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TITLE

The validity and reproducibility of perceptually regulated exercise responses during combined arm+leg cycling

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Abbreviations

ANOVA – Analysis of variance

CV – Coefficient of variation

HR – Heart rate

HR_{max} – Maximal heart rate

ICC – Intraclass correlation coefficient

LoA – Limits of agreement

PO – Power output

PPO – Peak minute power

RER – Respiratory exchange ratio

RPE – Rating of perceived exertion

RPE_A – Ratings of perceived exertion (arms)

RPE_L – Ratings of perceived exertion (legs)

RPE_C – Ratings of perceived exertion (central)

RPE_P – Ratings of perceived exertion (peripheral)

$\dot{V}_E$ – Pulmonary ventilation

$\dot{V}_{Epeak}$ – Peak pulmonary ventilation

$\dot{V}O_2$ – Oxygen uptake

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

ABSTRACT

Purpose Rating of perceived exertion (RPE) is a reliable method of assessing exercise intensity during arm and leg cycling. The aim of this study was to assess the validity and reproducibility of perceptually regulated exercise responses during combined arm+leg cycling. ***Methods*** Twelve males (age; 24.6 ± 5.3 years, height; 1.81 ± 0.7 m, mass; 83.1 ± 8.4 kg) initially undertook incremental exercise tests to volitional exhaustion for arm cycling (133 ± 14 W) and leg cycling (253 ± 32 W). On three subsequent occasions, participants undertook combined arm+leg cycling trials using two modified Monark ergometers involving three bouts of exercise at RPE 9, 13 and 17, in that order. Heart rate (HR), oxygen uptake ($\dot{V}O_2$) and pulmonary ventilation ($\dot{V}_E$) were recorded continuously. ***Results*** No significant differences were observed for HR (P = 0.086), $\dot{V}O_2$ (P = 0.525) and $\dot{V}_E$ (P = 0.899) between trials, whilst significant differences were observed between each level of RPE (all $P \leq 0.001$). For % peak $\dot{V}O_2$, the ICC increased with successive trials for all RPE levels. For % maximal HR the ICC generally decreased with successive trials. ***Conclusion*** RPE can be used as a reliable frame of reference for the production of exercise intensity during combined arm+leg cycling without any formal familiarisation. Since combined arm+leg cycling elicits a greater energy expenditure than arm or leg work alone, this novel mode of exercise might prove effective for aerobic conditioning and weight control.

INTRODUCTION

Among healthy individuals, the rating of perceived exertion (RPE) (6-20 scale; Borg, 1970) has demonstrated strong linear associations with oxygen uptake ($\dot{V}O_2$) and heart rate (HR) during leg-cycling (Skinner et al. 1973), arm-cycling (Borg et al. 1987), running (Robertson et al. 1982), swimming (Ueda and Kurokawa, 1995) and rowing (Marriott and Lamb, 1996). The RPE correlates with metabolic demand both where RPE is given as a response to a work rate (i.e. passive estimation tasks) (Eston and Brodie, 1986; Pandolf et al. 1984) and where RPE is used as an independent variable for regulating exercise intensity (i.e. active production tasks) (Eston et al. 2005; 2006; 2008; Faulkner et al. 2007). A number of studies have used the production procedure to validate the use of RPE for exercise prescription by using $\dot{V}O_2$, HR and/or power output (PO) as criterion variables, showing that distinct exercise intensities can be consistently reproduced (three or four repeated measures) across a range of RPE (i.e. 9, 13 and 17) (Buckley et al. 2000; Dunbar et al. 1994; Eston et al. 1987; Eston and Williams, 1988). However, it should be noted that these studies showed marked improvements in the reproducibility (as evidenced by narrower limits of agreement) of the exercise responses following additional trials. These findings indicate that the RPE system is a valid and reliable tool with which to control exercise intensity during popular modes of exercise (i.e. cycling and treadmill running).

The ability to control a given exercise intensity across a range of exercise modalities presents a highly desirable and useful application of the RPE system. However, caution must be used because physiological and perceptual responses differ according the size of the active skeletal muscle mass. In 1924, Collet and Liljestrand were the first to recognise that arm work elicited a greater physiological strain than leg work performed at the same metabolic rate (Collet and Liljestrand, 1924), indicating that participants have to work comparatively harder with the arms compared to the legs to maintain the same power output. It is therefore unsurprising that RPE is greater during arm cycling compared to leg cycling for the same absolute power output (Borg et al. 1987; Ekblom and Goldbarg, 1971; Eston and Brodie, 1986; Hill et al. 2014; Pandolf et al. 1984), which is likely explained by the relationship between subjective feelings of strain and the metabolic rate per unit mass of contracting muscle (Sawka, 1986). Importantly, perceptual sensitivity to process physiological information, and therefore the ability to perceive exertion, appears to be enhanced during arm cycling compared to leg cycling. Kang et al. (1998) compared $\dot{V}O_2$, HR and PO between estimation (50% and 70% $\dot{V}O_{2peak}$) and production trials during arm and leg cycling. It was reported that that the production errors (i.e. difference in $\dot{V}O_2$, HR and PO) between the estimation and production trials at both intensities were smaller during arm cycling than leg cycling (Kang et al. 1998). The greater production accuracy observed during arm cycling might be explained by either the reduction in extraneous sensory information processed using a smaller muscle mass (Pandolf et al. 1984) and/or greater localised muscle fatigue during arm cycling, which accentuates sensory input to the perceptual cognitive framework (Dunbar, 1992). Therefore, regardless of exercise intensity, the production accuracy of the RPE system appears to be dependent upon the size of the active skeletal muscle mass.

