Effects of different increments in workload and duration on peak physiological responses during seated upper-body poling

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This is a post-peer-review, pre-copyedit version of an article published in European Journal of Applied Physiology.
The final authenticated version is available online at: https://dx.doi.org/10.1007/s00421-019-04189-4

Abstract:

Purpose: To compare the effects of test protocols with different increments in workload and duration on peak oxygen uptake ($\dot{V}O_{2peak}$), and related physiological parameters during seated upper-body poling (UBP). **Methods:** Thirteen upper-body trained, male individuals completed four UBP test protocols with increments in workload until volitional exhaustion in a counterbalanced order: 20W increase/every 30s, 20W/60s, 10W/30s and 10W/60s. Cardio-respiratory parameters and power output were measured throughout the duration of each test. Peak blood lactate concentration (bLa_{peak}) was measured after each test. **Results:** The mixed model analysis revealed no overall effect of test protocol on $\dot{V}O_{2peak}$, peak minute ventilation (VE_{peak}), peak heart rate (HR_{peak}), bLa_{peak}, (all $p \geq 0.350$), whereas an overall effect of test protocol was found on peak power output (PO_{peak}), (p=0.0001), respiratory exchange ratio (RER) (p=0.024) and test duration (p<0.001). There was no difference in PO_{peak} between the 20W/60s (175±25W) and 10W/30s test (169±27W; p=0.092), whereas PO_{peak} was lower in the 10W/60s test (152±21W) and higher in the 20W/30s test (189±30W) compared to the other tests, (all p=0.001). In addition, RER was 9.9% higher in the 20W/30s- compared to the 10W/60s test protocol, (p=0.003). **Conclusions:** The UBP test protocols with different increments in workload and duration did not influence $\dot{V}O_{2peak}$ and can therefore be used interchangeably when $\dot{V}O_{2peak}$ is the primary outcome. However, PO_{peak} and RER depend upon the test protocol applied and the UBP test protocols can therefore not be used interchangeably when the latter are primary outcome parameters.

Keywords; upper-body exercise, exercise test protocol, aerobic capacity

Abbreviations

ACE – arm-crank ergometry

bLa_{peak} – peak blood lactate

HR_{peak} – peak heart rate

PO_{peak} – peak power output

RER – respiratory exchange ratio

RPE – ratings of perceived exertion

UBP- upper-body poling

$\dot{V}CO_2$ – carbon dioxide production

VE – minute ventilation

$\dot{V}O_{2peak}$ – peak oxygen uptake

W – watt

Acknowledgements

The authors are thankful and acknowledge the effort from the participant volunteers of the present study. The laboratory equipment was provided by NeXt Move, Norwegian University of Science and Technology (NTNU). *NeXt Move* is funded by the Faculty of Medicine at NTNU and Central Norway Regional Health Authority.

Compliance with ethical standards

All procedures in the present study are in accordance with the ethical standards of the Helsinki declaration. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Conflicts of interest

The authors declare no conflict of interest.

Introduction

Testing peak oxygen uptake ($\dot{V}O_{2peak}$) and associated cardiorespiratory parameters during upper-body exercise is relevant for determining endurance capacity in individuals with an impairment of the lower extremities and in able-bodied athletes involved in sports where upper-body exercise contributes to overall performance. The exercise modalities most commonly used in a clinical- and sport setting are arm-crank ergometry (ACE) and wheelchair ergometry (Gauthier et al. 2017b; Goosey-Tolfrey et al. 2006; Pelletier et al. 2013). However, in a sports context, specificity of the test mode is important for attaining a $\dot{V}O_{2peak}$ that is reflective of the endurance capacity in the respective sport. For example, in Para ice hockey, Para cross-country sit skiing and Para biathlon, testing $\dot{V}O_{2peak}$ in the upper-body poling (UBP) mode may be a more sport-specific alternative compared to the ACE or wheelchair ergometer mode. Furthermore, the reliability of seated UBP for testing $\dot{V}O_{2peak}$ has been established while employing different incremental and all-out closed-ended test protocols in able-bodied cross-country skiers (Baumgart et al. 2017).

