Title: The effects of an acute resistance exercise bout on appetite and energy intake in healthy older adults

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Abstract

Ageing is associated with reductions in appetite and food intake leading to unintentional weight loss. Such weight loss, particularly through muscle mass reduction, is associated with muscle weakness and functional decline, which represent predictors of poor health outcomes and contribute to frailty in older adults. Exercise-induced anorexia is an established phenomenon in young adults; however appetite and energy intake (EI) responses to resistance exercise are unknown in older adults. Twenty healthy older adults (68 ± 5 years, BMI 26.2 ± 4.5 kg·m^{-2}) undertook two 5-hour experimental trials. Participants rested for 30 minutes before being provided with a standardised breakfast (196 kcal, 75.2% carbohydrate, 8.9% protein and 15.9% fat). Participants then rested for 1-hour before completing: 1-hour resistance exercise bout followed by 2-hour of rest (RE) or, a control condition (CON) where participants rested for 3 hours, in a randomised crossover design. Appetite perceptions were measured throughout both trials and on cessation, an *ad libitum* meal was provided to assess EI. A repeated-mesures ANOVA revealed no significant condition x time interaction for subjective appetite (p = 0.153). However, area under the curve for appetite was significantly lower in the RE compared with CON (49 ± 8mm•hour^{-1} vs. 52 ± 9mm•hour^{-1}, p = 0.007, d = 0.27). There was no difference in EI (RE = 681 ± 246 kcal; CON = 673 ± 235 kcal; p = 0.865), suggesting that resistance exercise does not affect EI 2 hours post-exercise in older adults despite a significant but modest reduction in

appetite over a 5-h period. In conclusion, resistance exercise may be an appropriate means for optimising muscle mass adaptations without attenuating acute EI of older adults.

Keywords: Appetite, ageing, energy intake, resistance exercise, exercise-induced anorexia

Abbreviations

AUC = area under the curve

BMI = Body Mass Index

CON = Control

EI = Energy Intake

FFM (Fat-Free Mass)

Kg (kilogram)

MPS (Muscle Protein Synthesis)

RES = Resistance exercise

RMR = Resting Metabolic Rate

SD = Standard Deviation

VAS = Visual analogue Scale

$\dot{V}O_2$ = Maximal Oxygen Uptake

1-RM = One repetition max

5-RM= Five repetition max

1.0 Introduction

Energy intake is reduced with age which, in part, can be attributed to an age-associated reduction in appetite – termed the "anorexia of ageing" (Morley & Silver, 1988). As a result, unintentional weight loss (Roberts & Rosenberg, 2006) occurs predeominantly in skeletal muscle which exarcebates sarcopenia and frailty, and represents a significant predictor of poor clinical outcomes and functional decline (Rolland et al., 2011). Such outcomes are associated with an increased risk of morbidity and mortality (Evans, 2015).

From the age of ~40, skeletal muscle begins to decline at a rate of 0.47% and 0.37% per year in men and women, respectively (Mitchell et al., 2012). Rates of decline accelerate with age, reaching ~1-2% reductions per year between the age of 50-60 years (Doherty, 2003; Van Kan, 2009). This deterioration in muscle mass can be further augmented by physical inactivity and protein deficiencies (Landi et al., 2019). This likely mediates the reduction in energy expenditure in older adults (Frontera et al., 2000; Lexell et al., 1988), and drives the observed reduction in energy intake. As such, a vicious cycle ensues, whereby a muscle mass loss-induced reduction in energy intake perpetuates further losses in muscle mass due to protein-energy malnutrition.

Resistance exercise and the provision of exogenous amino acids represents a potent antisarcopenic stimulus for older adults through increased myofibrillar muscle protein synthesis (MPS) (Atherton & Smith, 2012; Yang et al., 2012). Additionally, following resistance exercise, the sensitivity of skeletal muscle to amino acids is heightened for up to 24 hours in facilitating an optimal muscle synthetic response (Burd et al., 2011; Rasmussen et al., 2000). Thus, the combination of resistance exercise and increased protein consumption is an established approach for increasing muscle mass and strength in older adults to offset poor outcomes (Morton et al., 2018). This attenuation of the reductions in skeletal muscle mass may facilitate increases in energy intake to overcome the vicious cycle that perpetuates unintentional weight-loss.

