

# Kent Academic Repository

## Full text document (pdf)

### Citation for published version

Hogg, James S. and Hopker, James G. and Coakley, Sarah Louise and Mauger, Alexis R. (2018) Prescribing 6-weeks of running training using parameters from a self-paced maximal oxygen uptake protocol. *European Journal of Applied Physiology* . ISSN 1439-6319. (In press)

### DOI

<https://doi.org/10.1007/s00421-018-3814-2>

### Link to record in KAR

<http://kar.kent.ac.uk/65903/>

### Document Version

Author's Accepted Manuscript

#### Copyright & reuse

Content in the Kent Academic Repository is made available for research purposes. Unless otherwise stated all content is protected by copyright and in the absence of an open licence (eg Creative Commons), permissions for further reuse of content should be sought from the publisher, author or other copyright holder.

#### Versions of research

The version in the Kent Academic Repository may differ from the final published version.

Users are advised to check <http://kar.kent.ac.uk> for the status of the paper. **Users should always cite the published version of record.**

#### Enquiries

For any further enquiries regarding the licence status of this document, please contact:

[researchsupport@kent.ac.uk](mailto:researchsupport@kent.ac.uk)

If you believe this document infringes copyright then please contact the KAR admin team with the take-down information provided at <http://kar.kent.ac.uk/contact.html>

1 **'Prescribing 6-wk of running training using parameters from a self-paced**  
2 **maximal oxygen uptake protocol'**

3

4 **Original Investigation**

5

6 James S. Hogg<sup>1</sup>, James G. Hopker<sup>1</sup>, Sarah L. Coakley<sup>2</sup>, Alexis R. Mauger<sup>1</sup>

7 <sup>1</sup>Endurance Research Group, School of Sport and Exercise Sciences, Faculty of  
8 Science, University of Kent, Chatham, UK

9 <sup>2</sup>Department of Sport and Exercise Sciences, University of Chichester,  
10 Chichester, UK.

11

12 **Address for correspondence**

13 Mr James S. Hogg  
14 School of Sport and Exercise Sciences

15 University of Kent

16 Chatham Maritime, Kent. ME4 4AG.

17 United Kingdom

18 Tel: 01634 202970

19 E-mail: [J.Hogg-580@kent.ac.uk](mailto:J.Hogg-580@kent.ac.uk)

20

21 **Abstract Word Count: 238**

22

23 **Text-Only Word Count: 3,736**

24

25 **Tables (3); Figures (2)**

26

27

28

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

31

32

33

34

35

36

37 **ABSTRACT**

38 **Purpose:** The self-paced maximal oxygen uptake test (SPV) may offer effective  
39 training prescription metrics for athletes. This study aimed to examine whether  
40 SPV-derived data could be used for training prescription. **Methods:** Twenty-four  
41 recreationally active male and female runners were randomly assigned between  
42 two training groups: (1) Standardised (STND) and (2) Self-Paced (S-P).  
43 Participants completed 4 running sessions a week using a global positioning  
44 system-enabled (GPS) watch: 2 x interval sessions; 1 x recovery run; and 1 x  
45 tempo run. STND had training prescribed via graded exercise test (GXT) data,  
46 whereas S-P had training prescribed via SPV data. In STND, intervals were  
47 prescribed as 6 x 60% of the time that velocity at  $\dot{V}O_{2max}$  ( $v\dot{V}O_{2max}$ ) could be  
48 maintained ( $T_{max}$ ). In S-P, intervals were prescribed as 7 x 120 s at the mean  
49 velocity of rating of perceived exertion 20 ( $vRPE20$ ). Both groups used 1:2  
50 work:recovery ratio. Maximal oxygen uptake ( $\dot{V}O_{2max}$ ),  $v\dot{V}O_{2max}$ ,  $T_{max}$ ,  $vRPE20$ ,  
51 critical speed (CS), and lactate threshold (LT) were determined before and after  
52 the 6-week training. **Results:** STND and S-P training significantly improved  
53  $\dot{V}O_{2max}$  by  $4 \pm 8\%$  and  $6 \pm 6\%$ , CS by  $7 \pm 7\%$  and  $3 \pm 3\%$ ; LT by  $5 \pm 4\%$  and  $7 \pm$   
54  $8\%$ , respectively (all  $P < 0.05$ ), with no differences observed between groups.  
55 **Conclusions:** Novel metrics obtained from the SPV can offer similar training  
56 prescription and improvement in  $VO_{2max}$ , CS and LT compared to training derived  
57 from a traditional GXT.

