Resistance and aerobic exercises do not affect post-exercise energy compensation in normal weight men and women

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Abstract:

Background: Previous research has reported no effect of exercise modality (aerobic vs. resistance) on energy intake (EI). However, the relatively low energy cost of resistance training, the absence of total energy expenditure (TEE) measurements and the short duration of these studies justify further investigation. **Objective:** To evaluate the effects of exercise modality on EI, TEE, non-exercise activity thermogenesis (NEAT) and post-exercise energy compensation (PEEC) measured acutely, as well as for 10 and 34 h following exercise. **Design:** Eight men and 8 women participated in three randomized crossover sessions: aerobic-based exercise, resistance-based exercise, and sedentary control. Exercise energy expenditure (ExEE) was continuously measured (indirect calorimetry) throughout the exercise sessions, which were designed to produce an isocaloric ExEE of 4 kcal/kg body weight. TEE and EI were monitored for 34 h post-exercise with biaxial accelerometers and a validated food menu, respectively. **Results:** There were no differences in EI between exercise modalities acutely, as well as 10 and 34 h following exercise. However, a modality by sex interaction was noted for acute EI. Men ate more after the resistance than after the aerobic session (1567 ± 469; 1255 ± 409 kcal, respectively; $P = 0.034$), while no differences were seen in women (568 ± 237; 648 ± 270 kcal, respectively; P = NS). No differences in TEE, NEAT and PEEC were found 10 h and 34 h post-exercise, while a positive correlation ($r = 0.897$; $P < 0.01$) was found between both modalities across participants for PEEC. **Conclusion:** Exercise modality does not impact PEEC when ExEE is controlled. Our results also show that within-individual PEEC seems to be relatively constant across exercise modality.

Keywords: Energy intake | Aerobic exercise | Resistance exercise | Compensation

Article:

Abbreviations: EI, Energy Intake; EE, Energy Expenditure; TEE, Total Energy Expenditure; PEEC, Post-exercise Energy Compensation; NEAT, Non-Exercise Activity Thermogenesis; ExEE, Exercise Energy Expenditure; CSEP, Canadian Society of Exercise Physiology; REE, Resting Energy Expenditure; VAS, Visual Analog Scale; RM; Repetition Maximum

1. Introduction

According to findings by Edholm [1] and Mayer [2], [3], [4], a central regulatory system is only able to strictly control energy intake (EI) above a certain threshold of energy expenditure (EE). This perfect match is defined as a 100% post-exercise energy compensation (PEEC), while an absence of changes in EI indicates a PEEC of 0%. In essence, recent studies have measured the acute effects of exercise on EI, but conflicting results have ensued. Certain studies noted an increase in EI following an exercise session [5], [6], [7], [8], while others noted no changes [9], [10], [11], [12], [13], [14], [15], or a decrease [16]. The discrepancy in these results may be in part due to certain factors which may impact post-exercise EI, such as sex [7], [17], [18], obesity [19], exercise intensity [7] and cognitive factors [5], [20], [21].

Non-exercise activity thermogenesis (NEAT), which is the EE associated to all activities or movements performed during our daily living outside of an organized exercise session [22], has been previously investigated in a whole-body indirect calorimeter. This study reported that NEAT may explain 100–800 kcal of inter-individual variations [23]. This is similar whether active, inactive individuals, or those with similar physical activity levels are compared [24]. It has also been demonstrated that trained and untrained men had the same level of NEAT following a bout of exercise [25]. As a result, it could be speculated that a change in NEAT could impact PEEC, but this has never been objectively measured under free-living conditions following an exercise session.

The majority of previous studies investigating the impact of an exercise session on energy balance have focused on the effects of aerobic-based exercises on subsequent EI. To our knowledge, only two studies have included an aerobic- and a resistance-based exercise session within the same study design. Balaguera-Cortes et al., [26] and Laan et al. [27] measured the impact of aerobic- and resistance-based exercises performed at 70% of the participant's maximal capacity for 45 min and 35 min, respectively, and found no significant differences in EI between sessions. However, the low energy cost of the resistance session compared to the aerobic session might explain the absence of differences (ExEE of 80 vs. 290 kcal, respectively). Additionally, post-exercise EI was only recorded for 30 min after exercise, and subsequent changes in TEE were not measured.

Taken together, the comparison between acute post-exercise EI following aerobic and resistance-based exercise sessions in previous studies is limited by a large discrepancy in the energy cost of exercise (ExEE). Furthermore, the objective measurement of TEE and EI over a longer period of time, in both men and women, following aerobic- and resistance-based exercise sessions within the same study design is warranted. The objective of the present study was to measure the effects of a 4 kcal/kg kilo calorie-clamped aerobic- and resistance-based exercise session on EI, TEE and total PEEC in men and women, acutely, as well as 10 and 34 h following the exercise trial. We hypothesized that resistance exercise would lead: 1) to greater EI and: 2) to lower NEAT over the 2-day testing period compared to the aerobic and control sessions. We also hypothesized that PEEC would be greatest after resistance exercise during this period compared to the aerobic and control sessions.