Nonetheless, there are caveats to this approach for increasing net energy balance when the acute appetite responses to both protein ingestion and resistance exercise are considered. Protein is the most satiating macronutrient (Westerterp-Plantenga, 2008). Both dietary protein (Poppitt et al., 1998) and whey protein supplementation (Mollahosseini et al., 2017) have been shown to reduce energy intake at subsequent meals, with similar findings recently observed in older adults (Butterworth et al. (2019). It is also well-established that strenuous aerobic exercise (≥60% of maximal oxygen uptake) acutely suppresses appetite in a phenomenon termed 'exercise-induced anorexia' (King et al., 1994). This suppression is transient, with appetite typically restored within 30 minutes after exercise, resulting in little effect on post-exercise energy intake when an ad libitum meal is provided at this time (King et al., 2013). Similarly, exercise-induced appetite suppression has been observed in response to resistance exercise in younger adults (Balaguera-Cortes et al., 2011; Broom et al., 2009) but the responses in older adults are yet to be established.

Understanding the appetite and energy intake responses to resistance exercise in older adults is important as it seems feasible that the anorexia of ageing and exercise-induced anorexia may interact to augment appetite-suppression after exercise. Thus, the present study aimed to determine the acute effects of resistance exercise on appetite perceptions and energy intake in healthy older adults.

It is hypothesised that resistance exercise will suppress appetite, compared with rest, but transiently so; as such it is expected that energy intake two hours after exercise will not differ between exercise and control conditions.

2.0 Methods

2.1 Participants

Twenty-one healthy, independently-living older adults were recruited to participate and 20 participants completed full the study design. Both genders were included in the analysis as evidence suggests males and females exhibit similar appetite and energy intake responses to exercise (Alajmi et al., 2016). The inclusion criteria were ≥60 years old, non-smokers, not taking medication known to influence appetite, weight stable for at least 3 months before the study (≤2 kg loss or gain), not currently attempting to lose or gain weight, and recreationally active (participating in moderate or vigorous physical activity at least 3 times per week) but without habitually completing resistance exercise. The study, which received institutional ethical approval, was conducted in accordance with the Declaration of Helsinki.

2.2 Preliminary Tests

Prior to the experimental trials, participants visited the laboratory to undergo screening, preliminary anthropometric measurements, familiarisation with the resistance exercise protocol and a five-repetition maximum (5RM) test. On arrival, baseline stature (to the nearest cm), body mass (to the nearest kg) and resting blood pressure (to the nearest mmHg) were measured by a stadiometer (Seca, Hamburg, Germany), scales (Seca, Hamburg, Germany), stethoscope and sphygmomanometer (Accoson Green Light 300, UK). Participants completed a food preference questionnaire to ensure acceptability of all food items available during the experimental trials. After participants had rested for 30 minutes, a full familiarisation session was conducted, in which all seven resistance exercises employed in the study were completed. Resistance machines were used as they were regarded safer to use compared with more complex free-weight exercises. The order in which each exercise was performed was: seated row, leg press, chest press, leg curl, lat pull down, leg extension and shoulder press. This was carried out in accordance with the American College of Sports Medicine position stand (Willoughby, 2015). As one repetition maximum (1-RM) testing is not recommended for older adults due to safety concerns, a five-repetition maximum (5-RM) test was used (Gail et al., 2015). One-repetition maximum value for the resistance exercises was subsequently estimated by the formula of Mayhew et al. (1992). This formula is evidenced to have high relative accuracy and low absolute error, providing a safe 1-RM prediction value for older adults starting a resistance training programme (Wood et al., 2002).