58

59

60

61

62

63

64

65

66

67

68

69

70

71

72

73

74

75

76

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

79

80 **ABBREVIATIONS:**

81

82	<b>ANOVA</b>	Analysis of variance
	<b>CS</b>	Critical speed
83	<b>GPS</b>	Global positioning system
	<b>GXT</b>	Graded exercise test
84	<b>HR<sub>max</sub></b>	Maximal heart rate
	<b>LT</b>	Lactate threshold
85	<b>LT1</b>	Lactate threshold 1
	<b>LT2</b>	Lactate threshold 2
86	<b>RER</b>	Respiratory exchange ratio
87	<b>RER<sub>max</sub></b>	Maximal respiratory exchange ration
	<b>RPE</b>	Rating of perceived exertion
88	<b>RPE<sub>max</sub></b>	Maximal rating of perceived exertion
	<b>STND</b>	Standardised
89	<b>S-P</b>	Self-paced
90	<b>SPV</b>	Self-paced $\dot{V}O_{2max}$ test
	<b>T<sub>max</sub></b>	Time in which $v\dot{V}O_{2max}$ can be maintained
91	<b>V<sub>E</sub>max</b>	Maximal minute ventilation
92	<b>VCO<sub>2</sub></b>	Carbon dioxide production
	<b><math>\dot{V}O_2</math></b>	Oxygen uptake
93	<b><math>\dot{V}O_{2max}</math></b>	Maximal oxygen uptake
94	<b><math>v\dot{V}O_{2max}</math></b>	Velocity at $\dot{V}O_{2max}$

95

96

97

98

99

100

101

102

103

104

105

106

107

108

109

110

111 **INTRODUCTION**

112 The graded exercise test (GXT) is a globally recognised test which offers valuable  
113 information on key aerobic parameters such as maximal oxygen uptake ( $\dot{V}O_{2max}$ ),  
114 and can be used to prescribe training for both elite athletes, and recreational  
115 exercisers. Recently, a novel approach to the traditional GXT has been proposed,  
116 termed the self-paced  $\dot{V}O_{2max}$  test (SPV), which consists of 5 x 2 min stages where  
117 speed or power is freely adjusted by the participant based on rating of perceived  
118 exertion (RPE) (Mauger and Sculthorpe, 2012; Borg, 1982). The SPV has been  
119 applied across a wide range of exercise modalities and ergometry despite its  
120 relative infancy (Mauger and Sculthorpe, 2012; Chidnok et al, 2013; Straub et al,  
121 2014; Hogg et al. 2015; Jenkins et al. 2017b; Lim et al. 2016; Scheadler and  
122 Devor, 2015).

123 The general consensus from published research to date suggests that the SPV  
124 provides comparable  $\dot{V}O_{2max}$  values to the GXT (Chidnok et al. 2013, Hogg et al.  
125 2015; Lim et al. 2016; Scheadler and Devor, 2015; Straub et al. 2014; Faulkner et  
126 al. 2015; Hanson et al. 2016), however the methodological differences and  
127 contrasting populations used may make direct comparisons between studies  
128 challenging. Higher  $\dot{V}O_{2max}$  values have been observed within the SPV test  
129 (Mauger and Sculthorpe, 2012; Jenkins et al. 2017b; Jenkins et al. 2017a; Astorino  
130 et al. 2015; Mauger et al. 2013), although all but one of these studies were cycling-  
131 based. However, the findings regarding differences in  $\dot{V}O_{2max}$  are less meaningful  
132 in terms of the utility of the test, with perhaps greater emphasis being placed on  
133 the practical advantages that the SPV has over the GXT. The problems associated  
134 with the GXT are well documented (Noakes, 2008), such as the incremental fixed-  
135 intensity nature of the test, unknown test duration, and creating a test environment  
136 that is possibly unnatural and irrelevant for “real” sporting performance. It has  
137 therefore been put forward that the SPV may represent a paradigm shift in  $\dot{V}O_{2max}$   
138 testing (Beltz et al. 2016), with self-paced protocols offering greater ecological  
139 validity due to the self-paced and closed-loop nature, whilst also circumventing  
140 the issue of estimating the ramp-rate and starting work rate for the researcher or  
141 practitioner (Poole and Jones, 2017).

142 The GXT offers additional metrics in addition to the measurement of  $\dot{V}O_{2max}$ , such  
143 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  
144 maintained ( $T_{max}$ ). However, the identification of  $T_{max}$  requires an additional test  
145 which adds to the impracticality of the GXT. Nevertheless,  $\dot{V}O_{2max}$ ,  $v\dot{V}O_{2max}$  and  
146  $T_{max}$  have been shown to be useful and viable parameters in running training and  
147 performance (Billat and Koralsztein, 1996; Esfarjani and Laursen, 2007; Manoel  
148 et al. 2017; Smith et al. 2003) and can be used to prescribe training and assess  
149 training adaptation. If similar metrics for training prescription could be acquired  
150 from the SPV, in a singular test, it would demonstrate utility over and above  
151 traditional GXT assessment of  $\dot{V}O_{2max}$ , especially as the SPV is an effective test  
152 for highly trained runners (Hogg et al. 2015; Scheadler and Devor, 2015), and has  
153 good test-retest reliability (Jenkins et al. 2017a). In addition, the SPV has recently  
154 been validated as a field test (Lim et al. 2016), which increases its accessibility to  
155 a variety of athletes and coaches. Therefore, the ability to prescribe training from  
156 the SPV would enhance the value and utility of the test. As such, this study aimed  
157 to investigate whether training prescribed via novel metrics derived from the SPV  
158 could result in comparable improvements in key aerobic parameters as training  
159 formulated from traditional GXT variables.

