


Review

Effect of Overnight Fasted Exercise on Weight Loss and Body Composition: A Systematic Review and Meta-Analysis

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Received: 31 October 2017; Accepted: 22 November 2017; Published: 25 November 2017

Abstract: It remains unclear whether training in fasted compared to fed states leads to greater weight loss and whether this practice results in beneficial or detrimental changes in body composition. We conducted a systematic review to examine the effect of overnight-fasted versus fed exercise on weight loss and body composition. Seven electronic databases were searched using terms related to fasting and exercise. Inclusion criteria were: randomised and non-randomised comparative studies; published in English; included healthy adults; compared exercise following an overnight fast to exercise in a fed state; used a standardized pre-exercise meal for the fed condition; and measured body mass and/or body composition. A total of five studies were included involving 96 participants. Intra-group analysis for the effect of fasted and fed aerobic exercise revealed trivial to small effect sizes on body mass. The inter-group effect for the interventions on body mass was trivial. Intra-group effects were small for % body fat and trivial for lean mass in females, with trivial effects also found for the inter-groups analyses. Whilst this is the first systematic review and meta-analysis to investigate this topic, caution is warranted when interpreting the findings due to the limited number of studies and hence insufficient data.

Keywords: weight loss; obesity; caloric restriction; exercise training

1. Introduction

It is well acknowledged that body mass and composition are factors that can influence athletic performance. Diet and exercise play an important role in weight loss and promoting positive changes in body composition [1]. Based on the first law of thermodynamics, an imbalance between energy intake and energy expenditure as a result of diet and/or exercise is accounted for by a gain or loss of body mass [2,3]. However, it is generally recognised that the energy balance principle is oversimplistic for individuals wanting to lose fat mass or gain lean mass. This was demonstrated by Longland et al. [4] who found higher compared to lower protein intake while following a hypocaloric diet, combined with intense exercise, led to greater increases in lean mass and loss of fat mass.

An interesting strategy that is claimed to aid weight loss and enhance the loss of fat mass is to perform aerobic exercise in a fasted state [5]. There are two types of fasting: the first type involves abstaining from food and fluids with exception of water (i.e., water fasting), and the second type involves abstinence from all food and fluids (i.e., dry fasting) [6,7]. Daily fasting is commonly performed and is referred to as the ‘overnight fast’ which for most people lasts between 8 to 12 h [8]. Furthermore, exercise in a fasted state may be more conveniently implemented when performed in the morning prior to breakfast (i.e., overnight-fasted). A recent review and meta-analysis examined the effect of aerobic exercise performed during fasted versus fed states in a total of 273 adult participants. The results of

this previous meta-analysis indicated that aerobic exercise performed in a fasted compared to fed state induces higher fat oxidation [9]. Fat oxidation refers to catabolic processes that generate energy for bodily functions (e.g., muscle contraction and repair of body tissue) [10]. In non-fasted states, aerobic exercise acutely increases fat oxidation compared to resting conditions, and following aerobic training there is an increased capacity to oxidize fat during aerobic exercise [11]. Supposedly, to induce a reduction in fat mass requires a negative fat balance which can be achieved through altering energy intake and/or expenditure such that fat oxidation exceeds fat intake. Therefore it seems plausible that the increased fat oxidation from performing aerobic exercise in a fasted compared to a fed state may lead to greater weight loss via the creation of a larger negative net fat balance.

Therefore, the purpose of the current review was to employ a systematic review format to examine the effects of overnight-fasted versus fed exercise on weight loss and body composition. Information gathered from this review may be useful to coaches, athletes, and personal trainers when devising exercise training programs targeting weight loss.

2. Methods

This review was conducted in accordance with the recommendations outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [12]. A search from the earliest record (shown in parentheses for each respective database) up to and including October 2017 was carried out using the following electronic databases: Medline (1946–), SPORTDiscus (1961–), Web of Science (1900–), Cinahl (1982–), AMED (1985v), Science Direct (1823–), and PubMed (1950–). The search strategy employed combination of the terms “fasting” or “intermittent fasting” or “water fasting” or “food deprivation” or “caloric restriction” or “food restriction” and “strength training” or “weight training” or “resistance training” or “progressive training” or “progressive resistance” or “resistance exercise” or “weight lifting” or “power training” or “power lifting” or “aerobic exercise” or “aerobic interval training” or “aerobic interval exercise” or “endurance exercise” or “aerobic training” or “endurance training” or “cardio training” or “high interval intensity training” or “HIIT” or “high intensity training” or “HIT” or “high intensity exercise” or “interval training” or “interval exercise” or “intermittent training” or “intermittent exercise”.