2.3 Experimental Trials

The participants undertook two experimental trials in a randomised order (resistance exercise (RE) and control (CON) which were completed individually and separated by at least seven days, using a counterbalanced crossover design. Participants completed a food diary in the 24 hours before the first experimental trial and replicated this before the second trial. Alcohol, caffeine and strenuous activity were not permitted during this 24-hour period; this was confirmed verbally on arrival. Confirmation of the replication of the 24-hour diary was attained by asking participants to complete another food diary for the 24 hours preceding the second trial. Participants arrived between 0700 and 0900 after an overnight fast of at least 10 hours and exerted themselves minimally when travelling to the laboratory, using motorised transport. One hour before arrival, participants ingested 300 mL of water to ensure euhydration.

Upon arrival at the laboratory, participants completed a baseline appetite questionnaire. After 30 minutes of rest, a standardised breakfast was consumed within a five-minute period. Participants rested for 60 minutes after the onset of breakfast before completing 60 minutes resistance exercise (RE) bout or remained resting within the laboratory (CON). Participants then rested (sitting reading, working at a desk or watching television), before being provided with an *ad libitum* lunch meal 120 minutes after exercise. After consumption of the *ad libitum* lunch meal, a final measure of subjective appetite was obtained, completing the trial.

2.4 Resistance exercise.

The resistance exercise bout involved two sets of 10-15 repetitions of each exercise at 40-50% of estimated 1-RM, with two minutes rest between sets before immediately moving to the next exercise. Total weight lifted was determined based on the amount of weight lifted (kg) for each exercise multiplied by the number of repetitions during all sets. Perceived ratings of exertion were measured using a 10-point scale at the end of each set (Borg, 1982). Exercises were completed in the order previously described in preliminary tests section and in accordance with ACSM guidelines (Willoughby, 2015).

2.5 Standardised Breakfast and Ad libitum Meal

The standardised breakfast consisted of a breakfast bar (Belvita Milk and Cereal Breakfast Bar), with an energy content of 196 kcal (75.2% carbohydrate, 8.9% protein and 15.9% fat). Participants were also fed an *ad libitum* pasta meal at 4.5 hours into each trial (2 hours after exercise). The *ad libitum* meal was designed to closely align with the UK dietary guidelines for macronutrient proportions (52% carbohydrate, 34%

fat and 14% protein (Public Health England, 2016) . The pasta-based meal consisted of penne pasta (Sainsbury's), cheddar cheese (Sainsbury's), tomato sauce (Sainsbury's) and olive oil (Sainsbury's). Pasta was cooked for 15 minutes in unsalted water at 700W before being mixed with the remaining ingredients and re-heated for 2 minutes at 700 W. Participants consumed the lunch in isolation to avoid any social influence on food intake and with no distractions. A bowl of the aforementioned meal was provided by an investigator and participants were instructed to eat until 'comfortably full', with no time limit set for eating. This bowl was replaced before the participant had emptied it, with minimal interaction, and this process continued until the participant was comfortably full (Deighton et al., 2016). This was done to ensure an empty bowl would not signal to terminate food consumption (Wansink, 2004). Food intake was calculated as the weighted difference in food before and after eating, this was then converted to calories using the manufacturer's nutritional information. Water was available at *ad libitum* during the first trial and this volume was provided to participants on the second trial. This ensured water intake was the same in both trials, controlling this as a potential confounding variable.

2.6 Subjective Appetite.

For the measure of subjective appetite, appetite perceptions (hunger, satisfaction, fullness and prospective food consumption (PFC)) were assessed at baseline and every 30 minutes thereafter using 100-mm visual analogue scales (VAS). Descriptors were anchored at each end describing the extremes (e.g. 'I am not hungry at all'/'I have never been more hungry') (Flint et al., 2000). A composite subjective appetite score (0-100) was calculated using the following formula: composite appetite score = (hunger + prospective food consumption + (100-fullness) + (100-satisfaction)/4)

(Stubbs et al., 2000). This single subjective composite score was used for ease of data analysis and presentation, as it has been shown that, with the original six question VAS technique (Hill & Blundell, 1982), the scores for each question co-vary to a large extent (Stubbs et al., 2000). A higher value is associated with a greater appetite sensation.

