‘Prescribing 6-wk of running training using parameters from a self-paced maximal oxygen uptake protocol’

Original Investigation

James S. Hogg[1], James G. Hopker[1], Sarah L. Coakley[2], Alexis R. Mauger[1]

[1]Endurance Research Group, School of Sport and Exercise Sciences, Faculty of Science, University of Kent, Chatham, UK

[2] Department of Sport and Exercise Sciences, University of Chichester, Chichester, UK.

Address for correspondence
Mr James S. Hogg
School of Sport and Exercise Sciences
University of Kent
Chatham Maritime, Kent. ME4 4AG.
United Kingdom
Tel: 01634 202970
E-mail: J.Hogg-580@kent.ac.uk

Abstract Word Count: 238

Text-Only Word Count: 3,736

Tables (3); Figures (2)

This manuscript is available as Gold Open Access from the European Journal of Applied Physiology: https://link.springer.com/journal/421

ABSTRACT

Purpose: The self-paced maximal oxygen uptake test (SPV) may offer effective training prescription metrics for athletes. This study aimed to examine whether SPV-derived data could be used for training prescription. **Methods:** Twenty-four recreationally active male and female runners were randomly assigned between two training groups: (1) Standardised (STND) and (2) Self-Paced (S-P). Participants completed 4 running sessions a week using a global positioning system-enabled (GPS) watch: 2 x interval sessions; 1 x recovery run; and 1 x tempo run. STND had training prescribed via graded exercise test (GXT) data, whereas S-P had training prescribed via SPV data. In STND, intervals were prescribed as 6 x 60% of the time that velocity at $\dot{V}O_{2max}$ ($_{v}\dot{V}O_{2max}$) could be maintained (T_{max}). In S-P, intervals were prescribed as 7 x 120 s at the mean velocity of rating of perceived exertion 20 ($_{v}$RPE20). Both groups used 1:2 work:recovery ratio. Maximal oxygen uptake ($\dot{V}O_{2max}$), $_{v}\dot{V}O_{2max}$, T_{max}, $_{v}$RPE20, critical speed (CS), and lactate threshold (LT) were determined before and after the 6-week training. **Results:** STND and S-P training significantly improved $\dot{V}O_{2max}$ by 4 ± 8% and 6 ± 6%, CS by 7 ± 7% and 3 ± 3%; LT by 5 ± 4% and 7 ± 8%, respectively (all $P < 0.05$), with no differences observed between groups. **Conclusions:** Novel metrics obtained from the SPV can offer similar training prescription and improvement in VO_{2max}, CS and LT compared to training derived from a traditional GXT.

KEY WORDS: Recreational runners, Running performance, Critical Speed, Endurance Training, Lactate Threshold

ABBREVIATIONS:

ANOVA	Analysis of variance
CS	Critical speed
GPS	Global positioning system
GXT	Graded exercise test
HR_{max}	Maximal heart rate
LT	Lactate threshold
LT1	Lactate threshold 1
LT2	Lactate threshold 2
RER	Respiratory exchange ratio
RER_{max}	Maximal respiratory exchange ration
RPE	Rating of perceived exertion
RPE_{max}	Maximal rating of perceived exertion
STND	Standardised
S-P	Self-paced
SPV	Self-paced $\dot{V}O_{2max}$ test
T_{max}	Time in which $v\dot{V}O_{2max}$ can be maintained
V_{Emax}	Maximal minute ventilation
VCO_2	Carbon dioxide production
$\dot{V}O_2$	Oxygen uptake
$\dot{V}O_{2max}$	Maximal oxygen uptake
$v\dot{V}O_{2max}$	Velocity at $\dot{V}O_{2max}$

INTRODUCTION

The graded exercise test (GXT) is a globally recognised test which offers valuable information on key aerobic parameters such as maximal oxygen uptake ($\dot{V}O_{2max}$), and can be used to prescribe training for both elite athletes, and recreational exercisers. Recently, a novel approach to the traditional GXT has been proposed, termed the self-paced $\dot{V}O_{2max}$ test (SPV), which consists of 5 x 2 min stages where speed or power is freely adjusted by the participant based on rating of perceived exertion (RPE) (Mauger and Sculthorpe, 2012; Borg, 1982). The SPV has been applied across a wide range of exercise modalities and ergometry despite its relative infancy (Mauger and Sculthorpe, 2012; Chidnok et al, 2013; Straub et al, 2014; Hogg et al. 2015; Jenkins et al. 2017b; Lim et al. 2016; Scheadler and Devor, 2015).

