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Research article

Validation of an Arm Crank Ergometer Test for Use in Sedentary Adults

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Abstract
The maximal oxygen uptake ($\dot{V}O_2$peak) test is an approved pre-operative examination tool, in a clinical setting: Both $\dot{V}O_2$peak and anaerobic threshold indicate a patient's physiological tolerance for major surgery and post-operative mortality, with cycle ergometry being routinely used for $\dot{V}O_2$peak tests in clinical settings, in many European countries. Nevertheless, the opportunities to assess populations with restricted mobility of the lower limbs are limited, as alternative methods (such as an arm-crank test protocol) to assess $\dot{V}O_2$peak are yet to be established. Twelve sedentary middle-aged adults (55.1 ± 5.0 years) performed two incremental protocols on an arm crank and cycle ergometer on separate occasions. During exercise, gas exchange was collected and analysed by an online breath-by-breath analysis system. Regression analysis showed that the model with dependent variable cycle ergometer $\dot{V}O_2$peak (CE$\dot{V}O_2$peak) in $ml·kg^{-1}·min^{-1}$ and independent variables arm crank $\dot{V}O_2$peak (ACE$\dot{V}O_{2peak}$) in $ml·kg^{-1}·min^{-1}$, lean body mass lower limbs (LBMLL) and total lean body mass (TLBM) fitted the population the best, with $r^2 = 0.87$, adj. $r^2 = 0.82$ and SEE = 3.14. The equation estimated with this model is: CE $\dot{V}O_{2peak}$ = 11.776 + 1.418 X ACE $\dot{V}O_{2peak}$($ml·kg^{-1}·min^{-}$) – 1.454 x TLBM + 3.967 X LLLBM. Our study suggests that arm cranking could be an alternative mode of exercise for sedentary middle-aged adults (and potentially in clinical settings) to assess the cardiorespiratory fitness of people with restricted lower-limb mobility.

Key words: Cardiopulmonary test, arm exercise, physiological responses, upper limbs.

Introduction

The cardiovascular and respiratory systems support increased energy requirements of the musculature during physical activity. The functional limit of the cardiovascular system can be best assessed through the maximal oxygen uptake test ($\dot{V}O_2$max), which is commonly defined as an index of cardiorespiratory fitness and typically reflects the upper limit of the body's ability to intake and consume oxygen (Åstrand and Saltin, 1961). Nevertheless, the term "peak oxygen uptake" ($\dot{V}O_2$peak) is used in the present paper, as it reflects more precisely a stress test in a clinical setting where the exercise test termination could be due to other than cardiorespiratory limitations. Recent research has explored how upper-limb aerobic exercise can be applied in clinical populations (Ilias et al., 2009). More specifically, this exercise modality seems to be appropriate for cardiorespiratory fitness assessments aimed at patients having limited functional capacity in the lower limbs. In clinical settings the cardiopulmonary exercise (VO_2peak) test has been established as an approved pre-operative examination (Weisman et al., 2003). More specifically, $\dot{V}O_2$peak and anaerobic threshold have been demonstrated as an index of patients' physiological tolerance for major surgery (Davies and Danjoux, 2010). Anaerobic threshold has also been associated with post-operative mortality (Older et al., 1999) and its concomitant use for pre-operative risk stratification (Orr et al., 2013). Moreover, arm exercise has been demonstrated to predict clinical outcomes (Chan et al., 2011; Ilias et al., 2009) and researchers reported that the prognostic value of the clinical data obtained during arm exercise may be equivalent to that reported for treadmill or cycle ergometer exercise (Dutcher et al., 2007; Myers et al., 2002).

Arm crank ergometry (ACE) seems to constitute a reliable mode of exercise that is able to assess all the physiological responses that are elicited during physical activity. Several factors are considered to play a vital role in eliciting significant physiological responses during arm crank ergometry including crank rate (Schrieks et al., 2011; Smith et al., 2001), the type of incremental protocol (Sawka et al., 1983; Smith et al., 2004), and the ramp slope during an incremental ramp protocol (Castro et al., 2010). These studies have demonstrated that a crank rate of 70 revolutions per minute is considered to be the optimal 'tempo' during a $\dot{V}O_2$peak test and that a continuous incremental ramp protocol induces higher values of oxygen uptake, ventilation and heart rate responses compared with slower crank rates. Furthermore, fast (increment: 2W/6 s) and slow (increment: 1W/6 s) ramp protocols seem equal in attaining peak oxygen uptake in healthy young individuals (Castro et al., 2010).

Cycle ergometry is routinely used in clinical settings in many European countries. In addition, cycle ergometry compared with treadmill testing is cost-effective, requires less space and is a feasible alternative in individuals who are obese or those presenting with orthopaedic, peripheral vascular, and/or neurological limitations. Therefore, it is a widely-used exercise modality in clinical populations. Nevertheless, a validated arm crank ergometer protocol whose values are strongly associated with cycle ergometer measures for the prediction of $\dot{V}O_2$peak has yet to be established.

