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Research Paper

Appetite responses over 24 hours before and after 12-weeks of resistance exercise in older male adults: Secondary data analysis of a randomised trial

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ABSTRACT

Background: Despite resistance exercise (RE) being a key component of landmark recommendations for weight control, there is still a paucity of data on the effects of RE on appetite. The aim of this study was to examine the effects of 12-weeks of RE on appetite.
Methods: Thirty-three older men (age: 67 ± 4 years; BMI: 25.4 ± 2.4 kg/m^2) were included in this secondary pooled data analysis of a 12-week randomised, double-blind, placebo-controlled, 4-arm parallel group trial. In the present analysis, RE (2x/week at 80% 1RM; $n = 17$) and no exercise (NE; continue habitual physical activity; $n = 16$) groups were pooled and compared to one another. Appetite profile was measured over 24 h inside a metabolic chamber at baseline and post 12-weeks using visual analogue scales (VAS). Area under the curve (AUC) was calculated using the trapezoidal method. Significance was set at $p < 0.05$.
Results: No significant group-by-time ($p \geq 0.08$) or group-by-time-by-time point ($p \geq 0.10$) differences occurred between groups for VAS hunger, satiety, fullness, prospective food consumption, or composite appetite score. Similarly, no significant differences were observed for 24-h VAS AUC for hunger ($p = 0.35$), satiety ($p = 0.58$), fullness ($p = 0.41$), prospective food consumption ($p = 0.21$), or composite appetite score ($p = 0.40$).
Discussion: The present study found no statistical effect on appetite following 12-weeks of RE in older adult males. RE should continue to be undertaken throughout the life course and be included as part of physical activity recommendations for optimal health in older adults due to the many physical, mental health and functional benefits.

1. Introduction

Body mass is regulated as a balance between energy intake (EI) and energy expenditure (EE). Exercise is an effective means by which to increase EE and has been shown to lead to short-term decreases in hunger [1–4] that does not necessarily lead to overeating at the next meal [5]. This phenomenon has been termed 'exercise-induced anorexia' [6].

Many studies examining the appetitive effects of exercise have focused on aerobic (cardiovascular), land-based exercise [5,7], but some have examined water-based exercise [8]. Resistance exercise (RE) is commonly recommended as part of public health guidelines promoting the benefits of physical activity throughout the life course due to supporting maintenance of skeletal muscle mass (SMM) and physical function [9]. Despite RE being a key component of landmark recommendations for weight control, such as those published by the American College of Sports Medicine [1], there is still a paucity of data on the effects of RE on appetite.

Immediately following an acute bout of RE, several studies have reported a brief suppression of various indices of appetite [10–13]. Broom et al. [10] demonstrated that a 90 min free-weight RE session suppressed appetite in lean, healthy, young adult males. This

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suppression coincided with the decline in the concentration of the orexigenic (appetite stimulating) gut peptide hormone acylated ghrelin. More recently, Johnson et al. [12] examined 20 healthy older adults who undertook two 5-h experimental trials in which participants completed a 1 h RE bout followed by 2 h of rest or, a control condition where participants rested for 3 h, in a randomised, crossover design. Appetite perceptions were measured throughout both trials and on cessation, an *ad libitum* meal was provided to assess EI. There was no significant treatment effect on subjective appetite; however, area under the curve (AUC) for appetite was significantly lower in the RE compared with control condition. In addition, there was no difference in EI suggesting that RE does not affect EI 2 h post-exercise in older adults despite a significant but modest reduction in appetite over a 5-h period.

In contrast to the aforementioned studies, others have not reported a suppression of either subjective appetite or acylated ghrelin following acute bouts of RE in either younger [14–16] or middled-aged adults [17]. Disparities can be explained by the intensity of the RE which influences session volume, as differences in hunger response have been reported following acute bouts of high and low intensity RE [11]. Further, acute studies to date report either minimal or no changes in the anorexigenic (appetite suppressing) hormones such as peptide tryosine-tryosine (PYY) and glucagon-like peptide-1 (GLP-1) [10,14,17]. Likewise, there does not appear to be any compensatory reduction or significant increase in EI for the remainder of the day in either young [13,15,18] or older adults [19].

The previously mentioned studies have all examined the effects of a single session of RE on appetite-related outcomes on either the same or the following day. Few studies have investigated the longitudinal effects of multiple bouts of RE on subjective appetite or hormonal markers. This is an oversight considering that people typically undertake RE multiple times per week in which at least 2–3 sessions per week is a recommendation of national physical activity guidelines in the UK [20].

Of the studies that have examined the longitudinal effects of RE, Guelfi, Donges, and Duffield [21] recruited middle-aged men who were either living with overweight or obesity to participate in 12 weeks of RE. They found no changes in subjective appetite or concentrations of acylated ghrelin, PYY or pancreatic polypeptide (PP) in either the fasted or postprandial state. In contrast, Shakiba et al. [22] examined young, adult, male students who were living with overweight and observed a decrease in fasting acylated ghrelin concentration and an increase in total PYY concentration following the completion of a RE programme. They concluded that changes in appetite hormones might be related to the increase in EE and subsequent loss of body mass following RE.