2.7 Statistical Analysis

Data were analysed using the Statistical Package for Social Sciences (SPSS) software version 26.0 for Windows (SPSS, Chicago, IL). Repeated measures ANOVA was used to examine differences between conditions over time. Area under the curve (AUC) values were calculated using the trapezoidal rule. Paired t-tests were used to evaluate differences between condition for AUC data and energy intake responses. Cohen's d effect size was calculated for t-tests. Effect sizes were interpreted as ≤0.2 trivial, >0.2 small, >0.6 moderate, >1.2 large, >2 very large, and >4 extremely large (Hopkins, 2004). A 10% (8-10mm) difference is typically seen as 'a reasonable and realistic difference in VAS scores (Flint et al., 2000). Power calculations determined that a sample size of 20 participants was required to detect a 10% (10mm) difference in appetite perceptions. These power calculations were performed using G*power with an alpha value of 5% and a power of 80% (Faul et al., 2007). Statistical significance was accepted at the 5% level. Results are given as means ± SD.

3.0 Results

Twenty healthy, independently-living older adults (13 females, 7 males) completed the study. All reported meeting physical activity recommendations of at least 150 minutes of moderate-vigorous physical activity each week. All participants, in successful completion of the resistance exercise familiarisation session, demonstrated the capacity in physical function to complete resistance exercise. Participant characteristics can be found in table 1.

Table 1. Participant characteristics

	Mean ±SD
Age (years)	68 ± 5
BMI (kg·m^{-2})	26.2 ± 4.5
Systolic Blood Pressure (mmHg)	134 ± 14
Diastolic Blood Pressure (mmHg)	81 ± 9

(SD: Standard Deviation, BMI: Body Mass Index)

3.1 Exercise Responses

All participants were able to complete the prescribed resistance exercise protocol. The total weight lifted during the 60 minutes' resistance exercise session was 7636.3 ± 157.5 kg. The mean rating of perceived exertion was 5 ± 1, representing "hard" exercise.

3.2 Subjective Appetite

Subjective appetite scores are shown in figure 1. There was no significant time x condition interaction (p = 0.153). There was a significant effect for condition (p = 0.007), with lower appetite perception in the RE condition across the trial. This was allied with a lower AUC for the entire study period in the RE condition (RE = 49 ± 8mm•hour^{-1}; CON = 52 ± 9mm•hour^{-1} , p = 0.007, d = 0.27; 95% CI of mean difference: 0.868 to 4.88; Figure 1).

3.3 Energy Intake

Energy intake during the *ad libitum* pasta meal was not significantly different between conditions (CON = 673 ± 235kcal; RE exercise = 681 ± 246kcal, p = 0.865, d = 0.03; 95% CI of mean difference: -413 to 350; Figure 2).

[Insert Figure 1]

[Insert Figure 2]

4.0 Discussion

This study demonstrates that an acute bout of resistance exercise induces a small and transient suppression of subjective appetite in older adults. The appetite profiles for the resistance exercise and resting control conditions suggest that the significant suppression across the resistance exercise condition appears to be driven by small reductions in appetite during (6mm difference in VAS score between conditions), and 30 minutes after (7mm difference) resistance exercise. This resulted in a significantly lower AUC value during the entirety of the trial period in the exercise condition. The transient nature of the suppression resulted in a convergence of appetite profiles prior to the *ad libiutm* meal consumed 2-hours after exercise. Accordingly, energy intake did not differ between the two conditions.

A strong body of evidence indicates that strenuous exercise (>60% $\dot{V}O_2$ max) leads to the transient suppression of appetite (Deighton & Stensel, 2014) termed exercise-induced anorexia (King et al., 1994). However, the extent to which this occurs in older adults is yet to be investigated. While the results of the current study do appear to demonstrate some agreement with previous research evidenceing a suppression of appetite with resistance exercise in young adults (Broom et al., 2009), the appetite response observed is much more modest. The significantly lower appetite perception over the trial period represented a difference in AUC of only 3mm·hour^{-1}, while the difference in VAS score between conditions did not exceed 7mm at any time point. Given that 8-10mm is typically accepted as the smallest meaningful change or difference in VAS score for subjective appetite (Flint et al., 2000), it is likely that the observed statistically significant difference in appetite AUC is not of practical significance.