160

161 **MATERIALS AND METHODS**

162 **Participants**

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

172

### 173 **Exercise Tests**

174 Participants were randomly allocated into two groups: ‘Standardised’ (STND)  
175 and ‘Self-paced’ (S-P). All participants completed a GXT, an SPV, and a sub-  
176 maximal lactate threshold (LT) test on a motorised treadmill (Saturn, HP Cosmos,  
177 Nussdorf-Traunstein, Germany), and a critical speed (CS) test as part of baseline  
178 testing on three separate occasions over a two wk period. The  $\dot{V}O_{2max}$  protocols  
179 were completed in a randomised order, 2-7 days apart and at the same time of day  
180 ( $\pm$ 2 h). Oxygen uptake ( $\dot{V}O_2$ ) (Metalyzer 3BR2, Cortex, Leipzig, Germany) and  
181 heart rate (T31, Polar Electro Inc, New York, USA) were recorded for the duration  
182 of the testing protocol. The online gas analysis system was calibrated prior to  
183 every test in accordance with the manufacturer’s guidelines. Before each test,  
184 participants performed a warm-up of their choice on the motorised treadmill,  
185 which was kept the same for all subsequent tests. The CS test was completed on  
186 an all-weather synthetic 400 m running track using the method outlined by  
187 Galbraith (2011). Briefly, this involved three runs at distances of 3600 m, 2400  
188 m, and 1200 m, each separated by 30 min recovery. For the lactate threshold (LT)  
189 protocol, participants completed 4 min stages on the treadmill with a capillary  
190 blood sample (Biosen C-Line, EKF Diagnostics, Barleben, Germany) taken at the  
191 end of each stage, with the velocity increasing by 1 km·h<sup>-1</sup> at the beginning of each  
192 stage. Starting speed was estimated based on each participant’s individual fitness  
193 level. The test was terminated once lactate threshold 1 (LT1) and lactate threshold  
194 2 (LT2) had been obtained, defined as blood lactate readings of 2 and 4 mmol·L<sup>-1</sup>,  
195 respectively. Before each test, participants were instructed to maintain similar  
196 eating habits, abstain from alcohol (24 h) and caffeine (8 h), and to avoid  
197 exhaustive or vigorous exercise (48 h). These conditions were verbally verified  
198 by the experimenter at each test visit. Following baseline testing all participants  
199 then undertook a 6 wk field-based training program, consisting of two high  
200 intensity interval training sessions, one recovery run, and a tempo run per wk.  
201 Training sessions were either based on data from the SPV or GXT [depending on  
202 group allocation]. Participants completed either a GXT, or SPV mid-training  
203 [depending on group allocation] in the third wk of the training programme. This  
204 test replaced one of the high intensity sessions for that wk, with its sole purpose  
205 to recalibrate interval session intensity in both groups. All baseline tests were then  
206 repeated in the immediate two-weeks that followed the 6 wk training intervention.

207

### 208 **Graded Exercise Test (GXT)**

209 The test commenced at a submaximal speed, gauged by the experimenter and  
210 subject, to help bring about volitional exhaustion within 8-12 min. Speed was  
211 increased by 1 km·h<sup>-1</sup> every 2 min and the test was terminated when participants  
212 reached volitional exhaustion. Treadmill gradient was set to 1%. All previously  
213 described cardiorespiratory measures were recorded during this stage and  
214 participants continued until volitional exhaustion. 6-20 RPE<sup>2</sup> was recorded 20 s

215 before the end of each stage. Verbal encouragement was given throughout.  
216  $\dot{V}O_{2max}$  was determined as the highest velocity that could be maintained for at  
217 least 30 s (Smith et al, 2003).

218

#### 219 Determination of $T_{max}$

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

227

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

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

239

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

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

250

#### 251 **Training programme**

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

259

#### 260 STND Group

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

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

271

272 S-P Group

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

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

283

## 284 **Statistical Analysis**

285 Prior to statistical analysis, data were checked and confirmed to be normally  
286 distributed. A paired samples t-test was performed to assess maximal value  
287 differences between protocols. Based on the achieved effect size, a post hoc power  
288 analysis demonstrated that the statistical power of the pre-post  $\dot{V}O_{2max}$  comparison  
289 was 0.93. To identify training responses for both training groups (group) and GXT  
290 and SPV protocols (protocol) for before and after training (time-point) a mixed  
291 model analysis of variance (ANOVA) was used. Where no interaction effect was  
292 identified between a variable and protocol (GXT and SPV), the protocol was  
293 omitted from further analysis of training responses for that variable. Participants'  
294 CS were calculated from the field test using a linear distance-time model. Partial  
295 eta-squared ( $\eta_p^2$ ) was used to report effect sizes, and statistical significance was  
296 accepted when  $P < 0.05$ . All statistical tests were completed using SPSS version  
297 24 (Chicago, IL, USA).