Recent studies have raised the question whether the RPE production procedures can be applied with similar success to combined arm+leg cycling, because perceptual sensitivity to process physiological information appears to be diminished when cyclical arm and leg movements are performed concurrently (Hill et al. 2018). For example, adding arm cycling to leg cycling for generation of a given power output elicits a greater metabolic load (i.e. $\dot{V}O_2$) with a reduced (Hoffman et al. 1996) or unchanged (Gutin et al. 1988) RPE. It has also previously been reported that combined arm+leg cycling appears to elicit a relatively greater physiological response (i.e. % HR_{max} and % $\dot{V}O_{2peak}$) than is perceived (Hill et al. 2018). As such, the use of RPE's for exercise prescription during combined arm+leg cycling is attractive because this approach can ensure users elicit a large metabolic load with a relatively low perceived effort (Hill et al. 2018), which should improve exercise tolerance. However, the accuracy and reproducibility of using RPE to control exercise intensity during combined arm+leg cycling has not been established. This matter is further complicated by the fact that combined arm+leg cycling is a more unfamiliar, complex and less efficient mode of exercise than leg and/or arm cycling alone (Gutin et al. 1988). This makes the expectation that there will be a greater variability in elicited physiological responses during this unique mode of exercise. The question therefore remains as to whether RPE can be a consistent and valid tool for exercise prescription during combined arm+leg cycling.

Therefore, the purpose of this study was to assess the reproducibility of perceptually controlled exercise responses during combined arm+leg cycling, by asking participants to produce exercise intensities on three separate occasions at three predetermined RPE levels (i.e. 9, 13, 17) (Buckley, Eston and Sim, 2000; Eston and Williams, 1988; Hartshorn and Lamb, 2003; Lamb, Eston and Corns, 1999). A secondary objective was to determine whether the $\dot{V}O_2$ and HR (i.e. % of maximum) responses for a given RPE were similar to those reported in guidelines for exercise modes using a similar active muscle mass (i.e. rowing, treadmill running, swimming). We hypothesised that at least one formal familiarisation session would be required to elicit consistent physiological responses using the RPE scale. Our second hypothesised was that the physiological strain (% $\dot{V}O_{2peak}$) experienced at each RPE level (i.e. 9, 13, 17) would be significantly greater than expected for existing exercise modes (i.e. arm and leg cycling). The rationale underlying this validation procedure was based on the assumption that if physiological responses at different levels of RPE are shown to be reliable and valid during combined arm+leg cycling, the RPE scale could be a valuable practical and non-invasive tool for monitoring, controlling, and prescribing the intensity of exercise.

METHODS

Participants

Twelve physically active males (age; 24.6 ± 5.3 years, height; 1.81 ± 0.07 m, mass; 83.1 ± 8.4 kg, BMI; 25.3 ± 2.1 kg.m^{-2}) volunteered to participate in this study. All participants were moderately active (IPAQ; 5.2 ± 1.1 h·wk^{-1}) undertaking 2–3 moderate to vigorous intensity exercise sessions per week in a range of sports (e.g., football, rugby, racket sports and/or athletics). Participants were recruited from the University student and staff population via word of mouth. During the first visit, the aims and objectives of the study were explained to participants before they completed a pre-screening physical activity and medical questionnaire. Inclusion criteria were as follows: (1) adults aged between 18 and 30 years (2) otherwise healthy without any contraindications to exercise and (3) naïve to combined arm+leg cycling. Participants were excluded from the study if they reported cardiovascular or pulmonary diseases, neurological disorders, orthopaedic pathology or musculoskeletal problems that would affect their ability to exercise safely. Written informed consent was obtained from all participants, after they were informed of the procedures and potential risks of the study. The study was carried out in accordance with the guidelines outlined in the declaration of Helsinki (1964) and all procedures of the study had previously received ethical approval by the University research ethics committee.

Experimental design

Participants visited the laboratory on five separate occasions, separated by at least 2 days but no more than 5 days (Buckley et al. 2000; Eston et al. 1988; Lamb et al. 1999). During the first two visits to the laboratory, to determine each individual's ergometer-specific peak power output (PPO) and oxygen uptake ($\dot{V}O_{2peak}$), participants completed individual maximal incremental step tests on both an arm-cycling and leg-cycling ergometer in a counterbalanced order. All participants had previously been familiarised to arm cycling. On three subsequent but separate occasions, participants undertook identical testing sessions involving three bouts of arm+leg cycling at RPE 13, 9 and 17, in that order. A fixed production order was chosen to avoid the effects of higher levels of fatigue (i.e. RPE 17) on the rest of the protocol. Additionally, we chose a mixed order as this approach requires participants to consider high and low levels of relative effort rather than just progressively upwards (Hartshorn and Lamb, 2003). All exercise tests were completed at the same time of day (± 1 hour) to control for physiological variation due to circadian rhythms. All test sessions took place between 9:00 h and 11:00 h (morning session) and 13:00 h and 15:00 h (afternoon session), in the same physiology laboratory, using the same ergometers. Participants were asked to refrain from caffeine/ alcohol consumption 12 hr prior to testing and participants were permitted to only consume water during experimental visits.

Instrumentation

Isolated arm cycling and leg cycling preliminary tests were performed on a mechanically braked ergometer (Monark, 824E, Ergomedic, Sweden) to determine relative exercise intensity during experimental trials. For the arm-cycling trial, the ergometer was clamped onto a sturdy table and foot pedals were replaced with pronated-position hand grips. The ergometer was height-adjustable which enabled the crank axis to be aligned with the centre of the glenohumeral joint. Arm cycling trials were performed in a seated position (knees flexed to 90º) without torso restraint. The arm leg cycling setup was the same as that described in our previous work (Hill et al. 2018). Participants performed arm cycling while concurrently cycling on a stationary ergometer. The arm ergometer was positioned in front of the participant and the height of the axis of rotation was adjusted to be aligned with the centre of the glenohumeral joint. The horizontal position of the leg ergometer in the sagittal plane was adjusted to ensure that participant’s elbows were slightly flexed when the arm was at the furthest point of the duty cycle. As there was no mechanical coupling between upper and lower limb ergometers, participants could crank both ergometers independently.

