Cardiorespiratory and perceptual responses to self-regulated and imposed submaximal arm–leg ergometry

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Original citation & hyperlink:
Hill, M, Talbot, C, Puddiford, M & Price, M 2018, 'Cardiorespiratory and perceptual responses to self-regulated and imposed submaximal arm-leg ergometry' European Journal of Applied Physiology, vol. 118, no. 5, pp. 1011-1019.
https://dx.doi.org/10.1007/s00421-018-3838-7

DOI 10.1007/s00421-018-3838-7
ISSN 1439-6319
ESSN 1439-6327

Publisher: Springer

Title: Cardiorespiratory and perceptual responses to self-regulated and imposed submaximal arm-leg ergometry

Authors

Mathew Hill[1,2], Christopher Talbot[2], Michael Puddiford[2], Michael Price[1]

Affiliations

[1] Faculty of Health and Life Sciences, Coventry University, Priory Street, Coventry, CV1 5FB, UK

[2] Ageing Research Centre, University of Northampton, Boughton Green Road, Northampton, NN2 7AL, UK

Corresponding author

Dr. Mathew Hill
Whitefriars Street
School of Life Sciences
Coventry University
CV1 2DS
Matt.hill@coventry.ac.uk

ABSTRACT

Purpose This study compared cardiorespiratory and perceptual responses to exercise using self-regulated and imposed power outputs distributed between the arms and legs. **Methods** Ten males (age; 21.7 ± 3.4 years) initially undertook incremental arm-crank ergometry (ACE) and cycle ergometry (CYC) tests to volitional exhaustion to determine peak power output (W_{peak}). Two subsequent tests involved 20-min combined arm-leg ergometry (ALE) trials, using imposed and self-regulated protocols, both of which aimed to elicit an exercising heart rate of 160 beats·min^{-1}. During the imposed trial, arm and leg intensity were set at 40% of each ergometer-specific W_{peak}. During the self-regulated trial, participants were asked to self-regulate cadence and resistance to achieve the target heart rate. Heart rate (HR), oxygen uptake ($\dot{V}O_2$), pulmonary ventilation ($\dot{V}_E$) and ratings of perceived exertion (RPE) were recorded continuously. **Results** As expected, there were no differences between imposed and self-regulated trials for HR, $\dot{V}O_{2,}$ and $\dot{V}_E$ (all $P \geq 0.05$). However, central RPE and local RPE for the arms were lower during self-regulated compared imposed trials ($P \leq 0.05$). Lower RPE during the self-regulated trial was related to preferential adjustments in how the arms (33 ± 5 % W_{peak}) and legs (46 ± 5 % W_{peak}) contributed to the exercise intensity. **Conclusions** This study demonstrates that despite similar metabolic and cardiovascular strain elicited by imposed and self-regulated ALE, the latter was perceived to be less strenuous, which is related to participants doing more work with the legs and less work with the arms to achieve the target intensity.

Key words: combined arm-leg ergometer, arm-cranking, concurrent exercise, whole body exercise, energy expenditure

ABBREVIATIONS

ALE – Arm-leg ergometry

ANOVA – analysis of variance

ACE – Arm-crank ergometry

CYC – Cycle ergometry

d - Cohen's *d* effect sizes

HR – Heart rate

RER – Respiratory exchange ratio

$\mathrm{RPE}_{\mathrm{C}}$ – Central rating of perceived exertion

$\mathrm{RPE}_{\mathrm{ARMS}}$ – Ratings of perceived exertion for arm musculature

$\mathrm{RPE}_{\mathrm{LEGS}}$ – Ratings of perceived exertion for leg musculature

$\dot{V}_{\mathrm{E}}$ – Pulmonary ventilation

$\dot{V}\mathrm{O}_2$ – Oxygen uptake

$\dot{V}\mathrm{O}_{2\mathrm{peak}}$ – Peak oxygen uptake

$\mathrm{W}_{\mathrm{peak}}$ – Peak power output

INTRODUCTION

When prescribing exercise for weight control or cardiorespiratory conditioning/rehabilitation, it is desirable to elicit a large metabolic load without imposing excessive cardiovascular or subjective strain (Gutin, Ang and Torrey 1988). A range of ergometers are available across a number of exercise modes that vary in their support of body mass and active skeletal musculature involved, including stair-steppers (Zeni, Hoffman and Clifford 1996), elliptical cross-trainers (Mier and Feito 2006), rowers (Hagerman et al. 1978), arm ergometers (Sawka 1986), leg ergometers (Kravitz et al. 1997), and arm-leg ergometers (Eston and Brodie 1986). Although all modes of exercise lead to increased caloric expenditure, different physiological responses exist between exercise modes utilising the arms, legs and those that use the arms and legs concurrently (Secher et al. 1977).