These longitudinal studies were conducted in young to middle-aged adults in which the findings may not be generalisable to older adults. Johnson et al. [23] investigated 39 healthy older adults (age: 66 ± 4 years; body mass index (BMI): 25.1 ± 3.5 kg/m^2) assigned to either a 12-week RE + whey protein supplementation group or a control group. Fat-free mass (FFM) (+1.2 kg; $p = 0.002$), postprandial subjective appetite (+8 mm; $p = 0.027$), *ad libitum* EI (+119 kcal; $p = 0.012$) and daily EI (+133 kcal; $p = 0.010$) increased from baseline to 12 weeks in the RE group. However, there is still a lack of longitudinal data in older adults. The aim of this study therefore was to examine the effects of 12-weeks of RE on subjective appetite in older males. We also examined the influence of body composition and components of 24-h EE at baseline and changes following RE on subjective appetite measures, since these have primarily been investigated in individuals who are lean and healthy, experiencing minimal change.

2. Materials and methods

Comprehensive accounts of the methods employed in this study have been published elsewhere [24–26]. Accordingly, only a brief overview of these are provided hereafter. Readers are advised to consult the referenced publications for detailed procedural information.

2.1. Participants and experimental design

Thirty-three older men (67 ± 4 years) were included in this analysis, which was a secondary pooled data analysis of a 12-week randomised, double-blind, placebo-controlled, 4-arm (control [CON], whey protein supplementation [PRO], resistance exercise + control [RE+CON] and resistance exercise + whey protein supplementation [RE+PRO]) parallel group trial [24,25]. The overall trial assessed the individual and combined effects of RE and whey protein supplementation on components of 24-h EE (of which resting metabolic rate [RMR] was the primary outcome) and substrate oxidation, body composition (i.e., FFM, skeletal muscle mass, fat mass), muscle strength and physical function, metabolic flexibility and insulin resistance, biomarkers related to sarcopenia (i.e., hormonal and inflammatory biomarkers), cognitive function, and subjective appetite. The majority of these outcomes have previously been published [24–32]. The present study presents the final data of the overall trial on subjective appetite. Females were excluded from the trial due to the relatively small sample size and prior work establishing sex differences on primary outcomes that would have likely resulted in large variability in primary study endpoints [33,34]. Males were studied due to reported greater annual declines in FFM per annum (3.0% vs. 1.7%) and shorter life expectancy compared to women [35]. The sample size is similar to that reported by Rocha et al. [36].

In the present analysis, RE (RE+CON + RE+PRO; $n = 17$) and no exercise (NE; CON + PRO; $n = 16$) groups were pooled and compared to one another. Complete descriptions of the eligibility criteria, experimental design, and group pooling for analysis have already been published [24–26]. While the statistical analysis of the four independent groups was not a primary focus of this manuscript, dietary intake data of these groups has been reported elsewhere [24], and appetite data descriptives and statistical analysis is reported in supplementary materials for transparency (Supplementary Tables 1–3). Regarding eligibility, participants were required to be: aged 60–80 years with a BMI 18.5–30 kg/m^2; a non-smoker; weight stable (± <3 kg change in the previous 6 months); naïve to RE for the previous 6 months; no past or existing history of cancer, diabetes mellitus, or cardiovascular, thyroid, or renal disease; and not taking statins, non-steroidal anti-inflammatory or metabolism-affecting drugs.

Although both groups consumed a nutritional supplement (95 kcal/serving) twice daily as a dietary intervention (whey protein or a carbohydrate control; RE group: $n = 9$ whey protein and $n = 8$ carbohydrate control; NE group: $n = 8$ whey protein and $n = 8$ carbohydrate control), dietary intervention was controlled for in the statistical analysis (detailed below) and no significant dietary intervention, or exercise + dietary intervention interactions on appetite outcomes occurred (see Supplementary Tables 2 and 3). Though, it is important to note that we previously observed a dietary intervention interaction on EI, with CON supplement increasing EI greater than PRO supplementation [28]. Therefore, EI and appetite data in this study of pooled groups, given the link between EI and appetite, should be interpreted with these data in mind. All measurements were taken at baseline and following the 12-week intervention. Ethical approval was granted by Coventry University Ethics Committee (project code: P59723) and the study was registered at clinicaltrials.gov as NCT03299972. All participants provided written informed consent in accordance with the Declaration of Helsinki.

2.2. Resistance exercise training

Participants performed supervised RE 2 x per week with >48 h between sessions. In each session, participants completed 3 sets of leg press, lateral row, hamstring curl, chest press, leg extension and shoulder press (in that order) on fixed RE machines (Life Fitness, Rosemont, Illinois, USA). Starting at 60% one repetition maximum (1RM) (10–12 repetitions per set), intensity was progressively raised by ~5–7% per week for the first four weeks to 80% 1RM (8 repetitions per set), where it

was kept constant until the end of the intervention. Participants completed each exercise to the point of volitional failure on the last set. When participants were able to execute >12 repetitions on the last set of each exercise and based on 1RM tests conducted every 4 weeks, the intensity was modified accordingly. Participants in the NE group were asked to continue their habitual physical activity.

2.3. Dietary intake and habitual physical activity

Dietary intake was recorded by participants recording their EI for three days—two during the week and one on the weekend—at baseline (before the intervention started) and in weeks 6 and 12 of the intervention. Dietary analysis software was used to examine food records for total EI and macronutrient consumption (Nutritics Version 5.097; Nutritics, Dublin, Ireland). Habitual physical activity was measured via a tri-axial accelerometer (Actigraph GT9X; Actigraph, Pensacola, Florida, USA), which participants wore continuously on the dominant wrist for 7 days in free-living at baseline (before the intervention started) and during week 12 of the intervention. At least 5 days of ≥10 h wear time was required for data to be included in the final analysis. The accelerometer was sampled at 80 Hz and was analysed in 60-s epochs for total activity (counts/day) using ActiLife (Version 6.13.4; Actigraph, Pensacola, Florida, USA).

