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The effects of training load during dietary intervention upon fat loss: A randomized cross-over trial

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ABSTRACT

To date no studies have compared resistance training loading strategies combined with dietary intervention for fat loss. Thus, we performed a randomised crossover design comparing four weeks of heavier- (HL; ~80% 1RM) and lighter-load (LL; ~60% 1RM) resistance training, combined with calorie restriction and dietary guidance, including resistance trained participants (*n*=130; males=49, females=81). Both conditions performed low-volume, (single set of 9 exercises, 2x/week) effort matched (to momentary failure), but non-work-matched protocols. Testing was completed pre- and post-each intervention. Fat mass (kg) was the primary outcome, and a smallest effect size of interest (SESOI) was established at 3.3% loss of baseline bodyweight. Body fat percentage, lean mass, and strength (7-10RM) for chest press, leg press, and pull-down exercises were also measured. An 8-week washout period of traditional training with normal calorie interspersed each intervention. Both interventions showed small statistically equivalent (within the SESOI) reductions in fat mass (HL: -0.67 kg [95%CI -0.91 to 0.42]; LL: -0.55 kg [95%CI -0.80 to -0.31]) which were also equivalent between conditions (HL – LL: -0.113 kg [95%CI -0.437 kg to 0.212 kg]). Changes in body fat percentage and lean mass were also minimal. Strength increases were small, similar between conditions, and within a previously determined SESOI for the population included (10.1%). Fat loss reductions are not impacted by resistance training load; both HL and LL produce similar, yet small, changes to body composition over a 4-week intervention. However, the maintenance of both lean mass and strength highlights the value of resistance training during dietary intervention.

Keywords: Body composition, Muscle size, Resistance training, Strength, Supervision

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Introduction

Resistance training (RT) is known to promote a number of favourable physiological and psychological adaptations including increased bone mineral density[1], reduced blood pressure[2], improved cognitive functioning[3], reduced anxiety[4], reduced depression[5], cognitive function[6], and improved self-esteem[7]. However, in addition to the strength and associated health improvements, RT is often performed for aesthetic purposes such as hypertrophy[8] and fat loss[9]. Recent research has suggested that muscle hypertrophy increases are similar whether training with heavier- (>60% 1-repetition maximum; RM) or lighter- (<60% 1RM) loads[10], and indeed, that adaptations are more likely a product of effort rather than external load[11]. However, whilst RT has been shown to increase metabolic rate[12], the evidence remains unclear as to the best loading strategies and repetition ranges to optimise energy expenditure (EE), and concurrently, fat loss.

Historically, prominent exercise organisations such as the American College of Sports Medicine (ACSM) have typically prescribed heavier loads with fewer repetitions for muscular strength and muscle growth, and lighter loads performed for higher repetitions for muscular endurance adaptations[13]. It seems likely that this guidance has prompted an "accepted wisdom" within resistance training; that people with the goal of reducing body fat, aspiring to attain a slim figure (i.e., more akin to the figure of an endurance athlete), should perform lighter-load resistance exercise, whereas persons looking to add muscle mass might be more inclined to train using heavier loads[8,14-15]. However, to our knowledge this has not been well researched.

Firstly, we should recognise the importance of resistance training within fat loss strategies, as a means of maintaining/increasing muscle mass. In that sense, it is important to differentiate between fat loss (which denotes a favourable change in body composition by retaining muscle mass and lowering body fat %), and weight loss (which does not differentiate between fat loss and a loss of muscle mass,). Research has repeatedly shown more favourable adaptations following dietary intervention alongside RT compared to dietary intervention alone. For example, Hunter, et al.[16] randomised overweight women into groups performing resistance training, aerobic training, and a control group, all with supervised nutritional support to consume ~3360kj / 800kcal per day to produce a weight loss of ~12kg over 21 weeks. Whilst the groups lost similar percentage body fat (RT=-11.3%, aerobic=-10.6%, control=-9.5%), the RT group maintained fat free mass (+0.4kg) whereas the aerobic training and control groups both lost fat free mass (-1.0kg, and -1.5kg, respectively). In support, Donnelly, et al.[17] also considered severe calorie restriction in obese females (~3360kj / 800kcal per day) for 90 days. Whilst a non-training control group showed no decrease-, a RT group showed significant increases- in muscle fibre cross-sectional area (CSA) of the thigh muscles. Furthermore, when tested for knee extensor strength, the control group decreased strength by ~9% whilst the RT group increased strength by ~37%. Both groups showed significant and similar decreases in body-fat percentage (6.1 ± 2.2% in RT and 5.1 ± 2. 1% in control). Other research supports positive changes in lean mass for diet and RT intervention groups compared to dietary intervention alone (+0.8k ±0.4kg, vs. -1.4 ±0.4kg), and have shown greater reductions in body fat with the addition of RT (-4.1 ±0.9kg, vs. -0.2 ±1.0kg, respectively[18]), and in particular when caloric restriction is combined with RT and higher protein intakes[19]. When promoting fat-loss strategies, maintaining, or encouraging growth of muscle mass is of particular importance as we age, especially since muscle mass is associated with favourable glucose metabolism and is a predictor of longevity in older adults[20].

EE during exercise is an important consideration and it has been suggested that the health benefits of regular exercise are associated with total EE[21]. Scott, et al.[22] compared EE for lighter/*endurance* loads (37%, 46%, and 56% 1RM) to heavier/*strength* loads (70%, 80%, and 90% 1RM) for a single set of bench press to failure reporting significantly greater overall EE for the endurance loads. More recently, Brunelli et al.[23] also reported slightly greater EE (~5 kcal) for lighter (30% 1RM; RT30) compared to heavier (80% 1RM; RT80) loads over three sets. Whilst the authors differences between total volume-load (i.e., repetitions x sets x load) between RT30 and RT80 conditions (2301.4 ±631.1kg and 1828.1 ±690.4kg, respectively; p=0.05), there was no difference for Borg's subjective perception of effort (RT30 = 17 ±2, RT80 = 16 ±2). However, when considering the total EE of the training session including excess post exercise oxygen consumption there was no difference between conditions. It might be plausible that small differences in energy expenditure might accumulate and result in fat loss over time. However, EE calculations for single exercises, and acute changes to metabolic rate are not necessarily indicative of longer-term reductions in fat loss and body composition changes - potentially due to other lifestyle factors and behavioural compensation resulting in ~55-64% less weight loss than expected[24]. Further, Miller, et al.[25] reported reductions in fat mass by both diet and diet +RT groups. However, lean mass increased following RT only, and these changes did not significantly affect resting EE.

Whilst the studies discussed support the benefits of combining RT with dietary strategies to promote fat loss and maintain/increase lean mass, there remains a dearth of research comparing different RT interventions (e.g., heavier- and lighter-load RT) with the goal of reducing body fat and improving body composition. Our understanding of whether resistance training load influences fat loss across the duration of an intervention is important since it might permit self-selection or allow people to use heavier- or lighter-loads based on access, confidence, physical condition, etc. With this in mind, the aim of this study was to consider the effects of low-volume, high effort (e.g., single sets performed to momentary failure), heavier- and lighter-load resistance training upon fat loss when combined with dietary guidance/support strategies, with secondary outcomes including strength increases and lean mass changes.