Wasserman's cycle ergometer test ramp protocol (Wasserman, 1976) is a validated and widely used test in the clinical setting when patients are assessed for either cardiovascular or cardiorespiratory limitations. This protocol is practical and preferable for patients as they do not experience sudden increases in work rate, which is the case with graded test protocols (Wasserman et al., 2012,

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p. 141-2). Nonetheless, some patients may not be able to pedal either due to lack of coordination and cycling experience and / or may experience seating discomfort during a long test. However, anecdotal reports from patients' highlight the most common reason for not being able to pedal is restricted lower limb mobility.

In cases where a cardiopulmonary test is essential for screening prior to surgery a predictive $\dot{V}O_2$peak value from an arm crank ergometer would be useful. The estimation of $\dot{V}O_2$peak from an arm crank test would be of use for clinicians not only for pre-operative risk stratification but also for routine cardiopulmonary exercise test (CPET) in adults with restricted lower limb mobility. For example during a CPET the clinician assesses the electrical signs of the heart through an electrocardiogram (ECG) and the cardiovascular responses such as $\dot{V}O_2$peak that would be induced by an arm crank test. However, there is lack of evidence for cut-off values in ACE $\dot{V}O_2$peak that would be of use for disease and/or mortality prognosis. Therefore, the application and usefulness of a predictive $\dot{V}O_2$peak equation resulting from an arm-crank test setting seems warranted.

The purpose of the present study is to produce an equation that will be able to predict cycle ergometer $\dot{V}O_2$peak, using ACE physiological outcomes as equation elements. The study would also determine the differences in physiological responses in ACE and a cycle ergometer test protocol in middle-aged adults with low-to-moderate cardiovascular risk, following the most recent ACE test protocol recommendations (e.g., Castro et al., 2010; Wasserman et al., 2012).

Methods

Participants

Twelve middle-aged adults (6 men and 6 women, mean age 55.1± 5) were recruited from the Sheffield Hallam University voluntary database. All participants lived a sedentary lifestyle, had office-based employment, with no training history as athletes of any sport. Participants underwent health screening to confirm the absence of any cardiovascular and/or metabolic disease. Each participant received a study information sheet and became aware of any possible risks before signing the consent form. The research was approved by the Human Ethics Committee of Sheffield Hallam University and complied with the principles laid down in the Declaration of Helsinki.

Sample size

A post-hoc analysis was performed according to the multiple regression analysis with input parameters of error (error probability = 0.05), the total sample size (n = 12) and the number of predictors (e.g., ACE$\dot{V}O_2$peak, lean body mass lower limbs, total lean body mass). The result showed a statistical power of 0.99 which indicates that the total sample size was sufficient to predict any relationships between these two exercise modes.

Experimental approach

Apart from a sedentary status, our inclusion criteria for participation consisted of ages ≥45 for men and ≥55 years for women, which are considered to be the cut-off age limits for each sex respectively, beyond which cardiovascular risk is increased according to American College of Sport Medicine (ACSM) guidelines (Pescatello et al., 2014). Participants were allowed ≥ 2 risk factors without symptomatic, or known cardiovascular, pulmonary, renal, or metabolic disease. Prior to each peak oxygen uptake test participants were requested to abstain from vigorous exercise, alcohol, caffeine and tobacco for a period of 24h and to have fasted for at least 3h prior to measurement. Moreover, resting ECG and blood pressure were assessed prior to the exercise tests to identify any contraindications to exercise. All the participants performed the exercise tests with the absence of any contraindications both at rest and during exercise. Each participant performed both the Wasserman's cycle ergometer and arm crank test in a randomly-assigned order separated by at least five days to assure for full recovery.

Pre-participation health screening

Participants were assessed for cardiovascular risk prior to participation. The health screening was consistent with the ACSM's guidelines for cardiovascular disease risk stratification (Pescatello et al., 2014). After health screening anthropometric measurements were performed [body mass (kg), stature (cm), body mass index (BMI) and upper- and lower-arm circumference (cm) according to guidelines (National Institutes of Health, 1998)] and seated blood pressure (mm Hg) was assessed. The participants that were classified as "low and moderate risk", after risk stratification, were eligible to take part in the study.