So far, studies using the ACE or wheelchair ergometer mode have employed exercise test protocols with different increments in speed (e.g. 0.1-0.6 m/s), slope (e.g. 2.7-4.8°) or resistance (e.g. 6-25 W) (Bar-Or and Zwiren 1975; Bhambhani et al. 1991; Gauthier et al. 2017b; Hutchinson et al. 2017; Leicht et al. 2009; Leicht et al. 2013; Price and Campbell 1997; Sawka et al. 1983; Smith et al. 2001) every 1 or 2 min. However, only few of the studies investigated the direct effect of different incremental protocols on the values of $\dot{V}O_{2peak}$ and peak power output (PO_{peak}) during upper-body exercise. In one study, Washburn and Seals (1983) compared continuous (increasing PO every 1 min) and discontinuous (increasing PO every 2 min separated by 1 min rest) ACE protocols and found no difference in $\dot{V}O_{2peak}$. In ACE protocols matched for workload, Smith et al. (2004) found no difference in $\dot{V}O_{2peak}$ between step-wise and ramp incremental protocols (20 W increase every 2 min vs 1 W/6 s, respectively). Furthermore, in ACE protocols matched for increment duration, no difference in $\dot{V}O_{2peak}$ was found between high- versus low-workload increment protocols (12 W/min vs. 6 W/min, respectively (Smith et al. 2006), and 2 W/6 s vs 1 W/6 s, respectively (Castro et al. 2010). However, in the latter two studies, PO_{peak} was significantly higher in the test protocols with higher increments in workload compared to the test with lower increments in workload.

Studies employing test protocols in an upper-body exercise mode apply different criteria for stopping a peak test and/or determination of $\dot{V}O_{2peak}$. The most common criteria for stopping a test are the inability to maintain a crank-rate at or above 40-80 revolutions per minute (Castro et al. 2010; Hutchinson et al. 2017; Pelletier et al. 2013; Smith et al. 2006; Smith et al. 2004; Smith et al. 2001; Washburn and Seals 1983), the inability to maintain a certain PO. In addition, common criteria for determining that $\dot{V}O_{2peak}$ has been reached are~~is~~ an achievement of > 80% of age predicted maximal HR and an RPE of > 17 (Leicht et al. 2009; Walker et al. 1986), a respiratory exchange ratio (RER) > 1.1 or a plateau in $\dot{V}O_2$ (change < 2.1 mL/kg/min) (Gauthier et al. 2017a) and reaching volitional exhaustion (Price and Campbell 1997). Methodological diversity in the abovementioned criteria may influence the validity of a “true” $\dot{V}O_{2peak}$ and make comparisons between studies difficult. Furthermore, for the studies that stop at the inability to maintain a certain PO, it remains unknown whether the $\dot{V}O_2$ at PO_{peak} is a valid value of $\dot{V}O_{2peak}$.

Whether test protocols with different combinations of workload and duration ~~duration and workload~~ increments influence $\dot{V}O_{2peak}$ and PO_{peak} in the seated UBP mode has not yet been investigated. Therefore, the primary aim of the present study was to compare $\dot{V}O_{2peak}$ and PO_{peak} during seated upper-body poling between the following incremental protocols until volitional exhaustion: 20 W increase every 30 s, 20 W/60 s, 10 W/30 s and 10 W/60 s. Unpublished observations made in our laboratory during UBP testing of both able-bodied and individuals with a spinal cord injury in the study of Baumgart et al. (2018) revealed an increase in $\dot{V}O_2$ despite a drop in PO. Therefore, the secondary aim was to investigate whether the $\dot{V}O_2$ value at the time-point where PO_{peak} was obtained differed from the $\dot{V}O_{2peak}$ value at the time point where the test was ended. Based on previous findings from studies using the ACE mode, our primary hypothesis was that no difference in $\dot{V}O_{2peak}$ would be found between the four test protocols and PO_{peak} would be highest in the protocol with the high workload-short duration increment (20 W/30 s) compared to the low workload-long duration increment (10 W/60 s). Our secondary hypothesis was that the value of $\dot{V}O_2$ at PO_{peak} would be lower compared to the value of $\dot{V}O_{2peak}$.