Methods

Experimental Design

This study was pre-registered on the Open Science Framework (https://osf.io/kd4ax). A crossover design was used whereby trained participants were randomly assigned to 4-weeks of 1-on-1 supervised RT using either a heavier- (HL; ~80% 1RM) or lighter-load (LL; ~60% 1RM), followed by an 8-week washout period where they returned to previous training (i.e., that they were performing prior to the intervention), and following this were assigned to the alternate training condition (e.g., if weeks 1-4 were HL, then weeks 13-16 were LL, and vice versa). The total duration of the study was 17-weeks, broken down in the following way: baseline testing was completed at week 0, re-testing was completed at week 5 (following the first intervention), at week 12 (following the 8-week washout period), and at week 17 (following the second intervention). During both 4-week training interventions participants trained 2 days/week and followed nutritional strategies which represented a 20% reduction in calorific intake, as well as maintaining a minimum protein consumption (1.5 g per kg of body mass). Support was provided by a personal trainer to discuss implementation of these strategies and to support compliance. HL and LL training interventions were not comparable by total volume-load (i.e., repetitions x sets x load) since it is evident that a greater number of repetitions, and thus a higher volume-load, is likely in the LL condition. However, parity was made by participants exercising to momentary failure (i.e., the same effort level), this is similar to the acute study by Brunelli et al.[23] All testing time-points included bod pod, and ~7-10 RM (to allow predicted 1RM) for chest press, leg press, and pull-down exercises. This research design allowed assessment of changes in body composition and strength following both HL and LL resistance training with caloric deficit and where nutritional support was provided. Ethical approval was granted from the first authors' institutional review board.

Participants

All participants were recruited from the existing pool of clients from Discover Strength, a chain of 1-to-1 supervised strength training studios. Inclusion criteria were >6 months resistance training experience with Discover Strength, this ensured all participants were familiar with supervised, high-effort (i.e., training to momentary failure and occasionally the use of advanced training techniques such as drop-sets, pre- or post-exhaustion, forced repetitions, etc.), low-volume (i.e., a single set of each exercise), and twice-weekly training practices. However, failure of screening meant that 15 participants were recruited with <6 months prior experience. We chose to deviate from the pre-registered protocol and opted to keep these participants in the main sample analysis but explored the sensitivity of our primary pre-registered outcome to their inclusion (see statistical analysis). Participants were instructed not to (and confirmed that they did not), engage in any muscle strengthening exercise outside of their supervised strength training sessions. Participants were also asked to maintain normal daily activities or other physical activities, exercise, and sports that they currently participated in (e.g., not to begin *additional* exercise strategies to enhance weight loss). Based on pre-registered sample size estimation from simulations (full details of which are included in the pre-registration https://osf.io/kd4ax) our recruitment target was 150 participants. Recruitment occurred in a single phase aiming for this. After completion of this we had recruited 130 participants, 115 of which had full data. All participants signed an informed consent form prior to any data collection. Demographic characteristics of the sample are shown in table 1.

Table 1. Participant demographic characteristics

Characteristic	**N = 130**[1]
Age (years)	45 (37, 56)
Sex	
Female	81 (62%)
Male	49 (38%)
Height (m)	1.70 (1.55, 1.85)
Training Experience (years)	2.75 (1.30, 5.50)
Fat Mass (kg)	23 (17, 33)
Fat Mass (%)	32 (23, 38)
Lean Mass (kg)	50 (46, 63)

[1] Median (IQR); n (%)

Testing

Strength was measured using a ~7-10 RM. Since participants were currently training at a Discover Strength location, they were tested across chest press, pull-down and leg press exercises using a load estimated from their pre-existing training load at a 2s concentric: 4s eccentric repetition duration. The predicted 7-10RM was used since it permitted these clients to perform testing as part of their workout without the need for a separate session to obtain a 1RM. Simply, following a warm-up specific to each machine (~5 repetitions at 50% of the testing load), and after 90 s of rest, the participants performed a set of repetitions to momentary failure (MF) using a 2-s concentric, 4-s eccentric repetition duration. The repetition duration was standardised to ensure that participants did not move quicker or slower in post-testing which would have produced differing results in the number of repetitions performed, and further; to eliminate external forces of momentum and maintain muscular tension. It was intended (i.e., pre-registered) that if participants exceeded 10 repetitions, they were instructed to stop and not continue to MF such that a rest of 5 min could be permitted before adjusting the load and attempting the ~7-10 RM again. However, given that data collection was conducted within Discover Strength training studios during other commercial activity, this proved to be too time consuming. As it was not considered essential that an exact ~7-10 RM load was identified the load that was initially estimated was used and participants performed a set to momentary failure using this. The resultant number of repetitions performed during testing for each exercise was 10.3±4.1, 8.9±3.0, and 10.7±3.6 for leg press, chest press, and pulldown respectively. Predicted 1RM was then calculated from the load used, and repetitions performed, using the equation by Baechle[26]:

$$1RM = weight \times (1+(0.033 \times number\ of\ repetitions)$$

The Baechle[26] equation produces the same predictions as the "Epley" equation which has shown high validity (r=0.92) when compared to 1RM strength testing for bench press in trained persons[27], and for bench press (r=0.99), squat (r=0.97), and deadlift (r=0.96), in untrained persons[28]. The use of submaximal repetition testing followed by calculations to estimate 1RM has previously been used to denote strength increases[29,30], furthermore, repetitions to failure at a submaximal load might be deemed a more ecologically valid assessment of strength since it better represents daily function compared to lifting a maximal load possible for a single repetition (e.g., 1RM testing). Additionally, this testing method can be incorporated into a training session as opposed to needing a specific testing session and eliminates the skill acquisition of practicing lifting heavier loads which might produce favourable adaptations for maximal strength assessment[31].

Body composition was estimated using both air displacement plethysmography (Bod Pod GS, Cosmed, Chicago, IL, USA) as well as anthropometric measures. Details of the test procedures for estimation of body composition using air displacement plethysmography have been previously described in detail elsewhere[32]. Briefly, whilst wearing minimal clothing (swimsuit or tight-fitting underwear) and a swim cap, participants were weighed using a calibrated digital scale. The participant was then seated in the Bod Pod for body volume measurement. From the body mass and body volume measurements, and predicted thoracic lung volumes, body density was estimated by the Bod Pod software and lean and fat mass estimations calculated using the Siri equation.

Training Intervention

Training was performed 2x/week (with at least 48 hours between sessions) using two different workouts (A & B) including the following exercises: chest press (A & B;), leg press (A & B;), pulldown (A & B;), pullover (A only;), hip adduction (A only;), hip abduction (A only;), heel raise (A only;), abdominal flexion (A only;), lumbar extension (A only;), pec fly (B only;), elbow flexion (B only;), knee flexion (B only;), knee extension (B only;), ankle dorsiflexion (B only;), and torso rotation (B only;). These exercises were chosen to present two whole-body workouts covering most major muscle groups in each session, and all major muscle groups each week. All exercises were performed for a single set and all participants using the same approximate relative load depending upon which intervention condition they were performing which was determined from the most recent strength testing. All training sessions were performed at a 1:1 (trainer: trainee) supervision ratio.