Historically, the vast majority of research that has examined the physiological responses to combined arm and leg ergometry (ALE) have been of an of an incremental nature, with a specific focus on comparing limitations in peak oxygen uptake ($\dot{V}O_{2peak}$) with exclusive arm-crank ergometry (ACE) and cycle ergometry (CYC) (Astrand and Saltin 1961; Bergh et al. 1976; Gleser, Horstman and Mello 1974; Hagan et al. 1983; Nagle, Richie and Giese 1984; Secher et al. 1974; Stenberg et al. 1967). Although previous research in this area have yielded mixed results, studies report relatively modest increases in $\dot{V}O_{2peak}$ (6-14 %) when combining ACE and CYC compared to CYC only (Gleser et al. 1974; Nagle et al. 1984; Reybrouck, Heigenhauser and Faulkner 1975; Secher et al. 1974). Nevertheless, the maximal exercise protocols in these studies were used as a model for the demonstration of physiological limitations to $\dot{V}O_{2peak}$, and as such, demonstrate little relevance to steady-state efforts experienced during typical training sessions.

Comparatively little is known about submaximal responses to ALE, despite the potential practical benefits that might be achieved from combining ACE and CYC in increasing caloric expenditure (Gutin et al. 1988). Unfortunately, the current arm-leg exercise database has failed to support such a theory. For example, early work by Eston and Brodie (1986) reported that combined ALE elicited the same cardiorespiratory and perceptual responses as CYC when performed at the same power output (49, 74 and 98 W). It was later reported that adding ACE to CYC for the generation of a given power output (25 – 175 W) results in a reduction in ratings of perceived exertion (RPE), and a small but significant increase in $\dot{V}O_2$ compared to when all the work was done with the legs (Hoffman et al. 1996). In studies comparing energy expenditure between different modes of exercise, ALE typically elicits a lower $\dot{V}O_2$ and HR compared to stair-stepping, treadmill running, rowing, cycling and cross-country skiing (Kravitz et al. 1997; Zeni et al. 1996). Accordingly, consensus has not been reached concerning the effects of adding submaximal ACE to CYC in eliciting a greater cardiorespiratory stimulus than leg CYC alone. The aforementioned studies examining submaximal responses to ALE utilised a single exercise device (i.e. Schwinn Airdyne®) which couples arm and leg movements to a single resistance mechanism. Therefore, both foot pedals and arm levers move together when one or the other is in operation (e.g. when one leg extends, the contralateral arm also extends). One major drawback of this approach is that the design of this type of ergometer does not allow for the differentiation of power output of the arms from that of the legs. Similarly, it is not possible to regulate the amount of arm or leg work done. Thus, participants could theoretically complete the exercise bout with very little or too much arm work. Another problem with this approach is that the only way to increase power output on the Airdyne® is to increase cadence, which may elicit ceiling effects in the production of higher exercise intensities.

We propose that the use of separate ergometers may enable individuals to manipulate the contribution of the upper or lower body, thus making it easier to sustain a given energy expenditure for a pronged period. In the only known study which has investigated cardiorespiratory and perceptual responses to submaximal ALE using separate arm and leg ergometers, Gutin et al. (1988) demonstrated marked increases in $\dot{V}O_2$ when 10% or 25% of the power output (160 W) was done by the arms compared to when all work was done by the legs, while RPE remain unchanged. These novel findings suggest that assigning some of the power output to the arms may allow a greater metabolic load to be maintained with no greater perceptual strain. In the absence of a rich literature base examining submaximal responses to combined ALE using separate ergometers, further understanding of the physiological and perceptual responses to this type of novel exercise is necessary. Given that regulation of exercise intensity is typically achieved by altering cadence or resistance, we were interested to know how individuals self-regulated these factors on separate arm and leg ergometers to achieve a target intensity (i.e. 160 beats·min^{-1}) and compare this to when these factors were fixed. Both self-regulated and imposed protocols were designed to elicit a target exercise intensity (i.e. 160 beats·min^{-1}). We hypothesised that similar cardiorespiratory responses would be observed between trials. However, we further hypothesised that when participants could self-select cadence and resistance to achieve the target intensity, RPE would be lower.

2. MATERIALS AND METHODS

2.1 Participants

Ten physically active, non-specifically trained males (age, 21.7 ± 3.4 years; mass, 73.6 ± 8.7 kg; height, 1.81 ± 0.05 m) volunteered to participate in the study. The study was carried out in accordance with the guidelines outlined in the declaration of Helsinki (1964) and the study objectives and procedures were approved by the institutional ethics committee. Participants completed a pre-screening medical questionnaire before providing written informed consent to participate. None of the participants reported cardiovascular or pulmonary diseases, orthopaedic pathology or musculoskeletal dysfunctions.

