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Oxygen consumption during concurrent training: influence of intra-session exercise sequence and aerobic exercise modality

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ABSTRACT: To compare the acute effects of different intra-session exercise sequences and aerobic exercise modalities during concurrent training sessions on oxygen consumption (VO_2) and energy expenditure (EE) in young women. Eleven young women volunteered to participate in this study and underwent tests of their dynamic strength and a maximal incremental test on both the treadmill and cycle ergometer. Four concurrent training sessions were performed: resistance-running (RRu), resistance-cycling (RC), running-resistance (RuR) and cycling-resistance (CR). The aerobic exercise lasted 30 minutes and was performed at a heart rate equivalent to 95% of the second ventilatory threshold. The resistance exercise lasted approximately 21 minutes and consisted of 4 sets of 10 RM in each exercise. The VO_2 was continuously evaluated through the portable gas analyser. No differences were found in the VO_2 between the intra-session exercise sequence independently of aerobic modality (i.e., RRu vs. RuR, and RC vs. CR), and the sessions with the running aerobic exercise showed greater VO_2 than sessions using cycling aerobic exercise in both exercise sequences ($VO_{2aerobic}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) – RRu: 27.5; RuR: 27.1; RC: 20.2; CR: 20.8). The present study showed that the intra-session exercise sequence during concurrent training does not influence VO_2. However, the optimal combination of resistance and aerobic exercise should include running in order to increase VO_2 and optimize EE.

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INTRODUCTION

Physical activity is recommended as an important component of weight loss and prevention of weight gain [1]. The main benefits of physical activity in weight management are the energy expenditure (EE) during the exercise [2] and the improvement of muscle mass, which results in a higher resting metabolic rate [3-5]. Considering the different characteristics of aerobic and resistance training, the former seems to be more effective to improve EE during exercise [4], while the latter is the best strategy to enhance muscle mass [6]. Thus, the association of both aerobic and resistance exercises in the same session (i.e., concurrent training) seems to be an efficient strategy for weight management and physical fitness improvement.

Few studies have analysed the metabolic responses resulting from a single bout of simultaneous aerobic and resistance exercises [2, 7, 8]. Vilacxa Alves et al. [2] assessed the effect of different exercise sequences (i.e., resistance-aerobic or aerobic-resistance) on oxygen consumption (VO_2) during concurrent training bouts. These authors found that the intra-session sequence does not affect the metabolic responses during the cycling aerobic or resistance exercise session [2]. On the other hand, Taipale et al. [8] found that performing resistance prior to running aerobic exercise induced greater VO_2 compared with aerobic exercise performed prior to resistance exercise. These disparate results could be explained by different ergometers (i.e., treadmill or cycle ergometer) used in the studies. Therefore, in view of the paucity of data regarding the effects of intra-session exercise sequence on VO_2 as well as the controversial results mentioned, this issue should be further investigated.

Another important issue regarding the exercise prescription for weight management is the aerobic modality performed. Comparing different aerobic exercise modalities, it has been reported that treadmill exercise produces greater VO_2 at same relative intensity when compared to the cycle ergometer, rowing ergometer, stair stepper and skiing simulator [9]. However, some heavier individuals have orthopaedic limitations, which may prevent intense or high-impact treadmill exercise. Therefore, the use of lower impact aerobic exercises, such as cycling, should be considered in weight management programmes [10], and concurrent training sessions using different aerobic modalities should be further investigated.

To the best of our knowledge, little is known about the most effective intra-session exercise sequence during combined resistance and aerobic exercise bouts in order to optimize their effect on VO_2. In addition, no study has compared the metabolic responses when using different modalities of aerobic exercise (i.e., cycling or running) during a concurrent training session. Therefore, the purpose of the present study was to compare the acute effects of different intra-session exercise sequences and aerobic exercise modalities during concurrent training sessions on VO_2 and EE in young women. Our hypothesis is that no differences in the VO_2 would be observed between intra-session exercise orders. In addition, we also hypothesized that concurrent training sessions using aerobic exercise on a treadmill would increase the VO_2 in a greater magnitude than sessions using a cycle ergometer.