The HL group performed each exercise using a 2 second concentric and 4 second eccentric repetition duration using a load equating to ~80% of predicted 1RM. The LL group performed each exercise using the same repetition duration using a load equating to ~60% of predicted 1RM. The repetition duration for training was standardised to that of the testing methods, and further; to eliminate external forces of momentum and maintain muscular tension during training. Both groups were required to continue repetitions to the point of momentary failure (MF; the point where despite their best efforts they cannot complete the concentric phase of a repetition[33]). Since participants were trained, and familiar with advanced overload principles, for all exercises other than those used for testing (e.g., chest press, leg press, and pull-down), 2 forced repetitions were performed. Once participants could perform repetitions/time under load above set upper ranges for either condition (e.g., >10 repetitions/>60 seconds for HL, and >20 repetitions/120 seconds for LL) loads were increased by ~5% as per previous recommendations and research[29,30]. Parity was maintained between groups by all participants in all groups training to MF[34].

During the washout period participants returned to their previous training at Discover Strength. This typically involved training with loads ~70% 1RM 2x/ week in either 1:1 or small group supervised sessions, and with the varied use of advanced training techniques such as drop-sets, pre- or post-exhaustion, forced repetitions, etc.

Nutritional Support

Nutritional support was provided to all participants through both HL and LL interventions but not through the 8-week washout period. At the onset of the intervention, and following bod-pod testing, an initial consultation was completed with one of the exercise physiologists to discuss reducing calorie intake by 20% - achieved based on initial bod-pod testing, and the software determined estimation of daily EE based on the “low-active” category. Furthermore, to maintain and promote increases in strength and muscle mass, all participants were encouraged to consume 1.5 grams of protein per kg of body mass. Finally, all participants were told to track all food consumption using MyFitnessPal and were guided to ask a personal trainer should they have any questions to support these nutritional strategies, and support compliance.

Statistical analysis

This study was pre-registered (https://osf.io/kd4ax) with change in fat mass (kg) (i.e., post-intervention minus pre-intervention) as our primary outcome and for which we attempted to power for statistical hypothesis testing. All other analyses and results should be considered descriptive and/or exploratory in nature. All analyses were conducted using R (v. 4.1.0; R Core Team, https://www.r-project.org/) and R Studio (R Studio Team, 2020), and all data and code are available in the supplementary materials (https://osf.io/prqew/).

For our primary pre-registered analyses, with a power of 80% and an alpha of 5%, we tested for both a difference (d), and equivalence (e) between conditions with the following null (H0) and alternative hypotheses (H1):

Difference

H0d: There will be no difference between HL and LL resistance training interventions on change in fat mass - upper or lower bound of the 95% confidence interval for between condition effect will include zero

H1d: There will be a difference between Hl and LL resistance training interventions on change in fat mass - upper and lower bound of the 95% confidence interval for between condition effect will exclude zero

Equivalence

H0e: The difference between HL and LL resistance training interventions on change in fat mass will differ from the smallest effect size of interest - upper and lower bound of the 90% confidence interval for between condition effect will be outside of or include the upper or lower limits of smallest effect size of interest

H1e: The difference between HL and LL resistance training interventions on change in fat mass will be equivalent to the smallest effect size of interest - upper and lower bound of the 90% confidence interval for between condition effect will be inside the upper or lower limits of smallest effect size of interest

The smallest effect size of interest for change in fat mass was determined as 3.3% loss of baseline body weight as fat mass based upon recommendations from American College of Sports Medicine Position Stand regarding weight loss[35] and that a previous study using a similar RT and dietary intervention over a ~4-week period found similar results[25]. A linear mixed effect model was fit using the "lme4" package[36] and which was essentially a within participant extension of an analysis of covariance model with adjustment for baseline measures. In Pinheiro-Bates modified Wilkinson-Rogers notation[37-38] this was:

Change in Fat Mass ~ Baseline Fat Mass + Intervention Condition + (1 | Participant)

Pairwise contrasts between intervention conditions were made to test for a difference, and equivalence testing was performed against the smallest effect size of interest to test for equivalence. Both were performed using the "emmeans" package[39]. As noted, we explored our primary pre-registered outcome for sensitivity to the inclusion of the 15 participants with <6 months experience.

For all secondary outcomes (fat mass as a percentage, lean mass, and strength outcomes) we similarly used a linear mixed effect model as specified above (i.e., with change scores as the dependent variable, intervention condition and baseline scores as a fixed effect, and random intercepts by participant). However, we did not explicitly conduct any statistical hypothesis testing for these outcomes. Instead, we opted to take an estimation-based approach[40-41] and focus presentation of the results of these models visually (model summary tables are included for reference). Thus, for all inferential secondary analyses, effect estimates and their precision along with conclusions based upon them, were interpreted continuously and probabilistically, considering data quality, plausibility of effects, and previous literature, all within the context of each outcome[42-43]. For strength outcomes, given that we have previous data regarding what the population sampled here consider the smallest meaningful change in strength to be (10.1%[44]), in data visualisation we include this for reference as the smallest effect size of interest. All data visualisations were made using "ggplot2"[45] and "patchwork"[46] packages. Model summary tables were produced using the "sjPlot" package.

Results

Primary pre-registered outcome – Change in fat mass

Testing the hypothesis of a difference between HL and LL conditions, pairwise contrast of estimated marginal means from the linear mixed effect model revealed no statistically significant difference ($\text{Contrast}_{(HL - LL)}$ = -0.113 kg [95%CI -0.437 kg to 0.212 kg], $t_{df = 124}$ = -0.687, p = 0.4932). However, testing the hypothesis of equivalence revealed that both HL and LL conditions produced changes statistically equivalent within the bounds of the smallest effect size of interest ($t_{df = 124}$ = -4.478, p < 0.0001). Paired comparisons and contrast between conditions for change in fat mass is shown in 1A and 1B, and table 2 shows the estimated marginal means for fat mass change (the mixed effect model summary table is available in the supplementary materials, see https://osf.io/79jn6/). Inferences were insensitive to the inclusion or exclusion of the 15 participants with <6 months experience (see https://osf.io/9ckwy/).