2.2 Preliminary tests

To determine each individual's ergometer-specific peak power output (W_{peak}), participants completed individual maximal incremental step tests on an ACE and CYC. Maximal tests were completed at the same time of day to avoid circadian rhythm effects, but separated by a minimum 72 h (Hill et al. 2014). Exercise tests were completed in a counter-balanced order. Both tests consisted of an incremental protocol on a mechanically braked ergometer (Monark, 824E, Ergomedic, Sweden). The CYC protocol started at a power output of 70 W with increments of 35 W every 4 min for the first four stages, followed by 3-min increments until volitional exhaustion. The ACE protocol involved an initial power output of 35 W, with increments of 20 W every 4 min for the first four stages, followed by 2-min increments thereafter until volitional exhaustion. We used 4 minute stages for ACE and CYC to aid accurate prediction of submaximal exercise intensities in subsequent protocols. For the ACE 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-cranking trials were performed in a seated position (knees flexed to 90º) without torso restraint. A cadence of 70 $\text{rev}\cdot\text{min}^{-1}$ 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 ($\dot{V}O_2$), carbon dioxide ($\dot{V}CO_2$), pulmonary ventilation ($\dot{V}_E$) and respiratory exchange ratio (RER). Expired gas data were averaged over the final 20 sec of each incremental stage and prior to reaching volitional exhaustion. 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_{ARMS} and RPE_{LEGS}) 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.

2.3 Arm-leg ergometry procedures

Participants performed ALE while seated on a cycle ergometer. As there was no mechanical coupling between the ergometers for the upper and lower limbs, participants could crank both ergometers independently. 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 (Fig. 1). The horizontal position of the leg ergometer in the sagittal plane was adjusted to ensure that participants elbows were slightly flexed when the arm was at the furthest point of the duty cycle. Seat height on the cycle ergometer was the same as W_{peak} trials.

****** Figure 1 about here ******

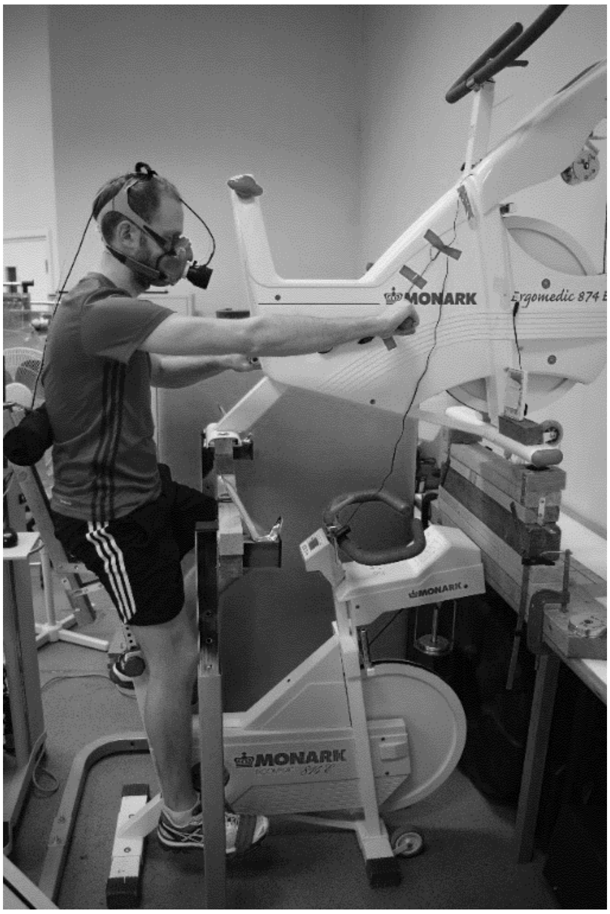

Fig. 1 Participant exercising with separate arm and leg ergometers (ALE) during the experimental tests

2.4 Familiarisation to arm-leg ergometry

Prior to self-regulated and imposed experimental trials, all participants completed a practice trial to ensure familiarisation to the combined ALE ergometer. Following a 4-min warm up at 35 W and 70 W for the arms and legs respectively, participants exercised for 16 min at 40% of individual's ergometer-specific W_{peak} (ACE, 50 ± 11 W; CYC, 96 ± 15 W). Participants were asked to maintain a cadence of 70 $rev \cdot min^{-1}$ for both the arms and legs. The principal investigator continually monitored cadence. If arm or leg cadence fluctuated more than 10 $rev \cdot min^{-1}$ from the imposed cadence, the experimenter instructed participants to either speed up or slow down until they could maintain a consistent cadence.

2.5 Imposed ALE trial

At least 72 h after the familiarisation trial, in a counter-balanced order, participants visited the laboratory on a further two occasions to perform 20-min self-regulated and imposed combined ALE trials. The imposed ALE trial initially began with a 4-min warm-up at 35 W and 70 W for the arms and legs, respectively. The power output was then adjusted to 40% of the individual's ergometer-specific W_{peak}

for the 5th minute of the exercise and fixed for the remaining 15 min. This intensity was chosen to elicit an exercising HR of ~160 beats·min^{-1}, which was determined by prior pilot testing and confirmed in the familiarisation trial. Participants were instructed to maintain a cadence of 70 rev·min^{-1} for both the arms and legs. The cadence display screen for the arms and legs were positioned on the cycle ergometer handle bars.