The general consensus from published research to date suggests that the SPV provides comparable $\dot{V}O_{2max}$ values to the GXT (Chidnok et al. 2013, Hogg et al. 2015; Lim et al. 2016; Scheadler and Devor, 2015; Straub et al. 2014; Faulkner et al. 2015; Hanson et al. 2016), however the methodological differences and contrasting populations used may make direct comparisons between studies challenging. Higher $\dot{V}O_{2max}$ values have been observed within the SPV test (Mauger and Sculthorpe, 2012; Jenkins et al. 2017b; Jenkins et al. 2017a; Astorino et al. 2015; Mauger et al. 2013), although all but one of these studies were cycling-based. However, the findings regarding differences in $\dot{V}O_{2max}$ are less meaningful in terms of the utility of the test, with perhaps greater emphasis being placed on the practical advantages that the SPV has over the GXT. The problems associated with the GXT are well documented (Noakes, 2008), such as the incremental fixed-intensity nature of the test, unknown test duration, and creating a test environment that is possibly unnatural and irrelevant for "real" sporting performance. It has therefore been put forward that the SPV may represent a paradigm shift in $\dot{V}O_{2max}$ testing (Beltz et al. 2016), with self-paced protocols offering greater ecological validity due to the self-paced and closed-loop nature, whilst also circumventing the issue of estimating the ramp-rate and starting work rate for the researcher or practitioner (Poole and Jones, 2017).

The GXT offers additional metrics in addition to the measurement of $\dot{V}O_{2max}$, such as the velocity at $\dot{V}O_{2max}$ ($_{v}\dot{V}O_{2max}$) and the time in which $_{v}\dot{V}O_{2max}$ can be maintained (T_{max}). However, the identification of T_{max} requires an additional test which adds to the impracticality of the GXT. Nevertheless, $\dot{V}O_{2max}$, $_{v}\dot{V}O_{2max}$ and T_{max} have been shown to be useful and viable parameters in running training and performance (Billat and Koralsztein, 1996; Esfarjani and Laursen, 2007; Manoel et al. 2017; Smith et al. 2003) and can be used to prescribe training and assess training adaptation. If similar metrics for training prescription could be acquired from the SPV, in a singular test, it would demonstrate utility over and above traditional GXT assessment of $\dot{V}O_{2max}$, especially as the SPV is an effective test for highly trained runners (Hogg et al. 2015; Scheadler and Devor, 2015), and has good test-retest reliability (Jenkins et al. 2017a). In addition, the SPV has recently been validated as a field test (Lim et al. 2016), which increases its accessibility to a variety of athletes and coaches. Therefore, the ability to prescribe training from the SPV would enhance the value and utility of the test. As such, this study aimed to investigate whether training prescribed via novel metrics derived from the SPV could result in comparable improvements in key aerobic parameters as training formulated from traditional GXT variables.

MATERIALS AND METHODS

Participants

Twenty-four recreationally active male (n = 16) and female runners (n = 8) (Mean ± SD: Age = 30 ± 9 years, body mass = 70 ± 13 kg, height = 172 ± 9 cm) volunteered to participate in this study. Sample size was estimated from power calculations (G-Power software, Franz Faul, Universitat Kiel, Germany) with mean and SD data from a similar training study (18). The study was conducted with the approval of the Ethics Committee of the School of Sport and Exercise Sciences at the University of Kent (Approval reference: Prop01.2014-15). All participants who volunteered read and signed a form of written informed consent before participation.

Exercise Tests

Participants were randomly allocated into two groups: 'Standardised' (STND) and 'Self-paced' (S-P). All participants completed a GXT, an SPV, and a sub-maximal lactate threshold (LT) test on a motorised treadmill (Saturn, HP Cosmos, Nussdorf-Traunstein, Germany), and a critical speed (CS) test as part of baseline testing on three separate occasions over a two wk period. The $\dot{V}O_{2max}$ protocols were completed in a randomised order, 2-7 days apart and at the same time of day (±2 h). Oxygen uptake ($\dot{V}O_2$) (Metalyzer 3BR2, Cortex, Lepzig, Germany) and heart rate (T31, Polar Electro Inc, New York, USA) were recorded for the duration of the testing protocol. The online gas analysis system was calibrated prior to every test in accordance with the manufacturer's guidelines. Before each test, participants performed a warm-up of their choice on the motorised treadmill, which was kept the same for all subsequent tests. The CS test was completed on an all-weather synthetic 400 m running track using the method outlined by Galbraith (2011). Briefly, this involved three runs at distances of 3600 m, 2400 m, and 1200 m, each separated by 30 min recovery. For the lactate threshold (LT) protocol, participants completed 4 min stages on the treadmill with a capillary blood sample (Biosen C-Line, EKF Diagnostics, Barleben, Germany) taken at the end of each stage, with the velocity increasing by 1 $km{\cdot}h^{-1}$ at the beginning of each stage. Starting speed was estimated based on each participant's individual fitness level. The test was terminated once lactate threshold 1 (LT1) and lactate threshold 2 (LT2) had been obtained, defined as blood lactate readings of 2 and 4 $mmol.L^{-1}$, respectively. Before each test, participants were instructed to maintain similar eating habits, abstain from alcohol (24 h) and caffeine (8 h), and to avoid exhaustive or vigorous exercise (48 h). These conditions were verbally verified by the experimenter at each test visit. Following baseline testing all participants then undertook a 6 wk field-based training program, consisting of two high intensity interval training sessions, one recovery run, and a tempo run per wk. Training sessions were either based on data from the SPV or GXT [depending on group allocation]. Participants completed either a GXT, or SPV mid-training [depending on group allocation] in the third wk of the training programme. This test replaced one of the high intensity sessions for that wk, with its sole purpose to recalibrate interval session intensity in both groups. All baseline tests were then repeated in the immediate two-weeks that followed the 6 wk training intervention.