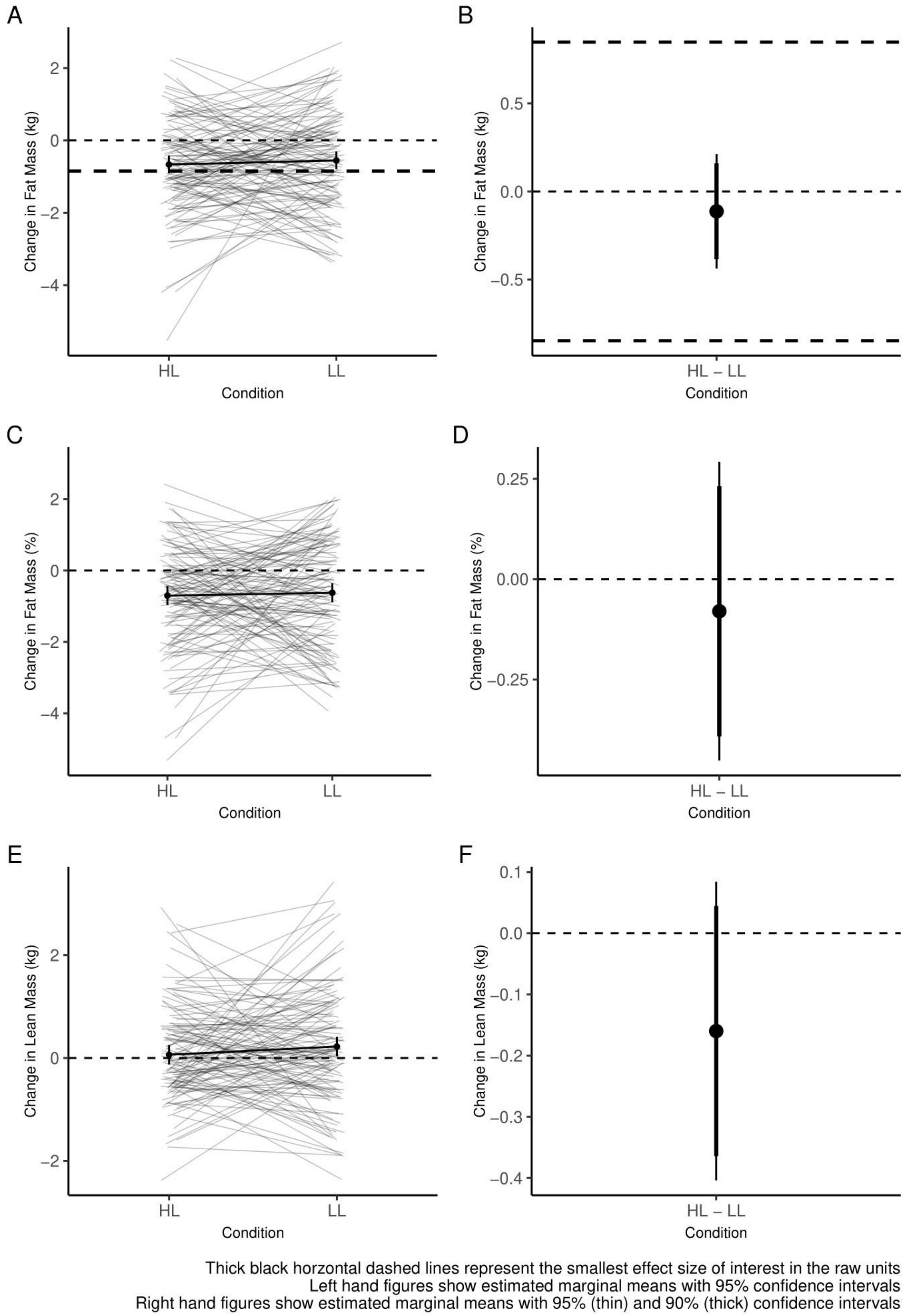

Figure 1. Body composition paired comparisons and contrasts for primary pre-registered outcome of change in fat mass (A, B) and both fat mass percentage (C, D) and lean mass (E, F).

Table 2. Estimated marginal means for changes in body composition between conditions

Outcome	Condition	Estimated Marginal Mean*	Lower 95%CI	Upper 95%CI
Fat Mass (kg)	HL	-0.67	-0.91	-0.42
	LL	-0.55	-0.80	-0.31
Fat Mass (%)	HL	-0.70	-0.97	-0.44
	LL	-0.62	-0.89	-0.36
Lean Mass (kg)	HL	0.06	-0.13	0.25
	LL	0.22	0.03	0.41

*Note, estimated marginal mean values are adjusted to for baseline covariates set to sample averages

Secondary outcomes – Body composition

Within condition, changes in fat mass were slightly smaller than the smallest effect size of interest (figure 1A). Changes in fat mass percentage obviously followed a similar pattern (figure 1C), and changes in lean mass were relatively small for both conditions (figure 1E). For both fat mass percentage (figure 1D) and lean mass (figure 1F) there does not appear to be any clear difference between conditions. Table 2 shows the estimated marginal means for changes (the mixed effect model summary table is available in the supplementary materials, see https://osf.io/79jn6/). Given the general lack of difference between conditions for the four-week intervention periods, we fit an additional exploratory mixed model with random intercepts by participants for time as a fixed effect across the entirety of the study to examine whether changes that occurred during the initial intervention periods were maintained through washout, and whether the subsequent intervention period changes ultimately resulted in more meaningful outcomes. Figure 2 shows the results of this for body composition outcomes. In general, it appears that initial intervention effects were maintained during washout and then further effects occurred during the second intervention period. For fat mass, the total effects over the 16-week intervention-washout-intervention period did result in the point estimate exceeding the smallest effect size of interest suggesting meaningful change in fat mass may have occurred; although, the confidence interval lower bound did still cross this threshold. The longitudinal model summary is available in the supplementary materials (https://osf.io/dw9z6/) and the estimated marginal means are shown in table 3.