298

## 299 **RESULTS**

### 300 SPV vs. GXT Protocol Data

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

302 The average stage-to-stage increase in  $\dot{V}O_2$  for all participants was calculated as  
303  $393 \pm 21 \text{ mL} \cdot \text{min}^{-1}$ , so that a plateau phenomenon was defined as a change in  $\dot{V}O_2$   
304  $\leq 197 \pm 10 \text{ mL} \cdot \text{min}^{-1}$  (or relative  $\dot{V}O_2$   $2.8 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ), between the highest 30  
305 s average obtained from each of the final two stages of the test for each participant.  
306 All participants achieved either a  $\dot{V}O_2$  plateau or satisfied secondary criteria  
307 across both GXT trials before and after training. Ninety-three percent of



308 participants satisfied secondary criteria across both SPV trials before and after  
309 training.

310

311 Differences in test protocols

312 Differences in test protocols for key variables for all participants are presented in  
313 Table 2. Pre and post-training data were combined to compare the GXT and SPV  
314 protocols. There were no significant differences in  $\dot{V}O_{2\max}$  between the GXT and  
315 SPV protocols ( $P = .578$ ). Maximal RER ( $RER_{\max}$ ) was significantly greater in  
316 the SPV compared to the GXT ( $P < .001$ ). There was no interaction effect between  
317 test protocol for either  $HR_{\max}$  or maximal minute ventilation ( $V_{E\max}$ ) ( $P = .212$ ;  $P$   
318  $= .319$ , respectively). Protocol duration was significantly longer in the GXT ( $P <$   
319  $.001$ ).  $RPE_{\max}$  was significantly greater in the SPV ( $P < .001$ ). There were no  
320 significant differences between the velocities associated with  $\dot{V}O_{2\max}$  and  $RPE_{20}$   
321 ( $P = .130$ ).

322

323 STND vs. S-P Training Data

324 Training prescription

325 Total prescribed training duration over the 6 wk period for both training groups  
326 was not significantly different ( $P = .651$ ). The STND had a prescribed total  
327 duration of  $804 \pm 90$  min whilst the S-P had a prescribed total duration of  $816 \pm$   
328  $0$  min. There was no significant difference between the mean interval session  
329 duration for both STND and S-P ( $37 \pm 8$  vs  $38 \pm 0$  min, respectively) ( $P = .679$ ).

330

331 Enter Table 1 here:

332

333 Responses to Training

334 Group data (pre- vs. post-training) are shown in table 3. As outlined in the  
335 methods, participants were grouped into either S-P or STND, and conducted both  
336 an SPV and GXT before and after the training intervention. There was no  
337 interaction effect for protocol duration between time-point, protocol and group  
338 ( $F_{1,22} = .561$ ,  $P = .462$ ,  $\eta_p^2 = .025$ ). As shown in Figure 1 and Table 3, there was  
339 an interaction effect between  $\dot{V}O_{2\max}$  and time-point ( $F_{1,22} = 7.461$ ,  $P = .012$ ,  $\eta_p^2$   
340  $= .253$ ) however there was no interaction effect observed between group and time-  
341 point ( $F_{1,22} = .003$ ,  $P = .954$ ,  $\eta_p^2 = .0001$ ). Whilst there was an interaction effect  
342 between  $V_{E\max}$  and time-point ( $F_{1,22} = 12.592$ ,  $P = .002$ ,  $\eta_p^2 = .364$ ), there was no  
343 interaction effect between time-point and group ( $F_{1,22} = .001$ ,  $P = .981$ ,  $\eta_p^2 =$   
344  $.0001$ ). There was no interaction effect for  $HR_{\max}$  between time-point and group  
345 ( $F_{1,22} = 1.063$ ,  $P = .314$ ,  $\eta_p^2 = .046$ ).

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

349 (14.3 + 1.3 km·h<sup>-1</sup> vs. 14.3 + 1.7 km·h<sup>-1</sup>, respectively), but  $\sqrt{\text{RPE20}}$  was greater  
350 than  $\sqrt{\dot{V}\text{O}_{2\text{max}}}$  after training (15.7 + 1.3 km·h<sup>-1</sup> vs. 15.2 + 1.3 km·h<sup>-1</sup>, respectively).  
351 CS improved in both groups ( $P < .001$ ) however there was no interaction effect  
352 between time-point and group ( $F_{1,21} = 3.006$ ,  $P = .098$ ,  $\eta_p^2 = .125$ ). Similarly,  
353 LT1 and LT2 improved in both groups ( $F_{1,21} = 14.637$ ,  $P < .001$ ,  $\eta_p^2 = .411$ )  
354 however there was no interaction effect between time-point and group ( $F_{1,21} =$   
355  $1.227$ ,  $P = .281$ ,  $\eta_p^2 = .055$ ).