3. Evaluation of Articles

Titles and abstracts of retrieved articles were individually evaluated by the two authors to assess their eligibility for review and meta-analysis according to the eligibility criteria detailed below. Any disagreements were settled by consensus with peers in the Department of Exercise and Sport Science, University of Sydney. Evaluation of full-text articles was required when abstracts did not provide sufficient information to assess eligibility for inclusion. In the event that an article had missing data or clarification of data was required, the corresponding author was contacted and the original data was requested. In the event that data was not able to be provided, the manuscript was excluded from review. Articles were eligible for inclusion if they met the following criteria: (1) randomized and non-randomized comparative studies; (2) published in English; (3) included healthy adults; (4) compared exercise following an overnight fast to exercise in a fed state; (5) used a standardized pre-exercise meal for the fed condition; and (6) measured body mass and/or body composition.

The two authors separately and independently evaluated full-text articles and conducted data extraction, using a standardized, predefined form. The data for the following variables were extracted: participant characteristics (sex, age, height, body mass, and training experience), fasting/nutritional intervention, exercise prescribed (training mode, training frequency, exercise intensity, sets, repetitions, rest between sets), and intervention length. Shortly after extractions were performed, the authors crosschecked the data to confirm their accuracy. Any discrepancies were resolved by mutual consent. Risk of bias in individual studies was assessed using the Cochrane risk of bias tool [13]. Studies were independently rated by the two authors and checked for selection bias, performance bias, detection bias, attrition bias, and reporting bias. Internal (intra-rater) consistency across items was checked

before the results were combined into a spreadsheet for discussion. Any discrepancies between ratings were resolved by mutual consent.

4. Statistical Analysis

Data is presented as mean \pm standard deviation (SD) or 95% confidence interval (CI). All analyses were conducted using Comprehensive Meta-Analysis version 2 software (Biostat Inc., Englewood, NJ, USA). The level of significance was set at $\alpha < 0.05$ and trends were declared at $p = 0.05$ – 0.10 . Effect size (ES) values were calculated as standardized mean differences (difference between mean post-test scores divided by pooled SD) and expressed as Hedges' g which corrects for parameter bias due to small sample size [14]. ESs were calculated from the pooled data for both intra- and inter-groups using a conservative random-effects model. An ES of 0.2 was considered a small effect, 0.5 a moderate effect, and 0.8 a large effect [15]. Between-study variability was examined for heterogeneity, using the I^2 statistic for quantifying inconsistency [16]. The heterogeneity thresholds were set at $I^2 = 25\%$ (low), $I^2 = 50\%$ (moderate), and $I^2 = 75\%$ (high) [16]. A funnel plot and rank correlations between effect estimates and their standard errors (SE), using Kendall's τ statistic [17], were used to examine publication bias only when a significant result ($p < 0.05$) was found.

5. Results

5.1. Description of Studies

The database search yielded 8135 potential studies with the addition of five studies identified from reference lists and external sources (Figure 1). Five studies met the eligibility criteria and were included in the systematic review and meta-analysis [18–22]. There were a total of 96 participants (60 males and 36 females) aged 21–27 years (Table 1). Three studies included only male participants [18,21,22] while the other two studies had only female participants [19,20]. The majority of participants had an exercise background such as track and field [20] or regularly played sports [18,21,22]. Participants for one study were described as being previously sedentary [19]. The exercise interventions involved 3–4 supervised sessions performed over 4–6 weeks. High intensity interval training (cycling) was performed in one study [19], continuous cycling in three studies [18,21,22], and continuous treadmill exercise in one study [20].

