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Reliability and validity of a self-paced cardiopulmonary exercise test in post-MI patients

Journal:	<i>International Journal of Sports Medicine</i>
Manuscript ID	IJSM-06-2016-5715-tt.R1
Manuscript Type:	Training & Testing
Key word:	cardiology, RPE, Aerobic Capacity, Pacing
Abstract:	<p>A self-paced peak oxygen uptake (VO₂peak) test (SPV) has been shown to produce higher VO₂peak values compared to standard cardiopulmonary exercise tests (sCPET), but has not been tested on any clinical population. This study aimed to assess the reliability of the SPV in a healthy population (study 1), and the validity and reliability of the SPV in post Myocardial Infarction (post-MI) patients (study 2). For study 1, twenty-five healthy participants completed three SPV's. For study 2, twenty-eight post-MI patients completed one sCPET and two SPV's. The SPV consisted of 5 x 2-min stages where participants were able to self-regulate their effort by using incremental 'clamps' in ratings of perceived exertion. The sCPET consisted of a 20 W/min ramp. Results demonstrated the SPV to have a coefficient of variation for VO₂peak of 4.7% for the healthy population, and 8.2% for the post-MI patients. Limits of agreement ranged between ± 4.22-$5.86 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, with the intraclass correlation coefficient ranging between 0.89-0.95. In study 2, there was a significantly higher VO₂peak achieved in the SPV ($23.07 \pm 4.90 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) against the sCPET ($21.29 \pm 4.93 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). It is concluded that these results provide initial evidence that the SPV may be a safe, valid and reliable method for determining exercise capacity in post-MI patients.</p>

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Manuscripts

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2
3 1 **Title:** Reliability and validity of a self-paced cardiopulmonary exercise test in post-MI
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5 2 patients

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8 3 **Abstract**

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10 4 A self-paced peak oxygen uptake ($\dot{V}O_{2\text{peak}}$) test (SPV) has been shown to produce higher
11
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28 13 variation for $\dot{V}O_{2\text{peak}}$ of 4.7% for the healthy population, and 8.2% for the post-MI patients.
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32 15 coefficient ranging between 0.89-0.95. In study 2, there was a significantly higher $\dot{V}O_{2\text{peak}}$
33
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35
36 17 ~~We conclude~~ It is concluded that these results provide initial evidence that the SPV
37
38 18 is may be a safe, valid and reliable method for determining exercise capacity in post-MI
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40 19 patients.
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49 21 **Key words:** cardiology, RPE, aerobic capacity, pacing
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26 Introduction

27 Cardiopulmonary exercise testing (CPET) is an increasingly popular tool that allows
28 clinicians to objectively assess the integrated response to exercise [29,48][27,41]. Moreover,
29 CPET derived exercise tolerance and capacity have been strongly correlated with overall
30 health status and mortality, and can therefore provide valuable diagnostic and prognostic
31 information for various patient populations [1,12,29,39][1,10,27,35]. One of the key
32 measures obtained from CPET is peak oxygen uptake ($\dot{V}O_{2peak}$), which is defined as the
33 highest amount of oxygen a person can utilise during dynamic exercise [7][5]. The
34 identification of $\dot{V}O_{2peak}$ has become a fundamental procedure when assessing
35 cardiorespiratory fitness, monitoring exercise intensity [7][5] and when risk stratifying
36 individuals prior to major surgical procedures [8][6]. Exercise testing soon after a Myocardial
37 Infarction (MI) is beneficial as it can provide information on a patient's future risk of a
38 subsequent cardiac event [15][13] and can be used in individualising exercise rehabilitation
39 programmes [32][29].

40

41 Traditionally, CPET is completed on a stationary bike or a treadmill using a maximal
42 incremental exercise test (MIE), whereby the intensity (speed or power output (PO))
43 increases by a set amount, for a given period of time, until volitional exhaustion is reached
44 [44][38]. For optimum values to be achieved it is suggested that participants reach volitional
45 exhaustion between 8-12 minutes [11][9]. Clinicians are therefore required to estimate the
46 most suitable starting intensity and work rate increments to ensure test validity. This
47 increases the risk of a test being unsuccessful due to participants either exceeding 12 minutes,
48 or worse, not lasting long enough for $\dot{V}O_{2peak}$ to be accurately measured. There has also been