2.4. Body composition

Body mass, FFM, and fat mass were measured in the morning by bioelectrical impedance analysis (BIA) (BC-418 MA; Tanita Corporation, Tokyo, Japan), at consistent times (± 1 h). Participants consumed the same breakfast before both assessments, voided their bladder prior to measurement, and wore minimal clothing.

2.5. Energy expenditure

Participants resided in a metabolic chamber for 24 h (from ~1930 h to 2000 h the next day) and underwent a controlled 24-h protocol, including standardised isocaloric meals (see Supplementary Table 4 for content and timings) and three bouts of 30-min step exercise (15 cm step at 75 steps/min) at set times (see Fig. 1 for metabolic chamber protocol in diagrammatical format). Energy Expenditure was calculated from continuous measurement of oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) by indirect calorimetry corrected for protein oxidation, using the equation of Brouwer [37]. Total EE (TEE) represented the EE between 2000 h and 2000 h; RMR was measured as the least restless 20-min period between 0720–0750 h following awakening at 0650 h with the participant supine, but awake, from 0700–0800 h; and, activity EE (AEE) and diet-induced thermogenesis (DIT) were calculated using the intercept method, as previously detailed [38–40]. Previously, we reported results for components of 24-h EE following RE and NE both unadjusted and adjusted for body composition (FFM and fat mass) [25]. For the purposes of the present analysis related to appetite, only unadjusted components of 24-h EE are reported. Participants were in energy balance at both baseline and 12 weeks as previously detailed [25].

2.6. Appetite profile

Appetite profile was measured over 24 h within the metabolic chamber at baseline and post 12-weeks by means of visual analogue scales (VAS) [41]. These were paper-based 100 mm scales with 'not at all' or 'extremely' anchored on either side, combined with questions on hunger, satiety, fullness, and prospective food consumption. Participants were asked to draw a vertical line through the 100 mm scale relating to their perception of the question asked. The lines were then measured (in mm) and a sub-sample ($n = 100$) were counter-measured. A composite appetite score was calculated as (hunger VAS + prospective

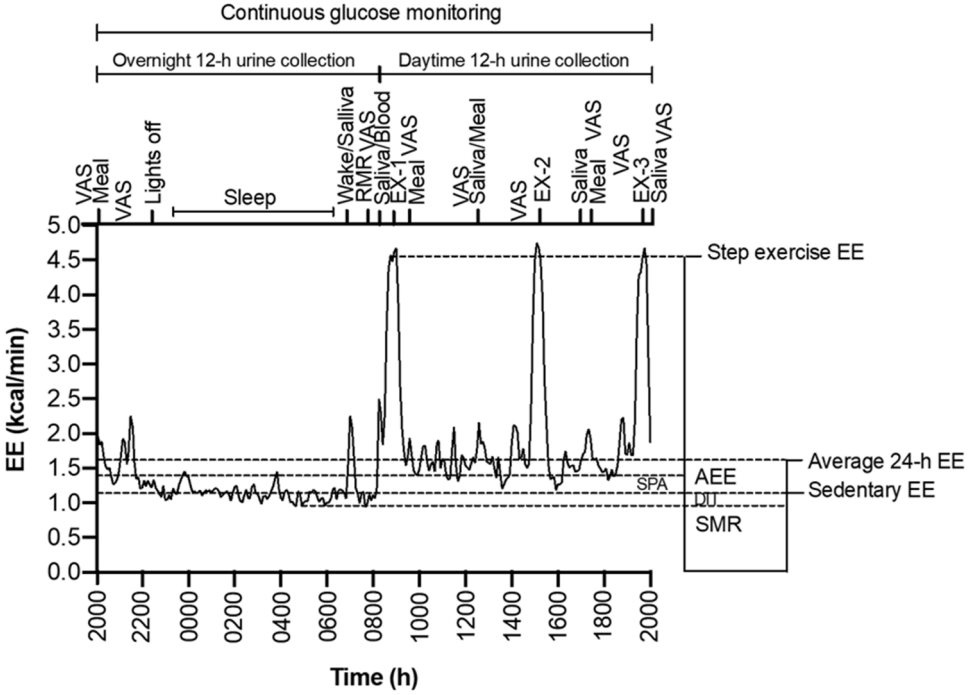


Fig. 1. Schematic of the 24-h metabolic chamber protocol. Energy expenditure (*y*-axis) is plotted against time (*x*-axis bottom) for one participant (ID: 008_baseline; age: 72 years). The protocol is noted on top of the *x*-axis. Components of 24-h EE calculated inside the metabolic chamber (not all reported herein) are illustrated with dashed lines. AEE, activity energy expenditure; DIT, diet-induced thermogenesis; EE, energy expenditure; EX-1, step exercise bout 1 (fasted); EX-2, step exercise bout 2; EX-3, step exercise bout 3; RMR, resting metabolic rate; SMR, sleeping metabolic rate (not reported herein); SPA, spontaneous physical activity (not reported herein); VAS, visual analogue scales. Adapted from [25].

food consumption VAS + [100-satiety VAS] + [100-fullness VAS)/4]). Validity and reproducibility of VAS to assess appetite have been previously confirmed [41] . Participants completed the VAS nine times (see Fig. 1) at:

Day 1:

- 1955 h – Pre evening meal
- 2130 h – 1.5 h post start of evening meal

Day 2:

- 0805 h – Pre fasted step exercise
- 0900 h – Immediately post fasted step exercise
- 1225 h – Pre lunch
- 1335 h – 1.25 h post start of lunch
- 1720 h – Pre dinner
- 1835 h – 1.25 h post start of dinner
- 1955 h – Post step exercise

Research staff within the laboratory did not consume food or drink in sight of participants to eliminate a food cue, but participants did have access to the time of day during the 24-h period. Area under the curve for appetite ratings were calculated over the 24 h measurement period using the trapezoidal method.