Graded Exercise Test (GXT)

The test commenced at a submaximal speed, gauged by the experimenter and subject, to help bring about volitional exhaustion within 8-12 min. Speed was increased by 1 $km{\cdot}h^{-1}$ every 2 min and the test was terminated when participants reached volitional exhaustion. Treadmill gradient was set to 1%. All previously described cardiorespiratory measures were recorded during this stage and participants continued until volitional exhaustion. 6-20 RPE[2] was recorded 20 s before the end of each stage. Verbal encouragement was given throughout. $_{v}\dot{V}O_{2max}$ was determined as the highest velocity that could be maintained for at least 30 s (Smith et al, 2003).

Determination of T_{max}

For the GXT, the time that $_{v}\dot{V}O_{2max}$ could be maintained (T_{max}) was measured in a separate bout of exercise (Smith et al. 2003). After a 20 min recovery (Nolan et al. 2014) following the GXT, participants warmed up on the treadmill at 60% $_{v}\dot{V}O_{2max}$ for 5 min. Participants were then allowed to stretch before remounting the treadmill with the speed being ramped up over 30 s until $_{v}\dot{V}O_{2max}$ was reached. Participants were then asked to continue until volitional exhaustion. Heart rate and expired gas were recorded throughout this test.

Self-Paced $\dot{V}O_{2max}$ Test

The SPV was completed as previously described by Hogg and colleagues (2015). Briefly, the SPV consisted of 5 x 2 min continuous stages with RPE increments of 11, 13, 15, 17 and 20. A zonal pacing system was used where the researcher would adjust the running speed based on the participant's positioning on the treadmill. Participants were informed about the self-pacing zones before the warm-up and then practiced moving between the zones after completing their individualised warm-up. Familiarisation of the 6-20 RPE scale and how to vary their speed according to a fixed RPE was provided via verbal explanation prior to the warm-up with specific emphasis given to considering their RPE for each given moment.

Determination of $\dot{V}O_{2max}$

Averaging of $\dot{V}O_2$ during GXT and SPV tests was performed over 30 s. $\dot{V}O_{2max}$ in the GXT and SPV was defined as the highest $\dot{V}O_2$ averaged for 30 seconds. A plateau in $\dot{V}O_2$ during the GXT was accepted if the change in $\dot{V}O_2$ during the highest 30 s average from each of the final two stages of the test were less than half of the normal stage-to-stage difference in $\dot{V}O_2$ during the initial linear parts of the test for each subject[23]. As an ancillary method to verify attainment of $\dot{V}O_{2max}$, secondary criteria were accepted when two of the following were attained: Heart rate (HR) within 10 bpm of age-predicted maximum; Respiratory exchange ratio (RER) $\geq$ 1.15 and RPE $\geq$ 17.

Training programme

All participants completed two high-intensity interval sessions per week, along with a recovery run and a tempo run. This equated to four exercise sessions per week. Participants were free to schedule the sessions throughout each week but were encouraged to not complete interval sessions and tempo run on consecutive days. All sessions were completed using an assigned global positioning system (GPS) watch (310XT, Garmin International Inc, KS, USA), and training was logged in a training diary

STND Group

For each interval session, participants completed 6 intervals at ${}_{v}\dot{V}O_{2max}$ with duration determined as 60% of T_{max} (Smith et al. 2003). A 2:1 ratio was used to determine the recovery stage duration in-between each interval. Recovery run intensity was calculated as 60% of their maximal heart rate (HR_{max}) obtained from the GXT. Participants were required to run for 30 min. This session was included to help ensure participants would not be encouraged to supplement their program with additional training.

Tempo run intensity was determined from the submaximal LT test and participants were required to run at a velocity calculated as 50% between LT1 and LT2 for 30 min.

S-P Group

For each interval session, participants completed 7 x 2 min intervals at a velocity corresponding to the mean velocity completed during the final (RPE20) stage of the SPV. A 2:1 ratio was used to determine the recovery stage duration in-between each interval. The recovery run was the same as in the STND group, but intensity was calculated as 60% of their HR_{max} obtained from the SPV.

Tempo run intensity was determined by calculating the ventilatory threshold (VT) via the V-Slope method from the $\dot{V}O_2$ and $\dot{V}CO_2$ data collected during the SPV (Beaver et al. 1986). The participants were then asked to run at an RPE that corresponded with the stage of the SPV in which the VT was achieved. The participants were asked to freely adjust their pacing to match the required RPE.