356

## 357 **DISCUSSION**

358 The primary finding of this study was that following a 6 wk period of training,  
359 recreational runner's aerobic fitness and running performance was increased by a  
360 similar magnitude, regardless of whether SPV or GXT data were used to prescribe  
361 training. Specifically,  $\dot{V}\text{O}_{2\text{max}}$  in the STND group improved by 4%, and by 6% in  
362 the S-P group. An improvement in  $\dot{V}\text{O}_{2\text{max}}$  in the region of ~3% has previously  
363 been defined as a meaningful improvement in performance (Kirkeberg et al,  
364 2010), as opposed to day-to-day variation. Previous literature has shown  
365 improvements in  $\dot{V}\text{O}_{2\text{max}}$  by ~6% when training at 106%  $\sqrt{\dot{V}\text{O}_{2\text{max}}}$  (Franch et al,  
366 1998) for similar training durations. However, in the aforementioned study the  
367 starting  $\dot{V}\text{O}_{2\text{max}}$  for the participants were significantly lower than those reported  
368 in the current study, which may suggest a greater level of trainability for  $\dot{V}\text{O}_{2\text{max}}$   
369 (Swain and Franklin, 2002) compared with the participants in the current study.  
370 Athletes of slightly higher training status' than those in the current study achieved  
371 little to no improvements in  $\dot{V}\text{O}_{2\text{max}}$  over 4-6 weeks of similar intensity training  
372 (Manoel et al. 2017; Smith et al. 2003; Denadai et al. 2006), but did show  
373 significant improvements in LT and 3-10 km running performance. Similar  
374 running programmes utilising interval training have also produced improvements  
375 in CS (Esfarjani and Laursen, 2007). This is supported by the findings of the  
376 current study that in both STND and S-P, CS improved by 7% and 3%,  
377 respectively. For LT1 and LT2, STND improved by 5% and 3% and S-P improved  
378 by 7% and 8%.

379 An important finding of this study is that the novel training parameter extracted  
380 from the SPV, ' $\sqrt{\text{RPE20}}$ ', is effective at prescribing running intensity for interval  
381 training. The  $\sqrt{\dot{V}\text{O}_{2\text{max}}}$  for the STND before and after training was  $14.3 \pm 0.9$  vs.  
382  $15.2 \pm 1.0$  km·h<sup>-1</sup> compared to the S-P's  $\sqrt{\text{RPE20}}$  of  $14.2 \pm 1.9$  vs.  $15.7 \pm 1.9$  km·h<sup>-1</sup>  
383 respectively. It is likely that the  $\sqrt{\text{RPE20}}$  may reflect a speed between  $\sqrt{\dot{V}\text{O}_{2\text{max}}}$   
384 and the maximal velocity achieved in a GXT ( $V_{\text{max}}$ ).  $V_{\text{max}}$  has recently been shown  
385 to be as beneficial as  $\sqrt{\dot{V}\text{O}_{2\text{max}}}$  for exercise prescription (Manoel et al. 2017), and  
386 like  $\sqrt{\text{RPE20}}$  is simple to calculate. Moreover,  $\sqrt{\text{RPE20}}$  has been shown to be  
387 repeatable regardless of the pacing strategy adopted during this final stage  
388 (Hanson et al. 2017). This should be reason to encourage further investigation to  
389 assess the potential of  $\sqrt{\text{RPE20}}$  in training prescription and its suitability as a  
390 performance parameter.

391 As the aim of the study was to investigate whether SPV-derived training  
392 parameters could offer similar improvements in aerobic fitness compared to GXT  
393 prescribed training, it was important that training prescription was similar  
394 between groups in both intensity and duration. To calculate interval duration for  
395 the STND, 60%  $T_{\text{max}}$  was used. Setting interval duration at 60% of an individual's  
396  $T_{\text{max}}$  has been shown to produce significant improvements in aerobic parameters  
397 and 3-10 km running performance (Esfarjani and Laursen, 2007; Manoel et al.  
398 2017; Smith et al. 2003). In the study by Smith and colleagues (2003), 60%  $T_{\text{max}}$

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

411 The similar  $\dot{V}O_{2max}$  found between both protocols in this study is in line with  
412 previous research (Chidnok et al. 2013; Hogg et al. 2015; Lim et al. 2016;  
413 Scheadler and Devor, 2015; Straub et al. 2014; Faulkner et al. 2015; Hanson et al.  
414 2016). Even though test duration was significantly longer in the GXT, the test still  
415 fell within the recommended duration of 8-12 minutes (Yoon et al. 2007), and the  
416  $\dot{V}O_{2max}$  achieved was not significantly different between protocols. Interestingly,  
417  $RER_{max}$  was significantly higher in the SPV, which has been observed in some  
418 (Mauger and Sculthorpe, 2012; Hogg et al. 2015; Jenkins et al. 2017b), but not all  
419 previous SPV literature (Lim et al. 2016; Straub et al. 2014; Faulkner et al. 2015;  
420 Astorino et al. 2015). Consequently, no consensus on whether the SPV produces  
421 a higher  $RER_{max}$  can be currently drawn. However, the authors speculate that this  
422 potential difference in  $RER_{max}$  may be due to the higher peak velocities  
423 experienced in the SPV compared to the GXT, indicative of a greater anaerobic  
424 contribution towards the end of the test. This is supported by the recent work of  
425 Hanson and colleagues (2017) who found, when comparing two SPV trials with  
426 different RPE20 pacing strategies, that  $RER_{max}$  was significantly greater in the  
427 SPV that adopted the more aggressive pacing strategy.

