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Regulating exercise intensity using ratings of perceived exertion during arm and leg ergometry

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Abstract The purpose of this investigation was to examine the validity of regulating exercise intensity using ratings of perceived exertion (RPEs) during arm crank and leg cycle exercise at 50 and 70% peak oxygen consumption ($\dot{V}O_{2peak}$). Ten men and seven women [26 (1) years old; mean (SE)] participated in this study. Each subject completed a maximal estimation trial and two submaximal exercise bouts (production trials) on both an arm and leg ergometer. During each maximal estimation trial, subjects were asked to give a RPE for each stage of the exercise. RPEs, heart rates (HR), and power outputs (PO) equivalent to 50 and 70% $\dot{V}O_{2peak}$ for each exercise mode were then estimated from plots of RPE versus oxygen consumption ($\dot{V}O_2$), HR versus $\dot{V}O_2$, and PO versus $\dot{V}O_2$, respectively. During the submaximal trials, subjects were instructed to select workloads on an arm and leg ergometer that produced the previously estimated RPEs. Comparisons were made for $\dot{V}O_2$, HR, and PO between the estimation and production trials for each mode at each exercise intensity. HR did not differ between the trials at either 50 or 70% $\dot{V}O_{2peak}$ during arm and leg ergometry. In addition, $\dot{V}O_2$ and PO did not differ between the trials at either 50 or 70% $\dot{V}O_{2peak}$ during arm ergometry and at 50% $\dot{V}O_{2peak}$ during leg ergometry. However, these two parameters were lower ($P < 0.05$) during the production trial [1.88 (0.15) $l \cdot min^{-1}$ and 89.1 (10.1) W, respectively] as compared to the estimation trial [2.08(0.14) $l \cdot min^{-1}$ and 102.4 (6.5)W, respectively] during leg ergometry at 70% $\dot{V}O_{2peak}$. In conclusion, using RPEs to regulate exercise intensity is physiologically valid during arm ergometry at both 50 and 70% $\dot{V}O_{2peak}$ and during leg ergometry at 50% $\dot{V}O_{2peak}$. However, this prescriptive approach remains questionable during leg cycle exercise at 70% $\dot{V}O_{2peak}$.

Key words Exercise prescription · Perceptions of exertion · Exercise mode · Intensity

Introduction

Ratings of perceived exertion (RPEs) have been shown to be a valid indicator of the degree of physical strain experienced during dynamic exercise (Borg 1982). Previous research has demonstrated a linear relationship between the RPE as measured by the Borg 15-point category scale (Borg 1970) and heart rate (HR) during various types of exercise including cycling, walking, and running (Edwards et al. 1972; Gamberale 1972; Lollgen et al. 1977; Skinner et al. 1973). This relationship indicates that RPEs could be used as an alternative to HR to prescribe exercise intensity. The use of RPEs for exercise prescription has a unique advantage in that this approach is easy for the exerciser to learn and requires no physiological monitoring or interruption of activity. This approach is also important for patients taking chronotropic medications that alter a normal HR-exercise intensity relationship.

In clinical practice, exercise prescription using RPEs often uses an estimation-production procedure (Dishman 1994; Noble 1982; Noble and Robertson 1996). This procedure requires an individual to estimate his/her perception of effort during a graded exercise test (GXT) and then to produce a previously estimated exertion by titrating the exercise intensity during subsequent training sessions. A number of studies have employed this procedure to validate the use of RPE for exercise prescription by using oxygen uptake ($\dot{V}O_2$), HR, and/or power output (PO) as criterion variables (Dunbar et al. 1992, 1994; Glass et al. 1992). Dunbar et al. (1992) found that both the HR and $\dot{V}O_2$ corresponding to a prescribed RPE did not differ between estimation and

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production trials during treadmill exercise at 50% maximal $\dot{V}O_{2max}$ and during leg cycle exercise at 50 and 70% peak $\dot{V}O_2(\dot{V}O_{2peak})$. Glass et al. (1992) also observed similarities in $\dot{V}O_2$ and HR between estimation and production trials during treadmill running at 75% HR reserve. Taken together, these findings suggest that the RPE system is a valid tool with which to regulate exercise intensity during leg cycling and running.