Any appetite suppression was transient, as well as small in magnitude. A such, appetite perceptions did not differ between trials at the time of the meal, and unsurprisingly, energy intake was thus unaffected two hours after exercise. This is in agreement with previous findings in young adults (Balaguera-Cortes et al., 2011; Ballard et al., 2009). However, such findings are not unequivocal, with Laan et al. (2010) demonstrating that resistance exercise resulted in a significantly higher mean energy intake compared with aerobic exercise and control conditions. Potential reasons for these discrepancies in results may include timing of the meal, intensity of the exercise, and types of foods offered. It is difficult to assert meaningfulness of any change in energy intake in a single meal; however the anorexia of ageing has been classified as an energy intake of <70% of the estimated needs (Landi et al., 2016). The present study demonstrated an +8 kcal difference in energy intake following resistance exercise compare to the control which is very small and unlikely to impact upon daily energy intake. Therefore completing multiple sessions per week in line with recommendations for resistance exercise in older adults would unlikely interefere with energy intake to induce a significant change in body weight.

The mechanisms by which acute resistance exercise may modulate appetite was not investigated in the present study, but may be pertinent to speculate. It has previously been shown that resistance exercise can reduce circulating concentrations of the orexigenic hormone ghrelin, (Broom et al., 2009; Balaguera-Cortes et al., 2011), which accompanied appetite suppression (Broom et al., 2009). Such reductions occurred during (Broom et al., 2009) and in the immediate post-exercise period (Broom et al., 2009; Balaguera-Cortes et al., 2011), aligning with the suppression in subjective appetite in the study of Broom et al. (2009). As such, the modest appetite response to resistance exercise seen in the present study may have been associated with a modest reduction in ghrelin, but speculation of this mechanistic link is presented with caution given the small magnitude of appetite suppression.

Given the known enhancements in fat-free mass after resistance exercise training in older adults (Schoenfeld et al., 2017), the present study suggests that resistance exercise in older adults is unlikely to induce prolonged appetite suppression and a subsequent reduction in food intake after individual resistance exercise bouts. The time-course of appetite recovery after the exercise bout suggests that post-exercise nutritional strategies to maximise adaptations in older adults (e.g., protein intake) should perhaps take place >60-min after exercise cessation, once appetite perceptions have returned to control values; certainly, our data shows that feeding is not compromised 2 hours after exercise. Additionally, given that the enhanced sensitivity to amino acids persists for 24 hours after resistance exercise there is no need to prioritise immediate post exercise feeding (Burd et al., 2011).

It is important for future research to investigate whether energy intake is affected when feeding occurs closer to exercise cessation in older adults. Individuals may choose to eat soon after exercise for reasons other than appetite perceptions, so understanding feeding responses in the more immediate post-exercise period is important to ensure the age-associated reductions in appetite and/or energy intake were not further exacerbated by resistance exercise. Understanding the time course of both appetite and feeding responses can help inform post-exercise feeding strategies for older adults. This was precluded from the present study to enable investigation of the time-course of appetite recovery after the resistance exercise bout. Most studies investigating the acute effects of exercise on energy intake tend to provide an *ad libitum* meal at defined time points during trials (Balaguera-Cortes et al., 2011; George & Morganstein, 2003; King et al., 2010; Deighton et al., 2013). Constraining participants feeding schedules may alter energy intake and limits the ability to analyse other impacts on eating behaviour such as feeding latency or eating frequency. With complete unrestricted access to common food items, King et al. (2013) found that a 60-minute bout of high-intensity running delayed feeding, increasing the length of time before participants voluntarily chose to eat. However, energy intake at this meal was unaffected by exercise. Thus, we hypothesise that the small and transient suppressive effects of exercise observed in the present study are unlikely to compromise energy intake in the post-exercise period, if individuals are allowed unrestricted feeding. Further research is warranted to confirm this, given the known reductions in appetite associated with ageing (Johnson et al., 2019). Overall, the findings of the present study suggest that although resistance exercise led to a small and transient suppression in appetite this was not sufficient to interfere with subsequent energy intake.

