Journal of Human Kinetics volume 53/2016, 179-187 DOI: 10.1515/hukin-2016-0021
Section III – Sports Training

DE GRUYTER OPEN

Comparison of Oxygen Uptake During and after the Execution of Resistance Exercises and Exercises Performed on Ergometers, Matched for Intensity

by

José Vilaça-Alves[1,2], Nuno Miguel Freitas[1], Francisco José Saavedra[1,2], Christopher B. Scott[3], Victor Machado dos Reis[1,2], Roberto Simão[4], Nuno Garrido[1,2]

The aim of this study was to compare the values of oxygen uptake (VO_2) during and after strength training exercises (STe) and ergometer exercises (Ee), matched for intensity and exercise time. Eight men (24 ± 2.33 years) performed upper and lower body cycling Ee at the individual's ventilatory threshold (VE/VCO_2). The STe session included half squats and the bench press which were performed with a load at the individual blood lactate concentration of 4 mmol/l. Both sessions lasted 30 minutes, alternating 50 seconds of effort with a 10 second transition time between upper and lower body work. The averaged overall VO2 between sessions was significantly higher for Ee (24.96 ± 3.6 ml·kg·min^{-1}) compared to STe (21.66 ± 1.77 ml·kg·min^{-1}) ($p = 0.035$), but this difference was only seen for the first 20 minutes of exercise. Absolute VO2 values between sessions did not reveal differences. There were more statistically greater values in Ee compared to STe, regarding VO_2 of lower limbs (25.44 ± 3.84 ml·kg·min^{-1} versus 21.83 ± 2·24 ml·kg·min^{-1}; $p = 0.038$) and upper limbs (24.49 ± 3.84 ml·kg·min^{-1} versus 21.54 ± 1.77 ml·kg·min^{-1}; $p = 0.047$). There were further significant differences regarding the moment effect ($p<0.0001$) of both STe and Ee sessions. With respect to the moment × session effect, only VO_2 5 minutes into recovery showed significant differences ($p = 0.017$). In conclusion, although significant increases in VO_2 were seen following Ee compared to STe, it appears that the load/intensity, and not the material/equipment used for the execution of an exercise, are variables that best influence oxygen uptake.

Key words: *strength training, ergometer exercises, aerobic exercise, ventilation.*

Introduction

There is consensus in the scientific community on oxygen uptake (VO_2) rates being higher during, and lower after, the performance of predominantly aerobic exercises when compared with traditional strength training exercises (STe) (Borsheim and Bahr, 2003; Burleson et al., 1998; Drummond et al., 2005; Gillette et al., 1994). However, in most studies, ergometer exercises (Ee) traditionally are used to perform what is known as aerobic-type exercise (Sultana et al., 2012; Wang et al., 2012; Wright et al., 2012); and bars, free weights or machines are used to perform traditional anaerobic-type STe (Bloomer 2005; De Sousa et al., 2012; Mukaimoto and Ohno, 2012; Scott et al., 2011). A relevant aspect to be considered is how to match the load and intensity between STe and Ee, respectively.

With respect to Ee, a percentage of the maximum or reserve heart rate or VO_{2max} is typically used to determine intensity. Traditional

[1] - *Sport Sciences Department, University of Trás-os-Montes e Alto Douro, Vila Real Portugal.*
[2] - *Research Center in Sports Sciences, Health Sciences and Human Development, Vila Real Portugal.*
[3] - *Exercise, Health and Sport Sciences, University of Southern Maine, Gorham, Maine.*
[4] - *School of Physical Education and Sports, Rio de Janeiro Federal University, Rio de Janeiro, Brazil.*

Authors submitted their contribution to the article to the editorial board.
Accepted for printing in the Journal of Human Kinetics vol. 53/2016 in September 2016.