To date, the validation of estimation-production procedures for the perceptual prescription of arm crank exercise intensity has received limited attention. Arm crank exercise is a mode that is commonly chosen for endurance conditioning using the upper extremities in rehabilitative medicine (American College of Sports Medicine 1994; Sawka 1986). For example, individuals who suffer from lower extremity injuries often use arm crank exercise as a training mode to improve their cardiorespiratory fitness during the rehabilitation process. Due to the fact that arm crank exercise involves the upper extremities, monitoring exercise intensity by traditional HR palpation is difficult and its implementation would have to result in an interruption of the exercise. As such, the use of RPEs for exercise prescription during arm crank exercise becomes especially attractive because this approach can ensure a continuous attainment of the exercise stimulus. Interestingly, the only study conducted thus far using upper body exercise has shown the occurrence of a consistently higher HR during the production compared to the estimation trial in wheelchair-bound children and adults (Ward et al. 1995). This result casts some doubt as to the effectiveness of the RPE system for regulating exercise intensity during upper body exercise.

Therefore, the primary purpose of this study was to examine whether the RPE measured during an arm GXT can be used to produce accurately a target exercise intensity on an arm crank ergometer. The production accuracy was determined by comparing $\dot{V}O_2$, HR, and PO at a given RPE between estimation and production trials. Since this validation procedure was performed during leg cycle exercise, the secondary purpose of the study was to examine whether the production accuracy is affected by the amount of muscle mass involved during exercise.

Methods

Subjects

Ten male and seven female volunteers served as subjects for the study. All subjects were healthy, free from any current orthopedic injury and were not engaged in any type of competitive sport at the time of the investigation. They were informed of the purpose of the experiment and gave their written consent to participate. All experimental procedures were evaluated and approved by the Institutional Review Board for Human Subjects Experimentation at Rowan University. The physical and physiological characteristics of the subjects are presented in Table 1.

Experimental design

Each subject completed one maximal GXT (estimation trial) and two submaximal exercise bouts (production trials) on both a leg cycle ergometer (Monarch 818, Monark-Crescent, Varberg, Sweden) and an arm cranking ergometer which was modified from a cycle ergometer (Monarch 818). The use of this modified arm crank ergometer was to ensure the same flywheel diameter for both the arm crank and leg cycle exercises (Bohannon 1986). The two estimation trials were presented in a counterbalance sequence and were undertaken prior to the production trials. The four production trials were presented in a randomized order. Subjects were instructed to be in a minimum of 4-h post-absorptive state prior to each trial. A minimum of 48 h separated each trial and all trials were completed within a 3-week period.

Table 1 Physical and physiological characteristics of subjects. Values are expressed as the mean (SD). ($\dot{V}O_{2peak}$ Peak oxygen consumption)

Variables	Total ($n = 17$)	Males ($n = 10$)	Females ($n = 7$)
Age (years)	26 (4)	25 (4)	27 (8)
Height (cm)	172 (8)	176 (4)	166 (4)
Body mass (kg)	76 (16)	84 (16)	65 (20)
% Body fat	18.1 (8.2)	13.8 (9.5)	24.1 (7.8)
Leg $\dot{V}O_2$ peak ($l \cdot min^{-1}$)	2.94 (0.78)	3.45 (0.58)	2.21 (0.82)
Arm $\dot{V}O_2$ peak ($l \cdot min^{-1}$)	2.13 (0.74)	2.66 (0.45)	1.38 (0.70)