1
2
3 49 a number of other limitations that have been brought to light regarding the general nature of
4 the current CPET protocol [41], in particular the patient is unaware of the test duration and
5 50 previous work suggests that knowledge of exercise duration can facilitate performance [33].
6
7 51 In addition the patient only has control over when they stop the test which adds a
8 52 psychological aspect to the test i.e. low motivation [41]. Recently, a novel self-paced CPET
9 53
10 54 protocol (SPV) was developed [36][32] to address the some of the aforementioned problems
11 55 with the traditional CPET protocol. The SPV uses a closed-loop self-paced design, consisting
12 56 of 5 x 2-min stages, where participants are able to regulate their work rate according to
13 57 specific their ratings of perceived exertion (RPE). Previous studies have concluded that the
14 58 SPV is able to produce significantly higher $\dot{V}O_{2peak}$ values when compared against traditional
15 59 CPET protocols [3,34,36], although not all studies have found this [13,47]. In recent years the
16 60 SPV protocol has raised a lot of discussion points [2,17,35,43] with some researchers
17 61 criticising the test [13,17,43]. Although, there is now a body of research which supports the
18 62 validity of the SPV, with all studies demonstrating it to produce at least similar $\dot{V}O_{2peak}$
19 63 values [3,13,34,36,47]. This type of test may be beneficial in clinical practice as it will reduce
20 64 the risk of acquiring unusable data, this is because all patient will have the opportunity to
21 65 complete the test at their own ability whilst meeting the recommended test time requirements.
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44 67 A number of studies have assessed the use validity of the SPV in 'healthy populations'
45 68 [13,34,36,47][11,31,32,40], however the reliability of this protocol has yet to be determined.
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47
48 69 Moreover, no research has investigated the reliability or validity of the use of the SPV in a
49 70 clinical population. There are a number of important benefits associated with completing
50 71 CPET in post-MI patients [15,32], therefore any test which may improve the validity and
51 72 reliability of this process should be of interest. Therefore two separate studies were
52 73 conducted ~~two separate studies~~; 1. To investigate the reliability of the SPV in an apparent
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3 74 “healthy” population, and; 2. To investigate the reliability and validity of the SPV in early
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5 75 post-MI patients. The hypotheses for the current study are that the SPV will be a reliable
6
7 76 indicator of key CPET derived variables in the healthy and clinical populations. The SPV will
8
9 77 also produce higher $\dot{V}O_{2peak}$ values compared to a traditional CPET protocol in the post-MI
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11 78 patients.
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17 80 **Materials & Methods**