2.7. Statistical analysis

Sample size calculations for the primary outcomes of the randomised trial have previously been published [24,25] but these were not appetite related so the findings need to be interpreted with caution. Post hoc power analysis of subjective appetite outcomes from this study indicated the sample size yielded between 11–45% statistical power to determine a statistically significant effect between RE and NE groups.

Statistical analysis was performed using JASP Version 0.15 (https://jasp-stats.org/). Data are presented as means ± SD and were checked for normality using the Shapiro-Wilk test. Non-normally distributed data were transformed by log transformations. If transformation was unsuccessful, non-parametric tests were utilised. Baseline characteristics were analysed by independent samples *t*-tests. A mixed-model ANCOVA was conducted on outcome variables, with time (baseline and 12 weeks for most outcomes; baseline, 6 weeks, and 12 weeks for self-report dietary intake) and time point (when applicable; 1955 h and 2130 h on day 1, and 0805 h, 0900 h, 1225 h, 1355 h, 1720 h, 1835 h and 1955 h on day 2) acting as the within-subjects factor, group (RE or NE) acting as the between-subjects factor, and corresponding baseline values and dietary intervention (protein or control) included as covariates. Dietary intervention was included as a covariate as this study was a pooled analysis of a 4-group trial, with all participants receiving a dietary intervention, as previously detailed above and elsewhere [24,25]. Non-parametric data were analysed using the Aligned Rank Transform (ART) Model and ANOVA, with the same covariates as above. Correlations were analysed using bivariate and partial correlation (Pearson's for parametric data and Spearman's rank-order coefficients for non-parametric data) for baseline and Δbaseline, respectively. Intervention group was controlled for in the Δbaseline correlations. Significance was set at $p < 0.05$.

3. Results

3.1. Participants

Thirty-nine older men were randomised: 33 (age: 67 ± 4 years; BMI: 25.4 ± 2.4 kg/m^2) completed the study and six withdrew (see Supplementary Figure 1 for participant flow). Baseline characteristics of the RE ($n = 17$) and NE ($n = 16$) groups, of which there were no significant differences between groups ($p \geq 0.26$), are shown in Table 1. The mean attendance to the RE sessions was 98 ± 3%.

Table 1
Baseline characteristics.

	RE ($n = 17$)	NE ($n = 16$)	*p* value
Age (years)	67 ± 4	66 ± 5	0.48
Height (m)	1.75 ± 0.08	1.78 ± 0.06	0.31
Body mass (kg)	78.6 ± 11.4	80.1 ± 8.6	0.68
BMI (kg/m^2)	25.5 ± 2.5	25.3 ± 2.2	0.81
FFM (kg)	59.2 ± 8.1	60.6 ± 4.4	0.55
Fat mass (kg)	19.4 ± 4.7	19.5 ± 5.8	0.95
TEE (kcal/day)	2457 ± 243	2473 ± 249	0.85
RMR (kcal/day)	1619 ± 190	1632 ± 200	0.86
AEE (kcal/day)	741 ± 149	729 ± 132	0.81
DIT (kcal/day)	137 ± 100	134 ± 99	0.95
DIT (% of EI)	5.5 ± 4.3	5.8 ± 4.1	0.84
Total activity (counts/day)	324,530 ± 41,496	257,482 ± 40,750	0.26

Data are means ± SD. *P* values refer to differences between groups analysed by independent samples *t*-test. AEE, activity energy expenditure; BMI, body mass index; DIT, diet-induced thermogenesis; EI, energy intake; FFM, fat-free mass; NE, no exercise group; RE, resistance exercise group; RMR, resting metabolic rate; TEE, total energy expenditure.

3.2. Dietary intake and habitual physical activity

Dietary intake data for both the RE and NE groups can be seen in Table 2. No significant differences in total EI ($p = 0.052$) or macronutrient intakes ($p \geq 0.07$) occurred between groups from baseline to week 12. Total activity significantly decreased from baseline to week 12 in the RE group greater than the NE group (−72,984 ± 145,933 counts/day vs. +32,428 ± 150,568 counts/day, $p = 0.046$).

3.3. Body composition

Fat-free mass significantly increased from baseline to 12 weeks in the RE group greater than the NE group (+1.0 ± 1.3 kg vs. +0.1 ± 0.8 kg, $p = 0.04$), but no changes in body mass ($p = 0.61$) or fat mass ($p = 0.16$) occurred between groups.

3.4. Energy expenditure

Changes in components of 24-h EE from baseline to 12 weeks can be seen in Table 3. No significant changes in TEE ($p = 0.18$), DIT ($p \geq 0.30$), nor AEE ($p = 0.11$) occurred between groups; however, RMR significantly increased, albeit by a small magnitude, in the RE group greater than the NE group (+30 ± 71 kcal/day vs. −40 ± 127 kcal/day, $p = 0.03$).

3.5. Subjective appetite

3.5.1. Baseline correlations

Significant positive correlations were observed at baseline for TEE and 24-h VAS AUC prospective food consumption ($r = 0.35$, $p = 0.048$), and RMR and 24-h VAS AUC hunger ($r = 0.40$, $p = 0.02$) and 24-h VAS AUC prospective food consumption ($r = 0.46$, $p = 0.007$; Table 4). Significant inverse correlations were observed between FFM and 24-h VAS AUC satiety ($r = -0.40$, $p = 0.02$), TEE and 24-h VAS AUC satiety ($\rho = -0.47$, $p = 0.006$) and 24-h VAS AUC fullness ($\rho = -0.35$, $p = 0.048$), and RMR and 24-h VAS AUC satiety ($r = -0.57$, $p < 0.001$) and 24-h VAS AUC fullness ($r = -0.39$, $p = 0.03$). No significant correlations were observed between baseline age, body mass, fat mass, AEE, or DIT, and any baseline 24-h VAS AUC appetite outcome.