Familiarization trial

Prior to the experimental trials, each subject underwent a familiarization trial. During this trial, the subject read a brief set of perceptual scaling instructions. These instructions have been used in a previous investigation (Kang et al. 1996). Any questions concerning the procedures for rating the intensity of perceived exertion were answered at this time. The subject also performed both the 10-min arm crank and leg cycle exercises at 50 rpm and at a PO that elicited a HR of up to 150 beats min^{-1}. During these exercise trials, both low and high anchors for the RPE scale were established. The low anchor was equated with pedaling the ergometer at 50 rpm with no resistance on the flywheel. The high anchor was equated with the most demanding exercise or physical work experience that the subject could recall. A rating of 7 was assigned to the low standard and a rating of 19 to the high standard. Subjects were instructed to rate their physical exertion relative to these low and high anchors during the subsequent experimental trials. During this session, the subjects' percent body fat was also measured using a skinfold technique described previously by Pollock et al. (1980).

Estimation trials

During each estimation trial, the subject performed a continuous incremental protocol on an arm crank ergometer or a leg cycle ergometer. The protocol used for arm crank and leg cycle tests was similar to those reported previously (Åstrand 1965; Sawka et al. 1983). The test was preceded by a 5-min warm-up period. The initial PO was 25 W for the arm crank test and 50 W for the leg cycle test. For both tests, the PO was increased by 25 W every 2 min. The pedal/crank rate for both the arm and leg tests was 50 rpm, with the cadence guided by a metronome. The test was terminated when the subject voluntarily stopped owing to exhaustion, or when the subject was unable to maintain the initial pedal/crank rate for 15 consecutive seconds. All subjects were verbally encouraged to continue the exercise until volitional exhaustion. A plateau in $\dot{V}O_2$, which is defined as an increment in $\dot{V}O_2$ of less than 100 ml (Chaloupka et al. 1997), was not generally observed at peak exercise intensities in the arm tests. However, a plateau as well as a respiratory exchange ratio greater than 1.10 were shown in all of the leg tests. These findings were consistent with what we have reported previously (Kang et al. 1997). The $\dot{V}O_2$, HR and RPE were measured during the last 20 s of each minute of exercise throughout the test so that two measurements were made before each workrate increment. The $\dot{V}O_{2peak}$ was determined by averaging the two highest measures obtained. Since the respiratory valve prohibited a verbal rating response, the subject indicated a RPE value by using either a finger signal or head movement in response to prompts by the investigator. Best-fit linear regressions in which RPE, HR and PO were plotted as a function of $\dot{V}O_2$ during each ergometer test were calculated for each subject. The RPE, HR and PO corresponding to 50 and 70% of the mode-specific $\dot{V}O_{2peak}$ for each subject were then determined from plots of RPE versus $\dot{V}O_2$, HR versus $\dot{V}O_2$, and PO versus $\dot{V}O_2$, respectively.

Production trials

During each production trial, subjects were instructed to select the PO on either the arm cranking or leg cycle ergometer that produced previously estimated RPEs equivalent to 50% or 70% of the mode-specific $\dot{V}O_{2peak}$. All production trials were performed at a constant pedal/crank rate of 50 rpm. Immediately prior to each production trial, the subject was informed of the RPE that was estimated by the subject at either 50% or 70% of $\dot{V}O_{2peak}$ during the estimation trial. Following a 5-min low-intensity warm-up period, the subject performed an 8-min production trial. During the first 3 min of the production trial, the subject selected a PO by instructing the investigator to make resistance adjustments until the achieved exercise intensity produced the target RPE that was determined from the estimation trial. All resistance adjustments were verified verbally by the investigator. Subjects had no knowledge of the actual ergometer PO. For the remaining 5 min the subject exercised at the self-selected PO. During the last 2 min of each production trial, $\dot{V}O_2$ and HR were measured every minute and the average of the two measures for each variable was then used for subsequent data analysis. All exercise tests were conducted in the Exercise Science Research Laboratory at Rowan University. The mean barometric pressure and laboratory temperature were 755 mmHg and 22°C, respectively.