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19
20 81 Twenty-five (12 females, 13 males) healthy participants (age = 26 ± 6 yr, weight = 68 ± 10
21
22 82 kg, height = 172 ± 9 cm) volunteered to participate in study 1. Study 1 was conducted
23
24 83 following institutional ethical approval of the researcher’s own University. For study 2,
25
26 84 thirty-seven patients undergoing phase III cardiac rehabilitation were asked to participate, out
27
28 85 of those, thirty agreed to take part. Two patients withdrew from the study, therefore twenty-
29
30 86 eight post-MI patients (2 females, 26 males) ~~undergoing cardiac rehabilitation volunteered to~~
31
32 87 ~~participate took part in study 2~~ (age = 58 ± 8 yr, weight = 89.5 ± 12 kg, height = 178 ± 8 cm,
33
34 88 days from MI event 57 ± 35). All participants recruited for study 2 already had their coronary
35
36 89 angiography and any interventions needed following their MI, and were thought to require no
37
38 90 further intervention or revascularisation. Study 2 was conducted following NHS ethical
39
40 91 approval (Brighton and Sussex REC: 12/LO/1737). Both studies met the ethical standards
41
42 92 outlined by Harris and Atkinson for the IJSM [21][18]. All participants gave their written
43
44 93 informed consent.
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50
51 95 For study 1 each participant visited the exercise-testing laboratory on three separate
52
53 96 occasions. During each visit participants were required to complete an SPV test. For study 2
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55 97 each patient was required to complete three exercise tests (a standard CPET protocol
56
57 98 (sCPET) and two SPV tests) in order to determine the tests’ validity and reliability. An
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3 99 | overview of the experimental procedures for both studies are provided in figure 1. The order
4
5 100 | in which participants completed the tests was in a randomised, counterbalanced crossover
6
7 101 | design. For both studies, each test was separated by at least 24 h and all tests were completed
8
9 102 | at the same time of the day (\pm 2 h). Participants were asked to refrain from drinking alcohol
10
11 103 | (24 h abstinence), eating (2 h abstinence), smoking (2 h abstinence), and not to perform any
12
13 104 | exercise in the 24 h prior to each test. In both studies, participants were required to complete
14
15 105 | a 5-min warm-up at a self-selected intensity during which they were also familiarised with
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17 106 | the process of freely adjusting their PO on the cycle ergometer.
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23 108 | ***INSERT FIGURE 1 HERE***
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28 110 | The SPV was completed on an air-braked cycle ergometer (Wattbike Trainer, UK), which
29
30 111 | allowed participants to continually vary their PO throughout the test. The SPV was conducted
31
32 112 | in accordance with the procedures previously outlined by Mauger and Sculthorpe [36][32]
33
34 113 | and consisted of 5 x 2-min stages (total test time of 10-min), where for each stage participants
35
36 114 | were able to continuously vary their PO, but with RPE (Borg's 6-20 scale) fixed to a level for
37
38 115 | each stage (RPE 11, 13, 15, 17 and 20), following an incremental format. Changes in PO
39
40 116 | were facilitated by the participants manually adjusting the cycle ergometer air brake and
41
42 117 | cadence at their own free will in order to produce a level of resistance that allowed them to
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44 118 | match the target RPE for each stage of the SPV.
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51 120 | The sCPET from study 2 was completed on an electro-magnetically braked cycle ergometer
52
53 121 | (Lode Corival), so that PO for each stage could be fixed according to the test requirements.
54
55 122 | The test followed a standard incremental ramp design. As previously used with other clinical
56
57 123 | populations, the test commenced with no resistance and gradually increased by 20 W per
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3 124 minute, standardized across all patients [10,16,20,26][8,14,17,24]. The test was stopped when
4
5 125 the patient felt like they could no longer continue or if they could no longer maintain more
6
7 126 than 60 RPM, despite verbal encouragement.
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11
12 128 During all exercise tests, expired gases were measured via the use of an online breath-by-
13
14 129 breath analysis system (Cortex Metalyzer, Cortex, NL). Expired gases, heart rate (HR), PO
15
16
17 130 and cadence were continuously recorded during the tests. A 12-lead ECG was used when
18
19 131 exercising the post-MI patients in study 2. After the test, $\dot{V}O_{2peak}$ was calculated as the
20
21 132 highest 30 second average $\dot{V}O_2$ ($L \cdot min^{-1}$ and $ml \cdot kg^{-1} \cdot min^{-1}$). ~~We did not assess for a $\dot{V}O_2$~~
22
23 133 plateau was not assessed which is why ~~we use~~ the term $\dot{V}O_{2peak}$ is used, rather than $\dot{V}O_{2max}$.
24
25 134 Peak cycling PO and minute ventilation ($\dot{V}E$) were also both calculated as the highest 30
26
27 135 second average value. The anaerobic threshold (AT) was determined using the V-slope
28
29 136 method with confirmation via the ventilatory equivalents ($\dot{V}E/\dot{V}O_2$ and $VE/\dot{V}CO_2$) and the
30
31 137 partial end-tidal ($P_{ET}O_2$ and $P_{ET}CO_2$) methods [23][20]. All AT's were independently
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33 138 assessed by two experienced researchers.
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40 140 All data was analysed using IBM SPSS Statistics version 21. Descriptive data is presented as
41
42 141 mean \pm standard deviation (SD). Statistical significance was set at 95% ($p < 0.05$). A sample
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44 142 size calculation was completed based upon the findings from the study by Mauger and
45
46 143 Sculthorpe [36]. The SD of the differences in $\dot{V}O_{2peak}$ between the two tests was $8.5 ml \cdot kg^{-1}$
47
48 144 $\cdot min^{-1}$ [36] and if it is assumed that the minimal clinically worthwhile differences between
49
50 145 the two tests is $5 ml \cdot kg^{-1} \cdot min^{-1}$, this equals to an effect size of 0.58. With this information it
51
52 146 was therefore estimated that a minimum sample size of 25 was needed to achieve a statistical
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54 147 power 80% and an alpha level of 0.05. Test-retest reliability was assessed via the use of 95%
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3 148 Limits of Agreement (LOA) using Bland-Altman plots [9][7], Confidence intervals (95% CI)
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5 149 of the coefficient of variation (CV), and intraclass correlation coefficients (ICC) were
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7 150 calculated to assess the variability of the repeated tests (Hopkins, A New View of Statistics.
8
9 151 Internet Society for Sports Science: <http://www.sportsci.org/resource/stats/index.html>
10
11 152 (2015)). It has been suggested that a CV of < 5% [24][21], and an ICC close to 1 both
12
13 153 indicate good test-retest reliability [5][3], with classifications for ICC ranging from
14
15 154 'questionable' (0.7 to 0.8) to 'high' (> 0.9) [5][3]. For study 1 differences in $\dot{V}O_{2peak}$, peak
16
17 155 PO, AT, peak HR and peak $\dot{V}E$ were assessed using a one-way repeated measures ANOVA.
18
19 156 For study 2, physiological responses from the 1st SPV test were compared to those obtained
20
21 157 from the sCPET, using a paired-samples t-test. Complete 2nd SPV test data was not achieved
22
23 158 for three of the patients in study 2, and so data from only SPV1 has been used in these cases.
24
25 159 The reasons for these three missing tests were; one patient had an unrelated illness and was
26
27 160 unable to attend their final test within the required timeframe; the other two miscalculated
28
29 161 their work rate during the RPE 17 stage causing a premature end to the test. The data of these
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31 162 two patients who did not meet the test requirements for SPV2 has been excluded from the
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33 163 main analysis, but complete data is also presented within the results section.
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165 Results