428

## 429 CONCLUSIONS

430 The ability to prescribe training for recreationally active males and females via  
431 SPV-derived parameters offers coaches and athletes valuable alternatives to  
432 traditional methods. Prescribing training via the SPV is as effective but more time-  
433 economical. Specifically, the same level of improvement in key aerobic fitness  
434 parameters can be obtained when training is set via novel training parameters  
435 collected from a single 10 min SPV test compared to that achieved using a GXT  
436 and a mandatory additional test to acquire  $T_{max}$  data. This alone may make the  
437 SPV more attractive to athletes and coaches, however, recent research regarding  
438 a field based SPV (Lim et al. 2016) may emphasise this further. Whilst a field-  
439 based SPV has been shown to produce a valid directly measured  $\dot{V}O_{2max}$ , future  
440 research should investigate whether  $\dot{V}O_{2max}$  can be accurately estimated from the  
441 field based SPV. If so, athletes and coaches would then be able to utilize a single  
442 10 min test on an athletics track, without expensive equipment, that would offer  
443 accurate  $\dot{V}O_{2max}$  estimation and data for effective training prescription. Therefore,  
444 the current findings demonstrate that training parameters derived from the SPV  
445 protocol can be used to prescribe effective running training that is similarly  
446 effective to training prescribed from GXT-derived parameters. Consequently, in  
447 the group that was prescribed training using SPV-derived parameters,  $\dot{V}O_{2max}$ ,  
448 LTs and CS showed similar improvements compared to runners who were  
449 prescribed training via the velocity at  $\dot{V}O_{2max}$  and LT zones, with training durations  
450 and intensities suitably similar between groups throughout training.

451

452 **ACKNOWLEDGEMENTS**

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

455

456 **CONFLICT OF INTEREST**

457 None

458

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

463

464 **REFERENCES**

- 465 1. Astorino TA, McMillan DW, Edmunds RM, Sanchez E (2015)  
466 Increased cardiac output elicits higher VO<sub>2</sub>max in response to self-  
467 paced exercise. *Appl Physiol Nutr Metab* 40(3):223-9.
- 468 2. Beaver W, Wasserman K, Whipp B (1986) A new method for detecting  
469 anaerobic threshold by gas exchange. *J Appl Physiol* 60(6):2020-27.
- 470 3. Beltrami FG, Froyd C, Mauger AR, Metcalfe AJ, Marino F, Noakes TD  
471 (2012) Conventional testing methods produce submaximal values of  
472 maximum oxygen consumption. *Br J Sports Med* 46(1):23-9.
- 473 4. Beltz NM, Gibson AL, Janot JM, Kravitz L, Mermier CM, Dalleck LC  
474 (2016) Graded exercising testing protocols for the determination of  
475 VO<sub>2</sub>max: Historical perspectives, progress, and future considerations. *J*  
476 *Sports Med*. doi:10.1155/2016/3968393.
- 477 5. Billat VL, Koralsztein J-P. Significance of the velocity at VO<sub>2</sub>max and  
478 time to exhaustion at this velocity (1996) *Sports Med* 22(2):90-108.
- 479 6. Borg GAV (1982) Psychophysical bases of perceived exertion. *Med Sci*  
480 *Sports Exerc* 14(5):377-381.
- 481 7. Chidnok W, Dimenna FJ, Bailey SJ, et al. (2013) VO<sub>2</sub>max is not  
482 altered by self-pacing during incremental exercise. *Eur J Appl Phys*  
483 113(2):529-39.
- 484 8. Denadai BS, Ortiz MJ, Greco CC, Mello MT De (2006) Interval  
485 training at 95% and 100% of the velocity at VO<sub>2</sub>max: Effects on  
486 aerobic physiological indexes and running performance. *Appl Physiol*  
487 *Nutr Metab* 31(6):737-743.
- 488 9. Esfarjani F, Laursen PB (2007) Manipulating high-intensity interval  
489 training: Effects on VO<sub>2</sub>max, the lactate threshold and 3000m running  
490 performance in moderately trained males. *J Sci Med Sport* 10(1):27-35.
- 491 10. Faulkner J, Mauger AR, Woolley B, Lambrick D (2015) The efficacy  
492 of a self-paced VO<sub>2</sub>max test during motorized treadmill exercise. *Int J*  
493 *Sports Physiol Perform* 10(1):99-105.
- 494 11. Franch J, Madsen K, Djurhuus MS, Pedersen PK (1998) Improved  
495 running economy following intensified training correlates with reduced  
496 ventilator demands. *Med Sci Sport Exerc* 30(8):1250-6.
- 497 12. Galbraith A (2011) A novel field test to determine critical speed. *J*  
498 *Sports Med Doping Stud* 1(1):1-4.
- 499 13. Hanson NJ, Reid CR, Cornwell KM, Lee TL, Schedler CM (2017)