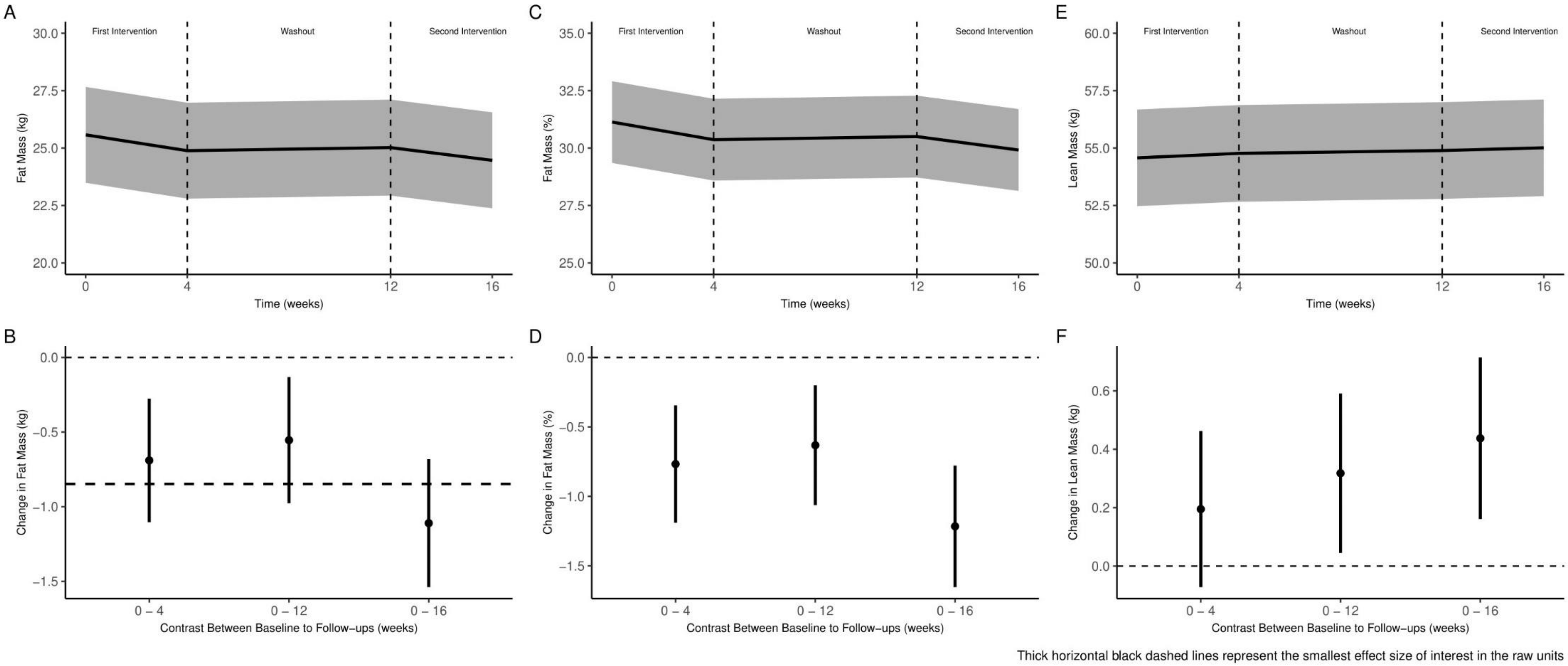

Figure 2. Results of combined longitudinal analysis for body composition outcomes over each intervention period and washout. Error bars are 95%CIs.

Table 3. Estimated marginal means for body composition pooled longitudinally

Outcome	Time (weeks)	Estimated Marginal Mean	Lower 95%CI	Upper 95%CI
Fat Mass (kg)	0	25.58	23.49	27.66
	4	24.89	22.80	26.97
	12	25.02	22.93	27.11
	16	24.47	22.38	26.56
Fat Mass (%)	0	31.13	29.35	32.91
	4	30.37	28.59	32.14
	12	30.50	28.72	32.28
	16	29.92	28.13	31.70
Lean Mass (kg)	0	54.57	52.47	56.68
	4	54.77	52.67	56.87
	12	54.89	52.79	57.00
	16	55.01	52.91	57.12

Secondary outcomes – Strength

Within condition, while both conditions produced changes in strength that clearly differed from zero, on average these did not exceed the smallest effect size of interest previously determined with this populations (figures 3A, 3C, 3D), nor were there meaningful differences between conditions for contrasts (figures 3B, 3D, 3F). Table 4 shows the estimated marginal means (the mixed effect model summaries for strength outcomes are available in the supplementary materials, see https://osf.io/7da6j/).

Table 4. Estimated marginal means for changes in strength between conditions

Outcome	Condition	Estimated Marginal Mean*	Lower 95%CI	Upper 95%CI
Leg Press (kg)	HL	8.63	6.95	10.31
	LL	7.23	5.56	8.91
Chest Press (kg)	HL	3.33	2.85	3.81
	LL	2.81	2.33	3.28
Pulldown (kg)	HL	10.06	8.22	11.90
	LL	8.39	6.55	10.22

*Note, estimated marginal mean values are adjusted to for baseline covariates set to sample averages

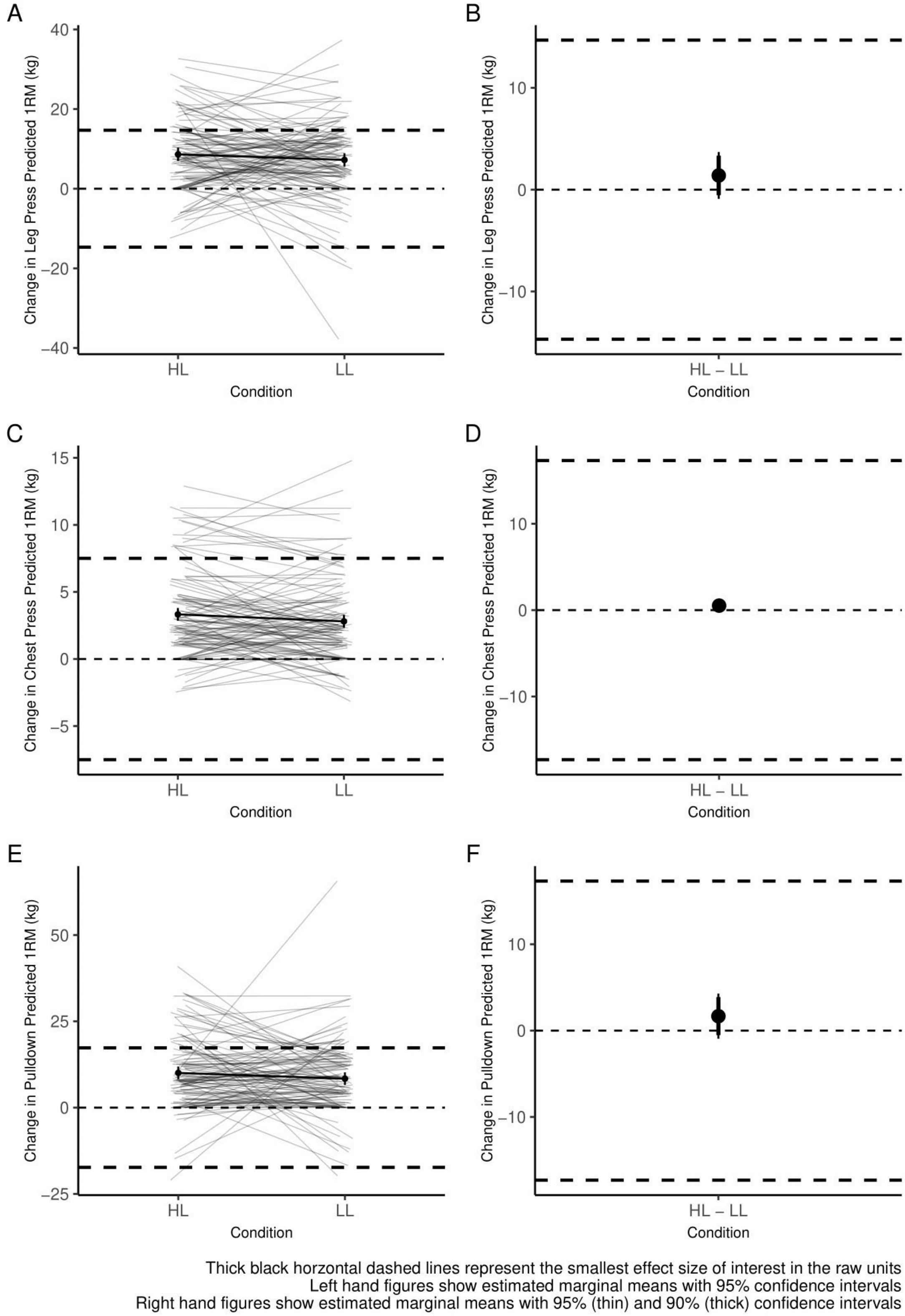

Figure 3. Strength paired comparisons and contrasts for change in leg press predicted 1RM (A, B), chest press predicted 1RM (C, D), and pulldown predicted 1RM (E, F).