2.6 Self-regulated ALE trial

As with the imposed trial, the self-regulated trial initially began with a 4-min warm up at 35 W and 70 W for the arms and legs, respectively. To match protocols and ensure that all participants started at the same relative intensity during the self-regulated trial and for comparative purposes with the imposed trial, we adjusted the workload to 40% of individual's ergometer-specific W_{peak} from minutes 4 to 5 of the protocol. Participants were instructed that they would have the opportunity to adjust resistance for 1 min at the 5, 10 and, 15 min time points during the test to achieve an exercising HR of 160 beats·min^{-1}. Heart rate was displayed on a screen at ~1 m from participants at eye level. If HR fluctuated by 10 beats·min^{-1} from the target intensity, the experimenter instructed participants to either reduce or increase the intensity. Participants were also instructed that they could adjust arm and leg cadence *ad libitum* throughout the test. The cadence display screen for the arm and leg ergometers were covered so that participants were not aware of the power output or cadence. All adjustments to resistance were made by the principal investigator, who asked participants if they would like the power output to be 'harder', 'easier' or 'the same' for the arms and legs. The adjustments requested by the participant were made in 100 g (arms) or 200 g (legs) increments. For both trials, $\dot{V}O_2$ and $\dot{V}_E$ were averaged in the last 20 sec of each 5 min period with HR and overall RPE recorded at the end of each 5 min period. Local RPE for the arms and legs were recorded at the 10, 15, and 20 min time points.

2.6 Statistical analysis

Data were analysed using IBM version 24.0 (SPSS Inc., Chicago, IL). For all analyses, normality (Shapiro–Wilk Test) and homogeneity of variance/sphericity (Mauchly Test) were checked prior to undertaking parametric tests. Paired *t*-tests were carried out to determine differences in peak physiological responses between ACE and CYE exercise tests. A two-way analysis of variance (ANOVA) with repeated measures on both factors (e.g. *treatment*; self-regulated and imposed × *time*; 5, 10, 15 and 20-min) was conducted to examine differences in cardiorespiratory and perceptual responses to combined ALE using self-regulated and imposed workloads. Power output and cadence during ALE trials were analysed by a three-way ANOVA (e.g. *treatment*; self-regulated and imposed × *time*; 5, 10, 15 and 20-min × *mode*; ACE and CYC). Post hoc analyses with the Bonferroni-adjusted α were conducted to determine comparisons, which were statistically significant. For ANOVA, effect sizes are reported as partial eta-squared value (η^2) where appropriate. Cohen's *d* effect sizes are reported for pairwise comparisons, where (*d*) = 0.2, 0.6, 1.2 and 2.0 indicated small, medium, large and very large effects, respectively. All values are expressed as mean ±SD. Statistical significance was accepted at $P \leq 0.05$.

3. RESULTS

3.1 Preliminary tests

Significant differences were observed between ACE and CYC for absolute and relative $\dot{V}O_{2peak}$ (P = 0.001, d = 1.2), W_{peak} ($P \leq 0.001$, d = 3.2), $\dot{V}_{Epeak}$ (P = 0.001, d = 0.8) and HR_{peak} (P = 0.001, d = 1.6). With the exception of peak local RPE (P = 0.343, d = 0.1) and RPE_C (P = 0.121, d = 0.1) where no differences were observed (Table 1), all variables were significantly greater for CYC compared to ACE.

****** Table 1 about here ******

Table 1 Peak cardiorespiratory and perceptual responses to ACE and CYC

Variable	**CYC**	**ACE**
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	3.17 ± 0.46 *	2.68 ± 0.34
$\dot{V}O_{2peak}$ ($ml \cdot kg \cdot min^{-1}$)	43.3 ± 4.0 *	36.7 ± 4.5
Peak Power Output (W_{peak})	235 ± 39 *	128 ± 28
$\dot{V}E_{peak}$ ($L \cdot min^{-1}$)	140.0 ± 19.9 *	123.6 ± 20.6
HR_{peak} ($beats \cdot min^{-1}$)	196 ± 6 *	187 ± 5
RPE_L	20 ± 0.0	20 ± 0.0
RPE_C	19 ± 1.0	18 ± 1.0

*significantly different to ACE ($P \leq 0.05$)

3.2 Self-regulated and imposed trials

Comparisons of cardiorespiratory responses between test conditions are presented in Fig. 2. $\dot{V}O_2$ ($F_{(3,72)}$ =.123, P =0.578, η^2 = .005), $\dot{V}_E$ ($F_{(3,72)}$ =.285, P =0.669, η^2 = .012) and HR ($F_{(3,72)}$ =.065, P =0.336, η^2 = .003) were not different between self-regulated and imposed trials. However, there was a main effect between self-regulated and imposed trials for RPE_{ARMS} (P =0.002, η^2 = .124) and RPE_C (P =0.001, η^2 = .196). Post hoc analysis revealed that RPE_{ARMS} was greater during imposed compared to self-regulated trials at minutes 15 and 20 (both d = 1.0) (Fig. 2). Similarly, RPE_C was greater during imposed compared to self-regulated trials at minutes 15 and (d = 2.0) 20 (d = 3.0) (Fig. 2). Main effects of time were observed for all measures ($P \leq 0.05$). The HR and $\dot{V}O_2$ for 20-min ALE were not significantly different between self-regulated and imposed trials when expressed as a percentage of upper and lower body peak tests (all $P \geq 0.05$) (Table 2).