Method

Participants

Thirteen, able-bodied male upper-body trained individuals (age 28.6 ± 3.3 years; body-mass 83.7 ± 11.9 kg; height 183.1 ± 5.1 cm), recruited from a list of former athletes in cross-country skiing at the Centre for Elite Sports Research, NTNU volunteered to participate in this study. The participants were familiar with upper-body poling from training cross-country skiing, approximately 2-3 times per week. The study was approved by the Norwegian Centre for Research Data (ID 51228) and conducted in accordance with the declaration of Helsinki. All participants signed an informed consent prior to inclusion and were made aware of the possibility to withdraw from the study at any point in time.

Design

A repeated measures design was used, where four incremental UBP test protocols were performed in a counterbalanced order: 20 W increase every 30 s, 20 W/60 s, 10 W/30 s and 10 W/60 s. The four test protocols were completed within a two-week period with a minimum of 48 hours between each test day. The tests were performed at approximately the same time of day to avoid variation between tests induced by diurnal fluctuations (Reilly et al. 2007).

Test set-up

Participants were instructed to refrain from heavy exercise and alcohol consumption 24 hours prior to, caffeine intake the day of and food intake 2 hours before testing. Body-mass and height were measured before testing on day one. Standardised instructions on the use of the BORG (6-20) scale for rating of perceived exertion (RPE) were given (Borg 1982). Participants were fitted with a short-range telemetric heart rate monitor (M400 Polar Electro Inc., Port Washington, NY, USA) and a mouthpiece and a nose clip (Hans Rudolph Inc., Kansas City, MO, USA). Furthermore, they tightly strapped themselves around the hips and thighs into a seat construction in front of the Concept2 ski-ergometer (Concept2, Inc., Morrisville, USA) (Figure 1). The seat construction (a modified weightlifting bench) was placed in front of the ski-ergometer to allow for simultaneous elbow extension, trunk and shoulder flexion during UBP. Participants performed a 3-min bout of UBP at RPE 9 to familiarise with the seated poling technique and to ensure proper seating. All had previous experience with cardiorespiratory measurements during double poling on the ski ergometer. Prior to testing, the participants were informed about the specific test protocol that was performed that day. Cardiorespiratory parameters were measured using open-circuit calorimetry, with expired gases passing through the mixing chamber of the Jaeger ergospirometer (Oxycon Pro, Jaeger, Viasys BV, Bilthoven, The Netherlands) which has previously been validated against the Douglas-bag technique (Foss and Hallén 2005). Before the tests, the ergospirometer was calibrated against a set mixture of gases (5% CO_2, 15% O_2) and against ambient air. The flow volume transducer was calibrated automatically. Average values were recorded in 10 s intervals. Power output (PO) per stroke was recorded by the ski-ergometer's internal software (Concept2, Morrisville, USA). An ErgStick (Endurance Sports Research Limited, United Kingdom) was connected to the PM4 monitor of the Concept2 ski ergometer and the application Float (ErgStick Ltd, United Kingdom) used to retrieve the raw data. In addition, a digital camera (Sony alpha a58, Sony Electronics Inc., San Diego, USA) was used as back up to record PO and stroke rate on the PM4 monitor.

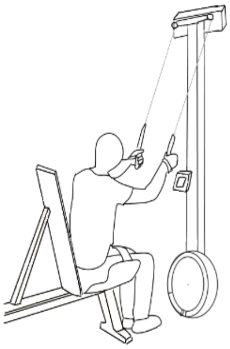

Figure 1. Test set-up with the participant seated in front of the Concept2 SkiErg.