Again, given the general lack of difference between conditions for the four-week intervention periods, we fit an additional exploratory mixed model with random intercepts by participants for time as a fixed effect across the entirety of the study to examine whether changes that occurred during the initial intervention periods were maintained through washout, and whether the subsequent intervention period changes ultimately resulted in more meaningful outcomes. Figure 4 shows the results of this for strength outcomes. In general, it appears that initial intervention effects were maintained during washout and then further effects occurred during the second intervention period. However, the total effects over the 16-week intervention-washout-intervention period did not clearly result in changes in strength that would be considered meaningful, instead suggesting that strength was largely maintained or only slightly improved across the duration of the study. The longitudinal model summary is available in the supplementary materials (https://osf.io/uvw24/) and the estimated marginal means are shown in table 5.

Table 5. Estimated marginal means for strength pooled longitudinally

Outcome	Time (weeks)	Estimated Marginal Mean	Lower 95%CI	Upper 95%CI
Leg Press (kg)	0	139.97	130.02	149.93
	4	150.37	140.42	160.33
	12	148.87	138.91	158.84
	16	153.49	143.52	163.46
Chest Press (kg)	0	72.85	65.50	80.21
	4	76.41	69.06	83.77
	12	75.94	68.58	83.30
	16	78.39	71.03	85.75
Pulldown (kg)	0	165.93	154.26	177.61
	4	178.32	166.65	190.00
	12	174.62	162.93	186.31
	16	180.23	168.54	191.92

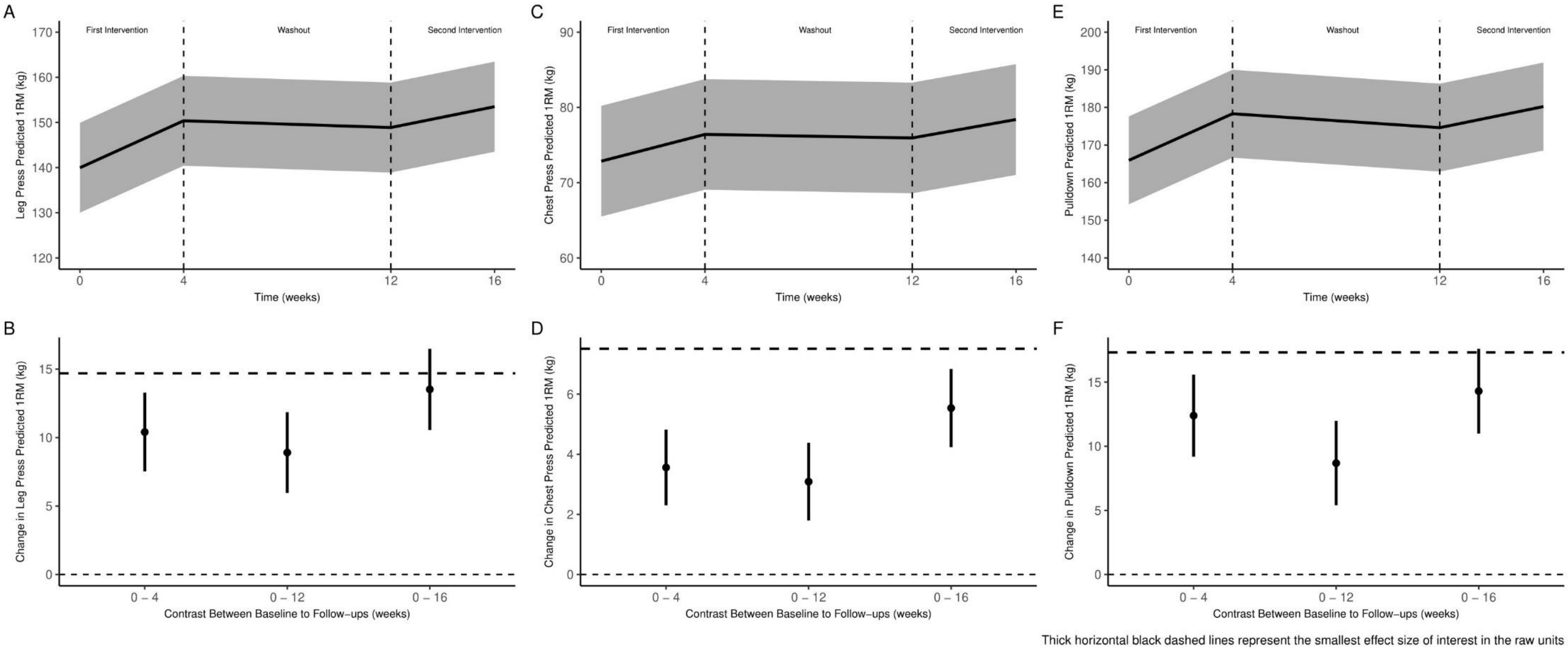

Figure 4. Results of combined longitudinal analysis for strength outcomes over each intervention period and washout. Error bars are 95%CIs.

Discussion

To our knowledge this represents the first empirical research with trained males and females comparing supervised, low-volume, high effort (e.g., single sets performed to momentary failure), heavier- and lighter-load resistance training for fat loss and body composition changes using a parallel-group, crossover design. As such, this presents a methodologically rigorous approach to comparing heavier- and lighter-load supervised between-group resistance training[47].

This study was pre-registered on the Open Science Framework (https://osf.io/kd4ax) considering the differences between heavier- and lighter-load resistance training adaptations with calorie deficit and nutritional support, upon fat mass (primary), body composition more generally, and strength (secondary) outcomes across a 4-week intervention. Analyses revealed no between-condition differences for reductions in fat mass or change in body fat percentage, and further that the difference between conditions for fat mass was statistically equivalent given our smallest effect size of interest. This suggests that any previously identified difference in EE during- or post-resistance exercise resulting from heavier- or lighter-load training[22-23], does not translate to differences in reduction of fat mass (kg) or body fat percentage over the course of longitudinal intervention. Within conditions, both HL and LL interventions showed similar reductions in fat mass (HL, m= -0.67kg; LL, m= -0.55kg), and body fat percentage (HL, m= -0.70%; LL, m= -0.62%) although neither reached our pre-determined bounds of smallest meaningful change (i.e., 3.3% loss of baseline weight as fat mass[25,35]). As a 4-week intervention period the present findings for fat mass and body fat percentage reductions are smaller than that reported for the first month of previous research considering diet and resistance training (e.g., -1.4kg, and -1.1%[25]). However, the study by Miller, et al. (2018) applied a higher volume (4-sets of 10 exercises) and higher training frequency (3x/week) than that used herein (1-set of 9 exercises, 2x/week). Further, participants were required to track and report back their dietary intake such that adherence to recommendations could be monitored. The participants in the present study performed approximately 15% of the total training volume of those in the Miller, et al.[25] study (e.g., 18 sets/week vs. 120 sets/week) and were not closely monitored but instead provided with general dietary recommendations and offered support if needed. As such it is perhaps unsurprising to see that body composition changes over the 4-week period were smaller. However, though they did not meet our smallest effect size of interest, deemed to be the fat loss required for health benefits[35], it is possible to say that fat loss albeit small did occur by dint of the confidence intervals on within group estimates from our model excluding zero. Thus, this might speak towards the efficacy of time efficient, effort-based prescription (e.g., low volume to momentary failure) compared to resistance training prescription based on load/volume/repetitions[48].