2. Materials and methods

2.1. Participants

Sixteen participants (8 women and 8 men) completed the three experimental sessions. All participants were individually interviewed to evaluate whether they met the inclusion criteria: 1) between the ages of 18 and 45 years; 2) participated in less than 150 min of exercise per week, which is below the Canadian Society of Exercise Physiology (CSEP) recommended physical activity guidelines for adults [28]; 3) no heart problems; 4) regular menstrual cycle; 5) non-diabetic; 6) stable weight (± 4 kg) within the last six months, and 7) no excessive consumption of alcohol, no drug/medication consumption and non-smoker. All participants were healthy and had no orthopedic complications that could limit exercise, and were not taking any medications that could affect cardiovascular function and/or metabolism. The study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human participants were approved by the University of Ottawa Ethics Committee. Written informed consent was obtained from all participants.

2.2. Procedure of the experimentation

This study used a randomized crossover design. Participants took part in a preliminary session followed by three experimental sessions. An overview of the protocol employed for each experimental session is presented in Fig. 1. A washout period of at least seven days separated each session. Women were only tested between days one and eight of the follicular phase [29]. Participants were instructed not to consume alcohol or engage in any type of exercise (e.g. playing sports or training) for at least 24 h prior to the start of each session, and during the data collection period, but were allowed to take part in their habitual non-structured physical activities (e.g. walking, cycling to school). Compliance to these details was verified via self-report before and after each session.

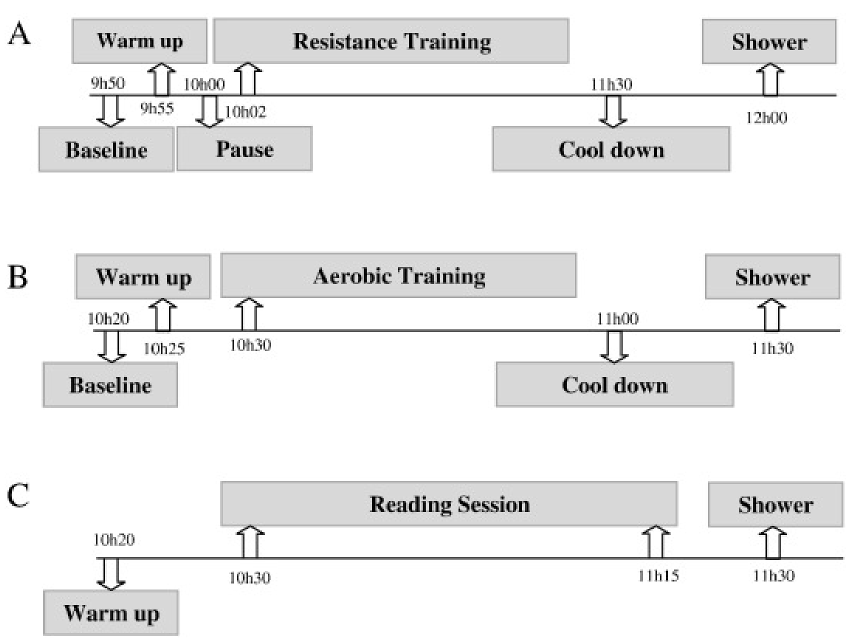

Fig. 1. Training session details. A) Resistance; B) aerobic; C) control.

2.3. Preliminary session

Participants arrived at the laboratory at 0900. Body weight was measured, and is described elsewhere [30]. Body composition was measured using dual-energy X-ray absorptiometry (GE-LUNAR Prodigy module; GE Medical Systems). Eating behavior traits were measured with the Three-Factor Eating Questionnaire [31]. A progressive exercise stress test to exhaustion was performed to measure participants' peak maximal oxygen consumption ($\dot{V}O_2peak$) on a treadmill. Participants were asked to abstain from eating and drinking coffee for at least 2 h prior to the test. The CSEP guidelines were followed [32], with each stage of the test lasting 2 min with a constant speed and an increasing grade to the point of exhaustion. Heart rate and perceived exertion measured with the Borg scale [33] were assessed at rest and at the end of each stage. Breath-by-breath samples of expired air were collected with a mouthpiece, and measurements of $\dot{V}O_2$ and respiratory exchange ratio were automatically collected using a Vmax 229 series metabolic cart (SensorMedics Corporation, Yorba Linda, CA, USA). Following a brief warm up (2 min at 3 mph, 2 min at 5 mph and 1 min at 3 mph), participants performed the test protocol. The test was terminated when at least two of the following criteria were achieved: 1) predicted maximal heart rate was reached; 2) respiratory quotient was above 1.1; 3) oxygen consumption remained stable or decreased with an increase in workload or 4) a Borg scale rating of ≥ 19 was reported by the participant. Peak oxygen consumption was considered as the highest $\dot{V}O_2$ value during the test. Finally, a maximal strength test was performed for 12 different exercises: these 12 exercises are presented in Appendix 1. The optimal position and range of motion for each exercise were explained to the participants for safety reasons. The weight of each exercise was adjusted until the participants were not able to do more than 12 (± 1) repetitions (70% of 1 repetition maximum (1RM)) [26]. Participants alternated between performing upper and lower body exercises to make sure that enough rest was given between sets.