Statistical Analysis

Prior to statistical analysis, data were checked and confirmed to be normally distributed. A paired samples t-test was performed to assess maximal value differences between protocols. Based on the achieved effect size, a post hoc power analysis demonstrated that the statistical power of the pre-post VO_{2max} comparison was 0.93. To identify training responses for both training groups (group) and GXT and SPV protocols (protocol) for before and after training (time-point) a mixed model analysis of variance (ANOVA) was used. Where no interaction effect was identified between a variable and protocol (GXT and SPV), the protocol was omitted from further analysis of training responses for that variable. Participants' CS were calculated from the field test using a linear distance-time model. Partial eta-squared (η^2_p) was used to report effect sizes, and statistical significance was accepted when $P < 0.05$. All statistical tests were completed using SPSS version 24 (Chicago, IL, USA).

RESULTS

SPV vs. GXT Protocol Data

Incidence of $\dot{V}O_2$ plateau in GXT and SPV Protocols

The average stage-to-stage increase in $\dot{V}O_2$ for all participants was calculated as 393 ± 21 mL·min^{-1}, so that a plateau phenomenon was defined as a change in $\dot{V}O_2$ $\leq 197 \pm 10$ mL·min^{-1} (or relative $\dot{V}O_2$ 2.8 mL·kg^{-1}·min^{-1}), between the highest 30 s average obtained from each of the final two stages of the test for each participant. All participants achieved either a $\dot{V}O_2$ plateau or satisfied secondary criteria across both GXT trials before and after training. Ninety-three percent of participants satisfied secondary criteria across both SPV trials before and after training.

Differences in test protocols

Differences in test protocols for key variables for all participants are presented in Table 2. Pre and post-training data were combined to compare the GXT and SPV protocols. There were no significant differences in $\dot{V}O_{2max}$ between the GXT and SPV protocols (P = .578). Maximal RER (RER_{max}) was significantly greater in the SPV compared to the GXT (P < .001). There was no interaction effect between test protocol for either HR_{max} or maximal minute ventilation (V_{Emax}) (P = .212; P = .319, respectively). Protocol duration was significantly longer in the GXT (P < .001). RPE_{max} was significantly greater in the SPV (P < .001). There were no significant differences between the velocities associated with $\dot{V}O_{2max}$ and RPE20 (P = .130).

STND vs. S-P Training Data

Training prescription

Total prescribed training duration over the 6 wk period for both training groups was not significantly different (P = .651). The STND had a prescribed total duration of 804 ± 90 min whilst the S-P had a prescribed total duration of 816 ± 0 min. There was no significant difference between the mean interval session duration for both STND and S-P (37 ± 8 vs 38 ± 0 min, respectively) (P = .679).

Enter Table 1 here:

Responses to Training

Group data (pre- vs. post-training) are shown in table 3. As outlined in the methods, participants were grouped into either S-P or STND, and conducted both an SPV and GXT before and after the training intervention. There was no interaction effect for protocol duration between time-point, protocol and group ($F_{1,22}$ = .561, P = .462, η_p^2 = .025). As shown in Figure 1 and Table 3, there was an interaction effect between $\dot{V}O_{2max}$ and time-point ($F_{1,22}$ = 7.461, P = .012, η_p^2 = .253) however there was no interaction effect observed between group and time-point ($F_{1,22}$ = .003, P = .954, η_p^2 = .0001). Whilst there was an interaction effect between V_{Emax} and time-point ($F_{1,22}$ = 12.592, P = .002, η_p^2 = .364), there was no interaction effect between time-point and group ($F_{1,22}$ = .001, P = .981, η_p^2 = .0001). There was no interaction effect for HR_{max} between time-point and group ($F_{1,22}$ = 1.063, P = .314, η_p^2 = .046).

There was an interaction effect between time-point and running velocity at $_{v}$RPE20 and $_{v}\dot{V}O_{2max}$ $F_{1,20}$ = 5.800, P = .026, η_p^2 = .225). As shown in figure 2, for both groups there were no differences in $_{v}\dot{V}O_{2max}$ and $_{v}RPE_{20}$ before training

(14.3 + 1.3 km·h^{-1} vs. 14.3 + 1.7 km·h^{-1}, respectively), but $_v$RPE20 was greater than $_v\dot{V}O_{2max}$ after training (15.7 + 1.3 km·h^{-1} vs. 15.2 + 1.3 km·h^{-1}, respectively). CS improved in both groups (P < .001) however there was no interaction effect between time-point and group ($F_{1,21}$ = 3.006, P = .098, η_p^2 = .125). Similarly, LT1 and LT2 improved in both groups ($F_{1,21}$ = 14.637, P < .001, η_p^2 = .411) however there was no interaction effect between time-point and group ($F_{1,21}$ = 1.227, P = .281, η_p^2 = .055).