Furthermore, changes in lean mass were not significant between- or within-training conditions. While this supports previous literature suggesting that both heavier- and lighter-load resistance training produce similar adaptative responses in muscle mass/hypertrophy (e.g., Lopez, et al. 2020), we should recognise that the use of air-displacement plethysmography, herein, is much less sensitive in detecting increases in muscle mass/hypertrophy compared to more direct measures (e.g., ultrasound and magnetic resonance imaging[49]). In combination, the relatively short duration of each intervention period (4-weeks), the trained nature of the participant sample, which is less likely to show a hypertrophic response compared to untrained persons[50], as well as the use of indirect measures of muscle mass, might go toward explaining a lack of increase in hypertrophy/muscle mass in either condition.

As a secondary outcome our study considered 7-10RM testing and from this, predicted 1RM, to assess strength increases for chest press, pull-down, and leg press exercises. Again, there were no clear differences between conditions and while small strength increases were identified within conditions these did not reach the smallest meaningful change based on our previous survey research with a client sample (n=134) from the Discover Strength locations (smallest meaningful change in strength has been identified by clients as 10.1%[44]). Of course, it's noteworthy that these were trained participants which, once again, are likely to show lesser strength increases compared to previously untrained persons[50].

Recognising the paucity of strength training research with a large sample size considering trained participants, we have also reported exploratory combined longitudinal analysis (i.e., the entire 16-week duration of the study, including both 4-week interventions and the 8-week washout period). Figures 2 and 4 show that, irrespective of previous changes through the first 4-week intervention, the second 4-week intervention seemed to produce similar results. Effectively, this presents a total change in fat mass of -1.35kg, and total change in body fat percentage of -2% (e.g., HL + LL). Markedly, there was no notable change to fat mass or body fat percentage during the 8-week washout period, suggesting the reductions were sustained for at least that time.

Despite the strengths of this study, we should recognise the potential limitations. Each intervention phase was only 4-weeks in duration, which might not have been sufficient to catalyse meaningful differences resulting from heavier- or lighter-load resistance training. Further, while dietary guidance was provided, and participants encouraged to reduce their calorie intake to 20% below the daily EE based on the "low-active" category from the bod-pod testing, there was no follow-up or confirmation that this was being performed successfully. In that sense, we consider this more a study of effectiveness of resistance training combined with dietary guidance *per se* rather than the efficacy of following such guidance with a high degree of fidelity (i.e., whether reducing calories by the given amount works to reduce body fat and improve body composition). Further, whilst nutritional support was available to each participant from an exercise physiologist, these are not registered dieticians or nutritionists and so this was minimised to answering questions (rather than checking up on participants) and was uncomplicated in nature (i.e., simple guidance on food choices for calorie reduction whilst meeting desired protein intake). In addition, whilst participants were encouraged to use MyFitnessPal, dietary intake was not assessed – again this lending itself to consideration of real-world effectiveness rather than efficacy. Finally, we acknowledge that the use of 7-10RM testing[26], whilst having high validity compared to 1RM testing (e.g., r=0.92-0.99[27,28]), is not a true test of maximal strength.

Conclusions

The aim of this study was to consider the effects of low-volume, high effort (e.g., single sets performed to momentary failure), heavier- and lighter-load resistance training upon fat loss when combined with dietary guidance/support strategies. Secondary outcomes included strength increases and lean mass changes. Based on the data presented fat loss (kg) and body fat percentage reductions are not impacted by resistance training load; both appear to produce similar, yet small, changes to body composition. The present study also reinforces the benefits of maintaining resistance training throughout a dietary intervention targeting fat loss, by demonstrating the retention of muscle mass. However, it is noteworthy, that as an assessment of effectiveness (rather than efficacy) it seems that dietary guidance (based on a reduction in calories and a maintenance of protein intake), and resistance training are not sufficient, over the time epoch considered, to produce meaningful changes in body composition. As such, while it is possible that with sufficient time meaningful changes may occur, it may be that more intensive intervention is required for shorter term changes.

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Author contributions
All authors conceived of, and designed, the study; LC and DG collected the data; JS carried out statistical analyses; all authors were meaningfully involved in interpreting data, and both drafting and critically revising the manuscript for intellectually important content.

REFERENCES

1. Shojaa M, von Stengel S, Kohl M, Schoene D, Kemmler W. Effects of dynamic resistance exercise on bone mineral density in postmenopausal women: a systematic review and meta-analysis with special emphasis on exercise parameters. Osteoporos Int 2020;31(8):1427-1444.
2. Abrahin O, Moraes-Ferreira R, Cortinhas-Alves EA, Guerreiro JF. Is resistance training alone an antihypertensive therapy? A meta-analysis. J Hum Hypertens 2021;35(9):769-775.
3. Nagamatsu LS, Handy TC, Hsu CL, et al. Resistance training improves cognitive and functional brain plasticity in seniors with probable MCI: a 6-month randomized controlled trial. Arch Intern Med 2012;172(8):666–668.

4. Gordon BR, McDowell CP, Lyons M, Herring MP. The Effects of Resistance Exercise Training on Anxiety: A Meta-Analysis and Meta-Regression Analysis of Randomized Controlled Trials. Sports Med 2017;47(12):2521-2532.
5. Gordon BR, McDowell CP, Hallgren M, Meyer JD, Lyons M, Herring MP. Association of Efficacy of Resistance Exercise Training With Depressive Symptoms: Meta-analysis and Meta-regression Analysis of Randomized Clinical Trials. JAMA Psychiatry 2018;75(6):566-576
6. Gallardo-Gómez D, Del Pozo-Cruz J, Noetel M, et al. Optimal dose and type of exercise to improve cognitive function in older adults: A systematic review and bayesian model-based network meta-analysis of RCTs. Ageing Res Rev 2022;76:101591.
7. Tsutsumi T, Don BM, Zaichkowsky LD, et al. Comparison of high and moderate intensity of strength training on mood and anxiety in older adults. Percept Mot Skills 1998;87(1):1003–1011.
8. Martino E, Fisher JP, Wink B, et al. "Lift Big-Get Big": The Impact of Images of Hyper-Muscular Bodies and Training Information. Res Q Exerc Sport 2021;92(3):500-513.
9. Fisher J, Sales A, Carlson L, Steele J. A comparison of the motivational factors between CrossFit participants and other resistance exercise modalities: a pilot study. J Sports Med Phys Fitness 2017;57(9):1227-1234.
10. Lopez P, Radaelli R, Taaffe DR, et al. Resistance Training Load Effects on Muscle Hypertrophy and Strength Gain: Systematic Review and Network Meta-analysis. Med Sci Sports Exerc 2021;53(6):1206-1216.
11. Fisher JP, Steele J, Androulakis-Korakakis P, et al. The strength-endurance continuum revisited: a critical commentary of the recommendation of different loading ranges for different muscular adaptations. J Trainology 2020;9(1):1-8.
12. MacKenzie-Shalders K, Kelly JT, So D, et al. The effect of exercise interventions on resting metabolic rate: A systematic review and meta-analysis. J Sports Sci 2020;38(14):1635-1649.
13. Ratamess NA, Alvar BA, Evetoch TK, et al. Progression models in resistance training for healthy adults. Med Sci Sports Exerc 2009;41:687- 708.
14. Choi PY. Muscle matters: Maintaining visible differences between women and men. Sexualities, Evolution & Gender 2003;5(2):71-81.
15. Dworkin SL. “Holding back”: Negotiating a glass ceiling on women's muscular strength. Sociol Perspect 2001;44(3):333-50.
16. Hunter GR, Byrne NM, Sirikul B, et al. Resistance training conserves fat-free mass and resting energy expenditure following weight loss. Obesity 2008;16(5):1045-51.
17. Donnelly JE, Sharp T, Houmard J, et al. Muscle hypertrophy with large-scale weight loss and resistance training. Am J Clin Nutr 1993;58(4):561-5.
18. Avila JJ, Gutierres JA, Sheehy ME, et al. Effect of moderate intensity resistance training during weight loss on body composition and physical performance in overweight older adults. Eur J Appl Physiol 2010;109(3):517-25.
19. Longland TM, Oikawa SY, Mitchell CJ, et al. Higher compared with lower dietary protein during an energy deficit combined with intense exercise promotes greater