MATERIALS AND METHODS

Participants

Eleven physically active and healthy young women volunteered to participate in this study (mean ± SD – age: 22.36 ± 2.25 years; height: 165.09 ± 6.63 cm; body mass: 59.35 ± 4.64 kg and body fat percentage: 22.07 ± 2.41%). The participants had engaged simultaneously in resistance and aerobic programmes for at least three months before the study, at least two times per week of each exercise using a similar workload during resistance (multiple sets until failure) and aerobic (20-45 min at 60-90% VO_2max) exercises, and were free of any musculoskeletal, bone and joint, or cardiac and pulmonary diseases. All participants reported a regular menstrual cycle at the beginning of the study and were taking contraceptive medications.

In order to participate in this study all participants were informed about the procedures and potential risks and gave their written informed consent. The study was approved by the local Research Ethics Committee and is in accordance with the Declaration of Helsinki.

Participants attended sessions on eight separate occasions, each separated by at least 48 h, and within a 21-day period. The tests and experimental protocols were performed at the same time of day to avoid variations related to circadian rhythms and under the same conditions (i.e., no vigorous exercise for at least 24 h, no stimulants for 12 h and no food 3-4 h before each experimental session). The local temperature was maintained at 21.0 ± 0.1°C throughout the tests and experimental protocols.

Measures

In the initial session, body mass and height were measured using an analogue medical scale and a stadiometer (FILIZOLA; Sao Paulo, Brazil). Body composition was assessed using the skinfold technique. Skinfold thickness was obtained with a skinfold caliper (LANGE; Cambridge, United Kingdom). A seven-site skinfold equation was used to estimate body density [11] and body fat was subsequently calculated using the Siri equation [12]. After that, participants completed one familiarization session to practise the strength and aerobic exercises they would further perform during the preliminary tests and experimental protocols.

Two sessions were randomly performed to evaluate the maximal and corresponding to the anaerobic threshold VO_2 and heart rate (HR) responses during use of the cycle ergometer (CYBEX, New York, USA) and treadmill (INBRAMED; Porto Alegre, Brazil). In the cycle ergometer maximal test, the participants initially cycled with a 25 W load in the first 2 min, which was progressively increased by 25 W every 1 min, whilst maintaining a cadence of 70-75 rpm, until exhaustion. The test was halted when participants were no longer able to maintain a cadence of over 70 rpm. The treadmill protocol consisted of an initial velocity of 5 $km \cdot h^{-1}$ with 1% inclination during 2 min. After this, the velocity was increased every 1 min by increments of 1 $km \cdot h^{-1}$, and the inclination was maintained until the subjects reached their maximal effort. The assessment was considered valid when some of the following criteria were met at the end of the test [13]: estimated maximal heart hate was reached (220-age); plateau in VO_2 with increase in the treadmill velocity; a respiratory exchange ratio greater than 1.15 was reached; maximum respiratory rate of at least 35 breaths per minute.

To evaluate the ventilatory data, a mixing-box-type portable gas analyser (VO2000, MEDGRAPHICS; Ann Arbor, USA) was used and had been previously calibrated according to the manufacturer's in-

Table 1. Performance variables of participants.

	Variables	Mean ± SD
STRENGTH TESTS	10 $RM_{bench\ press}$ (kg)	29.6 ± 3.2
	10 $RM_{upright\ row}$ (kg)	19.8 ± 1.9
	10 $RM_{leg\ press}$ (kg)	100 ± 7.5
	10 $RM_{knee\ extension}$ (kg)	38.6 ± 7.4
TREADMILL TEST	VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	41.1±3.2
	VO_{2AT} ($ml \cdot kg^{-1} \cdot min^{-1}$)	34.8 ± 3.5
	HR_{max} (bpm)	193.7 ± 4.7
	HR_{AT} (bpm)	182.6 ± 4.6
CYCLE ERGOMETER TEST	VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	35.1 ± 2.5
	VO_{2AT} ($ml \cdot kg^{-1} \cdot min^{-1}$)	25.8 ± 2.6
	HR_{max} (bpm)	183.9 ± 8.1
	HR_{AT} (bpm)	165.5 ± 7.3

Ten maximal repetitions tests (10 RM), maximal oxygen consumption (VO_{2max}) and maximal heart rate (HR_{max}), oxygen comsumption (VO_{2AT}) and heart rate corresponding to anaerobic threshold (HR_{AT}).

structions. The sampling rate of the collected values was 10 s, and the data were acquired using the Aerograph software. In addition, for the HR measures, a HR monitor (FS1, POLAR; Shanghai, China) was used. The AT was determined using the ventilation curve corresponding to the second point of exponential increase in the ventilation in relation to the load [14]. In addition, to confirm the data, AT was determined using the ventilatory equivalent for CO_2 (VE/VCO_2). Two experienced and independent blind physiologists detected the corresponding points through visual inspection according to the criteria described above. When the results were discordant, the graphs were assessed by a third physiologist.