Test protocol and measurements

After the three-minute familiarization period with the test set-up, a warm-up period was performed on the UBP ergometer, consisting of four 4-min submaximal stages at RPE 9 (very light), 11 (light), 13 (somewhat hard) and 15 (hard). On the first test day, participants were instructed to exercise according to the target RPE to determine the workload for each submaximal stage. The individual's average PO from each submaximal stage was then used during the 4-min submaximal stages on the remaining three test days. After a 5-min passive rest period, a 3-min active recovery at RPE 9 was completed to remove the accumulated blood lactate (bLa) from the submaximal stages. The incremental test started at the individual PO from the RPE 11 stage (rounded to the nearest 5 W value) and was increased according to the specific test protocol for that day (either 20 W/30 s, 20 W/60 s, 10 W/30 s or 10 W/60 s). The aim of starting at individual PO's from RPE 11, was to ensure that participants started at approximately the same relative intensity as well as to target similar test times within the test protocols. Stroke rate during all four tests was self-chosen and participants were instructed to continue poling despite not being able to maintain the desired PO for the specific increment as long as $\dot{V}O_2$ continued to increase. The tests were terminated, when – despite verbal encouragement – $\dot{V}O_2$ either plateaued (three values with < 2.0 mL·kg^{-1}·min^{-}

^{1} difference) or dropped by > 2.0 mL·kg^{-1}·min^{-1}. We argue that a plateau or drop in VO_2 are a valid way of knowing that a “true” VO_{2peak} was attained. The criterion of a drop is not abundant in exercise testing since tests are usually stopped when speed/incline/power output/etc cannot be maintained.

PO and stroke rate were~~as~~ interpolated at 1-s intervals in Matlab (R2016a; Mathworks Inc., Natick, MA). 30-s moving averages were calculated for PO and cardiorespiratory parameters and the highest values defined as peak values. In addition to PO_{peak}, total work done (TWD) in kilojoules (kJ) until PO_{peak} was reached, was calculated as TWD (kJ) = $\sum_{i=1s}^{s\ at\ POpeak} \text{instantaneaous PO(W)} \cdot 1s/1000$. HR was recorded every second and HR_{peak} was determined as the highest value of 3-s moving averages.

One and 3-min after each incremental test, a 20-µL capillary blood sample was drawn from the fingertip and bLa was analysed with the Biosen C-Line Sport lactate measurement system (EKF-diagnostic GmbH, Magdeburg, Germany). The higher of the two bLa values was defined as bLa_{peak}. Furthermore, RPE using the BORG scale, was recorded after each test as described by Shepard et al. (1992).

Statistical analysis

Statistical analyses were performed in SPSS version 24 (IBM Corporation, Armonk, NY, USA). Descriptive data are presented as mean ± SD and an α-level of 0.05 was used to indicate statistical significance. A mixed model analysis with a fixed coefficient and random intercept was used to investigate the overall effect of the incremental test protocol on peak cardiorespiratory parameters, bLa_{peak} and PO_{peak}, TWD (kJ) until PO_{peak} and stroke rate. Linear mixed model analyses as opposed to repeated-measures ANOVA were employed since we had missing data for some variables. A Friedman test was used to investigate the overall effect of the increment test protocol on the categorical variable, RPE. Post hoc tests without adjustment (LSD) were performed for pair-wise comparisons between the four test protocols. Normality of residuals was checked with the Shapiro-Wilk test. For the secondary aim a mixed model analysis was also used to investigate the overall difference between VO_2 at PO_{peak} and VO_{2peak} while adjusting for the differences between test protocols. Post hoc tests without adjustment (LSD) were performed for pair-wise comparisons between $\dot{V}O_2$ at PO_{peak} and $\dot{V}O_{2peak}$ within each test protocol