Arm crank test

The arm crank ergometer (Lode BV, Groningen, Netherlands) was adjusted to ensure alignment between the ergometer's crankshaft and the centre of the participant's glenohumeral joint. Participants' sitting position was set up to ensure that the elbows were slightly bent when the arm was outstretched. Participants were instructed to maintain their feet flat on the floor at all times. Due to different power capabilities two different protocols were identified for men and women. Men commenced at a workload of 30W and women at 20W. In both protocols the crank rate was maintained at 70 rev min-1 (Smith et al., 2001; 2007) and power requirements increased as a linear ramp at a rate of 10W min-1 and 6W min-1 for men and women, respectively (Smith et al., 2007). The test commenced with 3 minutes rest and then 3 minutes of warm-up (unloaded cranking). Rating of perceived exertion (RPE) ≥ 18 and/or inability to maintain a crank rate above 60 rev min-1 resulted in the termination of the test. After exercise termination an unloaded bout of 2 - 3 minutes exercise at a crank rate below 50 rev min-1 allowed for an active recovery period.

Wasserman's cycle ergometer test

Wasserman's cycle ergometer test was performed on an electromagnetic cycle ergometer (Lode Excalibur, Groningen, Netherlands). The test commenced with a 3 minute rest period followed by 3 minutes of unloaded pedalling. Participants were requested to maintain a cycle rate of 60 rev min-1 during the exercise test. The start load and the concomitant increments were individually calculated according to participants' estimated physical fitness and Wasserman's equations (Wasserman et al., 2012, p. 141-2). Rating of perceived exertion (RPE) $\geq$ 18 and/or inability to maintain a crank rate above 40 to 45 rev min-1 resulted in test termination. Following the exercise test 2-3 min of unloaded pedaling allowed for an active recovery period.

Measurements during exercise tests

During cardiopulmonary tests gas exchange was analysed by an online breath-by-breath analysis system (UltimaTM, Medical Graphics, UK). The gas analyser was calibrated before each test according to the calibration guidelines of the manufacturer. Heart rate (HR) breathing frequency, tidal volume (VT), minute ventilation ($\dot{V}E$), oxygen uptake ($\dot{V}O_2$) and volume of exhaled carbon dioxide ($\dot{V}CO_2$), as well as respiratory exchange ratio (RER) was displayed on a monitor (BreezeSuite, MGC Diagnostics, USA) on a breath-by-breath analysis. HR was continuously monitored using a Polar heart rate monitor (Polar FS1, Polar Electro, Kempele, Finland) and blood pressure was assessed using a manual sphygmomanometer (DuraShock DS54, Welch Allyn, USA) and stethoscope (Littman Classic II, 3M, USA). RPE was recorded during the last 10s of every minute during the exercise test until volitional exhaustion using Borg's scale 6-20 point (Borg, 1973). Peak power output and test duration was measured in both tests. $\dot{V}O_2$peak defined as the average oxygen uptake recorded from expired air during the final 30s of exercise.

Body composition analysis

The participant's stature was measured using a Hite-Rite Precision Mechanical Stadiometer. Body mass (kg), fat mass (kg), lean body mass (kg) segmented in upper- and lower-limbs were assessed by using bio-electrical impedance analysis (In Body 720, Seoul, Korea). Upper and lower arm circumferences were measured by a standard metric measuring tape (Seca 206, Birmingham, UK). BMI was the derivative of body weight in kilograms divided by height in meters squared ($kg \cdot m^{-2}$).

Statistical analysis

Data analysis was performed using SPSS software (version 23, IBM SPSS, New York, USA) and presented as mean ± SD. Cardiorespiratory measures, peak power and duration of the exercise tests were compared using paired sample t-tests. Pearson's correlation coefficient was used to correlate $\dot{V}O_2$ in $L \cdot min^{-1}$ and in $ml \cdot kg^{-1} \cdot min^{-1}$ and HR. Correlation coefficients were calculated for all physiological and anthropometrical variables. The variables most closely associated with $\dot{V}O_2$ were included in a backward stepwise linear regression analysis and supported the development of an equation to estimate $\dot{V}O_2$ values based on ACE $\dot{V}O_2$ and other physiological and/or anthropometrical outcomes. The predictors for cycle ergometer $\dot{V}O_2$ (CE $\dot{V}O_2$) that were included into the regression analysis were arm crank $\dot{V}O_2$ (ACE $\dot{V}O_2$) in $L \cdot min^{-1}$ and $ml \cdot kg^{-1} \cdot min^{-1}$, lean body mass lower (LBMLL) and upper limbs (LBMUL), lean body mass in total (LBM), HR, $\dot{V}E$, RER and sex. Statistical significance was set at $p<0.05$.

Results

Anthropometric characteristics

Participants' anthropometric characteristics are shown in Table 1. Men were significantly younger compared to women and that can be attributed to the sex specific different cut-off age limit at which age is considered as a cardiovascular risk factor. Anthropometrically, men have a higher lean body mass than women which is usually evident as the percentage of lean body mass on the upper limbs and the total lean body mass.