****** Figure 2 about here ******

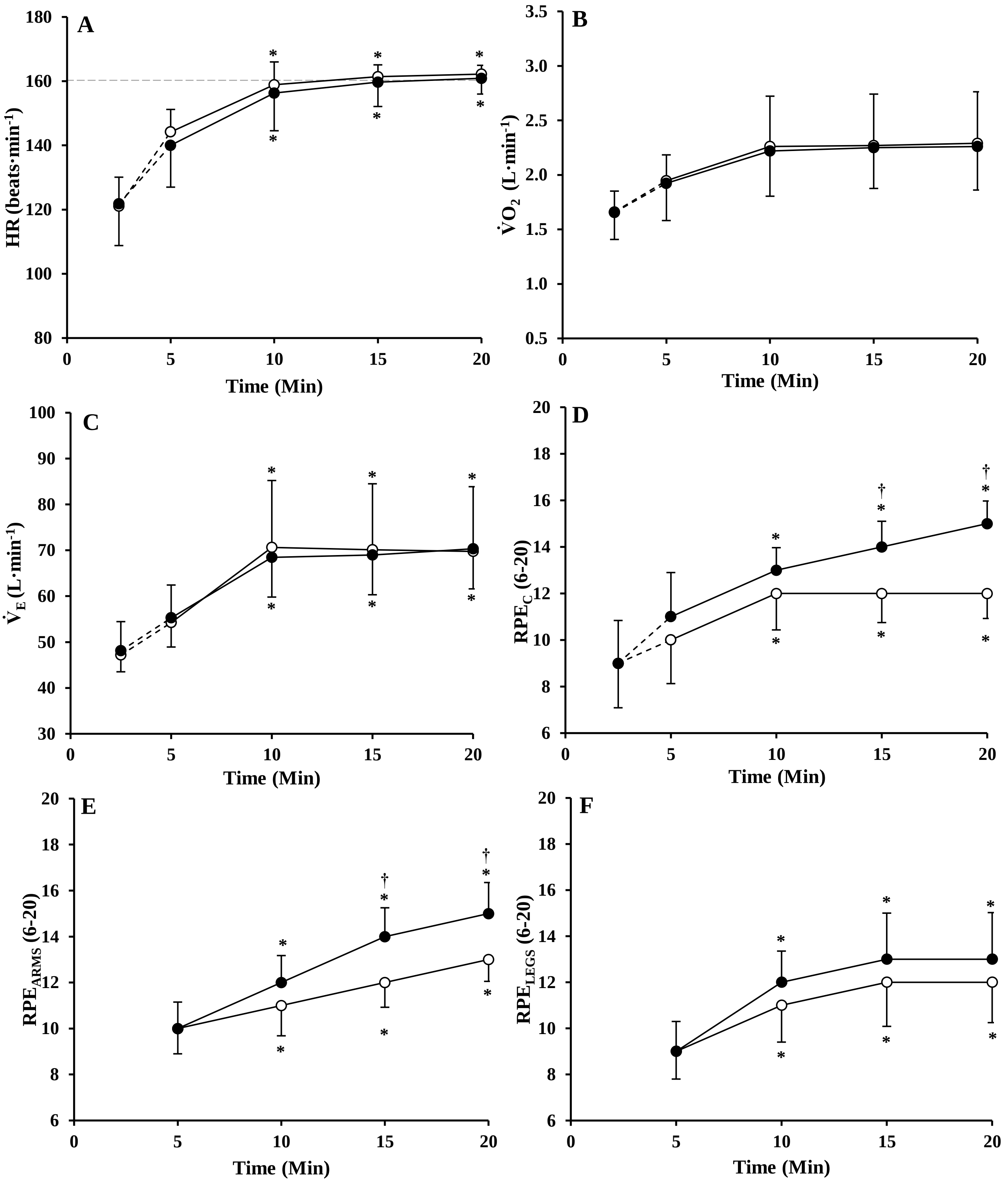

Fig. 2 Comparisons between self-regulated (○) and imposed (●) ALE for oxygen uptake (A), heart rate (B), pulmonary ventilation (C), central rating of perceived exertion (D), arm rating of perceived exertion (E) and leg rating of perceived exertion (F). NB; Horizontal dashed grey line in figure A

represents target HR. *significantly different to 5-min (*P* ≤0.05). †Significantly different to self-regulated trial at same time point (*P* ≤0.05)

