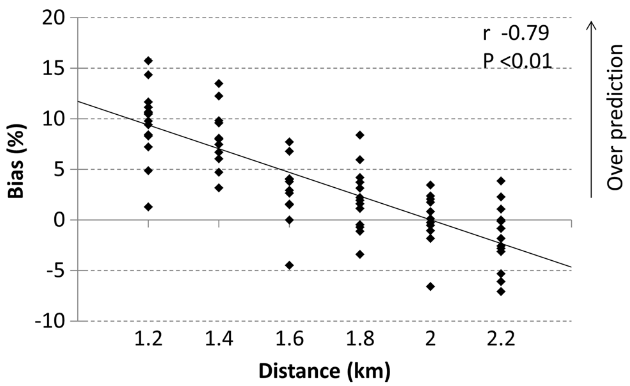

Fig. 3 Agreement between MAS and average time trial speed relative to time trial distance

length of time taken to complete a 2000 m TT (437 s on average in the athletes used in this study). The results of the present study, therefore, suggest that the average speed over a 2000 m TT may be used to predict MAS to quantify changes in physical fitness and prescribe future training loads and intensities. Predicting MAS using a short distance TT will also reduce the time and resource burden that GXT-derived measures of MAS may cause.

The finding of a 2000 m TT being optimal for MAS determination is in agreement with research suggesting that the duration/distance limit for which speed at $\dot{V}O_{2max}$ or MAS may be held is 333–522 s or 1669–2009 m (Lacour et al. 1990; Billat et al. 1995, 1999; Dupont et al. 2002). This range of values reported in previous literature is likely the result of inter-individual variability in physiological make-up and/or slight variations in protocols to determine MAS or velocity at $\dot{V}O_{2max}$ (i.e. continuous vs. discontinuous, 0.5 vs. 2 km h^{-1} increases in speed, 30 s vs. 6 min stage intervals, etc.) (Billat and Koralsztein 1996; Bosquet et al. 2002).

Another important finding was that the average speeds held over all TT distances correlated with MAS ($r = 0.69$–0.85). This is an intuitive finding since the six distances chosen to predict MAS require maximal efforts of between approximately 240 and 500 s; durations shown to elicit high levels of aerobic power or even $\dot{V}O_{2max}$ (Rodriguez 2000; Dupont et al. 2002; Caputo and Denadai 2008). Thus, since field-based assessments of MAS have been shown to elicit $\dot{V}O_{2max}$ (Leger and Boucher 1980; Lacour et al. 1989; Berthoin et al. 1994), TTs requiring a high contribution of aerobic power understandably correlate with MAS. Additionally, an inverse relationship between TT distance and the magnitude of bias between GXT-derived MAS and average TT speed was found. The average TT speed held over a distance of 1200 m produced the greatest over-prediction of MAS, and this over-prediction was incrementally reduced with each 200 m increase in TT distance until no bias was evident between MAS and average TT speed held over a distance of 2000 m. However, for TT distances greater than 2000 m, average TT speed then under-predicted MAS. Based on this inverse relationship between TT distance and magnitude of bias it was possible to derive an algorithm capable of predicting MAS from any TT distance between 1200 and 2200 m. This algorithm allows coaches to monitor MAS based on TT or race performances at different distances throughout the competitive season.

A limitation of this study is the use of a single protocol to derive a measure of MAS from a GXT. In the present study, MAS was assessed using a continuous incremental protocol of 1 km h^{-1} every two min until volitional exhaustion as per the original method proposed by Leger and Boucher (1980); however other researchers have used continuous or discontinuous incremental protocols of 0.5–2 km h^{-1} increases in speed for every 30 s–6 min period of work (Billat and Koralsztein 1996; Dupont et al. 2002; Bosquet et al. 2003). A review suggests that these subtle variations may result in an approximate 10 % difference in MAS (Billat and Koralsztein 1996). Thus, while MAS is purported to be a valid measure of aerobic performance (Leger and Boucher 1980), it may be considered a contrived variable when compared to the gold standard measure of $\dot{V}O_{2max}$, since this variable is reproducible across different maximal effort testing protocols within a specific exercise mode provided an optimal testing duration (Buchfuhrer et al. 1983). Nevertheless, MAS may be considered a more practically applicable variable since it can be easily utilised in the field (Ahmadi et al. 1991), and as such the present study focussed on MAS rather than $\dot{V}O_{2max}$. Given the subtle differences in protocols to derive MAS, it is unclear if the results of the present study can be extrapolated to measures of MAS derived from a different protocol; however, ensuring sufficient standardisation when performing repeated measures of a 2000 m TT to approximate MAS will allow changes in physical fitness to be detected.

The findings of the present study have been obtained using team sport athletes undertaking running exercise. Thus, while these results may be applied in team sport athletes with similar running demands, it is unknown how the findings may be applied in events involving pure running (e.g., sprinting and distance running), and in sports/events not involving running (e.g., swimming, cycling, rowing, etc.). Nonetheless, research in middle-distance runners and trained cyclists demonstrates that maximal aerobic speed/power may be held for a similar length of time to that obtained in the present study (~450–520 s) (Lacour et al. 1990; Caputo and Denadai 2008), while other studies suggest that efforts of high intensity exercise lasting ~300–480 s elicit high levels of aerobic power or even $\dot{V}O_{2max}$ in swimmers and rowers (Jensen et al. 1996; Rodriguez 2000). Consequently, a set distance TT in these athletes may have the potential to approximate a GXT-derived measure of maximal aerobic speed/power, though additional research would be required to confirm this.

Additionally, undertaking MAS and TT testing in the field caused this study to be affected by day-to-day variations in environmental conditions. One of the four testing visits may have presented more challenging conditions to the participants in comparison to the others (higher than average temperature), and thus may have affected TT performance. However, the effect of weather conditions was balanced across the different TT distances due to the randomised order in which the participants performed their TTs. Additionally, field testing is commonly employed by coaches and athletes, and performing data collection in the field has the greatest external validity.

Conclusions

The present study showed that MAS may be predicted from TT distances between 1200 and 2200 m, but that the average running speed over the course of a 2000 m TT had the smallest bias and narrowest limits of agreement compared with a GXT-derived measure of MAS. Thus, the average speed of a 2000 m TT may be used to approximate MAS to quantify training-induced changes in performance and prescribe individual specific training intensities. Additionally, a TT derived measure of MAS will minimise the specific burden associated with a GXT-derived measure of MAS.

Acknowledgments No financial assistance was required for this study.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.For this type of study (i.e., a retrospective study) formal consent was not required.

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