Although acute energy intake was unaffected by the resistance exercise in the present study, any delayed, compensatory free-living adjustments in energy intake were not assessed. Neither acute energy expenditure during the trials nor free-living energy expenditure during the remainder of the day were measured. While such measures may have been of interest, the aim of this study was to determine the presence, magnitude and time course of appetite responses to resistance exercise, with a secondary aim to determine any impact on acute energy intake. Elucidating such effects is important for planning resistance training programmes for older adults. As such, while it is acknowledged that energy expenditure will have increased during the exercise bout which would impact energy balance, measures of daily energy balance were not a focus of this initial exploratory investigation. Further, obtaining accurate and valid measures of daily energy balance is challenging given the limitations of current methodologies for estimates of energy expenditure during resistance exercise, and for the measure of free-living energy intake and expenditure (O'Driscoll et al., 2018).

Age-related muscle loss is a natural characteristic of ageing which occurs at a rate of 1-2% per year (Keller & Engelhardt, 2013). Given that resistance exercise is prescribed to preserve muscle mass, its efficacy to do so could be compromised if resistance exercise is shown to suppress appetite, compromise feeding, and hence reduce energy and protein intake. This is especially prudent, considering 25% of older adults over 65 years in the UK are considered to be protein-energy malnourished (Leij-Halfwerk et al., 2019) and the importance of adequate protein intakes to maximise the adaptations to resistance exercise training (Finger et al., 2015). The findings of this study suggest that any resistance exercise-induced appetite response is very modest and short-lived, and acute food intake 2-hours after exercise is not negatively impacted. As such, this can inform the recommended timing of resistance exercise and post-exercise feeding for older adults to maximise the effectiveness of resistance training programmes.

Although the present study has provided novel insights into the appetite and energy intake responses to acute resistance exercise in older adults, some limitations must be acknowledged. Firstly, participants were healthy, recreationally active older adults. The present study explored differences in appetite regulation in healthy older adults to establish whether these effects occur before disease or frailty. Thus, it is appreciated that the findings cannot be generalised to older adults who are frail and possess underlying co-morbidities. Additionally, the delayed provision of the *ad libitum* meal (to allow monitoring of appetite perceptions after exercise) prevented investigation of whether energy intake is affected when food is provided more immediately after resistance exercise. This study did not include any mechanistic investigation into the appetite responses observed during and after the resistance exercise bout, such as the measurement of circulating appetite-related hormone concentrations. Therefore, future research may benefit from the measurement of mechanistic variables alongside appetite perceptions and energy intake. Finally, it is acknowledged that this study observed very acute responses of appetite and energy intake. It is necessary for future research to determine any longer term adaptations in appetite and energy intake to chronic resistance training programmes in older adults.

In conclusion, the findings of the present study confirm a small, temporary suppression of appetite during and after resistance exercise in older adults which is likely not to be of practical significance. Any differences between conditions in appetite perceptions converged prior to the meal being provided and, in accordance, energy intake was unaffected two hours following exercise.This acute study would suggest that older adults can undertake resistance exercise to promote optimal muscle protein turnover and attenuate the loss of muscle mass without compromising acute energy intake. This is to be confirmed with longer-term observations, and chronic adaptive responses in appetite and energy intake to resistance training is yet to be identified. Future research should also investigate appetite responses to resistance exercise in less active, frail older adults whereby the anorexia of ageing may be more prevalent.

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Figure 1. (a) Subjective appetite during the resistance exercise (■) and control (●) conditions (means ± SD, *n* = 20). Dark rectangle indicates the resistance exercise and the white rectangles indicate consumption of test meals; (b) Area under the curve values for subjective appetite in the resistance exercise and control trials (means and line plots representing individual appetite scores; *n* = 20).

Figure 2. *Ad libitum* energy intake during the resistance exercise and control conditions (mean and line plots representing individual energy intake; *n* = 20).