DISCUSSION

The primary finding of this study was that following a 6 wk period of training, recreational runner's aerobic fitness and running performance was increased by a similar magnitude, regardless of whether SPV or GXT data were used to prescribe training. Specifically, $\dot{V}O_{2max}$ in the STND group improved by 4%, and by 6% in the S-P group. An improvement in $\dot{V}O_{2max}$ in the region of ~3% has previously been defined as a meaningful improvement in performance (Kirkeberg et al, 2010), as opposed to day-to-day variation. Previous literature has shown improvements in $\dot{V}O_{2max}$ by ~6% when training at 106% $_v\dot{V}O_{2max}$ (Franch et al, 1998) for similar training durations. However, in the aforementioned study the starting $\dot{V}O_{2max}$ for the participants were significantly lower than those reported in the current study, which may suggest a greater level of trainability for $\dot{V}O_{2max}$ (Swain and Franklin, 2002) compared with the participants in the current study. Athletes of slightly higher training status' than those in the current study achieved little to no improvements in $\dot{V}O_{2max}$ over 4-6 weeks of similar intensity training (Manoel et al. 2017; Smith et al. 2003; Denadai et al. 2006), but did show significant improvements in LT and 3-10 km running performance. Similar running programmes utilising interval training have also produced improvements in CS (Esfarjani and Laursen, 2007). This is supported by the findings of the current study that in both STND and S-P, CS improved by 7% and 3%, respectively. For LT1 and LT2, STND improved by 5% and 3% and S-P improved by 7% and 8%.

An important finding of this study is that the novel training parameter extracted from the SPV, '$_v$RPE20', is effective at prescribing running intensity for interval training. The $_v\dot{V}O_{2max}$ for the STND before and after training was 14.3 ± 0.9 vs. 15.2 ± 1.0 km·h^{-1} compared to the S-P's $_v$RPE$_{20}$ of 14.2 ± 1.9 vs. 15.7 ± 1.9 km·h^{-1} respectively. It is likely that the $_v$RPE20 may reflect a speed between $_v\dot{V}O_{2max}$ and the maximal velocity achieved in a GXT (V_{max}). V_{max} has recently been shown to be as beneficial as $_v\dot{V}O_{2max}$ for exercise prescription (Manoel et al. 2017), and like $_v$RPE20 is simple to calculate. Moreover, $_v$RPE20 has been shown to be repeatable regardless of the pacing strategy adopted during this final stage (Hanson et al. 2017). This should be reason to encourage further investigation to assess the potential of $_v$RPE20 in training prescription and its suitability as a performance parameter.

As the aim of the study was to investigate whether SPV-derived training parameters could offer similar improvements in aerobic fitness compared to GXT prescribed training, it was important that training prescription was similar between groups in both intensity and duration. To calculate interval duration for the STND, 60% T_{max} was used. Setting interval duration at 60% of an individual's T_{max} has been shown to produce significant improvements in aerobic parameters and 3-10 km running performance (Esfarjani and Laursen, 2007; Manoel et al. 2017; Smith et al. 2003). In the study by Smith and colleagues (2003), 60% T_{max}

resulted in an average interval duration of 6 x 133.4 ± 4.1 s. This equated to ~13 min of high intensity effort per interval session. In the current study, 7 intervals at 120 s [which also matched the stage duration of the SPV] resulted in ~14 min of high intensity effort, ensuring it was comparable to the STND group. Durations of 2 min have been shown to elicit responses closer to $\dot{V}O_{2max}$ compared to shorter intervals (O'Brien et al. 2008). Longer interval work periods may have resulted in a greater $\dot{V}O_{2max}$ improvement (Esfarjani and Laursen, 2007; O'Brien et al. 2008; Seiler and Sjursen, 2002) but also significantly increased the interval duration. As a consequence, the mean prescribed training duration for each interval session over the 6 wk training period was similar between groups (37 ± 8 vs 38 ± 0 min for STND and S-P, respectively). Total training time over the 6-week period was also similar (804 ± 90 vs 816 ± 0 min, for STND and S-P respectively).

The similar $\dot{V}O_{2max}$ found between both protocols in this study is in line with previous research (Chidnok et al. 2013; Hogg et al. 2015; Lim et al. 2016; Scheadler and Devor, 2015; Straub et al. 2014; Faulkner et al. 2015; Hanson et al. 2016). Even though test duration was significantly longer in the GXT, the test still fell within the recommended duration of 8-12 minutes (Yoon et al. 2007), and the $_{v}\dot{V}O_{2max}$ achieved was not significantly different between protocols. Interestingly, RER_{max} was significantly higher in the SPV, which has been observed in some (Mauger and Sculthorpe, 2012; Hogg et al. 2015; Jenkins et al. 2017b), but not all previous SPV literature (Lim et al. 2016; Straub et al. 2014; Faulkner et al. 2015; Astorino et al. 2015). Consequently, no consensus on whether the SPV produces a higher RER_{max} can be currently drawn. However, the authors speculate that this potential difference in RER_{max} may be due to the higher peak velocities experienced in the SPV compared to the GXT, indicative of a greater anaerobic contribution towards the end of the test. This is supported by the recent work of Hanson and colleagues (2017) who found, when comparing two SPV trials with different RPE20 pacing strategies, that RER_{max} was significantly greater in the SPV that adopted the more aggressive pacing strategy.