STe use a relative percentage of a one repetition maximum (1RM) to define the load (Braun et al., 2005; Burleson et al., 1998; Crommett and Kinzey, 2004). In our view, pairing or matching % VO_{2max} with % 1RM does not guarantee the same physiological intensity between both types of exercise (Bloomer 2005; Steele et al., 2012). To be predominantly aerobic for example, rhythmic and continuous exercises that work a large muscle group should be performed with an intensity at, but not above, the accumulation of 4 mmol/l blood lactate, and/or corresponding to the ventilatory threshold (Mukaimoto and Ohno, 2012); this is not at all ensured by using a percentage of 1RM. Thus, we hypothesised that the higher values of VO_2 during, and lower after, Ee as compared to traditional STe, were due to the variables defining the intensity or load and not the type of devices used.

The aim of the present study was to compare VO_2 rates during and after predominantly aerobic exercises performed on ergometers and traditional STe that were matched using the threshold concepts of ventilation (VE/VCO_2) and 4 mmol onset of blood lactate accumulation, respectively. The duration of each exercise period was 30 minutes.

Material and Methods

To investigate the effect of STe and Ee on VO_2, heart rate (HR) and ventilation (VE) values, subjects attended the laboratory for 14 different sessions (Figure 1). These sessions were performed after a 2 week period of adaptation and familiarisation with the exercises and protocols of this study. Anthropometric measurements (body mass, height and skin folds) were performed during the 1st session, followed by a 1RM test (bench press (BP) and half squat (HS), both with free weights); 1RM retests were completed during the 2nd session.

From the 3rd to the 10th session, tests were randomly conducted for determining the load to be used in STe (BP and HS) with percentages of 5, 10, 15 and 20% of 1RM to find the corresponding load at an accumulation of 4 mmol/l blood lactate.

In the 11th session, tests were performed to determine the intensity (~67% of VO_2 peak) to be used in Ee for the lower limbs (LL; cycle ergometry) and the 12th session was utilised for load testing of the upper limbs (UL; arm-cycle ergometry).

In the 13th and 14th sessions, the Ee and STe tests were randomly conducted, at the selected intensity and load (respectively), and the values of VO_2, HR and VE were collected 30 minutes before, during and after 30 minutes of the exercise sessions.

From the 1st to the 13th session, the time interval between sessions was 72 hours and between the 13th and the 14th sessions, 7 days. All subjects performed all sessions at the same time of the day (between 8 am and 10:30 am). Subjects did not perform any strenuous physical activity within 72 hours prior to the testing sessions and did not ingest any supplements, caffeine, or drugs/medications during that time period. Duplicate meals were consumed in the 24 hours preceding the 13th and 14th sessions.

Participants

The sample size was estimated through the statistics software Gpower based on the error of estimation α by 5%, the estimate of the effect size of 0.5, β power of 80% and the 95% confidence interval, which resulted in a minimum number of 8 individuals.

Eight active men (age 24 ± 2.33 years; body height 171.75 ± 7.67 cm; body mass 71.25 ± 5.78 kg; body fat (7 skin folds) (Jackson and Pollock, 1978) 7.05 ± 1.62%) completed all study procedures. All subjects included in the present study had been practising STe and Ee for at least 6 months with a minimum frequency of 3 times a week for STe and twice a week for Ee, regardless whether the modalities (ST and E) were performed during the same session or separately. Medical history and physical activity questionnaires were completed to verify whether there was any limitation that could prevent participation in the study (Anamnesis and Par-Q test) (American College of Sports Medicine, 2010). Subjects were then informed about study procedures, the possible risks and discomforts related to the experimental sessions, and then signed an informed consent form to participate. The study was conducted according to the Declaration of Helsinki and approved by the University of Trás-os-Montes and Alto Douro Research Ethics Committee (CE-013.0043).

Maximal Strength Testing

The protocol of the 1RM test has been previously described by Kraemer and Fry (1995)

and was used in the present study for the performance of BP and HS exercises (Panatta Sport, Italy). Both exercises had high 1RM test – re-test reliability (intraclass correlation coefficients): BP ICC>0.96; and HS ICC>0.97. To minimise possible error, the following strategies were adopted: (a) specific information on the procedures and execution of the exercise was presented to each subject before testing, (b) verbal encouragement was provided to the subject during the test to promote their best effort, (c) the same bar and weight disks were used in all sessions, and (d) the rate of movement was 30 repetitions per minute (60 beats/min: 1 second concentric, 1 second eccentric) controlled by a metronome (Korg MA-330, New York, USA).