Another session was performed to determine the strength exercise loads. 10 RM strength tests in the bench press, upright row, leg press and knee extension exercises were performed. Initially, participants warmed up for 5 min on a cycle ergometer, lightly stretched all major muscle groups, and performed specific movements for the test. Thereafter, each participant performed an attempt to lift an estimated weight determined by the investigator, for all exercises. Incremental increases of 5 kg were completed after each successful attempt until the 10 RM was reached. Each participant's maximal load was determined with no more than three attempts with a 5-min recovery between attempts. The order of exercises tested was alternated between upper and lower body movements to prevent muscle fatigue. Performance time for each contraction (concentric and eccentric) was two seconds, controlled by an electronic metronome (MA-30, KORG; Tokyo, Japan). Performance characteristics of participants are reported in Table 1.

Exercise protocols

The last four sessions were designed for the performance of concurrent training protocols, in which the same resistance training was performed with different modalities of aerobic exercise and sequences: resistance-running (RRu), resistance-cycling [7], running-resistance (RuR) and cycling-resistance (CR). The order of concurrent training protocols was randomized and performed with an interval of 48-96 h. The resting VO_2 was collected during the 30 min in the pre- and post-exercise period in the supine position. Each training session lasted approximately 51 min with the VO_2 evaluated continuously through the portable gas analyser with a sampling rate of one sample for each 10 s.

The aerobic exercise lasted 30 min and was performed at a HR equivalent to 95% of the AT (±3 bpm) obtained on a specific ergometer (i.e., the treadmill or cycle ergometer). The HR was individually monitored in order to maintain the intensity of exercise with adjustments of velocity (treadmill) or load (cycle ergometer). The resistance exercise lasted approximately 21 min and consisted of 4 sets until failure with the load corresponding to the participants' predetermined 10 RM test. Technique instruction and verbal inducements were provided to each participant during resistance exercises. If necessary, loads were adjusted from set to set to maintain the designated number of repetitions in each set. Four exercises were performed in the following sequence: bench press, knee extension, upright row, and leg press. These exercises were grouped in two blocks, in which the sets of the second exercise were performed during the rest of the first. An active interval of 2 min was allowed between sets. In the four experimental protocols 2 min of rest was used between the types of exercise.

The VO_2 throughout each protocol was calculated using the mean of 30 min of aerobic exercises and 21 min for strength exercises. To estimate the EE caloric equivalents of 5.05 and 4.98 $kcal \cdot LO_2^{-1}$ were used in resistance and aerobic exercise, respectively [15]. The total EE (EE_{total}) for each protocol was estimated by the sum of the EE during 51 min of exercise. The descriptive analysis of EE per minute (EE_{min}) during the session for each type of exercise was estimated by dividing the EE_{total} by the total exercise time.

Statistical analysis

Results are reported as mean ± SD. Normal distribution of data was checked with the Shapiro-Wilk test. Repeated measures one-way ANOVA was used to compare the resting VO_2 among different sessions. Statistical comparisons between intra-session sequences (resistance-aerobic or aerobic-resistance) and modalities of aerobic exercise (running or cycling) were tested using repeated measures two-way ANOVA. Significance was accepted when $\alpha=0.05$, and the SPSS statistical software package (version 22.0) was used to analyse all data.

Table 2. Oxygen consumption during aerobic ($VO_{2aerobic}$) and strength ($VO_{2strength}$) exercises.

	RC	CR	RRu	RuR	p
$VO_{2aerobic}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	20.2±1.6	20.8±2.2	27.5±2.8*	27.1±2.5*	p<0.001
$VO_{2strength}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	12.9±0.7	12.7±1.2	12.6±1.6	13.1±1.2	p=0.724

Data are means ± SD. *P<0.05 vs RC and CR.