Measurements

$\dot{V}O_2$ was determined using a two-way T-shaped breathing valve (Hans Rudolph 2700, Hans Rudolph, Kansas City, Mo., USA and a Cardio-Pulmonary Exercise System (Q-Plex1, Quinton Instruments, Seattle, Wash., USA). Q-plex 1 calibrations included a carbon dioxide infrared absorption sensor (0–10% measurement range), an oxygen zirconia oxide sensor (10–35% measurement range), and a pneumotachometer (0–12 l/s flow range). HR was determined using a 12-lead, electrocardiogram tracing apparatus (EK-10, Siemens Burdick, Milton, Wis., USA). RPEs were measured using a Borg-15 point category scale (Borg 1970).

Statistical analysis

A dependent *t*-test was used to compare $\dot{V}O_2$, HR, and PO at a given RPE between estimation and production trials for each exercise mode at each exercise intensity. For all statistical tests, the level of statistical significance was set at $P < 0.05$.

Results

Oxygen uptake

During the arm crank exercise no differences in $\dot{V}O_2$ were found between the estimation and production trials at the RPE equivalent to both 50 and 70% $\dot{V}O_{2peak}$. During leg cycle exercise at the RPE equivalent to 50% $\dot{V}O_{2peak}$, no difference in $\dot{V}O_2$ was found between the estimation and production trials. During leg cycle exercise at the RPE equivalent to 70% $\dot{V}O_{2peak}$, however, $\dot{V}O_2$ was lower ($P < 0.05$) during the production as compared to the estimation trial, and the difference in $\dot{V}O_2$ between the two trials was 0.20 $l \cdot min^{-1}$ (Table 2).

Table 2 Differences (Δ) in oxygen uptake between estimation and production trials. Values are given as the mean (SE) and are expressed in $l \cdot min^{-1}$. A negative sign (–) indicates that the production value was lower than the target value

Exercise mode	Estimation trial	Production trial	Δ
Arm crank			
50% $\dot{V}O_{2peak}$	1.07 (0.09)	1.09 (0.13)	0.02
70% $\dot{V}O_{2peak}$	1.49 (0.13)	1.45 (0.15)	−0.04
Cycle			
50% $\dot{V}O_{2peak}$	1.47 (0.10)	1.36 (0.13)	−0.11
70% $\dot{V}O_{2peak}$	2.08 (0.14)	1.88 (0.15)	−0.20*

* Significantly different between estimation and production trials ($P < 0.05$)

Heart rate

There were no differences in HR observed between the estimation and production trials during arm crank or leg cycle exercise at the RPEs equivalent to both 50 and 70% $\dot{V}O_{2peak}$ and 70% $\dot{V}O_{2peak}$, respectively (Table 3).

Power output

During the arm crank exercise, no difference in PO was found between the estimation and production trials at the RPE equivalent to both 50 and 70% $\dot{V}O_{2peak}$. During leg cycle exercise at the RPE equivalent to 50% $\dot{V}O_{2peak}$, no difference in PO was found between the estimation and production trials. During leg cycle exercise at the RPE equivalent to 70% $\dot{V}O_{2peak}$, however, PO was lower ($P < 0.05$) during the production than the estimation trial and the difference in PO between the two trials was 11.3 W (Table 4).

Table 3 Differences (Δ) in heart rate between estimation and production trials. Data are given as the mean (SE) and are expressed in $beats \cdot min^{-1}$. A negative sign (–) indicates that the production value was lower than the target value

Exercise mode	Estimation trial	Production trial	Δ
Arm crank			
50% $\dot{V}O_{2peak}$	113 (4)	112 (6)	−1
70% $\dot{V}O_{2peak}$	136 (4)	135 (6)	−1
Cycle			
50% $\dot{V}O_{2peak}$	123 (4)	119 (4)	−4
70% $\dot{V}O_{2peak}$	148 (4)	143 (5)	−5