****** Table 2 about here ******

Table 2 Heart rate and oxygen update during self-selected and imposed ALE protocols expressed as a percentage of peak upper and lower body HR and VO_2

Variable		**CYC**	**95% CI**	**ACE**	**95% CI**
% HR_{peak}	Self-regulated	82.7 ± 2.9	80.9 - 84.5	86.2 ± 3.2*	84.2 - 88.2
	Imposed	82.2 ± 2.5	80.7 - 83.7	85.1 ± 3.2*	83.1 - 7.1
% $\dot{V}O_{2peak}$	Self-regulated	71.2 ± 14.0	62.5 - 79.9	84.3 ± 18.5*	73.3 - 95.3
	Imposed	71.1 ± 7.1	66.6 - 75.5	84.3 ± 12.0*	77.0 - 91.7

3.3 Power output

Results from the ANOVA for power output revealed a non-significant treatment × mode × time interaction ($F_{(3,144)}$ =69.993, *P* =0.875, η^2 = .005). However, there was a significant treatment × mode interaction ($F_{(3,144)}$ =11.322, *P* =0.001, η^2 = .073). Post hoc analyses revealed that absolute power output for ACE was significantly lower during self-regulated compared to imposed trials at 10-min (*d* = 0.9), 15-min (*d* = 1.0) and 20-min (*d* = 0.9) of ALE (*P* ≤0.05). Conversely, CYC power output was significantly greater during self-regulated compared to imposed trials at 10-min (*d* = 0.6), 15-min (*d* = 0.7) and 20-min (*d* = 0.6) (*P* ≤0.05). Total power output was the same for self-regulated and imposed trials (*P* ≥0.05) (Fig. 3). Although the treatment × mode × time interaction for cadence was not significant ($F_{(3,144)}$ =1.746, *P* =0.160, η^2 = .035), there were significant treatment × mode ($F_{(1,144)}$ =85.913, *P* ≤0.001, η^2 = .374) and time × mode ($F_{(3,144)}$ =2.606, *P* =0.45, η^2 = .052) interactions. Post hoc analyses revealed that compared to the impose trial, where there were no differences in cadence between the arms and legs (*P* ≥0.05), individuals significantly reduced ACE cadence, and increase CYC cadence during self-regulated trials (Fig. 4). There were no interactions or main effects for resistance during ALE (*P* ≥0.05), with only n=2 participants opting to adjust this factor.

****** Figure 3 about here ******

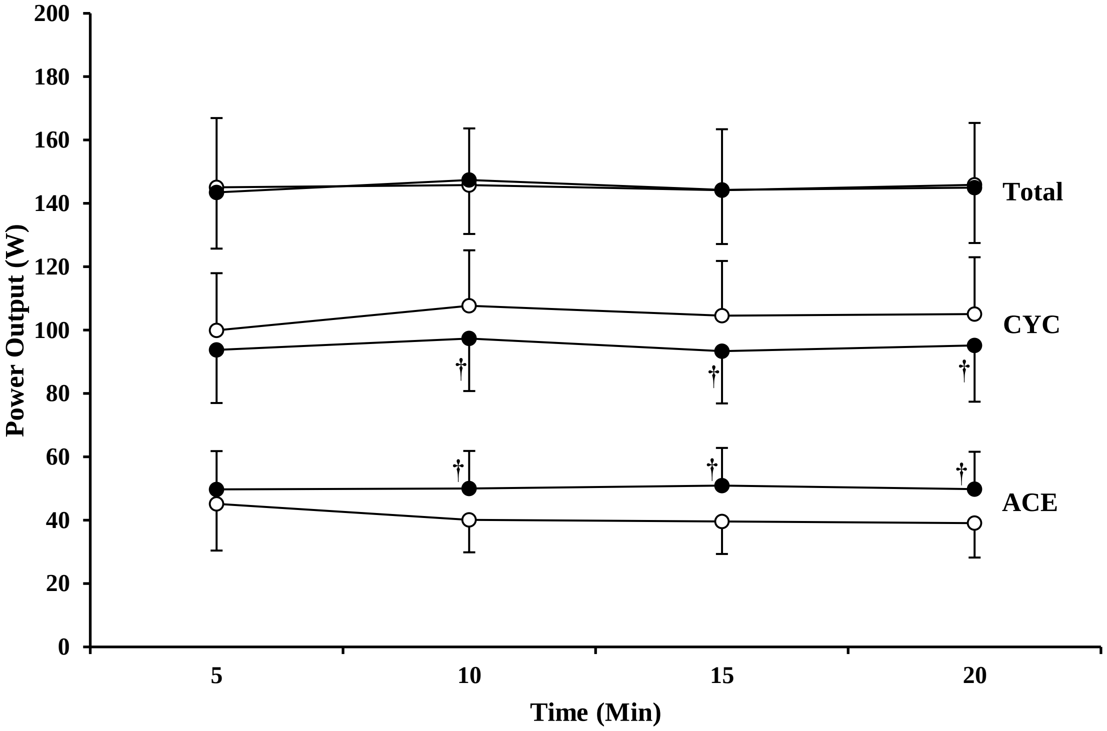

Fig. 3 Comparisons between self-regulated (○) and imposed (●) power output during ALE for ACE, CYC and total (ACE + CYC). †Significantly different to self-regulated trial at same time point