Results

An overview of the mean ± SD peak cardiorespiratory, PO_{peak}, bLa_{peak}, perceptual parameters and test duration are presented in Table 1. Time to exhaustion was shortest in the higher workload-shorter increment-duration test (20 W/30 s) (shorter duration test) and longest in the lower workload-longer increment-duration test (10 W/60 s) (longer duration test) (all comparisons $p< 0.001$). No difference in time to exhaustion was found between the 10 W/30 s and 20 W/60 s test protocols, (p=0.947) (moderate duration tests). Despite the differences in total test duration, no overall effect of test protocol was found on $\dot{V}O_{2peak}$ (p=0.813), HR_{peak} (p=0.413), bLa_{peak} (p=0.679), VE_{peak} (p=0.350), RPE (p=0.486) or stroke rate (p=0.097*)*. A plateau in $\dot{V}O_2$ (three values with < 2.0 mL·kg^{-1}·min^{-1} difference) or a drop by > 2.0 mL·kg^{-1}·min^{-1} was observed for all the participants tested. There was an overall significant effect of test protocol on PO_{peak} ($p< 0.001$). , TWD(kJ) (p<0.001), RER_{peak} (p=0.024) and a trend towards an effect on $\dot{V}CO_{2peak}$ (p=0.060). Pairwise comparisons revealed that PO_{peak} was highest in the test of overall shorter duration (20 W/30 s) and lowest in the test of longer duration (10 W/60 s) (all comparisons p=0.001), whereas no difference in PO_{peak} was found between the tests of moderate duration (20 W/60 s vs. 10 W/30 s), (p=0.092). RER was higher in the shorter duration (20 W/30 s) and one of the moderate duration test protocols (20 W/60 s) compared to the longer duration test protocol (10 W/60 s), (p=0.003 and p=0.038, respectively). An overall lower VO_2 at PO_{peak} was found compared to VO_{2peak} across test protocols (p<0.001) (Figure 2). Compared to the $\dot{V}O_{2peak}$ values, the values of $\dot{V}O_2$ at PO_{peak} was 10.4% lower in the shorter duration test (32.8 ± 5.8 vs. 36.2 ± 5.6, p = 0.005), 7.4 % (35.1 ± 5.0 vs. 37.7 ± 5.3, p=0.006) and 9.1% (35.3 ± 4.5 vs. 38.5 ± 5.1, p=0.001) lower in the moderate duration tests and 9.4% (37.2 ± 6.6 vs. 40.7 ± 5.9 $mL \cdot kg \cdot min^{-1}$, p=0.011) lower in the longer duration test. Due to technical problems with the application Float, data for some of the PO values over time went missing for some of the participants. This influenced the power of our results and the values for $\dot{V}O_2$ at PO_{peak} used in figure 2.

Table 1. Comparison of peak cardiorespiratory data between the four incremental upper-body poling test protocols in 13 upper-body trained individuals

	Test 1 (20 W/30 s)	**Test 2 (20 W/60 s)**	**Test 3 (10 W/30 s)**	**Test 4 (10 W/60 s)**
Test duration (s)	272±53	418±82$^{\#}$	405±930**	628±147*,§
Peak power output (W)	189±30	175±25$^{\#}$	169±27**	152±21§,†,*
Total work done (kJ)	27±7	40±12$^{\#}$	41±12**	63±15§,†,*
Stroke rate (strokes $\cdot min^{-1}$)	62 ±5	59 ±9	60±6	58±6
RPE	18.5±1.6	19±0.7	18.8±1.0	18.8±0.7
$\dot{V}O_{2peak}$ ($mL \cdot kg \cdot min^{-1}$)	36.3±5.0	37.2±5.3	37.0±4.9	38.2±6.1
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	3.02±0.45	3.08±0.45	3.07 ±0.43	3.05±0.32
$\dot{V}CO_{2peak}$ ($L \cdot min^{-1}$)	3.78±0.57	3.65±0.46	3.70±0.61	3.41±0.41§,*
VE_{peak} ($L \cdot min^{-1}$)	161±28	159±25.6	157.4±27.9	150.7±31.2
RER	1.33±0.12	1.29±0.10	1.27±0.11	1.21±0.1 §,†
HR_{peak} (beats $\cdot min^{-1}$)	169±14	170±12	167±16	170±12
bLa_{peak} ($mmol \cdot L^{-1}$)	10.8±2.1	10.7±2.3	10.4±1.8	10.7±1.9