Oxygen Uptake Assessment

A maximal cardiopulmonary exercise test was performed to determine peak VO_2 following a continuous incremental protocol on an upper body (UL) and lower body (LL) ergometer (SCIFIT Pro II, Berkshire, UK). All the protocols and materials used in the present study had been described by Vilaça Alves et al. (2012). The portable gas analyser (*COSMED® K4b², Roma, Italy*) and the HR monitor (*Wireless Double Electrode, Polar®, Kempele, Finland*) were calibrated before each test according to manufacturer instructions (Cosmed, 2001). The environmental conditions and materials/equipment used were the same for all sessions (before, during and after the exercises).

The ventilatory threshold for the Ee (UL and LL) was measured as the point from which the ventilatory equivalent or coefficient of carbon dioxide (VE/VCO_2) increased exponentially (after the increased ventilatory equivalent of oxygen - VE/VO_2).

Blood Lactate Assessment

In order to find the load that elicited a blood lactate concentration of 4 mmol/l for the STe, during the 13th and 14th sessions subjects remained at rest for 30 minutes in the same room where the measurement of a resting metabolic rate (RMR) was made prior to performing the exercises. Blood samples (25 microlitres of capillary blood) were collected from a finger tip before and immediately after the tests using a portable analyser: Accutrend ® Plus (Roche Diagnostics GmbH, COBAS, Vokietija, Germany). The portable analyser was calibrated every session with blood lactate concentrations of 2, 4, 10, 15 and 30 mmol/l Lactate-Kontrollsel (140 LCQ, Berlin, Germany).

These sessions consisted of 4 minutes of BP and HS exercises with the intensities of 5, 10, 15 and 20% of 1RM, performed at a rate of 60 beats/min: 1 second concentric, 1 second eccentric. The following formula was used to find the corresponding value of 4 mmol/l: load in STe = (4 mmol/l – blood lactate concentration value immediately below the 4 mmol/l) x (load corresponding to the blood lactate concentration above 4 mmol/l – load corresponding to the blood lactate concentration below 4 mmol/l) / (blood lactate concentration value immediately above the 4 mmol/l - blood lactate concentration value immediately below the 4 mmol/l) + blood lactate concentration value immediately above the 4 mmol/l.

Resting Metabolic Rate Measurements

Before the exercises in the 13th and 14th sessions, and after at least 12 hours of fasting, subjects were transported to the location of the tests by a member of the evaluation team. The subjects were then taken to a silent, low-light room, where they remained lying in a supine position with the back reclined on a marquise for 30 minutes, to evaluate oxygen uptake at rest. The RMR was calculated from the values of VO_2 measured during the last 10 minutes spent at rest, with the subjects being continuously measured by the portable gas analyser K4b². Immediately after the exercise session, the subjects returned to the same room for recovery VO_2 measurements for a 30 minute period.

Exercise Protocols

Ergometer exercise session (Ee). Subjects performed ergometer exercises at their individual ventilatory threshold intensity (VE/VCO_2), alternating the LL and UL exercises until the completion of the 30 minute session; exercise periods lasted 50 seconds with a 10 seconds transfer time between LL and UL.

Strength training exercise session (STe). The subjects performed HS and BP exercises for 30 minutes, with a load corresponding to an individual's blood lactate accumulation of 4 mmol/l, altering HS and BP the same way as in Ee (50 seconds exercise, 10 seconds transition time).

Since the load corresponding to a blood lactate concentration of 4 mmol/l in HS exercise

was relatively low, a wooden bar, with the same dimensions of the bar used to measure the 1RM (220 cm long; 25 mm in diameter), but only 2 kg in mass, was used. The STe were performed at a rate of 60 beats/min (1 second concentric, 1 second eccentric) until the end of the session and with exercise time (50 seconds) and transfer time (10 seconds) equal to Ee. In both sessions, the first exercise to be performed was LL.