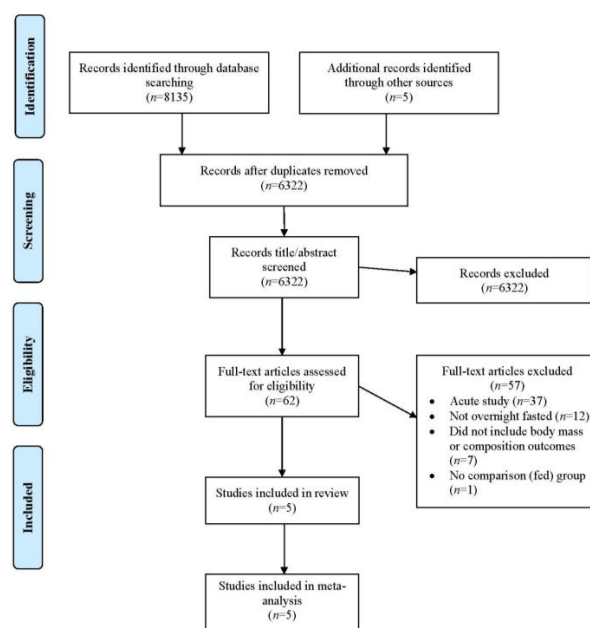


Figure 1. Flow chart of study retrieval process.

All five studies assessed changes in body mass [18–22], two studies assessed changes in body fat [19,20], one study assessed changes in lean body mass [19], and one study assessed changes in fat-free mass [20]. Body fat percentage was assessed via a BodPod in one study [20] and dual-energy X-ray absorptiometry (DXA) in another study [19]. For the meta-analysis, data from lean body mass and fat-free mass was combined as it has previously been shown not to impact results [23].

5.2. Effect on Body Mass and Composition

Table 2 details the effects of fasted versus fed exercise on weight loss and body composition. The intra-group effect sizes (ES) for fasted and fed exercise on body mass were found to be trivial to small for the combined, male, and female analyses (ES = 0.01 to −0.12) and were not significant (Table 2). The inter-group ES for the interventions on body mass for the combined, male, and female analyses were trivial (ES = 0.02 to 0.05) with no significant difference between interventions.

Analyses on % body fat and lean mass could only be performed on females because the studies that included males only did not include these outcome measures. The intra-group ES for fasted and fed exercise on % body fat for females were small (ES = −0.10 to −0.12) and were not significant (Table 2). The inter-group ES of the interventions on % body fat were trivial (ES = 0.05) and not significant. The intra-group ES of the intervention on lean mass for females were trivial (ES = 0.01) and were not significant (Table 2). The inter-group ES of the interventions on lean mass was also trivial (ES = 0.04) and not significant. For all the analyses (body mass, % body fat, and lean mass) there was no heterogeneity between studies ($I^2 = 0\%$).

5.3. Risk of Bias

All included studies randomised participants into intervention groups, however it was not identified whether they used an acceptable method of random sequence generation (Table 3). Therefore, these five studies were rated as having an unclear risk for random sequence generation. As per the previous item, the same ratings were given to all studies for allocation concealment. All studies were rated as high risk for blinding of participants (performance bias) and blinding of outcome assessment (detection bias). All studies were rated as low risk for incomplete outcome data due to no drop outs and no missing data, and all studies were rated as low risk for selective reporting.

Table 1. Participant and training characteristics of included studies.

Study	Group	Sex: M (%)	Age (Year)	Training Status	Exercise Prescription	Duration (wk)	Frequency (d/wk)
De Bock et al. [18]	Fasted (<i>n</i> = 10)	100	21.2 ± 0.4	Trained	Cycling: 60–120 min @ 75% 70-VO ₂ peak (supervised)	6	3
	Fed (<i>n</i> = 10)	100	21.2 ± 0.4	Trained			
Gillen et al. [19]	Fasted (<i>n</i> = 8)	0	27.0 ± 9.0	Untrained	Cycling: 10 × 60 s efforts @ 90% HRmax with 60 s recovery (supervised)	6	3
	Fed (<i>n</i> = 8)	0	27.0 ± 7.0	Untrained			
Schoenfeld et al. [20]	Fasted (<i>n</i> = 10)	0	23.8 ± 3.0	Trained	Treadmill: 60 min @ 70% MHR (supervised)	4	3
	Fed (<i>n</i> = 10)	0	21.0 ± 1.7	Trained			
Van Proeyen et al. [21]	Fasted (<i>n</i> = 10)	100	21.2 ± 1.0	Trained	Cycling: 2/wk = 60 min & 2/wk = 90 min. Cycling performed @ 70–75% VO ₂ max and running @ 85% VO ₂ max (supervised)	6	4
	Fed (<i>n</i> = 10)	100	21.2 ± 1.0	Trained			
Van Proeyen et al. [22]	Fasted (<i>n</i> = 10)	100	23.0 ± 1.1	Trained	Cycling: 2/wk = 60 min & 2/wk = 90 min performed @ ~70-VO ₂ max (supervised)	6	4
	Fed (<i>n</i> = 10)	100	22.1 ± 0.9	Trained			

Data is reported as mean ± SD or as a range. d = days; HRmax = heart rate maximum; M = males; MHR = maximal heart rate; min = minutes; s = seconds; VO₂ max = maximal oxygen consumption; wk = weeks.