2.4. Experimental sessions

An overview of the experimental design is presented in Appendix 2. Participants were asked to arrive at the laboratory at 0800 following a 12-hour overnight fast and were weighed upon arrival. During the first experimental session only, participants were asked to arrive at 0700 in order to measure resting energy expenditure (REE) via indirect calorimetry using a Vmax Encore 29 N metabolic cart (SensorMedics Corporation, Yorba Linda, CA, USA) or Deltatrac II Metabolic Monitor (Sensor Medics Corporation, Yorba Linda, CA, USA). The correlation coefficients between the two indirect calorimeters calculated with 12 participants in our laboratory were: $r = 0.990$ for the REE, $r = 0.992$ for the $\dot{V}O_2$ and $r = 0.969$ for the $\dot{V}CO_2$ values. After resting for 20 min, a 5-minute habituation period was performed before REE was assessed for 20 min. At 0830, a standardized breakfast was served during each session, which consisted of 78 g of thick sliced 100% whole wheat bread (D'Italiano®, 200 kcal), 18 g of peanut butter (Kraft Smooth Peanut Butter®, 108 kcal), 16.3 g of raspberry jam (Kraft Pure®, 52 kcal), 21 g of ultra mild cheddar cheese (P'tit Québec®, 80 kcal) and 225 g of orange juice (Tropicana Pure Premium®, 94 kcal). The meal was designed to have a food quotient of 0.85 and an energy content of 534 kcal. The participants had 15 min to consume this meal in its entirety.

At 0845, participants were asked to remain seated until the beginning of the training session, during which recreational reading was the only sedentary activity allowed.

2.4.1. Exercise session

During the resistance-based session, which started at 0945, participants were asked to perform resistance training (Appendix 1) at 70% of their 1RM, based on the intensity of the exercises determined by the 12 RM test completed in the preliminary session. The net ExEE of the exercise sessions was clamped at 4 kcal/kg. Exercises were grouped in pairs in order to increase EE per amount of time [34]. The order in which the pairs were performed is presented in Appendix 1. Each pair was performed four times with 10 repetitions for each exercise, and 2 min of rest was given between supersets. This protocol was repeated until target ExEE was reached. Extra series (e.g. leg press and leg curl exercises) were added if the targeted ExEE was not reached at the end of the protocol. Two water breaks of 5 min each (after the 8th and 16th pairs) were added to the protocol because the length of this exercise session was much longer than the aerobic exercise session. The participants were also able to remove the facemask used to measure ExEE during these water breaks. Five male participants were not able to complete the resistance session on their first try due to high exertion and dizziness. However, these five participants were able to complete this session at a later date. The aerobic-based exercise session started at 1020 and consisted of running on a treadmill at an intensity of 70% of the participants $\dot{V}O_2$peak until the target ExEE was reached. Lastly, during the control session, participants remained seated for the duration of the session and were only allowed to do recreational reading.

2.4.2. Energy expenditure measurement

ExEE during exercise sessions was measured continuously (with the exception of the two water breaks during the resistance session) using a portable indirect calorimetry unit equipped with a facemask that covered both the mouth and the nose (model K4b^2, COSMED, Chicago, IL) and displayed the values in real time on a laptop (Pavillion dv6, Hewlett-Packard) using the K4b^2 data management software (Version 9.1 b, COSMED, Chicago IL) [35]. Prior to the aerobic and resistance exercise sessions, a 5-minute warm-up was performed on a treadmill (2 min at 3 mph; 2 min at 5 mph; 1 min at 3 mph). Measurements were continued for 30 min following the aerobic and resistance exercises, while participants remained seated. Following this, participants were asked to take a shower (with the same time allowance and water temperature between sessions). Finally, using the Borg CR10 scale (Borg, 1982), the participants were asked to report how they would classify the intensity of each intervention.

2.4.3. Post exercise

A lunch was served 75 min following each intervention [36]. Ad libitum energy and macronutrient intake was measured with a validated food menu, as previously described in McNeil et al. [37]. During the aerobic and control sessions, lunch was served around 1215. Due to a longer exercise protocol, lunch was served around 1245 for the men and 1300 for the women during the resistance session (Fig. 1). After lunch, participants were asked to select the foods from the menu that they wanted to consume later that day (1400 to midnight), and for the following day (midnight to midnight). The selected food items were prepared, according to McNeil et al. [37]. At the same time, participants were fitted with two biaxial accelerometers (SenseWear Pro 3 Armbands©, HealthWear Bodymedia, Pittsburgh, PA) that were worn for 34 h following the intervention. One was placed around the upper arm (mid-distance between the acromion and the olecranon), while the second was placed around the thigh (mid-distance between the patella and the inguinal fold). The INNERVIEW software (version 4.02; Bodymedia, Pittsburgh, PA) was used to retrieve the data from both accelerometers. Posture allocation was determined using software developed to combine and time-align the data from the arm and the leg, with an overall accuracy of the model of 90 ± 4% in an unrestricted environment (Riou, M.-È. et al. unpublished). Additionally, the accelerometer placed around the upper arm was used to measure TEE (INNERVIEW software, version 4.02; Bodymedia, Pittsburgh, PA) [38], the step counts and the amount of time it was worn (%). Accelerometery data for one participant was excluded due to accelerometer malfunction and another due to extreme variations. Finally, an adapted version of the visual analog scales (VAS) [39] was administered throughout the day to measure appetite, i.e., during fasting (0845), after breakfast (time 0), as well as 30 and 60 min following breakfast. The same visual analog scales were administered 45 and 65 min following exercise, as well as immediately after lunch.