Preliminary trials

The leg cycling protocol started at a power output of 70 W with increments of 35 W every 3 min until volitional exhaustion. The arm cycling protocol involved an initial power output of 35 W, with increments of 20 W every 3 min until volitional exhaustion (Hill et al. 2014). A cadence of 70 rev·min^{-1} was employed throughout both trials. Expired gas was analysed using a breath-by-breath online gas system (Meta- Max, Cortex Biophsik, Borsdorf, Germany) for oxygen uptake ($\dot{V}O_2$) and pulmonary ventilation ($\dot{V}_E$). Expired gas data were averaged over the final 20 sec of each incremental stage and prior to reaching volitional exhaustion. Before each test, the analyser was calibrated for barometric pressure, volume and oxygen/carbon dioxide concentrations, in accordance with the manufactures guidelines. Barometric pressure was calibrated against pressure determined using a mercury barometer (F Darton & Co. Ltd, UK). Calibration of the gases was determined by sampling known concentrations of oxygen (15%) and carbon dioxide (5%) using calibration gas, as well as ambient air (assumed at 20.95% O_2 and 0.03% CO_2). The volume transducer was calibrated with a 3-litre capacity syringe (Hans Rudolph, USA). Heart rate (HR) was continually monitored (Polar Electro, Oy, Finland) and recorded in the final 10 s of each incremental stage and immediately upon reaching volitional exhaustion. A rating of perceived exertion for both local (working muscles; RPE_L) and central (cardiorespiratory; RPE_C) using the 6–20 point Borg scale (Borg 1982) was obtained at the same time as HR and immediately upon reaching volitional exhaustion. The following criteria were assessed in the incremental tests to establish whether a maximum effort had been given (1) a $HR_{max} \leq 10$ beats·min^{-1} or 5% of the age predicted maximum (i.e. 220-age for leg cycling or 200-age for arm cycling [Hill et al. 2016]), (2) peak blood lactate concentration $\geq$ 8.0 mmol·L^{-1}, (3) respiratory exchange ratio of $\geq$ 1.15, or (4) a rating of perceived exertion (RPE) (6-20 [Borg, 1970]) of $\geq$ 18 (Midgley et al. 2007).

Production trials

Production trials consisted of three exercise bouts at each of the pre-selected RPE's (13, 9 and 17), performed in that order. Participants were initially asked to arm crank and cycle at 70 rev·min^{-1} on the unloaded ergometers for 5 minutes. Each participant was then afforded three minutes to adjust power output to match the assigned RPE value. Participants were instructed that they could adjust arm and leg cadence *ad libitum* throughout the initial three minutes (Kang et al. 1998). Expired gas and HR were measured continuously in the 4th and final minute after power output was selected and recorded during the final 20 seconds of each bout. In additional to RPE_C, participants were also asked to provide an RPE for the arms (RPE_A) and legs (RPE_L). The cadence display screen for the arm and leg ergometers and breath-by-breath display screen were concealed so that participants were not aware of the power output or physiological markers. To reach the specified RPE level, the technician asked the participant (every 15 s) if they would like the workload to be 'harder', 'easier' or 'the same' for the arms and legs. The adjustments requested by the participant were made in 0.1 kg (arms) or 0.2 kg (legs) increments (Hill et al. 2018). While 3 min were allowed for this process, participants generally achieved their desired intensity with 30 – 60 s. The load applied to the arm and leg ergometer cradles were concealed from participants view to ensure effort was produced on a "feel-only" basis (Hartshorn and Lamb, 2003). The production trial was repeated twice more on separate days (3 – 5 days apart), but at the same time of day (± 1 hour). Power output of the arm and leg ergometers was measured in watts (calculated from cadence × external resistance) and was recorded for the last minute of each stage.

Statistical analysis

Data were analysed using SPSS version 20.0 (IBM Inc., Chicago, IL). For all analyses, normality (Shapiro–Wilk Test) and homogeneity of variance/sphericity (Mauchly Test) were checked. Paired *t*-tests were carried out to determine differences in peak responses between the incremental arm and leg exercise tests. Cohen's *d* is reported for peak physiological responses and were interpreted as trivial (0–0.19), small (0.20–0.49), moderate (0.50–0.79), and large (> 0.80). A two-way analysis of variance (ANOVA) with repeated measures of both factors (*RPE*; 9, 13, 17 × *trial*; 1, 2, 3) was conducted to examine differences in cardiorespiratory and perceptual variables between each of the three RPE levels and between each of the three trials. Where significance was achieved for main effects, Bonferroni-adjusted α were conducted to determine the location of pairwise differences. When the ANOVA was used, effect sizes are reported as partial eta-squared value (η^2) and reported where appropriate. Statistical significance was set at $P < 0.05$. In accordance with previous recommendations (e.g. Buckley *et al.* 2000), participants ability to reproduce the same exercise intensity for a given RPE was assessed by combined use of an intraclass correlation coefficient (ICC) (Atkinson and Nevill, 1998) and the bias±95% limits of agreement (95% LoA) (Bland and Altman, 1986). The ICC and 95% LoA analysis assessed inter-trial agreement for % $\dot{V}O_{2peak}$, % HR_{max} and power output at each of the three RPE levels for the following pairwise comparisons; trials 1 and 2 (T1-T2) and trials 2 and 3 (T2-T3).