Figure 1.

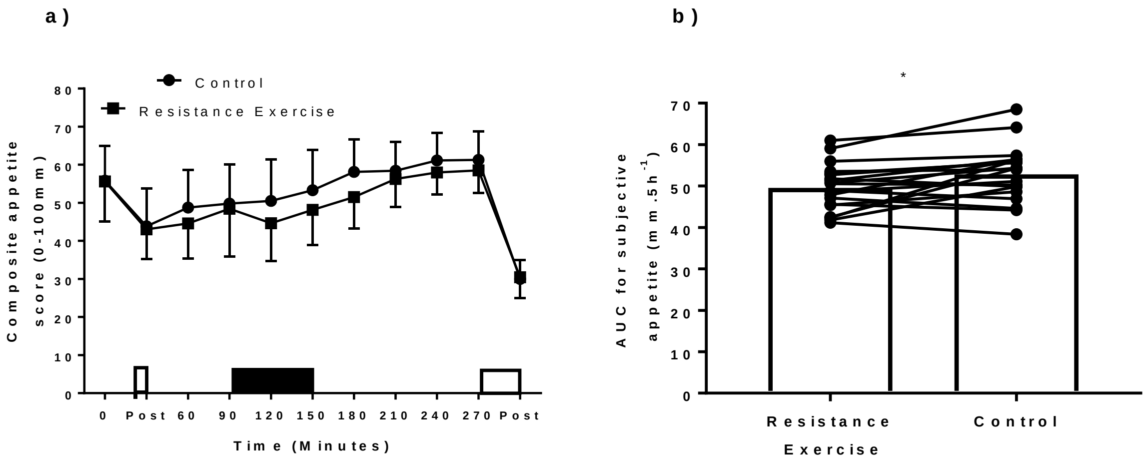
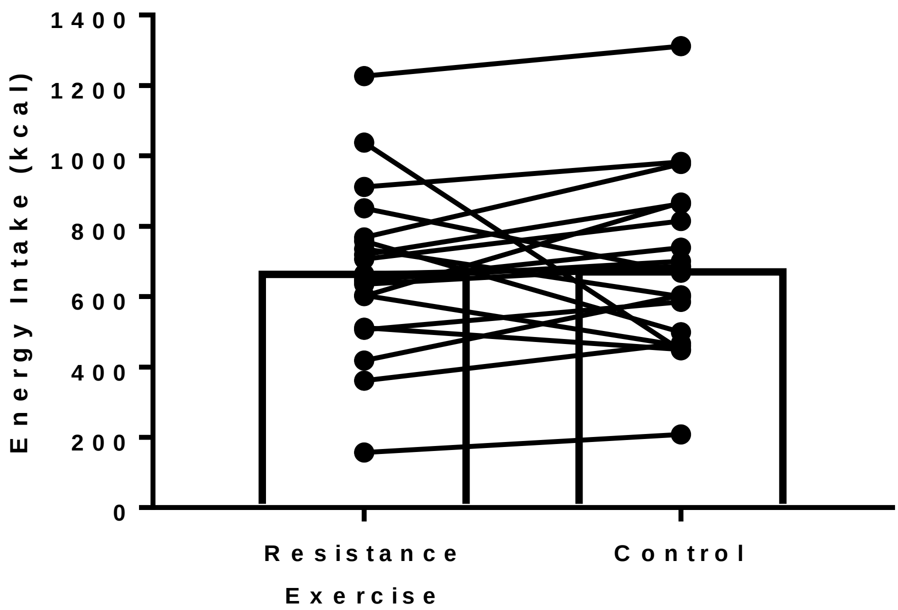

a)
b)
Control
Resistance Exercise
Composite appetite score (0-100mm)
80
70
60
50
40
30
20
10
0
0 Post 60 90 120 150 180 210 240 270 Post
Time (Minutes)
*
AUC for subjective appetite (mm.5h-1)
Resistance Exercise
Control

Figure 2.


Energy Intake (kcal)
1400
1200
1000
800
600
400
200
0
Resistance Exercise
Control