166 Study 1:

167 Table 1 represents a summary of the mean peak values for all the physiological variables
168 recorded during the three repeated SPVs.
169

170 ***INSERT TABLE 1 HERE***
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2
3 172 The CV for $\dot{V}O_{2\text{peak}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) was 4.2% (95% CI: 3.4-5.6%) for trials 2-1 and 5.1%
4
5 173 (95% CI: 4.2-6.8%) for trials 3-2. The mean CV for all three tests was 4.7% (95% CI: 3.8-
6
7 174 6.2%). A high level of agreement was found between trials 2-1 (ICC = 0.95) and trials 3-2
8
9 175 (ICC = 0.94). The LOA were $\pm 5.59 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ for trials 2-1 (Figure ~~2~~1a) and ± 5.86
10
11 176 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ for trials 3-2 (Figure ~~2~~1b).
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178 Participants demonstrated a mean CV of 5.5% (95% CI: 4.4-7.3%) for AT, 7.9% (95% CI:
18
19 179 6.3-10.6%) for peak PO, 1.7% (95% CI: 1.4-2.3%) for peak HR, and 7.2% (95% CI: 5.8-
20
21 180 9.6%) for peak $\dot{V}E$. The ICC for these three variables ranged between 0.91-0.97.
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182 Study 2

183 The CV for $\dot{V}O_{2\text{peak}}$ between SPV1 and SPV2 was 8.2% (95% CI: 6.6-10.9%). Therefore, if a
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185 184 patient achieved a $\dot{V}O_{2\text{peak}}$ of $23 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ a typical variation of $1.9 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ would
186
187 185 be expected. The ICC was 0.89 which represents a high level of agreement. The LOA was \pm
188
189 186 4.22 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ for the measure of SPV1 and SPV2 (Figure ~~2~~1c). ~~If we include~~ When the
190
191 187 SPV2 data for the two patients who were excluded from the main analysis are included, the
192
193 188 CV becomes 8.4% (95% CI: 6.8-11%), the ICC is unchanged, and the LOA become ± 4.52
194
195 189 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$.

191 ***INSERT FIGURE ~~2~~1 HERE***
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195

193 The CV for AT between SPV1 and SPV2 was 8.4% (95% CI: 6.8-11.2%). The ICC was 0.86
194
195 194 which suggests an 'acceptable' agreement [5][3]. The LOA was $\pm 3 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ for the
196
197 195 measure of SPV1 and SPV2 (Figure ~~2~~1d). If ~~we include~~ the SPV2 data for the two patients

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3 196 | who were excluded from the main analysis are included, the CV for AT becomes 8.6% (95%
4
5 197 | CI: 7-11.4%), the ICC is 0.84, and the LOA remain unchanged. There was a CV of 15.1%
6
7 198 | (95% CI: 12.1-20.4%) for peak PO, 4.7% (95% CI: 3.8-6.5%) for peak HR, and 11.5% (95%
8
9 199 | CI: 9.2-15.4%) for peak $\dot{V}E$. The ICC for these three variables ranged between 0.83-0.97,
10
11 200 | demonstrating a high level of agreement [5][3].
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15 201

16
17 202 | As shown in Table 2, patients achieved a significantly higher $\dot{V}O_{2peak}$ ($p < 0.01$) in the SPV
18
19 203 | compared with the sCPET. Patients also achieved a significantly higher peak PO, peak HR
20
21 204 | and peak $\dot{V}E$ in the SPV than in the sCPET ($p < 0.01$). There were no significant differences
22
23 205 | in AT between the SPV and the sCPET ($p > 0.05$).
24
25