RESULTS

Peak physiological responses

Significant differences were observed between arm cycling and leg cycling for absolute $\dot{V}O_{2peak}$ ($p \leq 0.001$), relative $\dot{V}O_{2peak}$ ($p \leq 0.001$), PPO ($p \leq 0.001$), $\dot{V}_E$ ($P = 0.012$) and HR_{max} ($p = 0.002$). With the exception of local RPE (p = 0.999) and RPE_C ($p = 0.884$) where no differences were observed (Table 1), all variables were significantly greater for leg cycling compared to arm cycling.

***** TABLE 1 NEAR HERE *****

Physiological and perceptual responses to three levels of RPE

Figure 1 illustrates the absolute physiological responses for the three trials at each of the three RPE levels. There were no trial × RPE interactions for HR ($F_{(4,48)}$ = 2.173, P = 0.086, η^2 = .153), $\dot{V}O_2$ ($F_{(4,48)}$ = .810, P = 0.525, η^2 = .063), or $\dot{V}_E$ ($F_{(4,48)}$ = .264, P = 0.899, η^2 = .022). However, the analysis did reveal significant differences in HR ($F_{(2,24)}$ = 277.530, $P \leq 0.001$, η^2 = .959), $\dot{V}O_2$ ($F_{(2,24)}$ = 228.106, $P \leq 0.001$, η^2 = .950), and $\dot{V}_E$ ($F_{(2,24)}$ = 383.449, $P \leq 0.001$, η^2 = .970) between the three RPE levels during each of the three trials. Post hoc analyses showed that all pairwise comparisons of the three RPE levels were significantly different to each other (all $P \leq 0.001$). Figure 2 illustrates the RPE responses for the three trials at each of the three RPE levels. None of the RPE''s were different to the prescribed levels (all $P > 0.05$), whilst all RPE responses were different between the three RPE levels during each of the three trials ($P < 0.05$).

***** FIGURE 1 NEAR HERE *****

***** FIGURE 2 NEAR HERE *****

Figure 3 illustrates the relative values of HR and $\dot{V}O_2$ for the three trials at each RPE level. There was no interaction between RPE × trial for either % HR_{max} ($F_{(4,44)}$ = .705, P = 0.593, η^2 = .056) or % $\dot{V}O_{2peak}$ ($F_{(4,44)}$ = .648, P = 0.631, η^2 = .060). However, there was a significant difference in % HR_{max} ($F_{(2,22)}$ = 245.967, $P \leq 0.001$, η^2 = .957) and % $\dot{V}O_{2peak}$ ($F_{(2,22)}$ = 213.180, $P \leq 0.001$, η^2 = .951) between the three RPE levels. *Post-hoc* analyses revealed that all pairwise comparisons between the three RPE levels were significantly different (all $P < 0.001$) for both % HR_{max} and % $\dot{V}O_{2peak}$.

***** FIGURE 3 NEAR HERE*****

Power output

Figure 4 illustrates absolute power output values for the arms and legs. There was no interaction between RPE × trial for either arm ($F_{(4,44)} = 41.954$, $P = 0.262$, $\eta^2 = .110$) or leg ($F_{(4,44)} = 1.365$, $P = 0.950$, $\eta^2 = .016$) power output. However, there was a significant difference in arm ($F_{(2,22)} = 70.353$, $P < 0.001$, $\eta^2 = .865$) and leg ($F_{(2,22)} = 122.449$, $P < 0.001$, $\eta^2 = .918$) power output between the three RPE levels (Fig. 2). Post hoc analyses revealed that all pairwise comparisons between the three RPE levels were significantly different (all $P \leq 0.001$) for arm and leg power output.

***** FIGURE 4 NEAR HERE *****

Reliability

Table 2 (% HR_{max}) and 3 (% $\dot{V}O_{2peak}$) shows the ICC and 95% LoA for each RPE level. Two-way ANOVA revealed no significant differences across the three trials for % HR_{max} ($F_{(2,22)} = .002$, $P = 0.998$, $\eta^2 = .000$) or % $\dot{V}O_{2peak}$ ($F_{(2,22)} = .070$, $P = 0.933$, $\eta^2 = .006$) at each of the three RPE levels (Table 2). The variability within the 95% LoA for % $\dot{V}O_{2peak}$ between trials (T1-T2 and T2-T3) decreased with successive trials for all three RPE levels. In contrast, the variability within the 95% LoA for % HR_{max} between trials (T1-T2 and T2-T3) increased with successive trials for all three RPE levels. For % $\dot{V}O_{2peak}$, the ICC increased with successive trials for all RPE levels (Table 3). For % HR_{max} the ICC generally decreased with successive trials (Table

2). In contrast, the variability within the 95% LoA for % HR_{max} between trials (T1-T2 and T2-T3) increased with successive trials for all three RPE levels.

***** TABLE 2 NEAR HERE *****

***** TABLE 3 NEAR HERE *****

DISCUSSION

The findings of this study were that; (1) RPE can be successfully used to differentiate exercise intensity during combined arm+leg cycling, (2) participants were able to repeat similar exercise intensities after two trials at each of the RPE levels, (3) % HR_{max} and % $\dot{V}O_{2peak}$ at each RPE level were more consistent with values reported for treadmill running than leg or arm cycling alone, (4) participants performed significantly more work with the legs and less with the arms to achieve the target RPE level.