Mean ± standard deviation for the four incremental tests. $\dot{V}O_{2peak}$=peak oxygen uptake, VE_{peak}=peak ventilation, RER=respiratory exchange ratio, HR_{peak}=peak heart rate, RPE=ratings of perceived exertion. bLa_{peak}=peak blood lactate. Significant differences at an α-level of 0.05 were determined between test 1 & 2:$^{\#}$, 1 & 3:**, 1 & 4:§, 2&4:† and 3 & 4:*

Note: For Test 4 (10W/60s), data of one participant on all variables was missing. Additionally, data for VO_2 at PO_{peak} was missing from 3-5 participants for the four test protocols due to a lack of continuous PO data.

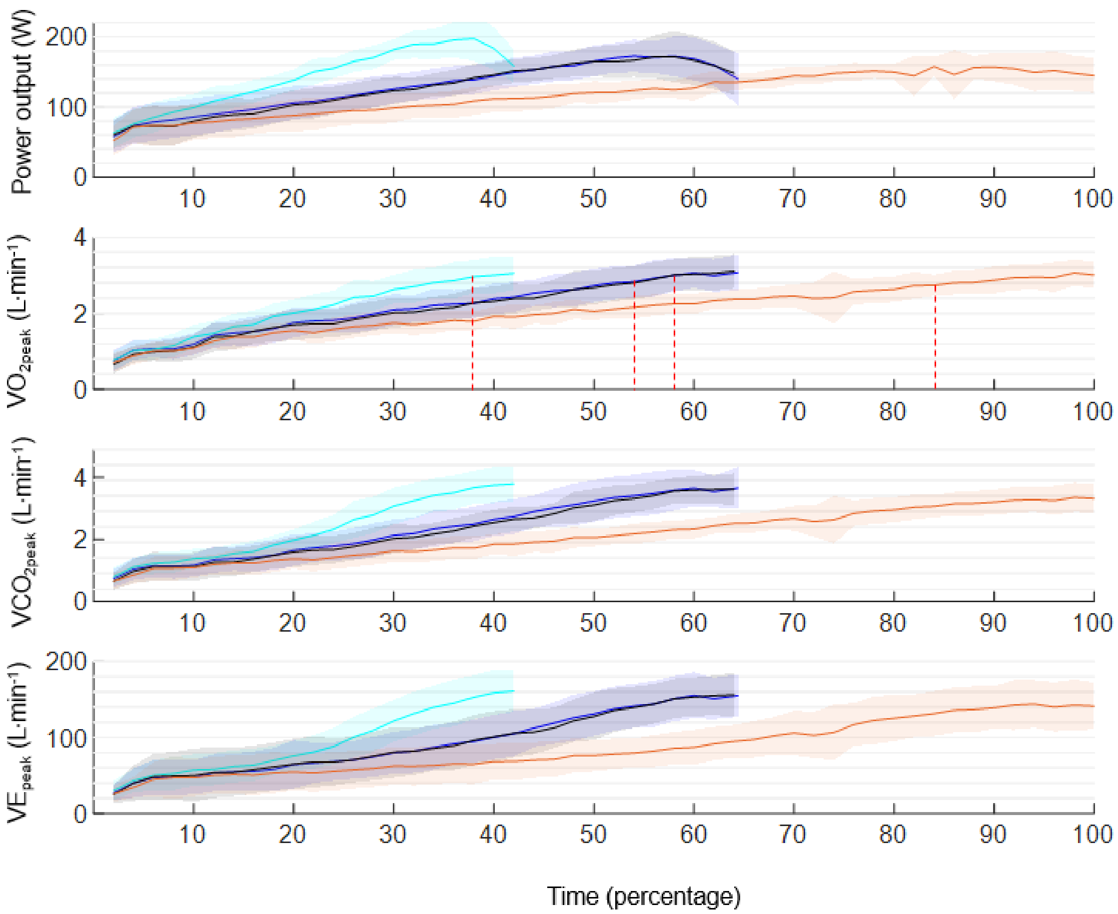

Figure 2. Power output, $\dot{V}O_2$, $\dot{V}CO_2$ and VE for the four test protocols in 13 male upper-body trained participants. On the x-axis time is given as percent. Light blue line: protocol with 20W increase every 30s, blue line: 20W/60s, dark grey line: 10W/30s and; light brown line: 10W/60s. Red dotted lines indicate $\dot{V}O_2$ at PO_{peak} for the four incremental test protocols. Participants were able to keep upper-body poling for 56 s, 1min 12 s, 56 s and 1min 22 s after reaching PO_{peak}, respectively.

Discussion

The aim of the present study was to compare $\dot{V}O_{2peak}$, related cardiorespiratory parameters and PO_{peak} between the following upper-body poling test protocols with incremental workloads to exhaustion: 20 W/30 s, 20 W/60 s, 10 W/30 s and 10 W/60 s. In line with our hypothesis, no overall effect of test protocol on $\dot{V}O_{2peak}$, VE_{peak}, HR_{peak} and bLa_{peak} was found, indicating that they can be used interchangeably when these parameters are of interest. In contrast, PO_{peak} was significantly higher in the test protocol of shorter duration (20 W/30 s) compared to the test protocols of moderate duration (20 W/60 s and 10 W/30 s) and longer duration (10 W/60 s). Additionally, the cardiorespiratory parameters RER_{peak} and $\dot{V}CO_{2peak}$ were higher in the test of shorter duration (20 W/30 s) compared to one test of moderate (10 W/30 s) and the longer duration test (10 W/60 s). In line with our secondary hypothesis, the $\dot{V}O_2$ at PO_{peak} was lower compared to the $\dot{V}O_{2peak}$ value within all test protocols.