Table 4 Differences (Δ) in power output between estimation and production trials. Data are given as the mean (SE) and are expressed in W. A negative sign (−) indicates that the production value was lower than the target value

Exercise mode	Estimation trial	Production trial	Δ
Arm crank			
50% $\dot{V}O_{2peak}$	30.6 (4.3)	30.9 (5.8)	0.3
70% $\dot{V}O_{2peak}$	49.6 (5.3)	45.3 (5.8)	−4.4
Cycle			
50% $\dot{V}O_{2peak}$	64.6 (5.0)	57.1 (8.5)	−7.5
70% $\dot{V}O_{2peak}$	102.4 (6.5)	91.1 (10.1)	−11.3*

* Significantly different between estimation and production trials ($P < 0.05$)

Discussion

In the present study, we found no differences in $\dot{V}O_2$, HR and PO between estimation and production trials during arm crank exercise at RPEs equivalent to both 50 and 70% $\dot{V}O_{2peak}$. The similarities in these physiological criteria indicate that the RPE system is a valid tool with which to gauge exercise intensity during upper body exercise. Since palpating HR during arm crank exercise often results in exercise interruption, such a validation suggests that using RPE to regulate intensity is a practical alternative, allowing the individual to monitor exercise intensity while exercising continuously. The present finding is in disagreement with that of Ward et al. (1995) in which it was reported that HRs are consistently higher during the production than the estimation trial in wheelchair-bound children and adults. The differences in HR may be attributed to a difference in the exercise equipment used between the two trials. In their study, an arm ergometer was used during the estimation trial, whereas each subject's own wheelchair was used for the production trial. In the present study, the same arm crank ergometer was used for both the estimation and production trials. In addition, Ward et al. used an exercise protocol that involved progressive increases in brake resistance at a constant crank rate in the estimation trial. In the production trial, however, subjects were required to produce a wheelchair speed on a track that elicited a given level of exertion. It is possible that the difference in workload parameter demonstrated between the estimation and production trials (i.e., resistance vs speed) could have contributed to the difference in HR observed in their study.

We also found no differences in $\dot{V}O_2$, HR, and PO between estimation and production trials during leg cycle exercise at the RPE equivalent to 50% $\dot{V}O_{2peak}$. This finding is consistent with previous reports (Dunbar et al. 1992, 1994) and provides additional evidence to support the use of RPEs for regulating exercise intensity. During leg cycle exercise at the RPE equivalent to 70% $\dot{V}O_{2peak}$, however, $\dot{V}O_2$ and PO were significantly lower during the production than during the estimation trial. The mean $\dot{V}O_2$ that was produced was about 1 MET (metabolic equivalent) below the target value and represented approximately 64% $\dot{V}O_{2peak}$ instead of the target 70% $\dot{V}O_{2peak}$. There was a trend towards a lower HR during the production than during the estimation trial, and the mean HR that was produced was 5 beats min^{-1} below the target value. Nevertheless, the difference did not reach statistical significance. The lower $\dot{V}O_2$ and PO observed during the production than during the estimation trial indicate that our subjects underproduced the exercise intensity when they exercised at a moderate-to-high intensity. This underproduction was also observed in a study by Chow and Wilmore (1984). They found that the HR that was produced at the RPE equivalent to 75% HR reserve was significantly lower than what was previously estimated. In addition, data from Dunbar et al. (1992) also showed a consistent trend towards an underproduction of criterion variables such as $\dot{V}O_2$ and HR, especially during exercise at 70% $\dot{V}O_{2peak}$. The mechanism responsible for this inconsistency between estimation and production trials is unclear. It appears that as exercise intensity increases, factors other than cardiorespiratory and metabolic strain, such as increased metabolic acidosis and elevated body temperature, may become more important physiological mediators for exertional perceptions. In light of this inconsistency, it is recommended that the approach of regulating intensity by RPE be implemented in conjunction with periodic HR monitoring when exercise is performed at a moderately high intensity.