Validity

The RPE levels of 9, 13 and 17 equated to mean values of 52%, 69% and 92% $\dot{V}O_{2peak}$ (relative to maximal leg cycling). These values are consistent with those typically reported for treadmill running (i.e., 49, 70 and 89% $\dot{V}O_{2peak}$, respectively) (Eston et al. 1987), but are considerably greater than previously reported for cycling (i.e., 36, 57 and 82% $\dot{V}O_{2peak}$, respectively) (Eston and Williams, 1988). Although it is difficult to compare responses between studies, these findings suggest that combining arm and leg cycling represents an increase in relative exercise intensity (i.e. $\dot{V}O_{2peak}$) of ~10-15% for each level of RPE. This was to be expected as the muscle mass engaged during combined arm+leg cycling equals or exceeds that achieved during treadmill running (Bergh *et al.* 1976; Secher *et al.* 1974; Stenberg *et al.* 1967). These findings are of practical importance because treadmill testing and/or training (i.e. weight bearing) is often problematic for individuals with poor balance and motor control (i.e. older adults or those with neurological disease).

Both absolute and relative physiological responses increased with greater RPE levels, indicating that participants understood the concept of using the RPE scale in production mode. This finding also indicates that using the RPE system is a valid tool with which to gauge and/or differentiate exercise intensity during combined arm+leg cycling. The present findings are also consistent with previous work, where it was reported that an RPE of 13 during 20-min self-controlled combined arm+leg cycling equated to ~71% of the $\dot{V}O_{2peak}$ achieved during leg cycling (Hill et al. 2018). However, as with previous investigations (Buckley *et al.* 2000), the % $\dot{V}O_{2peak}$ responses were varied (Fig. 4). For example, at RPE 9, 13 and 17, they were 36-70%, 52-89% and 73 – 121% of the leg cycling $\dot{V}O_{2peak}$, respectively. The between subject variability at each RPE level is likely explained by differences in cardiorespiratory fitness (Travilos and Marisi, 1996), unfamiliarly, inefficiency and/or the complexity of combined arm+leg cycling (Gutin et al. 1988).

Crucially, it is notable that combined arm+leg cycling appears to elicit a relatively greater physiological response than is perceived. The mechanism responsible for the mismatch between RPE and physiological responses is unclear. Metabolic efficiency (as determined by work and delta efficiency) is lower during arm compared to leg cycling at the same relative intensities (Kang et al. 1997). Whilst no studies have empirically examined the efficiency of combined arm+leg cycling, we cannot exclude the possibility that this is a very inefficient mode of exercise. For example, when arm cycling was added to leg cycling, Gutin et al. (1988) observed a marked increase in $\dot{V}O_2$ (~ 0.3 L min^{-1}) compared to leg only cycling, despite similar mean power outputs (159 vs 160 W, respectively) between modes. These findings provide clear evidence that combined arm+leg cycling reduces the gross efficiency of the movement. The increased metabolic cost of combined arm+leg cycling has previously been ascribed to the higher demand of the upper extremities and trunk stabilisation during unsynchronised arm and leg movements (Hill et al. 2018).

Reliability

The present results confirm previous observations that the reproducibility of metabolic responses (i.e., % $\dot{V}O_{2peak}$) generally improves with additional trials (Eston and Williams, 1988; Eston *et al.* 1999). Although several studies have examined RPE in production mode during leg cycling (Buckley *et al.* 2000; Dunbar *et al.* 1992; 1994; Eston and Williams, 1988) and arm cycling (Kang *et al.* 1998), the present study is the first to use a combined arm+leg ergometer to evaluate the reliability of reproducing distinct exercise intensities using RPE. When using HR data to judge the reliability of RPE to reproduce distinct exercise intensities, the ICC and 95%LoA results (Table 2) showed that with additional visits the RPE provided weaker reliability (i.e. wider LoA and lower ICCs). When using the same analysis for the $\dot{V}O_2$ criterion (Table 3), we observed that additional trials yielded better (narrower), limits of agreement, for all levels of RPE. These findings are in direct contrast to the findings of Buckley et al. (2000) who reported that HR reliability improved from trial 2 to 3, while $\dot{V}O_2$ reliability was weakened with subsequent cycling tests. It is important to note, however, that Buckley and colleagues used a different RPE scale (Braille RPE) and population (blind participants) to the present study. The implication for the non-improving trial-to-trial agreement found in this study is that the RPE scale may be unreliable for use in production mode when HR is used as the criterion. However, the narrow 95%LoA values for the $\dot{V}O_2$ criterion suggest that the physiological intensities were consistently reproduced at the same RPE levels across trials. For the % $\dot{V}O_{2peak}$, ICC values ranged from being unacceptable between trial 1 and 2 ($\leq$ 0.80), to good between trial 2 and 3 ($\geq$ 0.90) for RPE level 9. Although the ICC values increased for RPE 13 with additional visits, they remained unacceptably low. Likewise, there was also a small increase in ICC values with additional trials at RPE level 17, however, these values were moderate. The ICC value for % HR_{max} tended to decrease with additional trials, indicating a decline in the relative reliability of responses with practice. Despite the general decline in relative and absolute reliability for % HR_{max} with additional trials, the 95% LoA scores were generally good (e.g. ±7.4% to 4.0 %) and were considerably narrower than the values previously reported for leg cycling (Buckley *et al.* 2000; Hartshorn and Lamb, 2003; Eston *et al.* 2000). This was surprising as we initially hypothesised that at least a single exposure to combined arm+leg cycling would be required to achieve good between trial reliability when using the RPE scale.