This is the first study to examine the influence of test protocols with different increments in workload and duration on the peak physiological responses during seated UBP. The finding that $\dot{V}O_{2peak}$ was not different between the four protocols indicates that they tax the cardiorespiratory system equally. This is supported by no effect of test protocol on HR_{peak}, VE_{peak} and RPE. PO_{peak} was, however, 24% higher in the shorter-duration protocol and 15% and 11.2% higher in the two moderate- compared to the longer-duration test protocol. This finding is in line with several studies that use ACE (Castro et al. 2010; Smith et al. 2006) as well as leg cycling protocols (Bentley and McNaughton 2003; Bishop et al. 1998). These studies consistently find that high increments in workload lead to a higher PO_{peak}, shorter time until exhaustion but similar $\dot{V}O_{2peak}$ compared to protocols with lower increments in workload and longer time until exhaustion. The differences in PO_{peak} despite a similar $\dot{V}O_{2peak}$ in the shorter protocols are likely due to more anaerobic energy contribution, which is a consequence of reaching higher PO's sooner in the shorter protocols, hence an earlier recruitment of higher order motor units and an earlier transition to anaerobic metabolism. This is further supported by the higher RER and a trend towards a higher $\dot{V}CO_2$ during the shorter and moderate duration compared to the longer duration protocols in the current study. In the longer duration test protocol, the TWD (kJ) until PO_{peak} was 135% and 54-57% higher compared to the short and moderate test protocols, respectively. This likely caused a greater accumulation of localised muscular fatigue and as a result a lower PO_{peak} in the test protocol of longer duration. Despite the anaerobic indicators, $\dot{V}CO_{2peak}$ and RER, being higher in the overall shorter duration protocols, no effect of test protocol on bLa_{peak} was found. This finding is in contrast to Smith et al. (2006), where the test protocol with higher workload increments led to a higher bLa_{peak} compared to the protocol with lower workload increments. Overall, it depends on the outcome parameter of interest whether the four protocols of different workload and increment duration can be used interchangeably.