Physiological responses

Table 2 presents the physiological responses from the arm crank test and Wasserman's cycle ergometer test. The Shapiro-Wilk test was performed to test the normality of the data and Levene's test, $p \geq 0.05$, to confirm the homogeneity of variances. Absolute $\dot{V}O_2$ (1.84 ± 0.63 $L \cdot min^{-1}$) with a mean difference of [0.41 (0.12, 0.70) $L \cdot min^{-1}$, $p < 0.05$, ES: 0.89) and relative $\dot{V}O_2$ (23.1 ± 7.5 $ml \cdot kg^{-1} \cdot min^{-1}$) with a mean difference of [6.7 (3.6, 9.9) $ml \cdot kg^{-1} \cdot min^{-1}$, $p < 0.01$, ES: 1.34) were higher in cycle ergometry compared with arm crank, in all participants. HRpeak (150.7 ± 14.9 $beats \cdot min^{-1}$) and $\dot{V}E$peak (66.3 ± 18.6 $L \cdot min^{-1}$, STPD,) with mean differences of [8.3 (0.38, 16.12) $beats \cdot min^{-1}$, $p < 0.05$, ES: 0.67] and [14.8 (5.9, 23.6) $L \cdot min^{-1}$, $p < 0.01$, ES: 1.06], were also higher in cycle ergometry compared to arm crank. Whereas RERpeak was higher [-0.1 (-0.17, -0.03), $p < 0.01$, ES: 0.90] in arm crank (1.35 ± 0.1) compared to cycle ergometry, in all participants. Peak power was significantly higher in cycle

Table 1. Anthropometric characteristics. Data are means (±SD).

	Men (n = 6)	Women (n = 6)	Total (n = 12)
Age (years)	51.7 (4.7) **	58.5 (2.4)	55.1 (5.0)
Body weight (kg)	85.0 (12.3)	73.6 (13.4)	79.3 (13.6)
Height (m)	1.76 (.08) **	1.60 (.07)	1.68 (.10)
Body mass index ($kg \cdot m^{-2}$)	27.6 (4.4)	28.8 (5.9)	28.2 (5.0)
Upper arm circumference (cm)	31.8 (3.8)	29.2 (3.1)	30.5 (3.6)
Lower arm circumference (cm)	24.5 (2.4)	22.2 (1.5)	23.3 (2.2)
Lean body mass upper limbs (%)	8.8 (.6) ***	6.4 (.4)	7.6 (1.3)
Lean body mass lower limbs (%)	22.6 (3.6)	18.7 (3.3)	20.7 (3.8)
Total lean body mass (%)	70.6 (7.0) *	58.7 (8.7)	64.7 (9.8)

* $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$ compared to women.

Table 2. Physiological outcomes of the cycle ergometer and arm crank test. Data are means (±SD).

	Men (n = 6)		Women (n = 6)		Total (n = 12)	
	CE	ACE	CE	ACE	CE	ACE
$\dot{V}O_{2peak}$ (L·min^{-1})	2.2 ± 0.7	1.8 ± 0.5	1.48 ± 0.24*	1.06 ± 0.24	1.84 ± 0.63*	1.43 ± 0.54
$\dot{V}O_{2peak}$ (ml·kg^{-1}·min^{-1})	25.8 ± 9.5	19.0 ± 3.8	20.4 ± 4.0**	13.8 ± 2.5	23.1 ± 7.5**	16.4 ± 4.1
HR_{peak} (beats·min^{-1})	147.5 ± 18.4	140.7 ± 18.4	153.8 ± 11.0	144.2 ± 13.9	150.7 ± 14.9*	142.4 ± 15.6
Peak $\dot{V}E$ (L·min^{-1}, STPD)	78.6 ± 17.8	63.1 ± 7.0	53.9 ± 8.6*	40.0 ± 7.0	66.3 ± 18.6**	51.5 ± 13.8
Peak RER	1.25 ± 0.1	1.40 ± 0.1**	1.26 ± 0.1	1.31 ± 0.1	1.25 ± 0.1	1.35 ± 0.1**
Peak RPE	18.7 ± 1.0	19.2 ± 0.8	18.0 ± 1.9	18.7 ± 1.0	18.3 ± 1.5	18.9 ± 0.9
Test duration (min)	8.9 ± 2.7	8.0 ± 1.1	7.7 ± 1.0*	6.7 ± 0.5	8.3 ± 2.0	7.3 ± 1.0
Peak power (W)	203.3 ± 68.9*	100.0 ± 11.0	117.5 ± 21.4**	57.3 ± 6.7	160.4 ± 66.1***	78.7 ± 23.9

CE, Cycle ergometer; ACE, Arm crank; HR, heart rate; VE, minute ventilation; RER, respiratory exchange ratio; RPE, ratings of perceived exertion; STPD, standard temperature pressure dry. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ compared to the cycle ergometer test.