Practical applications

When prescribing exercise for cardiovascular conditioning or weight control, it is highly desirable to elicit a large metabolic stimulus without imposing excessive subjective strain. Combined arm+leg cycling appears to elicit a relatively greater physiological response than is perceived. From a practical perspective, we have used combined arm+leg cycling to intentionally increase metabolic demand. If the goal is to expend the greatest number of calories in a fixed period (i.e. for losing weight), combining arm and leg cycling might offer users "more bang for their buck". Indeed, it has already been reported that combining the arms and legs during dynamic high intensity exercise elicits greater cardiorespiratory training adaptations than leg training alone (Zinner et al. 2016). On the other hand, clinicians or health professionals prescribing combined arm+leg cycling as an exercise mode in cardiac rehabilitation or cardiorespiratory conditioning should be aware that "at-risk" individuals may inadvertently perform exercise at intensities higher than they perceive. Additionally, combining arm and leg cycling may enable individuals to delay localised fatigue of the arms or legs by alternating the contribution of the upper or lower body, thus making it easier to sustain an energy expenditure for a pronged period. Therefore, to achieve the same power output, participants may experience less fatigue in their arms or legs. In the present study, the arms contributed to ~35%, 29% and 27% of the total power output during RPE 9, 13 and 17, respectively. The greater contribution from the lower body, particularly during the higher RPE levels, is not surprising and is consistent with our previous findings (Hill *et al.* 2018). It is likely that participants in the present study were less familiar with arm compared to leg cycling and may have felt more comfortable increasing leg power output to achieve the desired RPE level. From a practical perspective, allowing participants to “take the edge off” the exercise by using the arms may offer individuals a greater effort/return ratio.

Limitations

The present study has some limitations that should be acknowledged. Firstly, relative physiological responses were expressed to a maximal cycling test and not a maximal combined arm+leg cycling test. Given that $\dot{V}O_{2peak}$ is up to 10% greater during combined arm+leg cycling compared to leg only cycling (Gleser et al. 1974; Nagle et al. 1984), the relative intensity in the present study may have been overestimated. Future studies should determine the validity and reproducibility of maximal incremental combined arm+leg cycling. Secondly, we included only three experimental visits. Therefore, it is not known whether a fourth trial would have yielded narrower (better) limits of agreement as a consequence of participations becoming more familiarised with the exercise mode and the RPE scale. Finally, we could only speculate that distributing work between the arms and legs leads to a lower efficiency (and higher energy expenditure), since we did not directly measure gross or mechanical efficiency in the present study. Future studies that wish to compare indices of mechanical efficiency between arm, leg and combined arm+leg cycling would be welcomed.

Conclusion

In summary, two major findings have emerged from the present experiment. Firstly, we found that the RPE system is a valid tool with which to gauge/differentiate exercise intensity during combined arm+leg cycling. Secondly, combined arm+leg cycling appears to elicit a relatively greater physiological response than is perceived. We also found that participants were able to repeat similar exercise intensities after two trials at each of the RPE levels and that participants performed more work with the legs and less with the arms to achieve the target RPE level. We believe that combined arm+leg cycling is a viable option for exercise testing and/or training which is likely to expand the population capable of performing exercise to include an even broader range of individuals with exercise limitations (i.e., poor balance and mobility).

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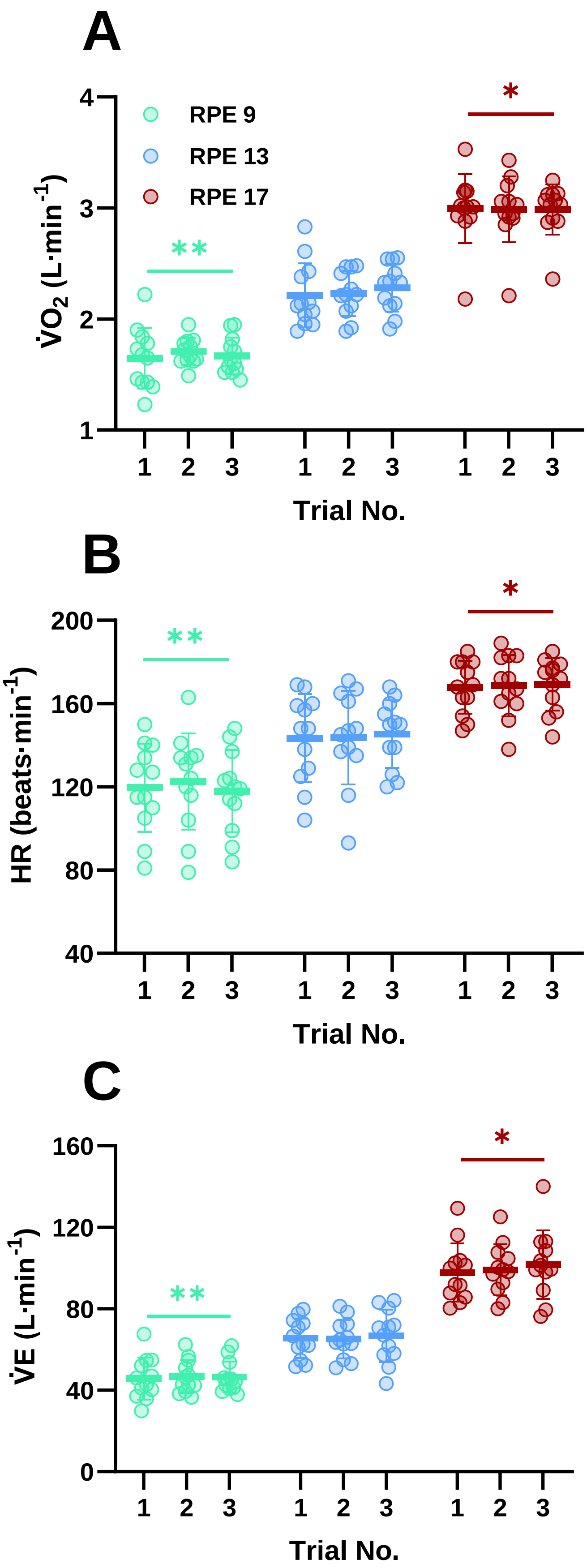
A
RPE 9
RPE 13
RPE 17
V̇O2 (L·min-1)
4
3
2
1
**
*
1 2 3 1 2 3 1 2 3
Trial No.
B
HR (beats·min-1)
200
160
120
80
40
**
*
1 2 3 1 2 3 1 2 3
Trial No.
C
V̇E (L·min-1)
160
120
80
40
0
**
*
1 2 3 1 2 3 1 2 3
Trial No.