26 206 | ***INSERT TABLE 2 HERE***
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31

32 208 | **Discussion**

33
34
35 209 | This is the first study to assess the SPV on a clinical population. The results of the current
36
37 210 | study demonstrated the SPV to be a reliable indicator of $\dot{V}O_{2peak}$ in a healthy population;
38
39 211 | which is mirrored by the post-MI patient population. The CV for $\dot{V}O_{2peak}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) in
40
41 212 | the healthy population was 4.7% and 8.2% for the post-MI patients. Post-MI patients
42
43 213 | achieved a higher $\dot{V}O_{2peak}$ compared to a sCPET protocol, which is in agreement with
44
45 214 | previous studies on healthy populations [34,36][31,32]. Previously published studies have
46
47 215 | investigated the reproducibility of physiological variables using sCPET protocols. Froelicher
48
49 216 | et al. [19][16] found that when using three popular maximal exercise treadmill protocols in a
50
51 217 | healthy population the CV for $\dot{V}O_{2peak}$ ranged from 4.1-5.8%. In addition, one study
52
53 218 | completed a succession of CPET tests on cardiac failure patients and reported the average CV
54
55 219 | for $\dot{V}O_{2peak}$ to be 5.7% [25][23]. Other studies have reported “good” test-retest reliability (CV
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3 220 for $\dot{V}O_{2\text{peak}} = 3.5\text{-}6.9\%$) during cycling MIE tests in patients with various respiratory
4
5 221 conditions [14,31,37][12,28,33]. CV's from previous research [12,22,27,32] investigating the
6
7 222 use of traditional protocols are lower than those from the post-MI group of the current study.
8
9
10 223 However, it is difficult to make direct comparisons between studies as different patient
11
12 224 populations were used.

225

17 226 ~~Our~~ The current study results demonstrated a CV for AT of 8.4% (study 2), which is
18
19 227 considered as acceptable for test-retest reliability in clinical populations [40][36]. Kothmann
20
21 228 et al. [28][26] found a CV of 10% for AT in Abdominal Aortic Aneurysm (AAA) patients
22
23 229 using a sCPET protocol. Identification of AT from CPET has become an increasingly
24
25 230 important tool in clinical exercise testing, primarily due to it giving an objective assessment
26
27 231 of cardiopulmonary function which does not require high levels of effort [42][37]. Previous
28
29 232 literature has demonstrated AT to be a useful predictor of mortality in patients with chronic
30
31 233 heart failure. This information can then be used to help prioritise patients for heart
32
33 234 transplantation [20][17]. The identification of AT prior to major surgery has also been shown
34
35 235 on a number of occasions to closely correlate with post-operative outcome [42,49][37,42]. It
36
37 236 is reassuring to see that in the current study there were no differences in AT when comparing
38
39 237 it between the SPV and the sCPET ($p > 0.05$), this combined with the reliability results
40
41 238 demonstrate that AT can be reliably determined via the SPV, which is of great importance in
42
43 239 clinical exercise testing.

240

51 241 As previously mentioned, two post-MI patients were excluded from the main reliability
52
53 242 analysis as they did not successfully complete a second SPV due to misjudging the required
54
55 243 work rate during stage RPE 17. However, when looking at their individual test data, both
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2
3 244 patients exercised long enough to demonstrate a valid AT and a $\dot{V}O_{2peak}$. When including
4
5 245 their exercise data into the reliability analysis the CV for $\dot{V}O_{2peak}$ increases from 8.2 to 8.4%
6
7 246 and CV for AT increases from 8.4 to 8.6%. From a clinical perspective it is encouraging to
8
9 247 see that even though these two patients did not complete the full 10-min, important CPET
10
11 248 data could still be obtained from the test.
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13