2.4.4. Calculations — post-exercise energy compensation (PEEC) and non-exercise activity thermogenesis (NEAT)

Based on EI, EE and ExEE, two additional variables were calculated: total PEEC and NEAT.

$$\mathrm{PEEC} = \left(\frac{[(\mathrm{EI} - \mathrm{ETctrl}) + (\mathrm{TEEctrl} - \mathrm{TEE})]}{\mathrm{ExEE}}\right) \times 100$$

$$\mathrm{NEAT} = \mathrm{EE} - \mathrm{REE} - \mathrm{TEF}$$

$$\mathrm{NEAT} = \mathrm{EE} - \mathrm{REE} - (\mathrm{EI} \times 0.1)$$

where EI is the ad libitum energy intake (food consumed either at lunch, during the first 10 h or over the entire measurement period (34 h)), ExEE is the energy cost of the exercise session, TEE is the EE measured with the accelerometers (calculated after the first 10 h or after 34 h), CTRL is the control session, REE is the resting EE and TEF is the thermic effect of food.

2.5. Statistical analyses

SPSS Software 17.0 (SPSS Inc., Chicago) was used for all analyses. The normality of all variables was assessed with a Shapiro–Wilk test and the Q–Q plots were visually inspected. A one-factor repeated measures ANOVA for mixed design (aerobic, resistance and control) with one between subject factor (sex) was used to assess the effects of exercise modality on EI, TEE, NEAT, PEEC, macronutrient intake and posture allocation. A repeated measures ANOVA with one within-subject factor [effect of condition (aerobic, resistance and control)] and one between subject factor (sex) was used to compare appetite scores. Paired-sample *t*-tests were used for *post hoc* comparisons with a Bonferroni adjustment of the significance level for multiple comparisons (3 comparisons). Paired-sample *t*-tests were used to compare the ExEE, exercise duration and perceived exertion of the two exercise sessions (aerobic and resistance). A Pearson correlation was used to compare the PEEC of the resistance and aerobic sessions. Independent *t*-tests were used to compare subject characteristics between sexes. Effects were considered significant at $P < 0.05$. Results are presented as means ± standard deviations.

3. Results

3.1. Characteristics of the participants

Participant characteristics are shown in Table 1. There were significant differences in body weight, height, V˙O2peak, body mass index and percentage of body fat between men and women. Nevertheless, body weight was similar between conditions (aerobic: 69.2 ± 12.5; resistance: 68.6 ± 12.3; control: 68.9 ± 12.4 kg; P = NS).

Table 1. Descriptive characteristics of participants (n = 8 men and 8 women).

Variable	Overall	Women	Men	*P* (between women and men)
Age (Y)	21.9 ± 2.6	22.8 ± 3.0	21.1 ± 2.0	NS
Body weight (kg)	68.7 ± 12.1	58.9 ± 5.4	78.5 ± 7.9	< 0.001
Height (cm)	173.0 ± 10.1	164.7 ± 5.3	181.3 ± 5.7	< 0.001
Body mass index (kg/m^2)	22.8 ± 1.8	21.7 ± 1.1	23.9 ± 1.8	< 0.05
V˙O2peak (ml/kg/min)	53.0 ± 8.6	45.9 ± 5.2	60.1 ± 3.9	< 0.001
Body fat (%)	20.6 ± 7.9	26.9 ± 5.1	14.2 ± 3.7	< 0.001

Y = years; kg = kilograms; cm = centimeters; kg/m^2 = kilograms per meter square; ml/kg/min = milliliters of oxygen per kilogram of bodyweight per minute; % = a fraction of 100.

3.2. Experimental conditions

As designed, there were no significant differences in ExEE between the two exercise modalities (aerobic: 274.5 ± 50.6 and resistance: 270.4 ± 56.3 kcal; P = NS). However, exercise duration was significantly lower during the aerobic vs. resistance session (24.3 ± 4.3 vs. 87.5 ± 11.4 min; respectively; $P < 0.001$). Perceived exertion measured on a Borg scale (1–10) after the exercise sessions was also different between both modalities (aerobic: 5.5 ± 1.8 and resistance: 7.1 ± 1.8; $P < 0.05$). It should be noted that during the 30 min following the interventions, EE was on average 9 kcal ($P < 0.05$) higher after the aerobic vs. the resistance session. However, values in both sessions had returned to near pre-exercise values at the end of the cool down period (data not shown).

3.3. Energy intake

As presented in Table 2, no significant differences in EI were observed between modalities. In addition, the effect size was small (0.050) on this main outcome revealing the absence of a clear trend between conditions. As expected, a significant difference was noted between sexes. Furthermore, there was a sex by exercise modality interaction for EI at lunch ($P < 0.05$). EI was higher in men after the resistance session (1567 ± 469 vs. 1255 ± 409, respectively; $P = 0.03$), whereas no difference between sessions was seen in women (339 ± 256 vs. 411 ± 274, respectively; P = NS) (Fig. 2). No significant differences between modalities or an exercise modality by sex interaction were found for lipid, protein and carbohydrate intakes at lunch, 10 and 34 h later (data not shown). As expected, absolute lipid, protein and carbohydrate intakes were higher in men compared to women for lunch, during the first 10 h and over the 34-hour period (data not shown). Lastly, no differences between exercise modality, sex and interactions were found for the different appetite scores measured with VAS (data not shown).

Table 2. Energy intake and energy expenditure throughout the experimental sessions.