Statistical Analysis

An analysis of the distribution type (Shapiro-Wilk test) was conducted and then sphericity was confirmed by means of the Mauchly's sphericity test. Subsequently, ANOVA univariate testing was applied to observe the existence of statistically significant differences between exercise sessions. An ANOVA for repeated measures with the model [7 moments x 2 exercise types] was used to assess the existence of statistically significant differences between the values of RMR and recovery VO_2 values (with a Bonferroni post-hoc test). The level of significance was set at 0.05. Values are presented as mean ± *SD*.

Results

The values regarding the characteristics of the subjects within each exercise session are presented in Table 1.

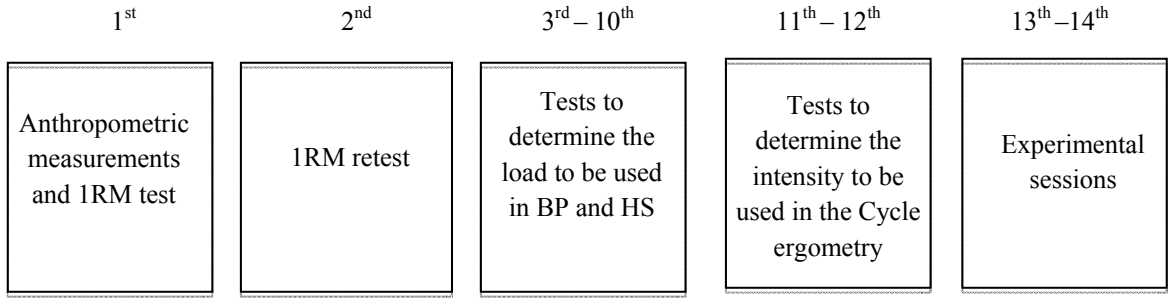

Figure 1

Timeline of the data collection

Table 1

Performance data collected on the first 12 sessions of the present study (n=8)

Variables	Mean ± SD
1RM Half Squat (kg)	115.63 ± 20.08
1RM Bench Press (kg)	81.88 ± 4.17
Peak VO_2 of Lower Limbs (ml/kg/min)	42.99 ± 4.52
Peak VO_2 of Upper Limbs (ml/kg/min)	32.24 ± 2.86
Load of Half Squat 4 mmol/l (kg)	3.0 ± 0.71
Load of Bench Press 4 mmol/l (kg)	10.5 ± 2.82
Ventilatory Threshold of Lower Limbs (ml/kg/min)	28.58 ± 3
Ventilatory Threshold of Upper Limbs (ml/kg/min)	21.79 ± 1.88
Load of Half Squat (%1RM)	2.70 ± 0.88
Load of Bench Press (%1RM)	12.83 ± 3.35
Ventilatory Threshold of Lower Limbs (%VO_{2max})	66.53 ± 2.5
Ventilatory Threshold of Upper Limbs (%VO_{2max})	67.62 ± 1.76

Table 2

Mean values and SD of the RMR, absolute and relative VO_2, Heart Rate, Ventilation, exercise and transition VO_2 of session and divided for Limbs (Lower and Upper) during strength training exercises and ergometers exercises (n=8).

Variable	STe session Mean ± SD	Ee session Mean ± SD
RMR (ml/kg/min)	4.73 ± 0.84	4.57 ± 0.5
Absolute VO_2 (l/min)	1.55 ± 0.22	1.77 ± 0.23
Relative VO_2 (ml/min/kg) *	21.66 ± 1.77	24.96 ± 3.6
Ventilation (l/min)	47.35 ± 8.33	55.48 ± 8.2
Heart Rate (bpm)	118.34 ± 16.07	129.17 ± 16.2
Exercise VO_2 (ml/kg/min) *	22.05 ± 1.61	25.82 ± 3.56
Transition VO_2 (ml/kg/min)	21.59 ± 2.19	23.48 ± 3.5
Absolute VO_2 of Lower Limbs (l/min)	1.56 ± 0.23	1.81 ± 0.25
Absolute VO_2 of Upper Limbs (l/min)	1.54 ± 0.22	1.74 ± 0.21
Relative VO_2 of Lower Limbs (ml/kg/min) *	21.83 ± 2.24	25.44 ± 3.84
Relative VO_2 of Upper Limbs (ml/kg/min) *	21.54 ± 1.73	24.49 ± 3.43
Ventilation of Lower Limbs (l/min)	49.01 ± 8.19	54.42 ± 7.99
Ventilation of Upper Limbs (l/min) *	45.69 ± 8.51	56.5 ± 8.49
Heart Rate of Lower Limbs (bpm)	120.87 ± 13.69	127.02 ± 16.44
Heart Rate of Upper Limbs (bpm)	115.72 ± 18.58	131.15 ± 15.94
Exercise VO_2 of Lower Limbs (ml/kg/min) *	22.44 ± 2.09	26.8 ± 3.82
Exercise VO_2 of Upper Limbs (ml/kg/min) *	21.65 ± 1.28	24.84 ± 3.33
Transition VO_2 of Lower Limbs (ml/kg/min)	27.07 ± 2.5	24.29 ± 3.22
Transition VO_2 of Upper Limbs (ml/kg/min) *	16.12 ± 2.32	22.68 ± 3.84