249

17 250 In agreement with data from a healthy population [36][32], post-MI patients achieved a
18
19 251 significantly higher $\dot{V}O_{2peak}$ (+8%) during the SPV compared with the sCPET ($P < 0.01$).
20
21 252 Peak HR and $\dot{V}E$ were also significantly higher in the SPV than in the sCPET ($p < 0.01$),
22
23 253 which is in support of previous work [18,22,34][15,19,31]. It is interesting to see that
24
25 254 previous studies which failed to find any differences in $\dot{V}O_{2peak}$ between the SPV and a
26
27 255 sCPET protocol also found no differences in HR and $\dot{V}E$ [13,47][11,40], potentially leading
28
29 256 to the observed differences in $\dot{V}O_{2peak}$. A recently published study [3][2] found significantly
30
31 257 higher maximal HR and cardiac output during the SPV compared to a sCPET protocol [3][2].
32
33 258 Astorino et al. [3][2] concluded that the greater cardiac output in the SPV suggests a greater
34
35 259 oxygen delivery to the exercising muscles, permitting a higher $\dot{V}O_{2peak}$ to be achieved. These
36
37 260 findings suggest that the SPV allows individuals to work to a higher physiological work rate
38
39 261 when compared to the sCPET. This may be a result of the nature of self-paced exercise
40
41 262 providing a more “comfortable” experience for patients. Previous research has in fact
42
43 263 suggested that self-paced exercise is less physiologically challenging when compared against
44
45 264 enforced paced exercise [30]. Being able to make slight adjustments in effort may minimise
46
47 265 fatigue and any peripheral discomfort associated with cycling, particularly in the early stages
48
49 266 of the test, which may ultimately lead to a greater work rate being able to be achieved in the
50
51 267 final stage [3][2]. In traditional CPET no adjustments in effort can be made and the only way
52
53 268 to stop any exercise related discomfort would be to stop. In addition, it may be that
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3 269 | knowledge of the test end-point in the SPV also contributes to the higher work rates achieved.
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5 270 | Indeed, previous literature has demonstrated that knowledge of exercise duration can improve
6
7 271 | exercise performance [33]. With all of this in mind, the current findings suggest that in a
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9
10 272 | clinical population, where cardiac function might be limited, the self-paced nature may in fact
11
12 273 | provide the patient the opportunity to work harder, producing a greater cardiac output and
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14 274 | therefore reaching a higher $\dot{V}O_{2peak}$. However, further research is required to support ~~these~~
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16 275 | speculations.
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21 277 | The mean sCPET time-to-exhaustion was 8 minutes 55 seconds (range = 5 min – 12 min 54
22
23 278 | sec) compared to the fixed 10 minutes of the SPV. Even though the sCPET mean test time
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25 279 | falls within the recommended criteria of 8-12 minutes [11][9], only 15 (of 28) participants
26
27 280 | successfully completed the test within this recommended time. Therefore, the lower $\dot{V}O_{2peak}$
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29 281 | in the sCPET could be attributable to only 54% achieving the recommended test time. A
30
31 282 | potential limitation of the current study was ~~the decision that we decided~~ to standardize
32
33 283 | sCPET work rate increments (20W/min) for all patients [10,16,26][8,14,24] instead of doing
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35 284 | so ~~on~~ an individual basis [38,39][34,35]. Individualising work rate increments may have
36
37 285 | resulted in more patients completing the CPET within the recommended time frame, although
38
39 286 | the subjectivity of such a choice would not have guaranteed a successful test in all patients.
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41 287 | This issue clearly highlights one of the key challenges practitioners face on a day-to-day basis
42
43 288 | when using CPET with clinical populations. Indeed, if patients are unable to exercise for a
44
45 289 | sufficient time the utility of test results is severely limited, resulting in a significant waste of
46
47 290 | finance and time for both patients and health service provider. In particular, an incorrect
48
49 291 | estimation of the work rate increments may lead to a test which is too short, or too long. A
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51 292 | test which is short in duration (< 8 min) is suggested to underestimate $\dot{V}O_{2peak}$ due to
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53 293 | increased glycolytic contribution to energy and enhanced fast-twitch muscle fibre recruitment
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3 294 [4]. In addition to this, a short test may only acquire limited information making it difficult to
4
5 295 confidently assess fitness. Conversely, if a test is long in duration (> 12 min) patients may
6
7 296 end up stopping due to such factors as boredom or increased local muscle fatigue [4], rather
8
9 297 than a result of their actual cardiopulmonary limit. The SPV eliminates the need for
10
11 298 practitioners to estimate the most appropriate starting intensity and work rate increments as it
12
13
14 299 is based on set levels of perceived exertion. Moreover, the closed loop nature of the SPV
15
16 300 ensures that each test lasts 10 minutes. The nature of the SPV gives patients the opportunity
17
18 301 to complete the test at their own ability whilst exercising for the recommended time to
19
20 302 achieve optimal physiological values. This therefore may increase the likelihood of obtaining
21
22 303 useable and representative data from patients. Thus, a protocol like the SPV may be a more
23
24 304 reliable way of acquiring time efficient and useable data than sCPET methods.
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31 306 ~~The significantly higher PO achieved in the SPV suggests that regardless of the self-paced~~
32
33 307 ~~nature, participants were willing to tolerate significantly higher work rates in the final stage~~
34
35 308 ~~(RPE 20), compared to that demanded by the sCPET. Knowledge of the test end-point in the~~
36
37 309 ~~SPV vs the open ended sCPET could contribute to the higher tolerance in work rate. Indeed,~~
38
39 310 ~~previous literature has demonstrated that knowledge of exercise duration can improve~~
40
41 311 ~~exercise performance [30]. It could also be suggested that the SPV provides patients with a~~
42
43 312 ~~more “comfortable” experience, as they are able to self-adjust their work rate, potentially~~
44
45 313 ~~making the higher perceived work rates more tolerable, especially when the end is proximate.~~
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49 314 There were no adverse events reported for the current study, providing support for the current
50
51 315 evidence base that maximal exercise testing is a safe procedure to perform on cardiac patients
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53 316 [6,27,46][4,25,39].
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3 318 A limitation of the current study is that different cycle ergometers were used in study 2.
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5 319 Previous research has suggested that different ergometers might result in differences in the
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7 320 metabolic and cardiovascular response [45]. However, different ergometers were a
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9 321 requirement of the different protocols, as the SPV required patients to freely adjust their PO,
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11 322 and the sCPET required accurate fixing of PO. Indeed, a similar differences in $\dot{V}O_{2peak}$ to that
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13 323 seen in the current study have been found by previous studies who used the same cycle
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15 324 ergometer in both the SPV and sCPET [3,36].
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326 **Conclusion**