Table 3. Linear regression analysis to estimate cycle ergometer $\dot{V}O_{2peak}$ based on anthropometrics and arm crank physiological outcomes.

Model	Variables	r^2	Adj. r^2	SEE
1	CE$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}), ACE$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}), ACE$\dot{V}O_2$peak (L·min^{-1}), LBMLL (%), LBMUL (%), TLBM (%), ACEHRpeak (beats·min^{-1}), ACEVEpeak (L·min^{-1}), ACERERpeak, Gender[a]	.900	.450	5.556
2	CE$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}), ACE$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}), ACE$\dot{V}O_2$peak (L·min^{-1}), LBMLL (%), LBMUL (%), TLBM (%), ACEHRpeak (beats·min^{-1}), ACEVEpeak (L·min^{-1}), ACERERpeak	.900	.633	4.536
3	CE$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}), ACE$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}), LBMLL (%), LBMUL (%), TLBM (%), ACEHRpeak (beats·min^{-1}), ACEVEpeak (L·min^{-1}), ACERERpeak	.900	.725	3.929
4	CE$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}), ACE$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}), LBMLL (%), LBMUL (%), TLBM (%), ACEVEpeak (L·min^{-1}), ACERERpeak	.900	.779	3.518
5	CE$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}), ACE$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}), LBMLL (%), LBMUL (%), TLBM (%),ACERERpeak	.892	.802	3.336
6	CE$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}), ACE$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}), LBMLL (%),TLBM (%),ACERERpeak	.886	.821	3.168
7	CE$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}), ACE$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1}), LBMLL (%),TLBM (%)	.872	.824	3.138

CE$\dot{V}O_2$peak, $\dot{V}O_2$peak in the cycle ergometer; ACE$\dot{V}O_2$peak, $\dot{V}O_2$peak in the arm crank test; LBMLL, lean body mass lower limbs; LBMUL, lean body mass upper limbs; TLBM, total lean body mass; ACEHRpeak, peak heart rate in the arm crank ergometer; ACEVEpeak, peak VE in the arm crank ergometer; ACERERpeak, peak RER in the arm crank ergometer. [a] Coded '0' for men and '1' for women.

ergometry (160.4 ± 66.1 W) compared to arm crank [82 (50, 114) W, $p < 0.001$, ES= 1.63].

Regression analysis

Correlation coefficient analysis between the arm crank and cycle ergometer, for absolute and relative $\dot{V}O_2$ and HR, showed that were strongly associated ($r = 0.78$, $p < 0.01$).

Regression analysis is illustrated in Table 3. The regression model with dependent variable CE$\dot{V}O_2$ in ml kg-1 min-1 and independent variables ACE$\dot{V}$O2 in ml kg-1 min-1, lean body mass lower limbs (LBMLL) and total lean body mass (TLBM) fitted the test population the best, with $r^2 = 0.87$, adj. $r^2 = 0.82$ and SEE = 3.14. The equation is: CE $\dot{V}O_{2peak}$ = 11.776 + 1.418 X ACE $\dot{V}O_{2peak}$ (ml·kg^{-1}·min^{-1}) – 1.454 x TLBM + 3.967 X LLLBM.

Discussion

The current study is the first to demonstrate a significant correlation between an arm crank and cycle ergometer for $\dot{V}O_2$ and HR. Between $\dot{V}O_2$ and HR, our study correlation demonstrated that the ACE $\dot{V}O_2$peak was strongly correlated with CE $\dot{V}O_2$ ($r = 0.78$, $\dot{V}O_2$ in ml·kg^{-1}·min^{-1}) suggesting its role as a predictor. Having established the relationship between these two measures, we then performed a regression analysis to explore the role of the other physiological outcomes, which would allow us to most accurately estimate cycle ergometer $\dot{V}O_2$ from the physiological and anthropometrical variables of ACE. For this reason, a regression analysis was performed to examine the complementary physiological outcomes to $\dot{V}O_2$ that would most accurately predict cycle ergometer $\dot{V}O_2$. Lower limb lean body mass and the total lean body mass together with arm crank $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}) constitute a valid estimation ($r^2 = 0.87$, SEE = 3.14) of cycle ergometer $\dot{V}O_2$. Moreover, Schrieks et al. (2011) compared treadmill to arm crank ergometer and presented a regression equation by which treadmill $\dot{V}O_2$ could be predicted by physiological parameters of ACE. Therefore, based on the findings of the current study arm cranking could be an alternative mode of exercise to be used in sedentary middle-aged adults and potentially to clinical populations to assess cardiorespiratory fitness in people with restricted lower limbs mobility.