** Significant difference between the Ste and eE groups ($p < 0.05$); VO_2 – Oxygen Uptake*

Table 3

Mean values and SD of relative VO_2 and Ventilation divided into intervals of 10 minutes during strength training exercises and ergometers exercises (n=8).

Variable	STe session Mean ± SD	Ee session Mean ± SD
VO_2 0-10 min (ml/kg/min) *	20.84 ± 1.27	24.89 ± 3.61
VO_2 10-20 min (ml/kg/min) *	21.83 ± 2	25.33 ± 3.65
VO_2 20-30 min (ml/kg/min)	22.31 ± 2.25	24.67 ± 3.57
Ventilation 0-10 min (l/min) *	44.14 ± 5.95	54.5 ± 8.73
Ventilation 10-20 min (l/min)	48.32 ± 9.07	56.52 ± 7.91
Ventilation 20-30 min (l/min)	49.65 ± 10.45	55.55 ± 8

** Significant difference between the STe and Ee groups ($p < 0.05$); VO_2 – Oxygen Uptake*

Table 4

Mean values and SD of the RMR and recovery oxygen uptake (VO_2), after strength training exercises and ergometers exercises (n=8).

Variable	Ste session Mean ± SD	Ee session Mean ± SD
RMR (ml/kg/min)	4.73 ± 0.84	4.57 ± 0.50
Recovery VO_2 0-5 min (ml/kg/min) †*	9.86 ± 1.38	11.47 ± 1.01
Recovery VO_2 5-10 min (ml/kg/min) †	6.00 ± 0.71	6.24 ± 0.80
Recovery VO_2 10-15 min (ml/kg/min) †	5.87 ± 0.82	5.77 ± 0.85
Recovery VO_2 15-20 min (ml/kg/min) †	5.65 ± 0,73	5.63 ± 0.68
Recovery VO_2 20-25 min (ml/kg/min) †	5.50 ± 0.49	5.38 ± 0.45
Recovery VO_2 25-30 min (ml/kg/min) †	5.50 ± 0.40	5.50 ± 0.54

** Significant difference between the STe and Ee groups ($p < 0.05$)*
† Significant difference from baseline (pre) values ($p < 0.05$)

No significant differences were found between sessions, ($p>0.05$), in the RMR, absolute VO_2, VE, HR and to transition VO_2 (Table 2). However, average relative VO_2 of the Ee session was significantly higher than that of the STe session ($F = 5.444$; $p = 0.035$; $\eta_p^2 = 0.230$) and average exercise VO_2 was also significantly higher during Ee when compared to STe ($F = 7.469$; $p = 0.016$; $\eta_p^2 = 0.348$). Significantly higher average values in Ee compared to STe were also found regarding relative VO_2 of LL ($F = 5.267$; $p = 0.038$; $\eta_p^2 = 0.273$), relative VO_2 of UL ($F = 4.732$; $p = 0.047$; $\eta_p^2 = 0.253$), VE of UL ($F = 6.469$; $p = 0.023$; $\eta_p^2 = 0.316$), exercise VO_2 of LL ($F = 8.020$; $p = 0.013$; $\eta_p^2 = 0.364$), exercise VO_2 of UL ($F = 6.374$; $p = 0.024$; $\eta_p^2 = 0.313$) and with transition VO_2 of UL ($F = 17.181$; $p = 0.001$; $\eta_p^2 = 0.551$) (Table 2).