- 500 Pacing strategy during the final stage of a self-paced VO<sub>2</sub>max (SPV)  
501 test does not affect maximal oxygen uptake. *Eur J Appl Physiol*.  
502 doi:10.1007/s00421-017-3656-3.
- 503 14. Hanson NJ, Scheadler CM, Lee TL, Neuenfeldt NC, Michael TJ,  
504 Miller MG (2016) Modality determines VO<sub>2</sub>max achieved in self-  
505 paced exercise tests: Validation with the Bruce protocol. *Eur J Appl*  
506 *Physiol* 116(7):1313-9.
- 507 15. Hogg JS, Hopker JG, Mauger AR (2015) The self-paced VO<sub>2</sub>max  
508 test to assess maximal oxygen uptake in highly trained runners. *Int J*  
509 *Sport Physiol Perform* 10(2):172-7.
- 510 16. Jenkins LA, Mauger A, Fisher J, Hopker J (2017a) Reliability and  
511 validity of a self-paced cardiopulmonary exercise test in post-MI  
512 patients. *Int J Sports Med* 38(4):300-306.
- 513 17. Jenkins LA, Mauger AR, Hopker JG (2017b) Age differences in  
514 physiological responses to self-paced and incremental VO<sub>2</sub>max  
515 testing. *Eur J Appl Physiol*. doi: 10.1007/s00421-016-3508-6.
- 516 18. Kirkeberg JM, Dalleck LC, Pettitt RW (2010) Validity of 3 protocols  
517 for verifying VO<sub>2</sub>max. *Int J Sports Med* 32(4):266-270.
- 518 19. Lim W, Lambrick D, Mauger AR, Woolley B, Faulkner J (2016) The  
519 effect of trial familiarisation on the validity and reproducibility of a  
520 field-based self-paced VO<sub>2</sub>max test. *Biol Sport* 33(3):269-75.
- 521 20. Manoel F de A, da Silva DF, de Lima JRP, Machado FA (2017) Peak  
522 velocity and its time limit are as good as the velocity associated with  
523 VO<sub>2</sub>max for training prescription in runners. *Sports Med International*  
524 *Open* 1(1):8-15.
- 525 21. Mauger AR, Metcalfe AJ, Taylor L, Castle PC (2013) The efficacy of  
526 the self-paced VO<sub>2</sub>max test to measure maximal oxygen uptake in  
527 treadmill running. *Appl Physiol Nutr Metab* 38(2):1211-6.
- 528 22. Mauger AR, Sculthorpe N (2012) A new VO<sub>2</sub>max protocol allowing  
529 self-pacing in maximal incremental exercise. *Br J Sports Med* 46(1):59-  
530 63.
- 531 23. Noakes TD (2008) Testing for maximum oxygen consumption has  
532 produced a brainless model of human exercise performance. *Br J Sports*  
533 *Med* 42(7):551-5.
- 534 24. Nolan PB, Beaven ML, Dalleck L (2014) Comparison of intensities and  
535 rest periods for VO<sub>2</sub>max verification testing procedures. *Int J Sports*  
536 *Med* 35(12):1024-9.
- 537 25. O'Brien BJ, Wibskov J, Knez WL, Paton CD, Harvey JT (2008) The  
538 effects of interval-exercise duration and intensity on oxygen  
539 consumption during treadmill running. *J Sci Med Sport* 11(3):287-90.
- 540 26. Poole DC, Jones AM (2017) CORP: Measurement of the maximal  
541 oxygen uptake (VO<sub>2</sub>max): VO<sub>2</sub>peak is no longer acceptable. *J Appl*  
542 *Physiol* 122(4):997-1002.
- 543 27. Scheadler CM, Devor ST (2015) VO<sub>2</sub>max measured with a self-  
544 selected work rate protocol on an automated treadmill. *Med Sci Sports*  
545 *Exerc* 47(10):2158-65.
- 546 28. Seiler KS, Sjursen JE (2002) Effect of work bout duration on  
547 physiological and perceptual responses to interval training in runners.  
548 *Med Sci Sport Exerc* 34(5):1613-21.
- 549 29. Smith TP, Coombes JS, Geraghty DP (2003) Optimising high-intensity  
550 treadmill training using the running speed at maximal (O<sub>2</sub>) uptake and  
551 the time for which this can be maintained. *Eur J Appl Physiol* 89(3-  
552 4):337-43.
- 553 30. Straub AM, Midgley AW, Zavorsky GS, Hillman AR (2014) Ramp-  
554 incremented and RPE-clamped test protocols elicit similar VO<sub>2</sub>max  
555 values in trained cyclists. *Eur J Appl Physiol* 114(8):1581-90.

556 31. Swain DP, Franklin B a (2002) VO2 reserve and the minimal intensity  
557 for improving cardiorespiratory fitness. Med Sci Sport Exerc  
558 34(1):152-7.  
559 32. Yoon B-K, Kravitz L, Robergs R (2007) VO2max, protocol duration,  
560 and the VO2 plateau. Med Sci Sports Exerc 39(7):1186-92.