	Means ± SD			***P***		
	Aerobic	**Resistance**	**Control**	**Modality**	**Sex**	**Modality × sex**
Energy intake (kcal) (n = 16)						
Lunch	952 ± 459	1068 ± 628	1032 ± 689	NS	0.001	0.024
10 h	2648 ± 1101	2392 ± 1095	2473 ± 1117	NS	0.001	0.001
34 h	5442 ± 2050	5524 ± 2327	5757 ± 2164	NS	0.001	0.001
Energy expenditure (kcal) (n = 14[a])						
10 h	1269 ± 308	1223 ± 329	1234 ± 323	NS	0.005	0.005
34 h	3830 ± 795	4052 ± 1051	3837 ± 793	NS	0.001	0.001
NEAT (kcal) (n = 14[a])						
10 h	451 ± 206	401 ± 222	411 ± 219	NS	NS	NS
34 h	1047 ± 363	1253 ± 441	1039 ± 524	NS	NS	NS

[a] n = 7 men and 7 women.

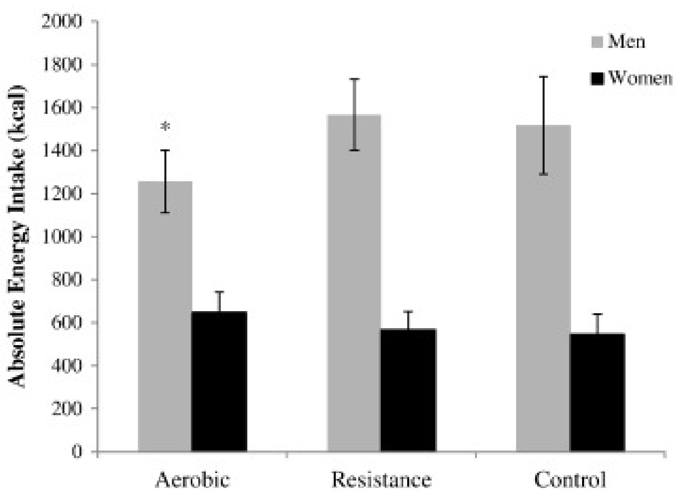

Fig. 2. Absolute energy intake at lunch across the experimental sessions for men and women. Values are presented as the mean for 8 men and 8 women ± SEM. * An interaction between intervention and sex was noted. This difference was observed in men between the resistance and the aerobic session ($P = 0.03$).

3.4. Energy expenditure

Data for TEE are shown in Table 2. No significant differences for TEE were found between the three conditions after 10 and 34 h. Similar to EI, the effect size (0.096) on this analysis also revealed the absence of a clear trend in the data. While no interaction was observed, men had a higher TEE after 10 and 34 h ($P < 0.01$ and $P < 0.001$, respectively). No significant differences for modalities, sex and interactions were noted for NEAT (Table 2). Similarly, no differences were noted for time spent walking, standing, sitting and lying down (data not shown).

3.5. Post-exercise energy compensation

As presented in Table 3, no differences for exercise modality, sex and interactions were found for total PEEC after 10 and 34 h. Correlation analyses were performed due to high inter-individual variations in PEEC across conditions. As shown in Fig. 3, a positive correlation was observed between PEEC measured following the aerobic and resistance sessions.

Table 3. Post-exercise energy compensation throughout the experimental sessions (n = 14).

Total post exercise	**Means ± SD**		***P***		
Energy compensation (%)	**Aerobic**	**Resistance**	**Modality**	**Modality × sex**	**Sex**
Day 1	57 ± 209%	16 ± 294%	NS	NS	NS
Total	− 52 ± 465%	− 83 ± 467%	NS	NS	NS

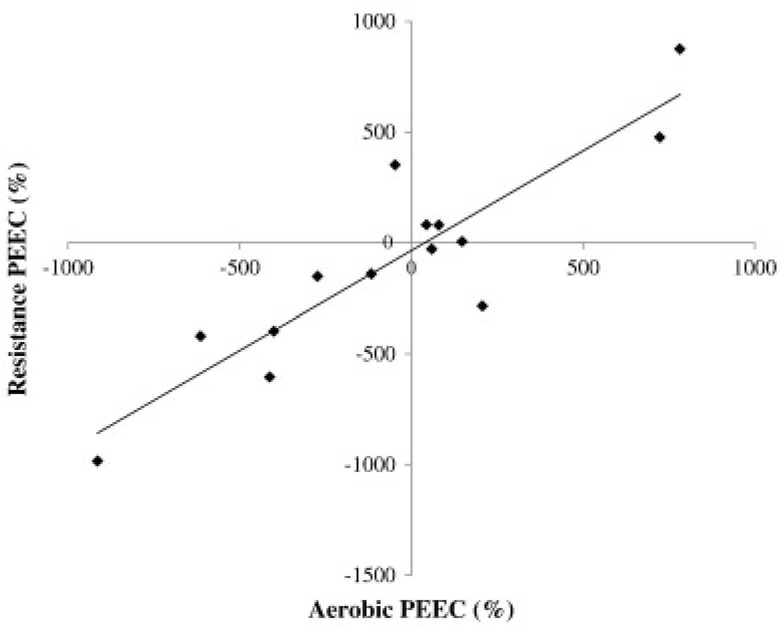

Fig. 3. Energy compensation values 34 h after the two training modalities. Values are presented as the mean for 7 men and 7 women ± SD. A correlation of 0.897 ($P < 0.01$) was calculated between the PEEC after the aerobic and resistance session.