Regarding the Ee session, significantly higher values were observed compared to STe in relative VO_2 from 0 to 10 minutes ($F = 8.955$; $p = 0.010$; $\eta_p^2 = 0.390$) and from 10 to 20 minutes ($F = 5.636$; $p = 0.032$; $\eta_p^2 = 0.287$) as well as in VE from 0 to 10 minutes ($F = 7.694$; $p = 0.015$; $\eta_p^2 = 0.355$) (Table 3). Significant differences between exercise sessions were not found regarding relative VO_2 from 20 to 30 minutes and VE from 10 to 20 and from 20 to 30 minutes (Table 3). Furthermore, there were no significant differences between sessions regarding the RMR and recovery VO_2 (Table 4). However, significant differences were observed in the time effect ($F = 184.501$; $p < 0.0001$; $\eta_p^2 = 0.929$) within the 2 sessions, namely the RMR which was significantly lower when compared to all the recovery moments ($p<0.05$) (Table 4), along with significant differences in the time effect x session ($F = 4.650$; $p = 0.015$; $\eta_p^2 = 0.249$). Only recovery VO_2 at 5 minutes revealed a significant difference between Ee and STe sessions (Table 4).

Discussion

We attempted to match the STe load with Ee intensity using the aerobic training concepts of ventilatory (for Ee) and lactate (for STe) thresholds. Based on this methodology, the Ee ventilatory threshold (i.e., VE/VCO_2) for UL and LL was found at 66.5% and 67.6% of VO_{2max}, respectively. Strength training at a 4 mmol lactate threshold resulted in exercise loads of 12.8% and 2.7% of a 1-RM for the BP and HS, respectively. At these intensities and loads, subjects alternated UL and LL exercise periods (50 seconds) with transition periods (10 seconds) for both STe and Ee, with a total exercise time of 30 minutes.

Under the conditions listed above, our

findings regarding STe loads were markedly lower compared to those of other strength training studies in which lifting loads were predominantly based on the acquisition of strength (e.g., at 60% of 1RM for untrained and 80% of 1RM or higher for trained individuals) (Rhea et al., 2003). Viewed together, average relative VO_2 ($ml \cdot kg \cdot min^{-1}$) for Ee often slightly, though significantly, exceeded that of STe (Table 2). Yet, differences were not found after 20 minutes of exercise (Table 3). No significant differences were found with respect to absolute VO_2 values ($ml \cdot min^{-1}$). Moreover, HRs were often higher in Ee, although the differences were non-significant. We may therefore conclude that, although not matched perfectly, a similar threshold was somewhat achieved for Ee and STe (a VE/VCO_2 threshold may reflect a greater intensity as compared to a 4 mmol blood lactate threshold (Meyer et al., 2005)).

Our research did not involve training *per se*, as only a single session was recorded to determine VO_2, HR and VE responses for each condition. However, it appears that the concepts of aerobic training are met when selecting rather low lifting loads. That is, a 4 mmol blood lactate concentration generated from 2.7% of 1RM for the HS and 12.8% of 1RM for the BP may have the potential to induce cardiovascular training effects over a 30 minute period (consisting of 15 minutes each of UL and LL work). Cardiovascular training adaptations have certainly been implicated with circuit resistance training modalities applying lifting loads of 40% 1RM providing a more whole-body type of conditioning (Gotshalk et al., 2004). Steele et al. (2012) further confirmed that lifting a weight to momentary muscular failure likewise improved cardiovascular variables. Thus, from an objective standpoint, a variety of resistance training modalities appear capable of achieving cardiorespiratory benefits. The STe loads used in our research are generally not thought to promote gains in strength, but resistance training guidelines have been reconsidered in terms of the unlikelihood of a single position statement for all (Carpinelli et al., 2004).