ACE elicited a $\dot{V}O_2$ (L·min^{-1}) approximately 22.3% less than cycling and 29% when adjusted for body weight (ml·kg^{-1}·min^{-1}), which was similar to findings from previous studies (Muraki et al., 2004; Orr et al., 2013). Moreover, it was observed in the current study that HR and $\dot{V}E$ were significantly greater in cycling than in arm cranking. These findings agree with previous studies (Muraki et al., 2004; Orr et al., 2013) and also with Schrieks et al. (2011) who utilised a comparable arm crank exercise protocol to compare it with a Bruce treadmill protocol.

The lower $\dot{V}O_2$ observed during arm exercise may be explained by the specificity of the muscle groups involved in that exercise mode. The primary working muscles during arm cranking, biceps and triceps brachii and the deltoid, are smaller and less conditioned compared with the leg muscles. These arm muscles have a greater amount of type II muscle fibres than the muscles of the legs (Turner et al., 1997) and consequently higher O_2 cost than slow-twitch (type I) fibres (Schneider, Wing, Morris, 2002). This leads to an increase in anaerobic metabolism in arm exercise which has been demonstrated to induce muscle deoxygenation in the triceps, peaking at only 50% of $\dot{V}O_2$ compared with above 80% in cycling (Muraki et al., 2004). Moreover, the exercise-induced metabolic responses differ between arm and leg muscles (Heldge, 2010). Evidence reports greater carbohydrate oxidation and lactate release for the arm musculature (Ahlborg and Jensen-Urstad, 1991) and lower oxygen extraction capacity, even in elite athletes who have intensively trained the upper body muscles over the years (Calbet, 2005). In addition, arm muscle has a lower oxidative capacity when compared to the vastus lateralis, despite the similarity in fibre type composition (Kiilerich et al., 2008) and capillarization (Heldge et al., 2008). The lower oxidative capacity in the human arm muscle is probably related to deconditioning due to the non-postural nature of upper body musculature.

Although anaerobic metabolism is the primary metabolic pathway in arm exercise compared to cycling, $\dot{V}E$ was significantly greater in cycling than arm cranking. This can be explained by the higher lactic acid accumulation during cycling than arm cranking at intensities exceeding 80% of $\dot{V}O_2$ which is proportionate to the muscle mass (Sawka et al., 1983). Consistent with our findings, other investigations have reported that $\dot{V}E$ is lower after arm cranking compared with cycling (Muraki et al., 2004, Schrieks et al., 2011).

A higher HR has been observed for cycling, as reported in previous studies (Muraki et al., 2004, Sanada et al., 2005, Schrieks et al., 2011) that compared leg with arm exercise. The higher HR could be explained by the greater muscle mass in the lower limbs that stresses the cardiovascular system more than the upper limb musculature. In contrast, RER values were significantly higher in the arm crank test in comparison with the cycle ergometer test; this may be directly linked to the greater lactic acid accumulation per regional skeletal muscle mass and the lower oxidative capacity of the exercising muscles in arm cranking. All our participants stopped the arm crank test due to muscle fatigue and not for cardiorespiratory limitations. This is another indication for a higher anaerobic metabolism in arm cranking compared to cycling. Muraki et al. (2004) measured the muscle deoxygenation in both modes of exercise and found that anaerobic metabolism was higher in arm cranking compared to cycling.

The key difference in the physiological responses between these two modes of exercise is apparently the greater muscle mass that is utilised by the lower limbs during cycling. Concomitantly, this stresses the cardiovascular system more than upper limb exercise and thus, certain values such as $\dot{V}O_2$, $\dot{V}E$ and HR are higher in cycling. However, this is not always the case with older adults or patients who may stop an exercise test prematurely due to muscle fatigue or other systemic abnormalities such as high blood pressure and/or ECG contraindications.

An equation that estimates CE $\dot{V}O_2$ from the physiological responses of ACE in sedentary middle-aged adults is a key finding of the current research study. The equation can be used by physicians in cases where middle-aged patients are required to perform a CPET for cardiovascular or mortality risk assessment before an operation. It is important to acknowledge that the average age of clinical populations for heart failure patients and/or chronic obstructive pulmonary disease patients is over 65 years old. Nevertheless, there are patients within those clinical populations below that age and other patients with obesity, diabetes and other cardiovascular risk factors with an average age of 55 ± 5 years old who present with mobility difficulties that would benefit from a CPET. A CPET determines the physical fitness of the individual and consists of both a cardiovascular and a mortality risk assessment. By converting the ACE$\dot{V}O_2$ to CE$\dot{V}O_2$ physicians obtain a comparable value of the patients' physical fitness which might be used for decision making. Therefore, the utility and the application of the equation could cover a broad spectrum of clinical and non-clinical populations of middle-aged adults with restricted lower limb mobility that are in need of clinical care.