CONCLUSIONS

The ability to prescribe training for recreationally active males and females via SPV-derived parameters offers coaches and athletes valuable alternatives to traditional methods. Prescribing training via the SPV is as effective but more time-economical. Specifically, the same level of improvement in key aerobic fitness parameters can be obtained when training is set via novel training parameters collected from a single 10 min SPV test compared to that achieved using a GXT and a mandatory additional test to acquire T_{max} data. This alone may make the SPV more attractive to athletes and coaches, however, recent research regarding a field based SPV (Lim et al. 2016) may emphasise this further. Whilst a field-based SPV has been shown to produce a valid directly measured $\dot{V}O_{2max}$, future research should investigate whether $\dot{V}O_{2max}$ can be accurately estimated from the field based SPV. If so, athletes and coaches would then be able to utilize a single 10 min test on an athletics track, without expensive equipment, that would offer accurate $\dot{V}O_{2max}$ estimation and data for effective training prescription. Therefore, the current findings demonstrate that training parameters derived from the SPV protocol can be used to prescribe effective running training that is similarly effective to training prescribed from GXT-derived parameters. Consequently, in the group that was prescribed training using SPV-derived parameters, $\dot{V}O_{2max}$, LTs and CS showed similar improvements compared to runners who were prescribed training via the velocity at $\dot{V}O_{2max}$ and LT zones, with training durations and intensities suitably similar between groups throughout training.

ACKNOWLEDGEMENTS

Adam Hart, Francesca Waters, Marcus Cram, and Stewart Clayton for their assistance with data collection.

CONFLICT OF INTEREST

None

All procedures performed in studies involving human participants were in accordance with ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

REFERENCES

1. Astorino TA, McMillan DW, Edmunds RM, Sanchez E (2015) Increased cardiac output elicits higher VO2max in response to self-paced exercise. Appl Physiol Nutr Metab 40(3):223-9.
2. Beaver W, Wasserman K, Whipp B (1986) A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol 60(6):2020-27.
3. Beltrami FG, Froyd C, Mauger AR, Metcalfe AJ, Marino F, Noakes TD (2012) Conventional testing methods produce submaximal values of maximum oxygen consumption. Br J Sports Med 46(1):23-9.
4. Beltz NM, Gibson AL, Janot JM, Kravitz L, Mermier CM, Dalleck LC (2016) Graded exercising testing protocols for the determination of VO2max: Historical perspectives, progress, and future considerations. J Sports Med. doi:10.1155/2016/3968393.
5. Billat VL, Koralsztein J-P. Significance of the velocity at VO2max and time to exhaustion at this velocity (1996) Sports Med 22(2):90-108.
6. Borg GAV (1982) Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14(5):377-381.
7. Chidnok W, Dimenna FJ, Bailey SJ, et al. (2013) VO2max is not altered by self-pacing during incremental exercise. Eur J Appl Phys 113(2):529-39.
8. Denadai BS, Ortiz MJ, Greco CC, Mello MT De (2006) Interval training at 95% and 100% of the velocity at VO2max: Effects on aerobic physiological indexes and running performance. Appl Physiol Nutr Metab 31(6):737-743.
9. Esfarjani F, Laursen PB (2007) Manipulating high-intensity interval training: Effects on VO2max, the lactate threshold and 3000m running performance in moderately trained males. J Sci Med Sport 10(1):27-35.
10. Faulkner J, Mauger AR, Woolley B, Lambrick D (2015) The efficacy of a self-paced VO2max test during motorized treadmill exercise. Int J Sports Physiol Perform 10(1):99-105.
11. Franch J, Madsen K, Djurhuus MS, Pedersen PK (1998) Improved running economy following intensified training correlates with reduced ventilator demands. Med Sci Sport Exerc 30(8):1250-6.
12. Galbraith A (2011) A novel field test to determine critical speed. J Sports Med Doping Stud 1(1):1-4.
13. Hanson NJ, Reid CR, Cornwell KM, Lee TL, Scheadler CM (2017)

Pacing strategy during the final stage of a self-paced VO2max (SPV) test does not affect maximal oxygen uptake. Eur J Appl Physiol. doi:10.1007/s00421-017-3656-3.