23
24 327 The results of the current study demonstrate that the SPV is a reliable method for determining
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26 328 $\dot{V}O_{2peak}$ in a healthy population, with acceptable reproducibility being seen in the clinical
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28 329 population. The SPV allowed post-MI participants to achieve a significantly higher $\dot{V}O_{2peak}$
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30 330 than the sCPET. This study provides initial evidence suggests that the SPV may be is a safe,
31
32 331 valid and reliable measure of $\dot{V}O_{2peak}$ in both clinical and healthy populations, and should be
33
34 332 considered as an accepted means of testing for exercise capacity. However, further robust
35
36 333 multicentre data is required to establish the safety of the SPV in such populations. Moreover,
37
38 334 the defined test duration and self-administered work rates associated with the SPV addresses
39
40 335 common issues that clinicians regularly have to overcome, and go some way to ensuring all
41
42 336 patients exercise for the recommended duration in order to obtain a valid and reliable CPET.
43
44 337 Future research should seek to assess the SPV in other clinical populations and the utility of
45
46 338 the SPV versus sCPET to inform clinical decision making on patient treatment.
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51 339

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2
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8
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14
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16
17 347 JGH].
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21
22 349 **Disclosures:** None.
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25 350
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28 351 **References**
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57 481 **Figure legend:**
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483 Figure 1. Graphical Schematic overview for of the experimental procedures protocols for of
484 study 1 and 2.

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486 Figure 2. Bland-Altman plots of a) differences in $\dot{V}O_{2\text{peak}}$ between trials 1 and 2 from study 1;
487 b) trials 2 and 3 from study 1; c) differences in $\dot{V}O_{2\text{peak}}$ between SPV1 and SPV2 from study
488 2; d) differences in AT between SPV1 and SPV2 from study 2. The solid horizontal line
489 represents mean difference, whilst the dashed lines represent the 95% LOA.

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Table 1: Peak values for physiological variables recorded during repeated SPV tests in the healthy population.

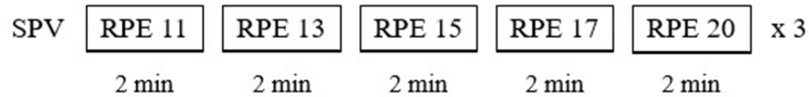
	SPV1	SPV2	SPV3
$\dot{V}O_{2\text{peak}}$ (L/min ⁻¹)	3.30 ± 0.86	3.23 ± 0.90	3.25 ± 0.92
$\dot{V}O_{2\text{peak}}$ (ml·kg ⁻¹ ·min ⁻¹)	48.56 ± 8.93	47.87 ± 9.28	47.85 ± 9.40
AT (ml·kg ⁻¹ ·min ⁻¹)	27.00 ± 6.83	26.67 ± 7.26	26.95 ± 7.34
HR (bpm)	184 ± 10	183 ± 11	182 ± 11
$\dot{V}E$ (L/min ⁻¹)	137.8 ± 38.9	133.3 ± 41.0	128.4 ± 39.1*
Peak PO (Watts)	312 ± 93	299 ± 109	304 ± 101

*significantly different to SPV1 (< 0.05), data are mean ± SD.