3.5.2. Changes over time

No significant group-by-time ($p \geq 0.08$) or group-by-time-by-time point ($p \geq 0.10$) differences occurred between groups from baseline to 12 weeks for VAS hunger, satiety, fullness, prospective food

Table 2
Self-report dietary intake during the intervention period.

	RE ($n = 17$)			NE ($n = 16$)			
	Baseline	6 weeks	12 weeks	Baseline	6 weeks	12 weeks	p value
Energy intake (kcal/day)	2076 ± 294	2292 ± 271	2183 ± 384	1917 ± 371	2029 ± 363	2009 ± 361	0.052
Carbohydrate intake (kcal/day)	244 ± 42	245 ± 46	257 ± 46	221 ± 46	218 ± 55	229 ± 54	0.59
Carbohydrate intake (%)	49.1 ± 10.4	44.7 ± 7.6	47.5 ± 6.9	46.4 ± 6.2	43.2 ± 10.1	45.3 ± 5.9	0.81
Protein intake (g/day)	82 ± 13	110 ± 28	106 ± 24	82 ± 14	103 ± 29	101 ± 29	0.70
Protein intake (g/kg/day)	1.0 ± 0.2	1.4 ± 0.3	1.4 ± 0.3	1.0 ± 0.1	1.3 ± 0.4	1.3 ± 0.4	0.07
Protein intake (%)	16.1 ± 1.9	19.9 ± 4.3	19.9 ± 5.4	17.2 ± 2.4	20.4 ± 5.9	20.7 ± 7.2	0.99
Fat intake (g/day)	73 ± 19	72 ± 16	65 ± 23	67 ± 20	74 ± 23	66 ± 21	0.89
Fat intake (%)	31.6 ± 6.6	30.2 ± 3.9	26.5 ± 5.9	31.5 ± 4.7	31.5 ± 8.2	28.9 ± 5.9	0.55

Data are means ± SD. Data were analysed by a mixed-model ANCOVA with time (baseline, 6 weeks and 12 weeks) acting as the within-subjects factor, group (RE or NE) acting as the between-subjects factor, and corresponding baseline values and dietary intervention (protein or control) included as covariates. *P* values refer to respective group-by-time interaction. NE, no exercise group; RE, resistance exercise group.

Table 3
Components of 24-h energy expenditure at baseline and 12 weeks.

	RE ($n = 17$)		NE ($n = 16$)		
	Baseline	12 weeks	Baseline	12 weeks	p value
TEE (kcal/day)	2457 ± 243	2424 ± 258	2473 ± 249	2412 ± 249	0.18
RMR (kcal/day)	1619 ± 190	1656 ± 183	1632 ± 200	1592 ± 169	0.03
AEE (kcal/day)	741 ± 149	652 ± 106	729 ± 132	741 ± 123	0.11
DIT (kcal/day)	137 ± 100	162 ± 66	134 ± 99	131 ± 106	0.30
DIT (% of EI)	5.5 ± 4.3	5.4 ± 2.9	5.8 ± 4.1	6.8 ± 4.3	0.31

Data are means ± SD. Data were analysed by a mixed-model ANCOVA with time (baseline and 12 weeks) acting as the within-subjects factor, group (RE or NE) acting as the between-subjects factor, and corresponding baseline values and dietary intervention (protein or control) included as covariates. *P* values refer to respective group-by-time interaction. AEE, activity energy expenditure; DIT, diet-induced thermogenesis; EI, energy intake; NE, no exercise group; RE, resistance exercise group; RMR, resting metabolic rate; TEE, total energy expenditure.

consumption, or composite appetite score (Fig. 2).

Similarly, no significant differences were observed from baseline to 12 weeks for 24-h VAS AUC for hunger ($p = 0.35$), satiety ($p = 0.58$), fullness ($p = 0.41$), prospective food consumption ($p = 0.21$), or composite appetite score ($p = 0.40$, Fig. 3).

Significant positive correlations were observed from baseline to 12 weeks for Δbody mass and Δfullness 24-h VAS AUC ($r = 0.40$, $p = 0.02$), and Δfat mass and Δfullness 24-h VAS AUC ($r = 0.40$, $p = 0.03$, Table 5). No significant correlations were observed for ΔFFM, ΔTEE, ΔRMR, ΔAEE, or ΔDIT and changes in any 24-h VAS AUC appetite outcome.

4. Discussion

The research evidence is conclusive that RE, which involves the voluntary contraction of targeted skeletal muscle against an external resistance through body weight, resistance machines, free weights, cables or bands, can increase SMM, strength and physical function regardless of sex or age [20]. However, it is inconclusive if multiple bouts of RE throughout the week, as part of a 12-week training programme, influences subjective appetite over 24-h, providing a sound rationale for undertaking the present study. To the authors' knowledge, we are the first to examine 24-h subjective appetitive responses following a longitudinal (12 weeks) RE programme in older adults with a BMI between 18.5–30 kg/m^2.