Figure 1 Mean ± SD and individual oxygen uptake (A), heart rate (B) and pulmonary ventilation (C) for the three trials at each level of RPE**.** NB: * Sig different to RPE 13, ** Sig different to RPE 13 and 17

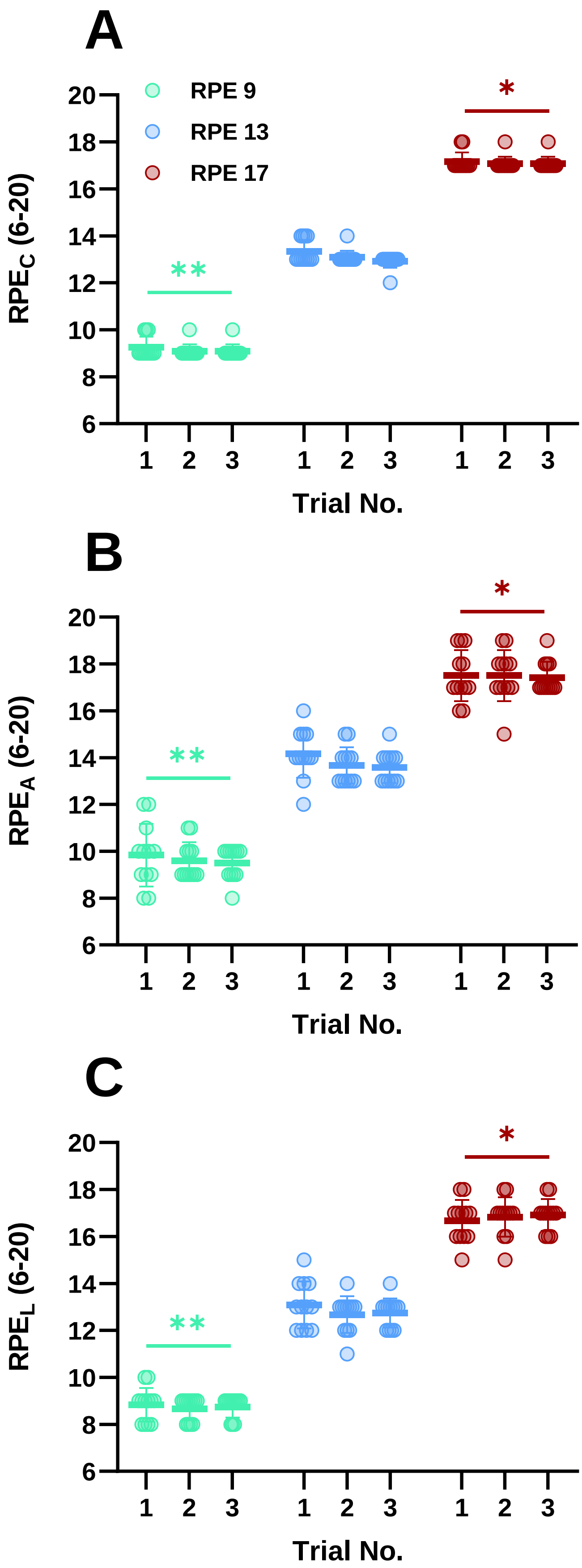
A
RPE 9
RPE 13
RPE 17
RPE$_C$ (6-20)
Trial No.
B
RPE$_A$ (6-20)
Trial No.
C
RPE$_L$ (6-20)
Trial No.

Figure 2 Mean ± SD and individual central RPE for the heart and lungs (A), local RPE for the arms (B) and local RPE for the legs (C) for the three trials at each level of RPE**.** NB: * Sig different to RPE 13, ** Sig different to RPE 13 and 17

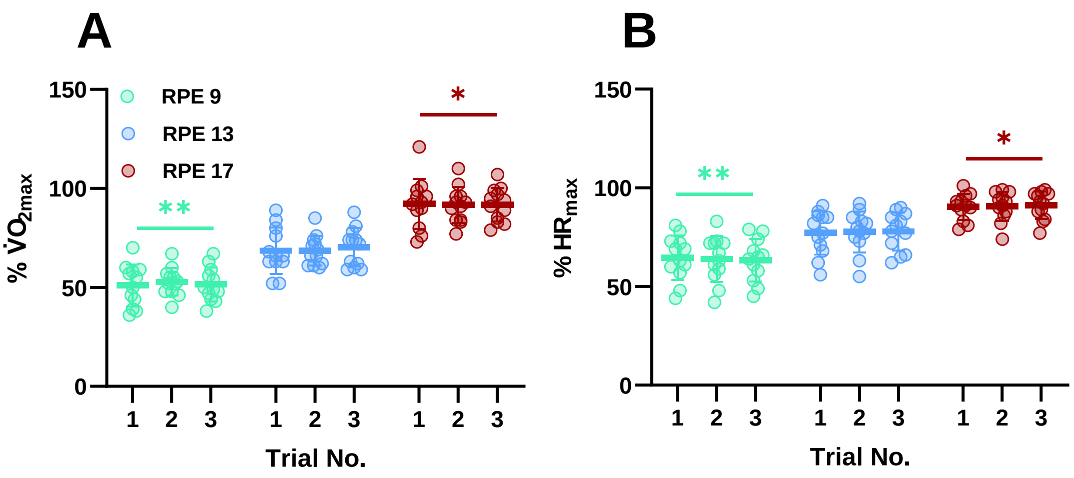

Figure 3 Mean ± SD and individual responses for %$\dot{V}O_{2peak}$ (A) and %HR_{max} (B) for the three trials at each level of RPE. NB: * Sig different to RPE 13, ** Sig different to RPE 13 and 17