We noticed that the production errors or the differences in $\dot{V}O_2$, HR and PO between the estimation and production trials (i.e., Δs) at both exercise intensities studied were smaller during arm crank than leg cycle exercise. For example, the absolute Δ values for both $\dot{V}O_2$ and HR at each exercise intensity were about 4–5 times greater during leg cycle than arm crank exercise. In addition, the significant differences in $\dot{V}O_2$ and PO between estimation and production that were associated with leg cycling at 70% $\dot{V}O_{2peak}$ were not observed during arm cranking at a similar intensity. Since the same mode of exercise was used for both the production and estimation trials during either the arm crank or leg cycle exercise, the differences in exercise mode as well as the sensory cues upon which subjects were instructed to focus do not appear to be factors responsible for the difference in production accuracy between arm cranking and leg cycling. The comparatively greater production accuracy observed during arm cranking, however, may be attributable to the smaller muscle mass involved during arm crank compared to leg cycle exercise. It has been suggested that dynamic activities involving a smaller muscle mass result in a greater localization of muscular fatigue and thus accentuate the sensory input to the perceptual cognitive framework (Dunbar 1992). Thus, it is likely that such a facilitated sensory process mediates a more accurate assessment of exertional intensity during arm crank than during leg cycle exercise, as demonstrated in the present study.

It is noteworthy that in the present study we employed an intramodal procedure in which the same mode of activity was used for both the estimation and production trials. In clinical settings, however, prescriptions for upper body exercise are often based upon the results of tests involving the lower extremities such as leg cycle or treadmill exercise. Thus, it is of importance to know whether the target exercise intensity that is determined during leg cycle or treadmill exercise can be reproduced during arm crank exercise. Previous studies that validated the perceptual regulation of exercise intensity with an intermodal procedure have used activities that involve primarily the lower extremities such as walking, running, or leg cycling (Dunbar 1992; Robertson et al. 1990). For example, Dunbar et al. (1992) have shown that at a given RPE, physiological responses such as $\dot{V}O_2$ and HR that are produced during leg cycle exercise are similar to the target values that were determined previously during treadmill exercise and vice versa. It should be noted that the activities used in these previous studies involved a common body region, such as legs, and that this may have made it possible for perceptual regulation to be transferable across different exercise modes. It remains to be determined whether the intermodal validity also holds when a completely different body region is used during exercise between estimation and production trials (i.e., arms vs legs).

In addition, the duration of the production trial in the present study was selected to be 8 min, during which the first 3-min period was used for subjects to establish an exercise intensity corresponding to a target RPE. A similar duration (i.e., 8–10 min) has also been used in previous studies in which an estimation-production procedure was used (Dunbar et al. 1992; Glass et al. 1992). A question is raised as to whether the use of RPEs to regulate exercise intensity is also valid during an exercise that lasts longer than 8 min. A recent study by Grant et al. (1993) has shown a progressive increase in the RPE beginning at 10 min into the exercise at 70–80% $\dot{V}O_{2max}$, despite a fairly stable $\dot{V}O_2$ and HR. Such a dissociation between the RPE and $\dot{V}O_2$ or HR indicates that a lower than target exercise intensity could be produced at a given RPE if exercise is performed at moderately high intensity for a longer period of time. In this context, the approach of regulating exercise intensity using RPEs should be further validated, especially during strenuous exercise, and the duration of the production trial should be longer than what was selected for the present study.

In conclusion, using RPEs to regulate exercise intensity is physiologically valid during arm ergometry at both 50 and 70% $\dot{V}O_{2peak}$ and during leg ergometry at 50% $\dot{V}O_{2peak}$. However, the efficacy of this prescriptive approach remains questionable during leg cycle exercise at 70% $\dot{V}O_{2peak}$. Regulating exercise intensity using RPEs should be further validated with the use of intermodal procedures in which a completely different body region is used during exercise between estimation and production trials, and by increasing the duration of production trial compared to that selected for the present study.

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