Post-exercise VO_2 was significantly higher than the RMR at all times throughout recovery in both sessions, with significantly higher VO_2 found only in Ee within the first 5 minutes of recovery (Table 4). The values of the present study concur with several studies indicating that recovery VO_2 remained significantly higher than the RMR for at least 30 minutes after exercise (Drummond et al., 2005; Foureaux et al., 2006; Hackney et al., 2008; Schuenke et al., 2002). Volume and intensity are the variables that most influence post-exercise VO_2 (Meirelles and Gomes, 2004), with the level of physical activity and gender of the subjects also influencing the magnitude and duration of the changes (Borsheim and Bahr, 2003; Warren et al., 2009). Braun et al. (2005) observed that circuit STe induced higher VO_2 during the first 30 minutes of recovery compared to treadmill exercise, and there were no significant differences between 30 and 60 minutes after exercise. It is noteworthy that the Braun et al.'s (2005) study used different loads and sessions: the STe session was performed first and in a circuit format; and the Ee session was performed after, with an intensity matched to the STe session.

Our study was not without limitations. Although the sample size was small (n=8) and the statistical power was not optimal (80%), the repeated measures design appeared sufficient to analyse differences between STe and Ee sessions. Moreover, standardising exercise intensity between STe and Ee is quite problematic, not only because of likely physiological and metabolic differences between muscle contractions at $\%VO_2$ versus %1RM, but also because as many as 25 lactate threshold concepts have been identified (Faude et al., 2009), as well as several gas exchange thresholds (Meyer et al., 2005); thus, our selection of a "threshold" may be subjective. However, this study can be the first step for future research to find the best way to control the intensity of aerobic exercise or strength exercise in order to make them comparable.

Conclusion

When exercise volume, intensity and loads were relativised in a predominantly aerobic (threshold) regime, the exercises performed with ergometers compared to traditional strength training exercises provoked somewhat similar responses, so that the load/intensity, and not the material/equipment used for the execution of an exercise, were variables that best influenced oxygen uptake. It can be concluded that strength exercises can also be used to improve oxygen uptake and cardiovascular fitness in the same way aerobic exercises do.

References

American College of Sports Medicine (ACSM). *ACSM's guidelines for exercise testing and prescription*. Phildelphia: Wolters Kluwer - Lippincott Williams & Wilkins; 2010

Bloomer RJ. Energy cost of moderate-duration resistance and aerobic exercise. *J Strength Cond Res,* 2005; 19: 878-882

Borsheim E, Bahr R. Effect of exercise intensity, duration and mode on post-exercise oxygen consumption. *Sports Med*, 2003; 33: 1037-1060

Braun WA, Hawthorne WE, Markofski MM. Acute EPOC response in women to circuit training and treadmill exercise of matched oxygen consumption. *Eur J Appl Physiol*, 2005; 94: 500-504

Burleson MA, O'Bryant HS, Stone MH, Collins MA, Triplett-McBride T. Effect of weight training exercise and treadmill exercise on post-exercise oxygen consumption. *Med Sci Sport Exer*, 1998; 30: 518-522

Carpinelli RN, Otto RM, Winett RA. A critical analysis of the ACSM position stand on resistance training: insufficient evidence to support recommended training protocols. *JEPonline*, 2004; 7: 1-60

Cosmed. *K4b² User manual*. 7th edition. Roma: Cosmed, 53-61; 2001

Crommett AD, Kinzey SJ. Excess postexercise oxygen consumption following acute aerobic and resistance exercise in women who are lean or obese. *J Strength Cond Res,* 2004; 18: 410-5

De Sousa NM, Magosso RF, Pereira GB, Souza MV, Vieira A, Marine DA, Perez SE, Baldissera V. Acute cardiorespiratory and metabolic responses during resistance exercise in the lactate threshold intensity. *Int J Sports Med*, 2012; 33: 108-113

Drummond MJ, Vehrs PR, Schaalje GB, Parcell AC. Aerobic and resistance exercise sequence affects excess postexercise oxygen consumption. *J Strength Cond Res*, 2005; 19: 332-337

Faude O, Kindermann W, Meyer T. Lactate threshold concepts: how valid are they? *Sports Med*, 2009; 39: 469-490

Foureaux G, Pinto KC, Damasco A. Effects of excess post exercise oxygen consumption and resting metabolic rate in energy cost. *Rev Bras Med Esporte*, 2006; 12: 351-355