4. Discussion

The main objective of the present study was to investigate the effects of isocaloric aerobic- and resistance-based exercise sessions on EI, TEE and PEEC in men and women over 34 h. Three main findings emerged from this study. First, no changes in EI were seen between sessions either acutely, after the first day, or over the 34 h measurement period. However, men ate more after the resistance than after the aerobic session, while no differences between exercise modalities were noted in women. Second, no changes in TEE were seen following each session. Third, there were no differences in PEEC between the two-exercise modalities, but a positive correlation was found between the two modalities across participants. The findings of this study are reinforced by the fact that the energy cost of the exercise modalities were matched, and that EI was measured not only immediately after exercise but also for the remainder of the day and the next day. In addition, TEE was objectively measured over 34 h, thus providing a complete overview of PEEC.

Previous studies have mainly focused on aerobic exercise when investigating post-exercise EI [6], [7], [8], [10], [13], [15], [21], [26], [27], [36], [40], [41], [42], [43], [44], while only three have assessed EI following resistance exercise [26], [27], [45]. Of these three studies, none clamped ExEE, and only two included both modalities in their design [26], [27]. Despite these discrepancies in study design, our results do corroborate those of Balaguera-Cortes et al. [26] and Laan et al. [27] where no differences in acute EI were noted between exercise modalities. Similarly, no differences in EI were noted on the exercise day or 34 h following exercise in the present study. However, men and women responded differently in terms of acute EI. More specifically, men had a lower EI after the aerobic exercise session vs. the resistance exercise session, while no differences in acute EI were noted between exercise modalities in women. Sex differences in EI were previously reported by Stubbs et al. [17], who noted that men had a slightly negative compensation following an aerobic exercise, while the women's compensation was positive for the same condition. Results from the present study add to the latter, by noting a greater EI in men following resistance vs. aerobic exercise. It may thus be suggested that the degree of EI in response to exercise in men may be dependent on exercise modality, at least acutely. Future studies would be needed to further confirm these results.

Measuring TEE and NEAT alongside measurements of EI following an exercise session represents one of the novel contributions of this study. Participants were asked to wear the accelerometer for 34 h outside of the laboratory environment following the intervention. Our results showed no differences 10 and 34 h following the exercise intervention across sessions. Furthermore, no differences in posture allocations were noted. These results suggest that exercise itself and the modality of exercise employed have no effect on subsequent TEE and NEAT in relatively young and healthy individuals. As Westerterp et al. [46] reported in their intervention study, increased EE due to training is not compensated by a decrease in leisure time activity. McLaughlin et al. [47] reported similar results in lean men and women, which suggests that NEAT was not affected by an 8-day training program. Given the important contribution of TEE to the energy balance, and the highly variable nature of NEAT (15% of TEE in sedentary individuals and 50% or more of TEE in active individuals) [48], more studies are needed to investigate this variable under free living conditions in different populations.

In order to obtain a complete depiction of PEEC, both sides of the energy balance have to be considered. No significant differences or interactions for PEEC were found in this study. On the other hand, we noticed large inter-individual variations for PEEC 34 h following exercise. The analyses that were performed revealed that PEEC was relatively stable within individuals between exercise modalities ($r = 0.897$; $P < 0.01$). This observation suggests that even if different individuals may present very different PEEC in response to varying exercise modalities, the response within an individual to the same variation in exercise is somewhat constant. This is the first study to report that the PEEC of an individual following an exercise session of the same caloric cost will be greatly influenced by individual characteristics, rather than the exercise modality per se.

The time required to match the ExEE of the two exercise modalities was about three times greater for the resistance exercise (24 vs. 88 min). This highlights the relatively low energy cost of resistance training as opposed to weight bearing continuous activities when they are performed at similar relative intensities (70% of $\dot{V}O_2$peak vs. 70% of 1RM). Similarly, using our continuous measurement of EE with indirect calorimetry, we were able to show that aerobic exercise elicited a slightly higher EE for the 30 min that followed the exercise sessions. However, EE returned to baseline values after this period. Though this study was not designed to compare the energy cost of aerobic vs. resistance exercise, the results nonetheless warrant prudence when discussing the effects of resistance exercise on ExEE. Future studies designed to address this question more directly are needed.

There are some limitations to this study. The 4 kcal/kg energy clamp may not have been a strong enough stimulus for the aerobic session, even if it was reported as being sufficiently intense (exertion values) during the resistance session. In fact, it took on average 60 min more to achieve the ExEE target during the resistance exercise session. Also, participants could have eaten foods other than that provided to them; but compliance to this variable was verified via self report for each experimental session. Additionally, lunch was served slightly later during the resistance session for all participants, even though the resistance exercise session started 30 min earlier. However, in order to prevent differences between modalities, lunch was served 75 min after the end of each exercise session, which is in agreement with the findings of King et al. [36], who reported that participants ate on average 81 min after an exercise session. Finally, we cannot generalize these results to the general population due to our small sample size and fitness level of our population. However, it should be noted that the effect sizes were also really small. In fact, calculations on data from EI, one of the main outcomes of this study, revealed that 108 participants would have been needed to obtain a significant effect on the main model. This reveals the absence of clear trend in the data in favor of our initial hypotheses.

In summary, exercise modality does not impact EI and EE, regardless of perceived exertion [26], or whether the calories expended or the duration of the exercises [26], [27] were clamped. However, our results show that men ate more immediately following resistance exercise, which was not the case for women even if this effect disappears when EI is measured over 2 days. As for PEEC, our results showed that each individual tends to maintain a relatively constant pattern of PEEC, and this independently of exercise modality.

Acknowledgments

SC and ÉD designed the research. SC, JM, ML and ÉD conducted the research. SC, MER and ÉD analyzed the data. All authors were involved in writing the paper and had final approval of the submitted and published version.