RESULTS

Comparison among resting VO_2 values on different experimental days confirmed that the participants started the different exercise protocols with similar metabolic rates on all days (p=0.785). Moreover, the 30 min post-training VO_2 values showed no significant differences among the four experimental sessions (p=0.246).

No differences were found in the VO_2 between different intra-session exercise sequences independently of aerobic modality. Running exercise showed greater VO_2 than cycling exercise in both exercise sequences. In relation to the VO_2 verified during resistance exercise (i.e., 21 min), the results showed no significant differences among the four protocols. No significant aerobic modality*sequence interaction was verified for these variables. These results are shown in Table 2.

The descriptive analysis of the EE during the total time of the session and during the four experimental protocols is presented in Figure 1 and Table 3, respectively. No significant differences were found in the EE_{total} between the intra-session exercise sequences (resistance-aerobic or aerobic-resistance). Also, running exercise showed greater EE_{min} than cycling exercise.

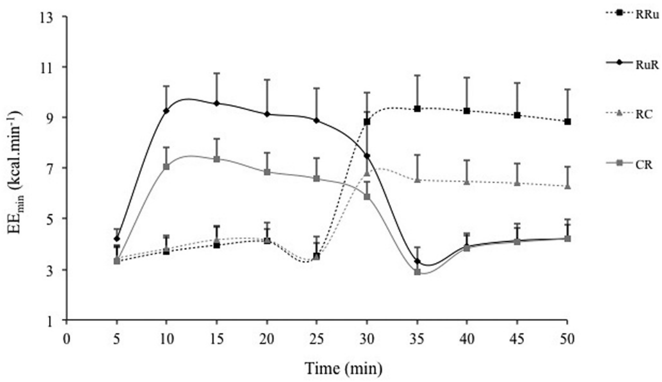

FIG. 1. Energy expenditure (EEmin) against time for both intra-session sequence and modalities of aerobic exercise (resistance-running: RRu; running-resistance: RuR; resistance-cycling: RC and cycling-resistance: CR).

DISCUSSION

The primary findings of the present study were the absence of differences in VO_2 and EE between the different intra-session exercise sequences investigated during concurrent training sessions using two different aerobic modalities. In addition, the results of the present study showed that running promoted higher VO_2 than cycling exercise when performed at the same relative intensity, and it should be considered in order to optimize the EE during concurrent training sessions. The similar resting VO_2 values on different experimental days confirmed that the participants started the different exercise protocols with similar metabolic rates on all days and the changes found in the VO_2 during the sessions were attributable to the effort required by the training.

Controversial results have been obtained in studies evaluating the metabolic responses during different intra-session exercise sequences of concurrent training. Some studies have shown that previous resistance exercise improves the EE during subsequent running aerobic exercise [7, 8]. In these studies, the intensity used during aerobic exercise was based on a fixed speed, and it is possible that the residual fatigue resulting from the first activity (resistance exercise) could have increased the metabolic responses during the second activity (aerobic training). In order to maintain the same speed during aerobic exercise performed after resistance, higher demands of VO_2 should be reached. The results of the present study have found similar VO_2 between concurrent training sessions performed with resistance exercises before or after aerobic exercise, which is in accordance with a previous study [2]. In ours and the above-mentioned study a fixed percentage of HR was used to prescribe the intensity of aerobic exercise, adjusting the speed (or load) when necessary. These methodological differences could explain in part the differences among studies.

Table. 3. Total energy expenditure (EE_{total}) during different intra-session sequence (SEQ, resistance-aerobic and aerobic-resistance) and with different modalities of aerobic exercise (AE, cycling and running).

		Resistance-Aerobic		Aerobic-Resistance		AE	SEQ	AE*SEQ
		Mean	SD	Mean	SD	p	p	p
EE_{total} (kcal)	Cycling	266.25	±27.29	263.37	±29.34	<0.001	0.820	0.645
	Running	326.16	±42.58	327.01	±45.77			

Data are means ± SD.

Another possible explanation for the differences between the results of previous studies could be the ergometer used for the aerobic exercise. Running aerobic exercise was used when differences between sequences were found [7, 8], whereas cycling exercise was used in a study without differences [2]. Nevertheless, we obtained the same results independently of the modality of aerobic exercise, showing that different intra-session exercise sequences do not affect the VO_2 during concurrent training sessions, whether performing running or cycling aerobic exercise, when the aerobic intensity prescription is based on HR.