****** Figure 4 about here ******

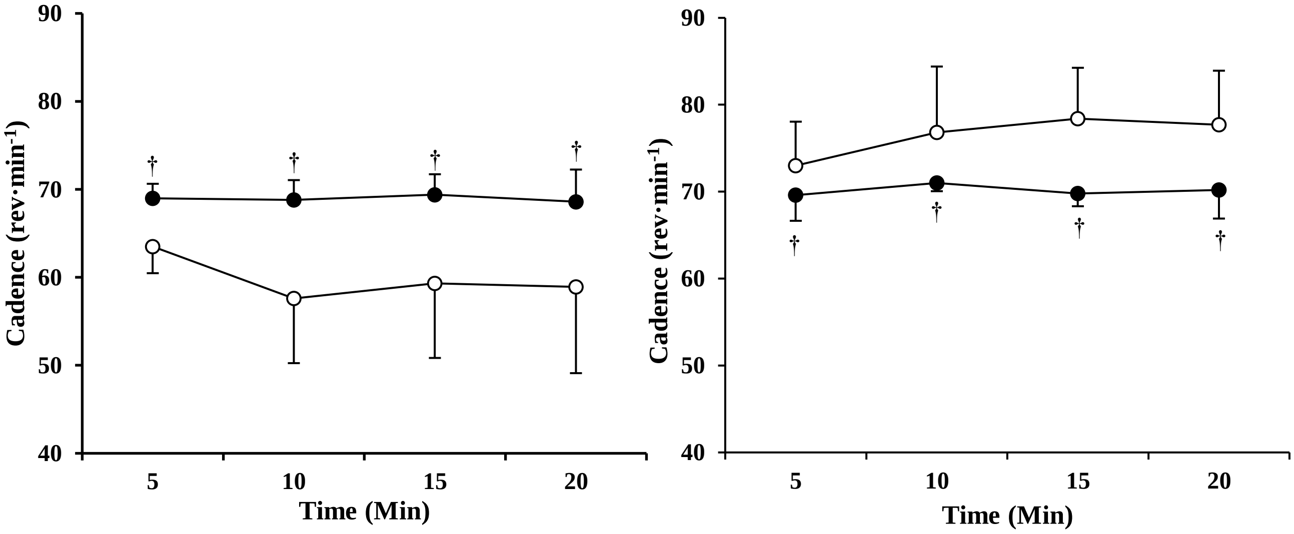

Fig. 4 Comparisons between self-regulated (○) and imposed (●) for cadence during ALE for ACE (left) and CYC (right). †Significantly different to self-regulated trial at same time point

DISCUSSION

The purpose of this study was to compare the cardiorespiratory and perceptual responses to combined ALE using self-regulated and imposed power outputs distributed between the arms and legs. An important distinction and strength of this study is the utilisation of two separate ergometers where the arms and legs were not coupled to the same resistance mechanism. Such an approach ensured that we could measure and regulate the relative contribution of the arms and legs to the total exercise intensity. The current findings indicate that self-regulating the distribution of work between the arms and legs to achieve a target intensity was perceived to be less strenuous than the imposed trial, despite similar cardiorespiratory responses between conditions. The lower RPE during the self-regulated trial was related to participants preferentially performing more work with the legs and less work with the arms to achieve the target intensity. These novel findings provide an important extension to the current ALE literature by demonstrating that individuals can delay localised fatigue of the arms or legs by modulating the contribution of the upper or lower body musculature to achieve a given exercise intensity.

An important distinction to make in the present study is the context in which we use the term "self-regulated" exercise. Traditionally, self-regulated (or self-selected) exercise allows individuals to choose their preferred exercise intensity (Haile, Gallagher and Robertson 2015). However, in the present study, the only factors that were self-regulated were the cadence and resistance of the exercise (i.e. power output). Therefore, while both exercise conditions were, by definition, "imposed", they differed in the way the target intensity could be achieved. While we acknowledge that this approach fails to consider individual's preference for certain exercise intensities, it was not the aim of this study to investigate cardiorespiratory and perceptual responses to self-selected ALE in the traditional sense. Instead, this study was designed to test how participants modulated the contribution of the arms and legs to achieve the target exercise intensity. Given our study design, we initially hypothesised that the self-regulated protocol would result in similar cardiorespiratory responses but lower RPE than when exercise cadence and resistance were imposed. The results support this hypothesis. During 20-min of ALE, both central and local RPE were consistently 1 – 3 points lower during self-regulated compared to imposed trial. However, as expected, there were no differences in $\dot{V}O_2$, $\dot{V}_E$ and HR between treatments. The reduced RPE at the same physiological strain between conditions is explained by modulated distribution of work done by the arms and legs. During the self-regulated trial participants reduced cadence for the ACE component while increasing cadence for the CYC component, resulting in a ~7% reduction in ACE power output and a ~5% increase in CYC power output. However, total power output (i.e., arms plus legs) was the same between imposed and self-regulated protocols. These findings may indicate a potential positive perception of the "self-regulated" exercise, or conversely negative perception of the imposed exercise (Parfitt et al. 2000).