The key findings are that there were no statistically significant effect on changes in subjective hunger, satiety, fullness, prospective food consumption, or composite appetite score following 12-weeks of RE. This compares with the findings of Guelfi, Donges, and Duffield [21], who undertook a 12-week programme of RE though in middle-aged adults. Whilst we were underpowered to detect a statistically significant change, the lack of a noticeable descriptive data change is reassuring as there is a commonly held misbelief (which is likely due to poor misrepresentation in the mainstream media) that exercise increases hunger and makes individuals eat more, leading to overeating and weight gain. This is a barrier to exercise, particularly if living with overweight or obesity due to the fear of eating more, encouraging a positive energy balance and further weight gain.

It has also been posited that older age is associated with reduced appetite which contributes to sarcopenia termed 'anorexia of ageing', a condition characterised by reductions in appetite and increased satiety [42]. It affects ~20% of older adults [43]. The findings of the present study are positive because undertaking a 12-week RE programme did not lead to any adverse effects on appetite that could potentially lead to reduced EI that would be counterproductive to increasing or maintaining SMM in order to reduce the risk of sarcopenia. Through undertaking RE, participants accrue all of the benefits of maintaining or gaining SMM to combat sarcopenia yet maintain a similar appetite which can lead to sufficient food and protein intake as long as the individual undertakes the necessary nutritional and dietary practices.

Our findings do however contradict those of Johnson et al. [23] who reported a statistically significant increase in subjective appetite following 12 weeks of RE. However, Johnson et al. [23] assessed subjective appetite through means of a single test meal (breakfast), whereas the present study assessed subjective appetite over 24 h (including multiple meals and step exercise). Also, the volume of RE was greater in the study of Johnson et al. [23] due to the higher number of exercises per session. A dose response has been shown with aerobic forms of activity with a threshold of ~60–65% $\dot{V}O_2$ peak needed to influence appetite markers [5]. Finally, whilst both groups in the present study consumed an energy-matched supplement (whey protein or a carbohydrate control) twice daily (95 kcal/serving; 190 kcal/day; although this was not part of the present analysis), only participants in the RE group in the study by Johnson et al. [23] consumed a dietary supplement (30 g/day of whey protein; 169 kcal per day). Therefore, participants in the RE group may have become more accustomed to the higher daily energy intake over time, potentially increasing their appetite to a single meal test. These methodological differences may explain the disparities between studies.

The reason and mechanism for our finding of no statistical effect on change in appetite following chronic RE training is highly speculative as

Table 4
Baseline correlations between age, body mass and composition, and components of 24-h energy expenditure and 24-h area under the curve (AUC) appetite visual analogue scales (VAS).

	Hunger AUC (mm x 24 h)	Satiety AUC (mm x 24 h)	Fullness AUC (mm x 24 h)	Prospective food consumption AUC (mm x 24 h)	Composite Appetite Score AUC (mm x 24 h)
Age (years)	$r = -0.24$	$r = 0.26$	$r = 0.30$	$r = -0.33$	$r = 0.07$
Body mass (kg)	$r = 0.06$	$\rho = -0.34$	$r = -0.18$	$r = 0.11$	$r = -0.04$
FFM (kg)	$r = -0.003$	$r = -0.40$*	$r = -0.18$	$r = 0.33$	$r = 0.09$
Fat mass (kg)	$r = 0.11$	$\rho = -0.24$	$r = -0.13$	$r = -0.001$	$r = -0.19$
TEE (kcal/day)	$r = 0.13$	$\rho = -0.47$[a]	$\rho = -0.35$*	$r = 0.35$*	$r = 0.05$
RMR (kcal/day)	$r = 0.40$*	$r = -0.57$[b]	$r = -0.39$*	$r = 0.46$[a]	$r = 0.06$
AEE (kcal/day)	$r = -0.08$	$r = -0.23$	$r = -0.17$	$r = 0.04$	$r = 0.05$
DIT (kcal/day)	$r = -0.05$	$r = 0.09$	$r = 0.04$	$r = 0.13$	$r = -0.03$

Data were analysed using bivariate correlation (Pearson's for parametric data and Spearman's rank-order coefficients for non-parametric data). AEE, activity energy expenditure; DIT, diet-induced thermogenesis; FFM, fat-free mass; RMR, resting metabolic rate; TEE, total energy expenditure. *$p < 0.05$.
[a] $p < 0.01$.
[b] $p < 0.001$.

we did not measure gut peptide hormone responses as our study was not intended to determine appetite-related mechanistic outcomes. One potential explanation may be related to the significant decrease in habitual physical activity outside of the RE programme and physical activity within the metabolic chamber as previously detailed [25], which we previously postulated may have occurred as a mechanism to maintain energy balance. In support, an association has recently been reported between physical activity and appetite in older adults [44]. Studies examining acute hormonal responses to RE during and for a short time after have reported decreases in concentrations of orexigenic hormones and increases in concentrations of anorexigenic hormones [10,22]. Fluctuations in gut peptide hormones as a result of each of the RE sessions may have therefore occurred in the present study, but the chronic response may have been negligible to influence 24-h subjective appetite measured post the 12-week programme. However, we can neither confirm nor refute this, so it is important that future research studies measure a wide range of gut peptide hormones which were prohibitively expensive in the present study.

The finding that there was a significant correlation between RMR and 24-h VAS hunger and prospective food consumption AUCs at baseline was not unexpected. There is a growing body of evidence to suggest that RMR (in which FFM is the largest contributor) has a large influence on appetite. Blundell et al. [45] highlighted the role of RMR and EE in hunger and appetite control and posited that FFM but not BMI or fat mass is closely associated with appetite, self-determined meal size, and daily energy intake. This has clear implications for the understanding of weight regulation and further stresses the importance of physical activity and exercise throughout the life course.