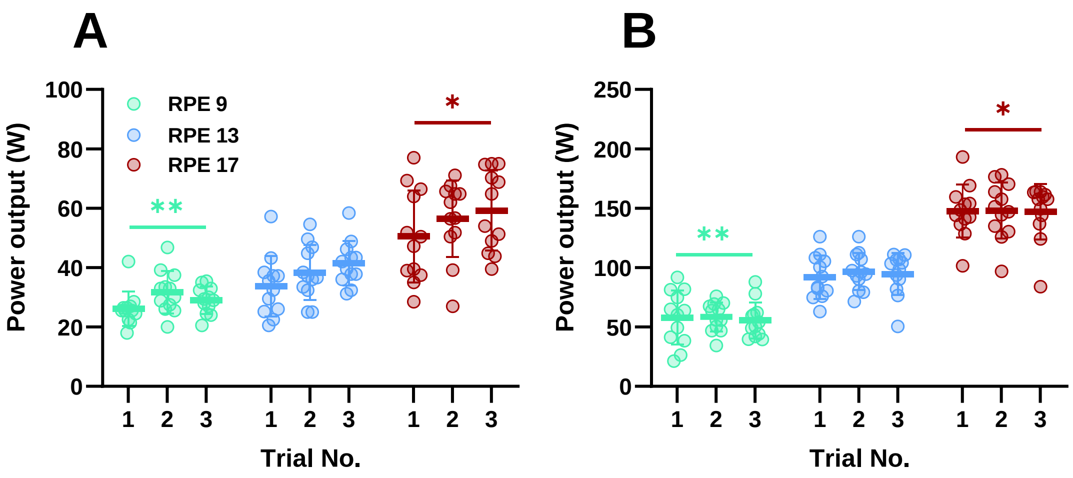

Figure 4 Mean ± SD and individual power output for arm (A) and leg (B) cycling for the three trials at each level of RPE. NB: * Sig different to RPE 13, ** Sig different to RPE 13 and 17. All PO were significantly greater during leg compared to arm cycling for each RPE level.

Table 1 Mean ± SD peak cardiorespiratory and perceptual responses to leg cycling and arm cycling

	Leg cycling	**Arm cycling**	**Cohens *d***
$\dot{V}O_{2peak}$ (L·min^{-1})	3.27 ± 0.33	2.52 ± 0.27*	2.49
$\dot{V}O_{2peak}$ (ml·kg·min^{-1})	39.8 ± 5.7	30.5 ± 3.6*	1.95
PPO (W)	253 ± 32	133 ± 14*	4.86
$\dot{V}_{Epeak}$ (L·min^{-1})	134.0 ± 17.7	110.2 ± 14.3*	1.23
HR_{max} (beats·min^{-1})	186 ± 4	179 ± 9*	1.01
RPE_L	20 ± 0.1	20 ± 0.1	0.0
RPE_C	18 ± 2.0	18 ± 2.0	0.0

*Significantly different different to leg cycling ($p < 0.05$)

Table 2 % HR_{max} intraclass correlation coefficient (ICC), bias 95% limits of agreement (±95%LoA) and coefficient of variation (CV) for pairwise comparisons across three ratings of perceived exertion 9, 13 and 17

	RPE 9		**RPE 13**		**RPE 17**	
	T1-T2	T2-T3	T1-T2	T2-T3	T1-T2	T2-T3
ICC (95%CI)	0.94 (0.79 to 0.98)	0.81 (0.46 to 0.94)	0.87 (0.61 to 0.96)	0.74 (0.31 to 0.92)	0.84 (0.54 to 0.95)	0.67 (0.17 to 0.89)
Bias (±95%LoA)	0.6 (4.3)	0.7 (7.1)	0.5 (5.7)	-0.3 (7.4)	-0.3 (4.0)	-0.4 (6.0)
CV (%) (±SD)	3.2 (4.1)	7.0 (4.0)	4.1 (3.4)	6.2 (3.6)	2.3 (1.9)	3.6 (2.9)

Table 3 % $\dot{V}O_{2peak}$ intraclass correlation coefficient (ICC), bias 95% limits of agreement (±95%LoA) and coefficient of variation (CV) for pairwise comparisons across three ratings of perceived exertion 9, 13 and 17

	RPE 9		**RPE 13**		**RPE 17**	
	T1-T2	T2-T3	T1-T2	T2-T3	T1-T2	T2-T3
ICC (95%CI)	0.65 (0.16 to 0.88)	0.90 (0.69 to 0.97)	0.64 (0.12 to 0.88)	0.67 (0.19 to 0.89)	0.84 (0.54 to 0.95)	0.88 (0.63 to 0.96)
Bias (±95%LoA)	-1.8 (7.6)	1.3 (3.5)	-0.1 (8.5)	-1.8 (7.0)	0.6 (6.4)	-0.2 (4.5)
CV (%) (±SD)	8.2 (6.2)	4.4 (2.4)	6.8 (5.0)	5.3 (5.1)	3.7 (3.0)	2.8 (1.7)