Limitations of the study

A limitation of the current study could be considered the recruitment of different muscle masses and muscle fibre types between arm and leg exercise. These differences could lead to exercise-induced exertion either due to cardiorespiratory or local muscle fatigue limitations. Nevertheless, in the current study we recorded incidents where the participants prematurely ended the cycle ergometer test due to local muscle fatigue - which could be an indication of weak muscles in the lower limbs and poor physical conditioning. We also stress that the deliberate age restriction in our study intended to simulate the age and fitness of several clinical populations and individuals with restricted lower limb mobility.

Our participants did not perform a maximal oxygen uptake test, rather they undertook a peak oxygen uptake test due to their age and low level of physical fitness. A peak oxygen uptake test warrants several test termination causes other than cardiorespiratory limitations for many clinical populations (Pescatello et al., 2014).

Conclusions

The current study is the first to demonstrate a strong correlation between a routinely used cycle ergometer test (Wasserman's protocol) and an arm crank test to assess cardiorespiratory fitness in people with restricted lower limb mobility. The arm crank test could be used as an alternative to cycle ergometry by accurately predicting $\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$) in sedentary middle-aged adults. Future research should focus upon comparing these protocols in older patients and/or younger people to examine test reproducibility.

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References

Ahlborg, G. and Jensen-Urstad, M. (1991) Metabolism in exercising arm vs. leg muscle. *Clinical Physiology* **11(5),** 459-468.

Åstrand, P.O. and Saltin, B. (1961) Oxygen uptake during the first minutes of heavy muscular exercise. *Journal of Applied Physiology* **16(6),** 971-976.

Balady, GJ., Chaitman, B., Driscoll, D., Foster, C., Froelicher, E., Gordon, N., Pate, R., Rippe, J. and Bazzarre, T. (1998) Recommendations for cardiovascular screening, staffing, and emergency policies at health/fitness facilities. *Circulation* **97(22),** 2283-2293.

Borg, G.A. (1973) Perceived exertion: a note on "history" and methods. *Medicine and Science in Sports* **5(2),** 90-93.

Calbet, J.A., Holmberg, H.C., Rosdahl, H., Van Hall, G., Jensen-Urstad, M. and Saltin, B. (2005) Why do arms extract less oxygen than legs during exercise? *American Journal of Physiology. Regulatory, Integrative and Comparative Physiology* **289(5),** R1448-1458.

Castro, R.R., Pedrosa, S., Chabalgoity, F., Sousa, E.B. and Nobrega, A.C. (2010) The influence of a fast ramp rate on peak cardiopulmonary parameters during arm crank ergometry. *Clinical Physiology Functional Imaging* **30(6),** 420-425.

Chan, A.K., Ilias-Khan, N.A., Xiam, H., Inman, C. and Martin, W.H. (2011) Arm exercise stress perfusion imaging predicts clinical outcome. *Journal of Applied Physiology* **111(6),** 1546-1553.

Davies, S.H. and Danjoux, G.R. (2010) Preoperative assessment of patients for vascular surgery. *Anaesthesia & Intensive Care Medicine* **11(5),** 170-173.

Dutcher, JR., Kahn, J., Grines, C. and Franklin, B. (2007) Comparison of left ventricular ejection fraction and exercise capacity as predictors of two- and five-year mortality following acute myocardial infarction. *The American Journal of Cardiology* **99(4),** 436-441.

Heldge, J.W., Damsgaard, R., Overgaard, K., Andersen, J.L., Donsmark, M., Dyrskog, S.E., Hermansen, K., Saltin, B. and Daugaard, JR. (2008) Low-intensity training dissociates metabolic from aerobic fitness. *Scandinavian Journal of Medicine & Science in Sports* **18(1),** 86-94.

Heldge, J.W. (2010) Arm and leg substrate utilization and muscle adaptation after prolonged low-intensity training. *Acta Physiologica (Oxford, England)* **199(4),** 519-528.

Ilias, N.A., Xiam, H., Inman, C. and Martin, W.H. (2009) Arm exercise testing predicts clinical outcome. *American Heart Journal* **157(1),** 69-76.

Kiilerich, K., Birk, J.B., Damsqaard, R., Wojtaszewski, J.F. and Pilegaard, H. (2008) Regulation of PDH in human arm and leg muscles at rest and during exercise. *American Journal of Physiology. Endocrinology and Metabolism* **294(1),** E36-42.

Muraki, S., Tsunawake, N. and Yamasaki, M. (2004) Limitation of muscle deoxygenation in the triceps during incremental arm cranking in women. *European Journal of Applied Physiology* **91(2-3),** 246-252.

Myers, J., Prakash, M., Froelicher, V., Do, D., Partington, S. and Atwood, JE. (2002) Exercise capacity and mortality among men referred for exercise testing. *The New England Journal of Medicine* **346(11),** 793-801.