It should be noted that too fast and/or high workload increments may result in short times until exhaustion due to a rapid onset of muscle fatigue (Scheuermann et al. 2002), which may further lead to not reaching the highest possible $\dot{V}O_{2peak}$. In the present study, similar values for $\dot{V}O_{2peak}$ were found comparing incremental test protocols with time until exhaustion in the range of 4 min 32 s to 10 min 45 s. In this context it is important to consider that the well-trained nature of the participants, which includes a fast cardio-respiratory adaption to an increase in exercise intensity, in the present study likely influenced the ability to reach $\dot{V}O_{2peak}$ within the short duration test protocol. In order to find the upper and lower limits of test protocol duration for attaining $\dot{V}O_{2peak}$, future studies should assess the effects of even shorter and longer duration incremental UBP test protocols. This should also be specifically addressed in in participants with a disability (i.e. spinal cord injury or an amputation).

Furthermore, $\dot{V}O_{2peak}$ may also be influenced by the criteria used for stopping the $\dot{V}O_{2peak}$ tests. For example, in the study by Smith et al. (2006) tests were stopped once participants were not able to maintain a crank-rate at or above 75 revolutions per minute, whereas the participants in our study were allowed to continue poling despite a drop in PO as long as $\dot{V}O_2$ did not plateau or drop. If we had used a drop in PO as stop criteria for the tests in the present study, $\dot{V}O_{2peak}$ would have been underestimated by 3.5 mL·kg ·min^{-1} in the shorter duration protocol, 2.6 and 3.2 mL·kg ·min^{-1} in the moderate duration protocols and 3.4 mL·kg ·min^{-1} in the longer duration protocol. Despite a drop in PO, we observed that $\dot{V}O_2$ still increased (Figure 2). Speculatively, this might be related to an increased recruitment of "stabilising" muscles in the trunk and possibly the lower legs. This increased active muscle mass might contribute to an increase in $\dot{V}O_2$ towards $\dot{V}O_{2peak}$ despite not directly contributing to power production, i.e. making the movement less efficient. Furthermore, it may be associated with a "lag" in $\dot{V}O_2$ response, where adjustment in cardiac output, VE and arterio-venous O_2 uptake is not instantaneous. Therefore, the responses in $\dot{V}O_2$ lag behind the increase in PO, and this lag has been found greater in the higher/shorter increments (Davis et al. 1982) and greater during arm- compared to leg exercise (Koga et al. 1996). These findings are important to consider when adapting future test protocols with the UBP and other upper-body exercise modes.

Conclusion

The present study demonstrated that UBP test protocols with different increments in workload and duration in the range from 20 W/30 s to 10 W/60 s do not influence $\dot{V}O_{2peak}$, VE_{peak}, HR_{peak} and bLa_{peak}, and may therefore be used interchangeably when these parameters are of interest. However, the protocols with increments of short duration and/or high workloads resulted in a higher PO_{peak}, RER and a shorter time until exhaustion compared to increments of lower workload and longer duration. Therefore, the protocols cannot be used interchangeably when the latter parameters are of interest. Furthermore, this study showed that allowing participants to continue poling despite a drop in PO as long as $\dot{V}O_2$ do not plateau or drop, leads to a higher VO_{2peak}. Our results are limited to upper-body trained male individuals, therefore the extent to which our findings apply when testing athletes with a disability remains to be investigated.

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Figure captions

Figure 1 Test set-up with the participant seated in front of the Concept2 Ski-Ergometer. This figure has previously been published by our research group (Baumgart et al. 2017). Permission of reprint has been granted

Figure 2 Power output, $\dot{V}O_2$, $\dot{V}CO_2$ and VE for the four test protocols in 13 male upper-body trained participants. On the x-axis time is given as percent. Light blue line: protocol with 20 W increase every 30 s, blue line: 20 W/60 s, dark grey line: 10 W/30 s and; light brown line: 10 W/60 s. Red dotted lines indicate $\dot{V}O_2$ at PO_{peak} for the four incremental test protocols