References

[1] Edholm OG, Fletcher JG, Widdowson EM, McCance RA. The energy expenditure and food intake of individual men. Br J Nutr 1955;9(3):286–300.

[2] Mayer J, Marshall NB, Vitale JJ, Christensen JH, Mashayekhi MB, Stare FJ. Exercise, food intake and body weight in normal rats and genetically obese adult mice. Am J Physiol 1954;177(3):544–8.

[3] Mayer J, Roy P, Mitra KP. Relation between caloric intake, body weight, and physical work: studies in an industrial male population in West Bengal. Am J Clin Nutr 1956;4(2):169–75.

[4] Mayer J, Thomas DW. Regulation of food intake and obesity. Science 1967;156(3773):328–37.

[5] Finlayson G, Bryant E, Blundell JE, King NA. Acute compensatory eating following exercise is associated with implicit hedonic wanting for food. Physiol Behav 2009;97(1):62–7.

[6] George VA, Morganstein A. Effect of moderate intensity exercise on acute energy intake in normal and overweight females. Appetite 2003;40(1):43–6.

[7] Pomerleau M, Imbeault P, Parker T, Doucet E. Effects of exercise intensity on food intake and appetite in women. Am J Clin Nutr 2004;80(5):1230–6.

[8] Verger P, Lanteaume MT, Louis-Sylvestre J. Human intake and choice of foods at intervals after exercise. Appetite 1991;18(2):93–9.

[9] Hubert P, King NA, Blundell JE. Uncoupling the effects of energy expenditure and energy intake: appetite response to short-term energy deficit induced by meal omission and physical activity. Appetite 1998;31(1):9–19.

[10] Imbeault P, Saint-Pierre S, Almeras N, Tremblay A. Acute effects of exercise on energy intake and feeding behaviour. Br J Nutr 1997;77(4):511–21.

[11] King NA, Blundell JE. High-fat foods overcome the energy expenditure induced by high-intensity cycling or running. Eur J Clin Nutr 1995;49(2):114–23.

[12] King NA, Burley VJ, Blundell JE. Exercise-induced suppression of appetite: effects on food intake and implications for energy balance. Eur J ClinNutr 1994;48(10):715–24.

[13] King NA, Lluch A, Stubbs RJ, Blundell JE. High dose exercise does not increase hunger or energy intake in free living males. Eur J Clin Nutr 1997;51(7):478–83.

[14] Lluch A, King NA, Blundell JE. No energy compensation at the meal following exercise in dietary restrained and unrestrained women. Br J Nutr 2000;84(2):219–25.

[15] Vatansever-Ozen S, Tiryaki-Sonmez G, Bugdayci G, Ozen G. The effects of exercise on food intake and hunger: relationship with acylated ghrelin and leptin. J Sport Sci Med 2011;10(2):283–91.

[16] Westerterp-Plantenga MS, Verwegen CRT, Ijedema MJW, Wijckmans NEG, Saris WHM. Acute effects of exercise or sauna on appetite in obese and nonobese men. Physiol Behav 1997;62(6):1345–54.

[17] Stubbs RJ, Sepp A, Hughes DA, Johnstone AM, Horgan GW, King N, et al. The effect of graded levels of exercise on energy intake and balance in free-living men, consuming their normal diet. Eur J Clin Nutr 2002;56(2):129–40.

[18] Stubbs RJ, Sepp A, Hughes DA, Johnstone AM, King N, Horgan G, et al. The effect of graded levels of exercise on energy intake and balance in free-living women. Int J Obes 2002;26(6):866–9.

[19] Kissileff HR, Pi-Sunyer FX, Segal K, Meltzer S, Foelsch PA. Acute effects of exercise on food intake in obese and nonobese women. Am J Clin Nutr 1990;52(2):240–5.

[20] Hill JO, Melby C, Johnson SL, Peters JC. Physical activity and energy requirements. Am J Clin Nutr 1995;62(5 SUPPL.):1059S–66S.

[21] Unick JL, Michael JC, Jakicic JM. Affective responses to exercise in overweight women: initial insight and possible influence on energy intake. Psychol Sport Exerc 2012;13(5):528–32.

[22] Colley RC, Hills AP, King NA, Byrne NM. Exercise-induced energy expenditure: implications for exercise prescription and obesity. Patient Educ Couns 2010;79(3):327–32.

[23] Ravussin E, Lillioja S, Anderson TE, Christin L, Bogardus C. Determinants of 24-hour energy expenditure in man. Methods and results using a respiratory chamber. J Clin Invest 1986;78(6):1568–78.

[24] Black AE, Coward WA, Cole TJ, Prentice AM. Human energy expenditure in affluent societies: an analysis of 574 doubly-labelled water measurements. Eur J Clin Nutr 1996;50(2):72–92.

[25] Schulz LO, Nyomba BL, Alger S, Anderson TE, Ravussin E. Effect of endurance training on sedentary energy expenditure measured in a respiratory chamber. Am J Physiol 1991;260(2 Pt 1):E257–61.

[26] Balaguera-Cortes L, Wallman KE, Fairchild TJ, Guelfi KJ. Energy intake and appetite-related hormones following acute aerobic and resistance exercise. Appl Physiol Nutr Metab 2011;36(6):958–66.

[27] Laan DJ, Leidy HJ, Lim E, Campbell WW. Effects and reproducibility of aerobic and resistance exercise on appetite and energy intake in young, physically active adults. Appl Physiol Nutr Metab 2010;35(6):842–7.