National Institutes of Health. (1998) Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults--The Evidence Report. *Obesity Research* **6(2),** 51S-209S.

Older, P., Smith, R., Courtney, P. and Hone, R. (1993) Preoperative evaluation of cardiac failure and ischemia in elderly patients by cardiopulmonary exercise testing. *Chest* **104(3),** 701-704.

Older, P., Hall, A. and Hader, R. (1999) Cardiopulmonary exercise testing as a screening tool for perioperative management of major surgery in elderly. *Chest* **116(2),** 355-362.

Orr, JL., Williamson, P., Anderson, W., Ross, R., McCafferty, S. and Fettes, P. (2013) Cardiopulmonary exercise testing: arm crank vs cycle ergometry. *Anaesthesia* **68(5),** 497-501.

Pescatello, L.S., Arena, R., Riebe, D. and Thompson, PD. (2014) ACSM's guidelines for exercise testing and prescription. 9th edition. *Baltimore: Wolters Kluwer/ Lippincott Williams & Wilkins.*

Sanada, K., Kearns, C.F., Kojima, K. and Abe, T. (2005) Peak oxygen uptake during running and arm cranking normalized to total and regional skeletal muscle mass measured by magnetic resonance imaging. *European Journal of Applied Physiology* **93(5-6),** 687-693.

Sawka, M.N., Miles, D.S., Petrofsky, J.S., Wilde, S.W. and Glaser, R.M. (1982) Ventilation and acid-base equilibrium for upper body and lower body exercise. *Aviation, Space, and Environmental Medicine* **53(4),** 354-359.

Sawka, MN., Foley, ME., Pimental, NA., Toner, MM. and Pandolf, KB. (1983) Determination of maximal aerobic power during upper body exercise. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology* **54(1),** 113-117.

Schneider, D.A., Wing, A.N. and Morris, N.R. (2002) Oxygen uptake and heart rate kinetics during heavy exercise: a comparison between arm cranking and leg cycling. *European Journal of Applied Physiology* **88(1-2),** 100-106.

Schrieks, I.C., Barnes, M.J. and Hodges, L.D. (2011) Comparison study of treadmill versus arm ergometry. *Clinical Physiology and Functional Imaging* **31(4),** 326-331.

Smith, P.M., Price, M.J. and Doherty, M. (2001) The influence of crank rate on peak oxygen consumption during arm crank ergometry. *Journal of Sports Sciences* **19(12),** 955-960.

Smith, PM., Doherty, M., Drake, D. and Price, MJ. (2004) The influence of step and ramp type protocols on the attainment of peak physiological responses during arm crank ergometry. *International Journal of Sports Medicine* **25(8),** 616-621.

Smith, PM., Price, MJ., Winter, EM., Jones, Am., Davison, RC., Bromley, PD. and Mercer, TH. (2007) *Sport and exercise physiology testing guidelines: The British Association of Sports and Exercise Sciences guide*. In: Volume One: Sport testing. 2nd edition. *London: Routledge.*

Turner, DL., Hoppeler, H., Claassen, H., Vock, P., Kayser, B., Schena, F. and Ferretti, G. (1997) Effects of endurance training on oxidative capacity and structural composition of human arm and leg muscles. *Acta Physiologica Scandinavica* **161(4),** 459-464.

Wasserman, K. (1976) Testing regulation of ventilation with exercise. *Chest* **70(1),** 173-178.

Wasserman, K., Hansen, JE., Sue, DY., Stringer, WW., Sietsema, KE., Sun, XG. and Whipp, BJ. (2012) *Exercise testing and interpretation.* 5th edition, Philadelphia: Wolters Kluwer/ Lippincott Williams & Wilkins.

Weisman, I.M., Marciniuk, D., Martinez, F.J., Sciurba, F., Sue, D. and Myers, J. (2003) *ATS/ACCP statement on cardiopulmonary exercise testing: II.* Indications for cardiopulmonary exercise testing. *American Journal of Respiratory Critical Care Medicine* **167(2),** 211-277.

Key points

- Arm cranking could be used as an alternative mode of exercise to assess $\dot{V}O_2$peak in older adults with restricted lower limbs mobility.
- Lean body mass has been demonstrated to be as one of the essential predictive variables for the cycling $\dot{V}O_2$peak prediction by using the physiological responses from the arm cranking. That indicates the strong relationship of the musculature with the cardiorespiratory system in $\dot{V}O_2$peak tests.
- ACE elicited a $\dot{V}O_2$peak ($L \cdot min^{-1}$) approximately 29% less than cycling and 41% when adjusted for body weight ($ml \cdot kg \cdot min^{-1}$) which is corollary to the involvement of smaller muscle groups in arm cranking.

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