Kang et al. [16] assessed the impact of performing resistance exercises at different intensities on EE and substrate utilization during subsequent aerobic exercise. Their results demonstrated that 3 sets of 10 repetitions performed at the intensity of 90% of 8 RM optimized EE during subsequent aerobic exercise, when compared to performing the same aerobic exercise alone. In the present study, we used a slightly higher overload (set x repetitions x load) during resistance exercises (i.e., 4 sets of 10 RM), but the EE during subsequent aerobic exercise was not different when compared to the opposite sequence (i.e., aerobic-resistance). A possible explanation of these discrepancies could be the influence of time under tension during the different concurrent training sessions. Our resistance training sessions lasted 21 min and had the time under tension per set controlled throughout the sessions, while previous studies did not provide sufficient information about it. Therefore, possible differences in the time under tension resulting from different exercise orders in the previous studies could help to explain these discrepancies, although this hypothesis remains speculative.

Regarding the metabolic effects of different aerobic modalities, our results showed that running aerobic exercise produced a higher VO_2 compared to the cycling aerobic exercise performed at the same relative intensity (i.e., HR equivalent to 95% of AT), which is in accordance with previous results [9]. In view of this, it should be highlighted that running exercise seems to be the best strategy to enhance EE during aerobic exercise prescription. Taking into consideration these results, it is important to point out the magnitude of this difference. In the present study, the VO_2 during 30 min of cycling was equivalent to approximately 80% of the VO_2 during treadmill exercise. Although running exercise promoted a higher metabolic response than cycling, the former may not be best exercise strategy for some heavier individuals. Running is considered a lower-limb high impact exercise, and therefore these individuals should avoid it in order to prevent possible injury [10, 17]. In this case, cycling exercise seems to be a good alternative for these subjects, and the knowledge of its metabolic responses in comparison with running exercise should be considered in order to adjust the time of exercise and compensate the lower VO_2.

A recent study suggested that different aerobic exercise modalities influence the excess postexercise oxygen consumption (EPOC), since running induced greater EPOC than cycling [18]. Likewise, different intra-session exercise sequences during concurrent training may influence the EPOC [7, 19]. However, our results demonstrated no differences in the post-exercise VO_2 values when performing different intra-session sequences or using different aerobic modalities. In accordance with our findings, Oliveira & Oliveira [20] demonstrated that different intra-session exercise sequences during concurrent training do not affect the EPOC magnitude. The discrepancy between these results may be due to variations in study design such as exercises performed, total overload, recovery intervals, and energy assessment protocol [21].

The American College of Sports Medicine suggests an EE equivalent of 1200 to 2000 kcal/week to prevent a weight gain greater than 3% in most adults [1]. In the present study, 30 min of aerobic exercise performed at HR equivalent to 95% of AT promoted an EE of 248 kcal during running and 185 kcal during cycling exercise, whereas 21 min of strength exercises performed with 4 sets of 10 RM achieved an EE of approximately 84 kcal. Therefore, one single session of concurrent training lasting 51 min was enough to promote an EE ranging approximately from 270 to 330 kcal, depending on aerobic modality, in physically active young women. These results indicate that concurrent training sessions shorter than one hour are effective strategies to increase weekly EE, which may help weight control and enhance exercise adherence.

Some limitations should be addressed in order to properly interpret the results. Our sample consisted of young women only, therefore limiting the generalization of our findings to the male population. Moreover, the EE resulting from the concurrent exercise protocols must be carefully extrapolated to overweight/obese women and participants with a different training status (e.g., sedentary, highly trained) and should be taken into account in future studies.

CONCLUSIONS

In summary, the present study showed that the intra-session exercise sequence during the concurrent training prescription does not influence the VO_2, independently of modality of aerobic exercise. However, the optimal combination of resistance and aerobic exercise should include running in order to increase VO_2 during exercise. The present results bring new information regarding effective strategies to optimize the benefits of physical activity in weight management. Considering that concurrent training is an excellent exercise to enhance EE, it seems feasible to use this type of training to obtain these benefits using different strategies during the exercise session, such as different modalities of aerobic exercise and different exercise sequences.

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