14. Hanson NJ, Scheadler CM, Lee TL, Neuenfeldt NC, Michael TJ, Miller MG (2016) Modality determines VO2max achieved in self-paced exercise tests: Validation with the Bruce protocol. Eur J Appl Physiol 116(7):1313-9.
15. Hogg JS, Hopker JG, Mauger AR (2015) The self-paced VO2max test to assess maximal oxygen uptake in highly trained runners. Int J Sport Physiol Perform 10(2):172-7.
16. Jenkins LA, Mauger A, Fisher J, Hopker J (2017a) Realiability and validity of a self-paced cardiopulmonary exercise test in post-MI patients. Int J Sports Med 38(4):300-306.
17. Jenkins LA, Mauger AR, Hopker JG (2017b) Age differences in physiological responses to self-paced and incremental VO2max testing. Eur J Appl Physiol. doi: 10.1007/s00421-016-3508-6.
18. Kirkeberg JM, Dalleck LC, Pettitt RW (2010) Validity of 3 protocols for verifying VO2max. Int J Sports Med 32(4):266-270.
19. Lim W, Lambrick D, Mauger AR, Woolley B, Faulkner J (2016) The effect of trial familiarisation on the validity and reproducibility of a field-based self-paced VO2max test. Biol Sport 33(3):269-75.
20. Manoel F de A, da Silva DF, de Lima JRP, Machado FA (2017) Peak velocity and its time limit are as good as the velocity associated with VO2max for training prescription in runners. Sports Med International Open 1(1):8-15.
21. Mauger AR, Metcalfe AJ, Taylor L, Castle PC (2013) The efficacy of the self-paced VO2max test to measure maximal oxygen uptake in treadmill running. Appl Physiol Nutr Metab 38(2):1211-6.
22. Mauger AR, Sculthorpe N (2012) A new VO2max protocol allowing self-pacing in maximal incremental exercise. Br J Sports Med 46(1):59-63.
23. Noakes TD (2008) Testing for maximum oxygen consumption has produced a brainless model of human exercise performance. Br J Sports Med 42(7);551-5.
24. Nolan PB, Beaven ML, Dalleck L (2014) Comparison of intensities and rest periods for VO2max verification testing procedures. Int J Sports Med 35(12):1024-9.
25. O'Brien BJ, Wibskov J, Knez WL, Paton CD, Harvey JT (2008) The effects of interval-exercise duration and intensity on oxygen consumption during treadmill running. J Sci Med Sport 11(3):287-90.
26. Poole DC, Jones AM (2017) CORP: Measurement of the maximal oxygen uptake (VO2max): VO2peak is no longer acceptable. J Appl Physiol 122(4):997-1002.
27. Scheadler CM, Devor ST (2015) VO2max measured with a self-selected work rate protocol on an automated treadmill. Med Sci Sports Exerc 47(10):2158-65.
28. Seiler KS, Sjursen JE (2002) Effect of work bout duration on physiological and perceptual responses to interval training in runners. Med Sci Sport Exerc 34(5):1613-21.
29. Smith TP, Coombes JS, Geraghty DP (2003) Optimising high-intensity treadmill training using the running speed at maximal (O2) uptake and the time for which this can be maintained. Eur J Appl Physiol 89(3-4):337-43.
30. Straub AM, Midgley AW, Zavorsky GS, Hillman AR (2014) Ramp-incremented and RPE-clamped test protocols elicit similar VO2max values in trained cyclists. Eur J Appl Physiol 114(8):1581-90.

31. Swain DP, Franklin B a (2002) VO2 reserve and the minimal intensity for improving cardiorespiratory fitness. Med Sci Sport Exerc 34(1):152-7.
32. Yoon B-K, Kravitz L, Robergs R (2007) VO2max, protocol duration, and the VO2 plateau. Med Sci Sports Exerc 39(7):1186-92.

Figure Legends

Figure 1. Mean ± SD Differences in VO_{2max} between the STND and S-P training groups before and after training.

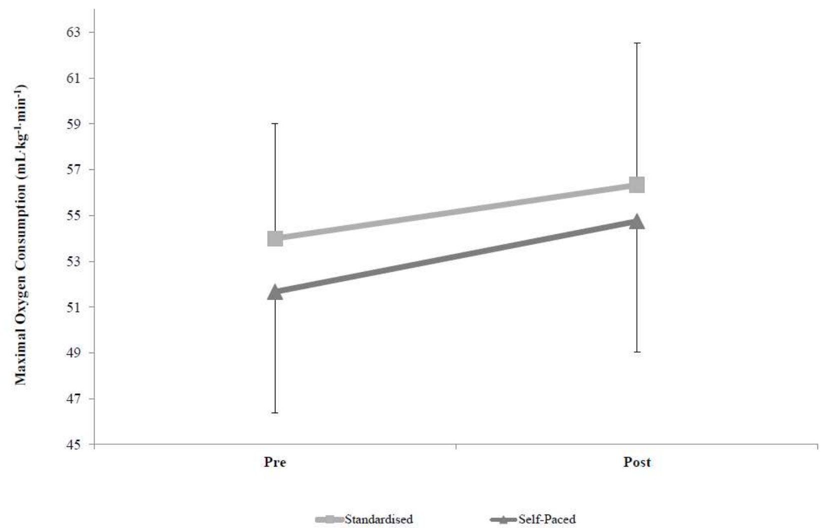

Figure 2. Mean ± SD Differences in the velocities ${}_{v}\dot{V}O_{2max}$ and ${}_{v}RPE20$ for all participants for before and after training.