561

562

563

564

565

566

567

568

569

570

571

572

573

574

575

576

577

578

579

580

581

582

583

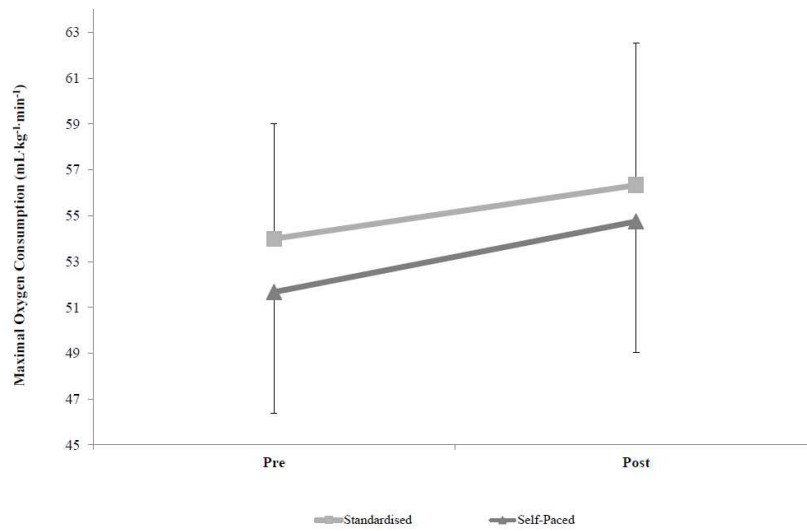
584

585

586

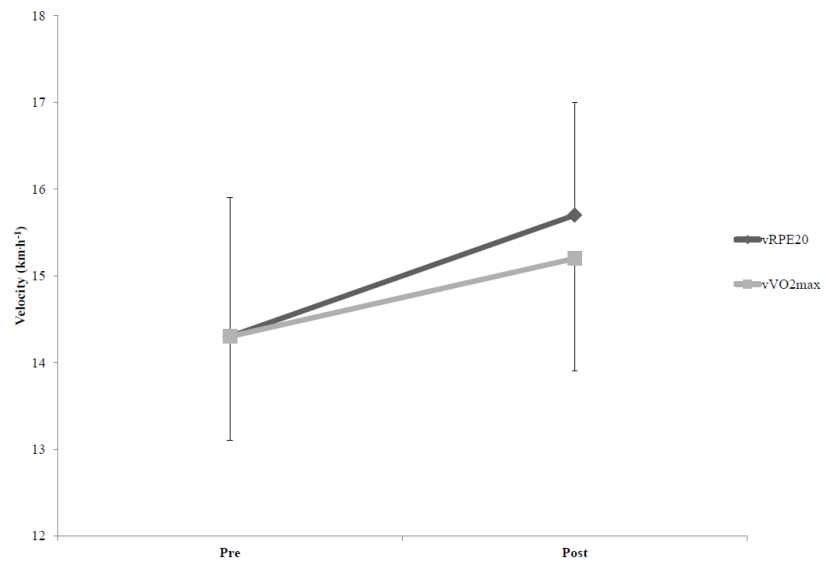
587 **Figure Legends**

588 **Figure 1.** Mean  $\pm$  SD Differences in  $\dot{V}O_{2\max}$  between the STND and S-P  
589 training groups before and after training.



590

591 **Figure 2.** Mean  $\pm$  SD Differences in the velocities  $v\dot{V}O_{2\max}$  and  $vRPE20$  for all  
592 participants for before and after training.



593

594

595

596

597

598

599

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

Rep. Subject	Training Prescription			
	Interval session x 2		Tempo Run	Recovery Run
	Weeks 1-3	Weeks 4-6	Weeks 1-6	Weeks 1-6
<b>STND</b>	Work: 6 x 167 s @ 15 km·h <sup>-1</sup> Recovery: 5 x 334 s @ 8 km·h <sup>-1</sup>	Work: 6 x 141 s @ 16 km·h <sup>-1</sup> Recovery: 5 x 282 s @ 8 km·h <sup>-1</sup>	30 min @ 11.3 km·h <sup>-1</sup>	30min @ 115 bpm
<b>S-P</b>	Work: 7 x 120 s @ 15.6 km·h <sup>-1</sup> Recovery: 6 x 240 s @ 8 km·h <sup>-1</sup>	Work: 7 x 120 s @ 16.3 km·h <sup>-1</sup> Recovery: 6 x 240 s @ 8 km·h <sup>-1</sup>	30 min @ RPE13	30 min @ 114 bpm

602

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

604

605

606

607

608

609

610

611

612

613

614

615

616

617

618

619

620

621

622

623

624

625



626

627 **Table 2.** Mean  $\pm$  SD peak values for physiological and intensity variables  
628 recorded during both GXT and SPV protocols across both before and after  
629 training for all participants.

630

Variable	Protocol	
	GXT	SPV
$\dot{V}O_{2max}$ (mL·kg <sup>-1</sup> ·min <sup>-1</sup> )	54 $\pm$ 5.8	54 $\pm$ 0.7
HR <sub>max</sub> (beats/min)	186 $\pm$ 12	184 $\pm$ 11
V <sub>E</sub> max (L/min)	135.4 $\pm$ 29.4	137.2 $\pm$ 24.8
RER <sub>max</sub>	1.15 $\pm$ 0.02	1.21 $\pm$ 0.00*
$\sqrt{v}\dot{V}O_{2max} / \sqrt{v}RPE_{20}$ (km·h <sup>-1</sup> )	14.8 $\pm$ 1.3	15 $\pm$ 1.5
Mean test time (min)	11 $\pm$ 1*	10 $\pm$ 0
RPE <sub>max</sub>	19 $\pm$ 1	20 $\pm$ 0*

631

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

634

635

636

637

638

639

640

641

642

643

644

645

646

647

648

649

650

651

652

653

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

657

658

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

659

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