[28] Physiology TCSfE: CSEP guidelines' communiqué; 2011 [In. Ottawa].

[29] Saeki Y, Atogami F, Takahashi K, Yoshizawa T. Reflex control of autonomic function induced by posture change during the menstrual cycle. J Auton Nerv Syst 1997;66(1–2):69–74.

[30] McNeil J, Riou ME, Razmjou S, Cadieux S, Doucet E. Reproducibility of a food menu to measure energy and macronutrient intakes in a laboratory and under real-life conditions. Br J Nutr 2012;108(7):1316–24.

[31] Stunkard AJ, Messick S. The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. J Psychosom Res 1985;29(1):71–83.

[32] Physiology TCSfE: professional fitness & lifestyle consultant resource manual; 1996:2.

[33] Borg GAV. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 1982;14(5):377–81.

[34] Kelleher AR, Hackney KJ, Fairchild TJ, Keslacy S, Ploutz-Snyder LL. The metabolic costs of reciprocal supersets vs. traditional resistance exercise in young recreationally active adults. J Strength Cond Res 2010;24(4):1043–51.

[35] Pinnington HC, Wong P, Tay J, Green D, Dawson B. The level of accuracy and agreement in measures of FEO2, FECO2 and VE between the Cosmed K4b2 portable, respiratory gas analysis system and a metabolic cart. J Sci Med Sport 2001;4(3):324–35.

[36] King JA, Wasse LK, Stensel DJ. Acute exercise increases feeding latency in healthy normal weight young males but does not alter energy intake. Appetite 2013;61:45–51.

[37] McNeil J, M-E Riou, Razmjou S, Cadieux S, Doucet ë. Reproducibility of a food menu to measure energy and macronutrient intakes in a laboratory and under real-life conditions. Br J Nutr 2012;108(7):1316–24.

[38] St-Onge M, Mignault D, Allison DB, Rabasa-Lhoret R. Evaluation of a portable device to measure daily energy expenditure in free-living adults. Am J Clin Nutr 2007;85(3):742–9.

[39] Marsh-Richard DM, Hatzis ES, Mathias CW, Venditti N, Dougherty DM. Adaptive Visual Analog Scales (AVAS): a modifiable software program for the creation, administration, and scoring of visual analog scales. Behav Res Methods 2009;41(1):99–106.

[40] Deighton K, Zahra JC, Stensel DJ. Appetite, energy intake and resting metabolic responses to 60 min treadmill running performed in a fasted versus a postprandial state. Appetite 2012;58(3):946–54.

[41] Jokisch E, Coletta A, Raynor HA. Acute energy compensation and macronutrient intake following exercise in active and inactive males who are normal weight. Appetite 2012;58(2):722–9.

[42] King JA, Miyashita M, Wasse LK, Stensel DJ. Influence of prolonged treadmill running on appetite, energy intake and circulating concentrations of acylated ghrelin. Appetite 2010;54(3):492–8.

[43] Maraki M, Tsofliou F, Pitsiladis YP, Malkova D, Mutrie N, Higgins S. Acute effects of a single exercise class on appetite, energy intake and mood. Is there a time of day effect? Appetite 2005;45(3):272–8.

[44] Tremblay A, Simoneau JA, Bouchard C. Impact of exercise intensity on body fatness and skeletal muscle metabolism. Metab Clin Exp 1994;43(7):814–8.

[45] Ballard TP, Melby CL, Camus H, Cianciulli M, Pitts J, Schmidt S, et al. Effect of resistance exercise, with or without carbohydrate supplementation, on plasma ghrelin concentrations and postexercise hunger and food intake. Metab Clin Exp 2009;58(8):1191–9.

[46] Westerterp KR. Alterations in energy balance with exercise. Am J Clin Nutr 1998;68(4):970S–4S.

[47] McLaughlin R, Malkova D, Nimmo MA. Spontaneous activity responses to exercise in males and females. Eur J Clin Nutr 2006;60(9):1055–61.

[48] Levine JA. Nonexercise activity thermogenesis (NEAT): environment and biology. Am J Physiol Endocrinol Metab 2004;286(5 49-5):E675–85.

Appendix 1. Resistance session protocol

Superset	# of series
Incline bench	× 4
Lateral pull down	
120 second break	
Leg press	× 4
Leg curl	
120 second break	
Chest press	× 4
Seated row	
120 second break	
Leg extension	× 4
Calf raises	
120 second break	
Lateral raises	× 4
Pectoral fly	
120 second break	
Overhead press	× 4
Calf press	
120 second break	

Appendix 2. Experimental protocol for the three sessions

Time	Aerobic session	Time	Resistance session	Time	Control session
Day 1		Day 1		Day 1	
0800	Arrival to the laboratory Anthropometric measurements	0800	Arrival to the laboratory Anthropometric measurements	0800	Arrival to the laboratory Anthropometric measurements
0830	Standard breakfast	0830	Standard breakfast	0830	Standard breakfast
0845	Reading period	0845	Reading period	0845	Reading period
1020	Aerobic training	0945	Resistance training		
1215	Lunch	1245	Lunch	1215	Lunch
1400	Take home food Accelerometers	1400	Take home food Accelerometers	1400	Take home food Accelerometers
Day 2		Day 2		Day 2	
	Take home food		Take home food		Take home food
	Accelerometers		Accelerometers		Accelerometers