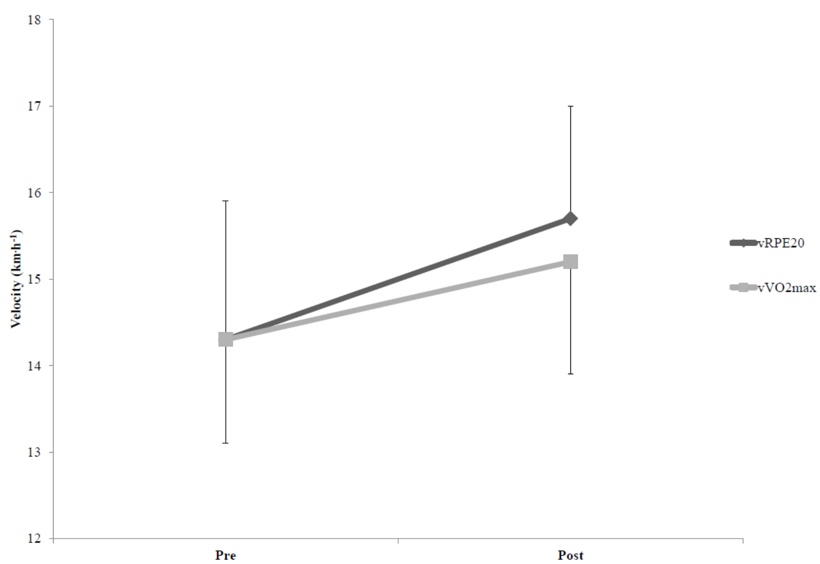

Table 1. Training prescription for a representative subject in both training groups.

	Training Prescription			
Rep. Subject	**Interval session x 2**		**Tempo Run**	**Recovery Run**
	Weeks 1-3	**Weeks 4-6**	**Weeks 1-6**	**Weeks 1-6**
STND	Work: 6 x 167 s @ 15 $km{\cdot}h^{-1}$ Recovery: 5 x 334 s @ 8 $km{\cdot}h^{-1}$	Work: 6 x 141 s @ 16 $km{\cdot}h^{-1}$ Recovery: 5 x 282 s @ 8 $km{\cdot}h^{-1}$	30 min @ 11.3 $km{\cdot}h^{-1}$	30min @ 115 bpm
S-P	Work: 7 x 120 s @ 15.6 $km{\cdot}h^{-1}$ Recovery: 6 x 240 s @ 8 $km{\cdot}h^{-1}$	Work: 7 x 120 s @ 16.3 $km{\cdot}h^{-1}$ Recovery: 6 x 240 s @ 8 $km{\cdot}h^{-1}$	30 min @ RPE13	30 min @ 114 bpm

STND = Standardised training group, S-P = Self-paced training group

Table 2. Mean ± SD peak values for physiological and intensity variables recorded during both GXT and SPV protocols across both before and after training for all participants.

Variable	Protocol	
	GXT	**SPV**
$\dot{V}O_{2max}$ (mL·kg^{-1}·min^{-1})	54 ± 5.8	54 ± 0.7
HR_{max} (beats/min)	186 ± 12	184 ± 11
V_{Emax} (L/min)	135.4 ± 29.4	137.2 ± 24.8
RER_{max}	1.15 ± 0.02	1.21 ± 0.00*
$_{v}\dot{V}O_{2max}$ / $_{v}$RPE20 (km·h^{-1})	14.8 ± 1.3	15 ± 1.5
Mean test time (min)	11 ± 1*	10 ± 0
RPE_{max}	19 ± 1	20 ± 0*

*****Denotes significant difference within the group for the given variable between pre and post testing ($p<0.05$).

Table 3. Mean ± SD maximal values for physiological and threshold variables recorded before and after training for both training groups. In the STND all data is provided via the GXT and by the SPV for the S-P.

	Training Group			
Variable	**Standardised (STND)**		**Self-Paced (S-P)**	
	Pre	Post	Pre	Post
$\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	54 ± 5.0	56.3 ± 6.2*	51.7 ± 5.3	54.8 ± 5.7*
V_{Emax} (L/min)	130.2 ± 22.6	134.7 ± 20.4*	134.3 ± 28.7	141.5 ± 29.0*
HR_{max} (beats/min)	190 ± 13	188 ± 13	181 ± 13	182 ± 9
Critical speed ($m.s^{-1}$)	3.47 ± .03	3.70 ± .03*	3.47 ± .04	3.59 ± .05*
LT1 ($km \cdot h^{-1}$)	10 ± 1.2	10.5 ± 1.2*	9.7 ± 1.5	10.5 ± 1.3*
LT2 ($km \cdot h^{-1}$)	11.7 ± 1.2	12.2 ± 0.8*	11.1 ± 1.8	12.1 ± 1.5*

*****Denotes significant difference within the group for the given variable between pre and post testing ($p<0.05$).