Table 2: Physiological variables recorded over the sCPET, SPV1 and SPV2 in post-MI patients.

	sCPET (n = 28)	SPV1 (n = 28)	SPV2 (n = 25)
$\dot{V}O_{2\text{peak}}$ (L/min ⁻¹)	1.90 ± 0.50	2.05 ± 0.48*	2.00 ± 0.43
$\dot{V}O_{2\text{peak}}$ (ml·kg ⁻¹ ·min ⁻¹)	21.29 ± 4.93	23.07 ± 4.90*	22.68 ± 4.79
AT (ml·kg ⁻¹ ·min ⁻¹)	12.63 ± 2.41	13.06 ± 2.39	13.21 ± 2.76
HR (bpm)	129 ± 18	138 ± 14*	136 ± 19
$\dot{V}E$ (L/min ⁻¹)	82.0 ± 27.1	94.5 ± 25.9*	91.1 ± 26.2
Peak PO (Watts)	171 ± 43	209 ± 78*	200 ± 64
TTE (seconds)	535 ± 130	600 ± 0*	600 ± 0

*significantly different from the sCPET (< 0.05), data are mean ± SD.

Study 1 (healthy):**Study 2 (post- MI patients):**

sCPET (visit 1 or 2)

Ramp 20 W/min ⁻¹

SPV (visit 1 or 2)

RPE 11

RPE 13

RPE 15

RPE 17

RPE 20

2 min 2 min 2 min 2 min 2 min

SPV (visit 3)

RPE 11

RPE 13

RPE 15

RPE 17

RPE 20

2 min 2 min 2 min 2 min 2 min

Figure 1. Schematic of the experimental protocols for study 1 and 2.

175x121mm (96 x 96 DPI)

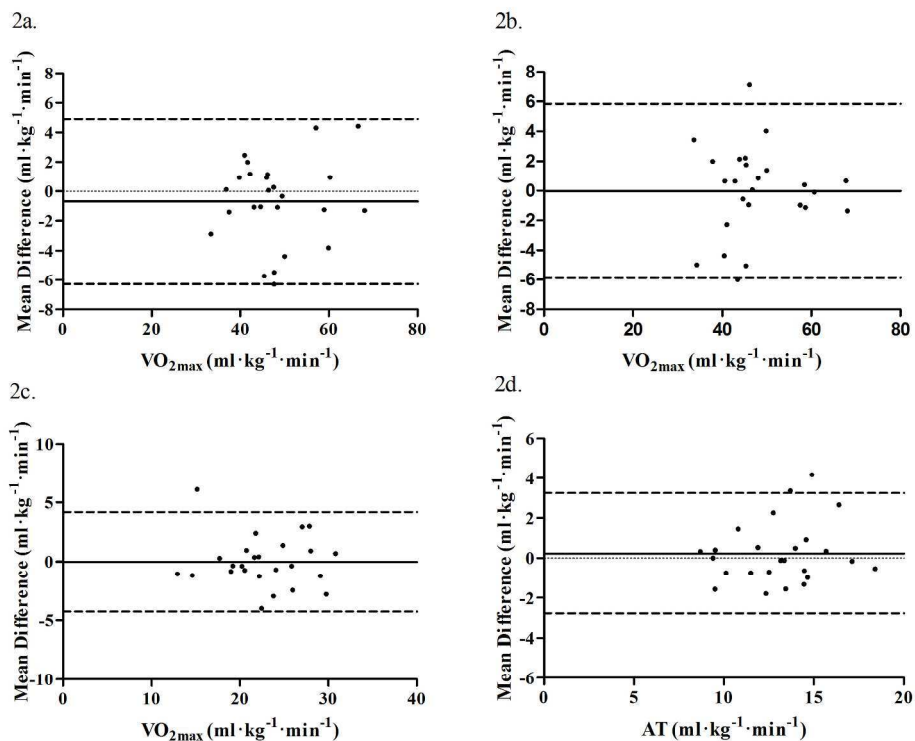


Figure 2. Bland-Altman plots of a) differences in VO_{2peak} between trials 1 and 2 from study 1; b) trials 2 and 3 from study 1; c) differences in VO_{2peak} between SPV1 and SPV2 from study 2; d) differences in AT between SPV1 and SPV2 from study 2. The solid horizontal line represents mean difference, whilst the dashed lines represent the 95% LOA. † †

224x178mm (300 x 300 DPI)



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