5. Strengths and limitations

The present study has several strengths. Most notably, the simultaneous measurement of subjective appetite and EE over 24 h under highly controlled conditions inside a metabolic chamber in a population of older adult men following a 12-week RE programme is a novel aspect of this study.

Despite all RE sessions requiring travel to the exercise science facilities at Coventry University, mean attendance was 98 ± 3%, which most importantly is a testament to the commitment of the participants and indicative of their willingness to comply with trial procedures, but also the high quality of the supervision and guidance they received during their participant journey. Such high attendance to the training programme also provides reassurance that older adults are willing to participate in supervised RE programmes regardless of age.

A limitation of this study is the relatively small number of participants, so appetite data was underpowered, as previously highlighted. However, such a limitation is inherent in work of this nature, particularly due to the high participant burden of spending 24 h in the metabolic chamber on two occasions, notwithstanding some participants having to follow exercise and dietary supplementation practices. However, the sample size is similar to a training study that examined the chronic effects of a 12-week aerobic exercise programme on appetite markers in men [36].

As women account for a large proportion of the older population in England, i.e., 55% over 65 years [46], and have a high prevalence of sarcopenia [47], the exclusion of women is recognised as a limitation of this study. Our findings in males may not be generalisable to women and in addition, the inclusion of only older adult healthy men with a normal to overweight BMI must also be acknowledged as a limitation. Individuals living with obesity may have been more sensitive to changes in body mass and body composition as a result of RE, so potential differences in responses based on weight status needs to be examined in the future.

Finally, the failure to measure chronic gut peptide hormone responses and acute EI responses using a mixed meal tolerance test via an *ad-libitum* buffet or homogenous meal due to monetary constraints is a

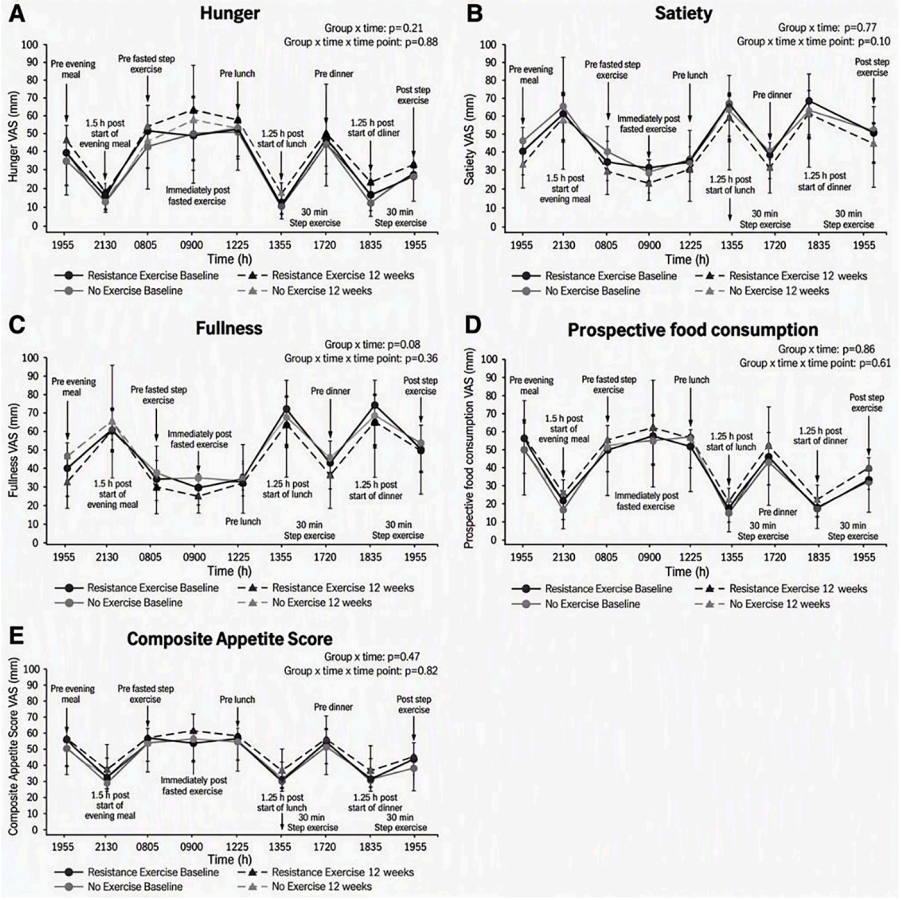


Fig. 2. Visual analogue scales (VAS) at each time point during the 24-h metabolic chamber visit at baseline and 12 weeks (means ± SD). Data were analysed using a mixed-model ANCOVA, with time (baseline and 12 weeks) and time point (1955 h and 2130 h on day 1, and 0805 h, 0900 h, 1225 h, 1355 h, 1720 h, 1835 h and 1955 h on day 2) acting as the within-subjects factors, group (RE or NE) acting as the between-subjects factor, and corresponding baseline values and dietary intervention (protein or control) included as covariates. Non-parametric data were analysed using the Aligned Rank Transform (ART) Model and ANOVA, with the same covariates as above.