Several factors could be responsible for the altered distribution of work between the arms and legs. Firstly, differences in the amount of cycling and arm-crank experience should be taken into account.

For example, participants in the present study were less familiar with ACE compared to CYC and may have felt more comfortable increasing leg cadence and resistance. Another possibility is different effects of increasing cadence in one muscle group on another exercising muscle group (i.e., none reciprocal response). For example, Sakamoto et al. (2007) showed that during ALE, changes in arm cadence had no effect on leg cadence, while arm cadence was significantly decreased when leg cadence was either increased or decreased. According to Sakamoto et al. (2014) when individuals adjust leg cadence to a set value, volitional control of arm cycling might be attenuated and descending inputs from supraspinal areas to the spinal motor system for arm cycling might be reduced. Overall, the perception of "less effort" during the self-regulated trial is an important finding, because the use of uncoupled ergometers 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.

Studies using mechanically coupled arm-leg devices (i.e. Schwinn Airdyne®) have yielded mixed results. For example, Hoffman et al. (1996) reported a small increase in $\dot{V}O_2$ for a given power output with combined ALE compared to CYC, while Eston and Brodie (1986) concluded that $\dot{V}O_2$ at a given power output for these modes was the same. As already discussed, the design of this type of ergometer does not allow for the differentiation or regulation of power output of the arms from that of the legs. Conversely, when ACE was added to CYC using separate uncoupled ergometers (i.e. as in the present study), Gutin et al. (1988) showed a marked increase in $\dot{V}O_2$ (~0.3 L·min^{-}1) compared to leg only CYC, despite similar mean power outputs (159 W vs 160 W, respectively) between modes. These findings provide clear evidence that combined ALE using separate ergometers for the arms and legs reduces the gross efficiency of the movement. From a clinical perspective, ALE may be more readily tolerated by a broader range of people by allowing them to burn more calories at relatively low level of perceived effort. For instance, an RPE of 12-13 should typically equate to ~40 – 59 % $\dot{V}O_{2peak}$ or ~55 – 69% HR_{peak} (Buckley and Eston 2006). Indeed, Zeni et al. (1996) reported that ALE (using the Schwinn Airdyne®) at an RPE of 13 elicited a relative HR_{peak} and $\dot{V}O_{2peak}$ of ~68% and 50%, respectively. However, in the present study, an RPE of 12-13 elicited % HR_{peak} (~82%) and % $\dot{V}O_{2peak}$ (~71%) responses that should correspond to a significantly greater RPE of ~14 – 16 (Table 2) (Buckley and Eston 2006). It is not clear why there appears to be a greater physiological strain (% of $\dot{V}O_{2peak}$) experienced during ALE using separate ergometers (i.e Gutin et al. 1988) compared to ALE using mechanically coupled ergometers (i.e. Eston and Brodie 1986; Hoffman et al. 1996). We speculate that more energy may be used to stabilise the trunk when both the arms and legs are not synchronised, as in the present study. When the arms and legs are synchronised (i.e. Schwinn Airdyne®), there may be less contribution to stabilise the torso. Further, the use of the arms in the lower position, as with the Schwinn Airdyne®, may be more efficient (Gutin et al. 1988). These factors remained to be investigated.

Limitations

The present study is not without limitations. First, we included only one formal familiarisation session for ALE, which may take longer than for exclusive ACE or CYC, as the movement is more complex and less familiar. Despite this, the consistent physiological responses between the self-regulated and imposed trial suggest that one formal familiarisation may be enough for repeatable cardiorespiratory responses, although this needs to be confirmed with future research. Second, we included only healthy young male adults which preclude us from generalising our findings to females and/or older age groups. In addition, the self-regulated trial only allowed autonomy of cadence and resistance of the exercise, but not the exercise intensity. While we acknowledge the inherent limitations of referring to this condition as “self-regulated”, this was the study design that allowed us to answer our research questions.

CONCLUSION

In conclusion, the results of this study demonstrate that that the utilisation of separate arm and leg ergometers during ALE appears to elicit a relatively greater physiological response than is perceived (% of $\dot{V}O_{2peak}$). Despite similar cardiovascular (i.e. 160 beats·min^{-1}) and metabolic responses, the self-regulated condition was perceived to be less strenuous than the imposed condition, which is related to participants performing more work with the legs and less with the arms to achieve the target intensity. From a practical perspective, allowing participants to “take the edge off” the exercise may offer individuals a greater effort/return ratio.

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