Gillette CA, Bullough RC, Melby CL. Postexercise energy expenditure in response to acute aerobic or resistive exercise. *Int J Sport Nutr*, 1994; 4: 347-360

Gotshalk LA, Berger RA, Kraemer WJ. Cardiovascular responses to a high-volume continuous circuit resistance training protocol. *J Strength Cond Res*, 2004; 18: 760-764

Hackney KJ, Engels HJ, Gretebeck RJ. Resting energy expenditure and delayed-onset muscle soreness after full-body resistance training with an eccentric concentration. *J Strength Cond Res*, 2008; 22: 1602-1609

Jackson AS, Pollock ML. Generalized equations for predicting body density of men. *Brit J Nutr*, 1978; 40: 497-504

Kraemer W, Fry A. *Strength testing; Development and evaluation of methodology. Physiological assessment of human fitness*. Edited by Maud J, Foster C. Champaign Ill: Human Kinetics, 115-138; 1995

Meirelles CM, Gomes PS. Acute effects of resistance exercise on energy expenditure: revisiting the impact of the training variables. *Rev Bras Med Esporte,* 2004; 10: 131-138

Meyer T, Lucia A, Earnest CP, Kindermann W. A conceptual framework for performance diagnosis and training prescription from submaximal parameters – theory and application. *Int J Sports Med*, 2005; 26: 1-11

Mukaimoto T, Ohno M. Effects of circuit low-intensity resistance exercise with slow movement on oxygen consumption during and after exercise. *J Sports Sci*, 2012; 30: 79-90

Rhea MR, Alvar BA, Burkett LN, Ball SD. A meta-analysis to determine the dose response for strength development. *Med Sci Sport Exer*, 2003; 35: 456-464

Schuenke MD, Mikat RP, McBride JM. Effect of an acute period of resistance exercise on excess post-exercise oxygen consumption: implications for body mass management. *Eur J Appl Physiol*, 2002; 86: 411 – 417

Scott CB, Leighton BH, Ahearn KJ, McManus JJ. Aerobic, anaerobic, and excess postexercise oxygen consumption energy expenditure of muscular endurance and strength: 1-set of bench press to muscular

fatigue. *J Strength Cond Res*, 2011; 25: 903-908

Steele J, Fisher J, McGuff D, Bruce-Low S, Smith D. Resistance training to momentary muscular failure improves cardiovascular fitness in humans: a review of acute physiological responses and chronic physiology adaptations. *JEPonline*, 2012; 15: 53-80

Sultana F, Abbiss CR, Louis J, Bernard T, Hausswirth C, Brisswalter J. Age-related changes in cardio-respiratory responses and muscular performance following an Olympic triathlon in well-trained triathletes. *Eur J Appl Physiol*, 2012; 112: 1549-1556

Vilaça Alves J, Saavedra F, Simão R, Novaes J, Rhea MR, Green D, Reis VM. Does aerobic and strength exercise sequence in the same session affect the oxygen uptake during and postexercise? *J Strength Cond Res*, 2012; 26: 1872-1878

Wang B, Tian Q, Zhang Z, Gong H. Comparisons of local and systemic aerobic fitness parameters between finswimmers with different athlete grade levels. *Eur J Appl Physiol*, 2012; 112: 567 – 578

Warren A, Howden EJ, Williams AD, Fell JW, Johnson NA. Postexercise fat oxidation: effect of exercise duration, intensity, and modality. *Int J Sport Nutr Exerc Metab*, 2009; 19: 607-623

Wright HE, Selkirk GA, Rhind SG, McLellan TM. Peripheral markers of central fatigue in trained and untrained during uncompensable heat stress. *Eur J Appl Physiol*, 2012; 112: 1047 – 1057

Corresponding author:

José Vilaça - Alves
Centro de Investigação em Desporto, Saúde e Desenvolvimento Humano
Universidade de Trás-os-Montes e Alto Douro
Edifício Ciências do Desporto - Quinta de Prados
5001-801 Vila Real – PORTUGAL
Phone: +351 259 350 000
Fax: +351 259 350 480
E-mail: josevilaca@utad.pt