lean mass gain and fat mass loss: a randomized trial. Am J Clin Nutr 2016;103(3):738-46
20. Srikanthan P, Karlamangla AS. Muscle mass index as a predictor of longevity in older adults. Am J Med 2014;127(6):547-53.
21. Farinatti, PTV, Simão R, Monteiro WD, et al. Influence of exercise order on oxygen uptake during strength training in young women. J Strength Cond Res 2009;23:1037–1044
22. Scott CB, Leighton BH, Ahearn KJ, McManus JJ. Aerobic, anaerobic, and excess postexercise oxygen consumption energy expenditure of muscular endurance and strength: 1-set of bench press to muscular fatigue. J Strength Cond Res 2011;25(4):903-8.
23. Brunelli DT, Finardi EAR, Bonfante ILP, et al. Acute low- compared to high-load resistance training to failure results in greater energy expenditure during exercise in healthy young men. PLoS One 2019;14(11):e0224801
24. Dhurandhar EJ, Kaiser KA, Dawson JA, et al. Predicting adult weight change in the real world: a systematic review and meta-analysis accounting for compensatory changes in energy intake or expenditure. Int J Obes 2015;39(8):1181-7.
25. Miller T, Mull S, Aragon AA, et al. Resistance Training Combined With Diet Decreases Body Fat While Preserving Lean Mass Independent of Resting Metabolic Rate: A Randomized Trial. Int J Sport Nutr Exerc Metab 2018;28(1):46-54.
26. Baechle TR, Earle RW. Essentials of strength training and conditioning. Human Kinetics; 2008.
27. Whisenant MJ, Panton LB, East WB, Broeder CE. Validation of submaximal prediction equations for the 1 repetition maximum bench press test on a group of collegiate football players. J Strength Cond Res 2003;17(2):221-7.
28. LeSuer DA, McCormick JH, Mayhew JL, et al. The accuracy of prediction equations for estimating 1-RM performance in the bench press, squat, and deadlift. J Strength Cond Res 1997;11:211-3
29. Fisher JP, Carlson L, Steele J, Smith D. The effects of pre-exhaustion, exercise order, and rest intervals in a full-body resistance training intervention. Appl Phys Nutr Metab 2014;39(11):1265-70.
30. Fisher JP, Carlson L, Steele J. The effects of breakdown set resistance training on muscular performance and body composition in young men and women. J Strength Cond Res 2016;30(5):1425-32.
31. Fisher J, Steele J, Smith D. High-and low-load resistance training: interpretation and practical application of current research findings. Sports Med 2017;47(3):393-400.
32. Dempster PH, Aitkens SU. A new air displacement method for the determination of human body composition. Med Sci Sports Exerc 1995;27(12):1692-7.
33. Steele J, Fisher J, Giessing J, Gentil P. Clarity in reporting terminology and definitions of set endpoints in resistance training. Muscle Nerve 2017;56(3):368-374.

34. Dankel SJ, Jessee MB, Mattocks KT, et al. Training to Fatigue: The Answer for Standardization When Assessing Muscle Hypertrophy? Sports Med 2017;47(6):1021-1027.
35. Donnelly JE, Blair SN, Jakicic JM, et al. American College of Sports Medicine Position Stand. Appropriate physical activity intervention strategies for weight loss and prevention of weight regain for adults. Med Sci Sports Exerc 2009;41(2):459-71.
36. Bates D, Mächler M, Bolker B, Walker S. Fitting Linear Mixed-Effects Models Using lme4. J Stat Soft 2015;67(1):1-48.
37. Wilkinson GN, Rogers CE. Symbolic description of factorial models for analysis of variance. J Royal Stat Soc: Series C (Applied Statistics) 1973;22(3):392-9.
38. Pinheiro JC, Bates DM. Linear mixed-effects models: basic concepts and examples. Mixed-effects models in S and S-Plus 2000:3-56.
39. Lenth RV. emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.6.1. 2021.
40. Gardner MJ, Altman DG. Confidence intervals rather than P values: estimation rather than hypothesis testing. Br Med J (Clin Res Ed) 1986;292(6522):746-50.
41. Cumming G. The new statistics: Why and how. Psychological science. 2014;25(1):7-29.
42. Amrhein V, Trafimow D, Greenland S. Inferential statistics as descriptive statistics: There is no replication crisis if we don't expect replication. Am Stat 2019;73:(Suppl. 1):262-70.
43. McShane BB, Gal D, Gelman A, et al. Abandon statistical significance. Am Stat 2019;73:(Suppl. 1):235-45.
44. Carlson L, Gschneidner D, Steele J, Fisher JP. Short-term supervised virtual training maintains intensity of effort and represents an efficacious alternative to traditional studio-based, supervised strength training. Physiol Behav 2022; 249:113748.
45. Wickham H. ggplot2: elegant graphics for data analysis. Springer; 2016.
46. Pedersen TL. Patchwork: The composer of plots. R package version, 1(0). 2020. Available online at: https://CRAN.R-project.org/package=patchwork (accessed February, 2022).
47. Dwan K, Li T, Altman DG, Elbourne D. CONSORT 2010 statement: extension to randomised crossover trials. Brit Med J 2019;366:l4378
48. Fisher JP, Steele J, Smith D. Intensity of effort and momentary failure in resistance training: Are we asking a binary question for a continuous variable? J Sport Health Sci 2022; online ahead of print: https://doi.org/10.1016/j.jshs.2022.03.002.
49. Schoenfeld B, Fisher J, Grgic J, et al. Resistance training recommendations to maximize muscle hypertrophy in an athletic population: Position stand of the IUSCA. Int J Strength Cond 2021;1(1).
50. Ahtiainen JP, Pakarinen A, Alen M, et al. Muscle hypertrophy, hormonal adaptations and strength development during strength training in strength-trained and untrained men. Eur J Appl Physiol 2003; 89(6):555-63.