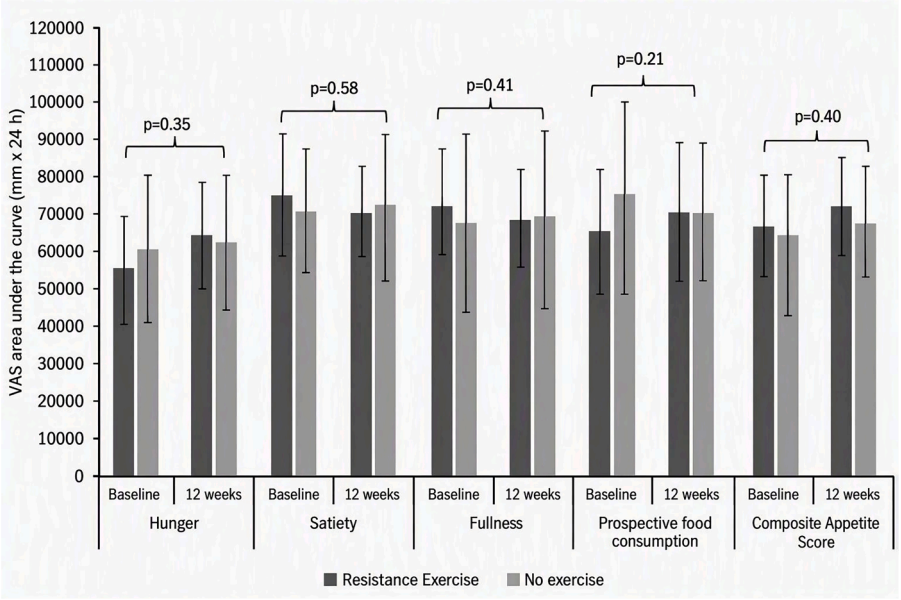


Fig. 3. Twenty-four-hour visual analogue scales (VAS) area under the curve (AUC) at baseline and 12 weeks (means ± SD). Data were analysed using a mixed-model ANCOVA with baseline value and dietary intervention (protein or control) included as covariates.

Table 5
Correlations between changes in body mass and composition, and components of 24-h energy expenditure and changes in 24-h area under the curve (AUC) appetite visual analogue scales (VAS).

	ΔHunger AUC (mm x 24 h)	ΔSatiety AUC (mm x 24 h)	ΔFullness AUC (mm x 24 h)	ΔProspective food consumption AUC (mm x 24 h)	ΔComposite Appetite Score AUC (mm x 24 h)
ΔBody mass (kg)	$\rho = -0.09$	$\rho = 0.01$	$r = 0.40^*$	$r = 0.13$	$\rho = -0.19$
ΔFFM (kg)	$r = 0.06$	$r = -0.09$	$r = 0.02$	$r = 0.30$	$r = 0.07$
ΔFat mass (kg)	$r = -0.12$	$r = 0.23$	$r = 0.40^*$	$r = -0.06$	$r = -0.27$
ΔTEE (kcal/day)	$\rho = -0.19$	$\rho = -0.09$	$\rho = 0.03$	$\rho = 0.06$	$\rho = -0.14$
ΔRMR (kcal/day)	$\rho = -0.10$	$\rho = -0.07$	$r = -0.04$	$\rho = 0.22$	$\rho = -0.02$
ΔAEE (kcal/day)	$r = -0.32$	$r = 0.24$	$r = 0.05$	$r = -0.14$	$r = 0.01$
ΔDIT (kcal/day)	$r = 0.25$	$r = -0.07$	$r = -0.08$	$r = 0.14$	$r = -0.04$

Data were analysed using partial correlation (Pearson's for parametric data and Spearman's rank-order coefficients for non-parametric data) controlled for intervention group. AEE, activity energy expenditure; DIT, diet-induced thermogenesis; FFM, fat-free mass; RMR, resting metabolic rate; TEE, total energy expenditure. $^*p < 0.05$.

limitation and means that any mechanistic statements are highly speculative and warrant examining.

6. Future research

Given the importance of appetite and EI in energy homeostasis, understanding the key individual characteristics and behaviours that adjust appetitive measures after exercise has important implications for weight management which ultimately impacts on people's health. Further studies are therefore demanded to elucidate how adiposity, age, physical activity and sex affect appetite, EI, and appetite-related hormone responses to acute and chronic RE throughout the life course.

Whilst replication studies are typically and unjustly not funded and therefore not undertaken, a research priority is to see if these findings in older adult males are repeated by other research groups. It is also very important as a research priority to examine if these findings are generalisable to middle-aged and older adult females and would be important to control for menstrual cycle as well as oral contraceptive use if these lines of enquiry are being pursued as they can influence appetite [48,49].

7. Practical application

Ageing is associated with declines in SMM and components of 24-h EE, which may result in energy imbalance, increased fat mass, sarcopenic obesity and poor metabolic health. Resistance exercise is well tolerated in both healthy and frail older adults with very few adverse events reported in the literature [50]. Since the present study identified no significant adverse effects on appetite, RE should continue to be undertaken throughout the life course and must continue to be included as part of physical activity recommendations for optimal health in old age.

In conclusion, the findings of the present study found no statistical effect on subjective appetite following a 12-week RE programme in older adult males. Older adults should therefore continue to undertake RE throughout their lifespan, particularly those individuals in their later years due to the many undisputed physical and functional benefits. Resistance exercise should continue to be promoted by government and healthcare professionals globally.

Data availability

Data will be made available on request.

Ethics declaration

Written informed consent to take part in the study and to publish the article has been obtained from all participants or their legal representatives. The privacy rights of participants have been observed.

This study was performed in compliance with relevant laws, regulatory frameworks and guidelines where the research took place. This study was approved by the Coventry University (Approval No P59723).

The results of this clinical trial and any associated work have been posted in a registry. This clinical trial was registered with number NCT03299972 (clinicaltrials.gov).

CRediT authorship contribution statement

Corbin Griffen: Writing – review & editing, Writing – original draft, Validation, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Derek Renshaw:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **John Hattersley:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Martin O. Weickert:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Michael Duncan:** Writing –

review & editing, Supervision, Methodology, Conceptualization. **David R. Broom:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare no conflicts of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.physbeh.2026.115512.

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