Table 2. The effects of fasted versus fed exercise on weight loss and composition.

Study	Fasted Exercise					Fed Exercise					Between Groups		
	<i>n</i>	Pre-Training	Post-Training	Hedges' <i>g</i>	95% CI	<i>n</i>	Pre-Training	Post-Training	Hedges' <i>g</i>	95% CI	Hedges' <i>g</i>	95% CI	<i>p</i>
Body Mass (Males)													
De Bock et al. [18]	10	74.3 ± 2.8	74.2 ± 3.0	−0.03 (0.29)	−0.60 to 0.54	10	75.3 ± 3.0	75.5 ± 2.9	0.06 (0.29)	−0.51 to 0.63	0.10 (0.43)	−0.74 to 0.94	0.82
Van Proeyen et al. [21]	10	73.3 ± 9.8	74.1 ± 8.8	0.08 (0.29)	−0.49 to 0.65	10	70.2 ± 11.4	71.6 ± 10.7	0.12 (0.29)	−0.45 to 0.69	0.06 (0.43)	−0.78 to 0.90	0.89
Van Proeyen et al. [22]	10	76.0 ± 4.6	75.8 ± 4.3	−0.04 (0.33)	−0.61 to 0.53	10	77.6 ± 3.7	76.9 ± 3.4	−0.18 (0.29)	−0.75 to 0.39	−0.12 (0.43)	−0.96 to 0.72	0.77
Mean Effect	-	-	-	0.01 (0.17)	−0.33 to 0.33	-	-	-	0.01 (0.17)	−0.33 to 0.33	0.02 (0.20)	−0.36 to 0.41	0.90
Body Mass (Females)													
Gillen et al. [19]	8	79.0 ± 15.0	79.0 ± 15.0	0.01 (0.31)	−0.62 to 0.62	8	77.0 ± 12.0	77.0 ± 13.0	0.01 (0.31)	−0.62 to 0.62	0 (0.47)	−0.93 to 0.93	1.00
Schoenfeld et al. [20]	10	62.4 ± 7.8	60.8 ± 7.8	−0.19 (0.29)	−0.76 to 0.39	10	62.0 ± 5.5	61.0 ± 5.7	−0.16 (0.30)	−0.73 to 0.41	0.08 (0.43)	−0.76 to 0.92	0.84
Mean Effect	-	-	-	−0.10 (0.21)	−0.52 to 0.32	-	-	-	−0.09 (0.21)	−0.51 to 0.33	0.05 (0.32)	−0.58 to 0.67	0.88
Body Mass (Combined)													
Mean Effect	-	-	-	−0.04 (0.13)	−0.30 to 0.22	-	-	-	−0.03 (0.13)	−0.29 to 0.23	0.02 (0.20)	−0.36 to 0.41	0.90
% Body Fat (Females)													
Gillen et al. [19]	8	42.3 ± 8.1	41.6 ± 7.8	−0.08 (0.32)	−0.70 to 0.54	8	40.9 ± 5.8	40.1 ± 5.4	−0.13 (0.32)	−0.75 to 0.49	0.01 (0.47)	−0.91 to 0.94	0.98
Schoenfeld et al. [20]	10	26.3 ± 7.9	25.0 ± 7.7	−0.15 (0.29)	−0.72 to 0.42	10	24.8 ± 8.4	24.1 ± 8.5	−0.08 (0.29)	−0.64 to 0.49	0.07 (0.43)	−0.77 to 0.91	0.87

Table 2. Cont.

Study	Fasted Exercise					Fed Exercise					Between Groups		
	<i>n</i>	Pre-Training	Post-Training	Hedges' <i>g</i>	95% CI	<i>n</i>	Pre-Training	Post-Training	Hedges' <i>g</i>	95% CI	Hedges' <i>g</i>	95% CI	<i>p</i>
Mean Effect	-	-	-	−0.12 (0.21)	−0.54 to 0.30	-	-	-	−0.10 (0.21)	−0.52 to 0.32	0.05 (0.32)	−0.58 to 0.67	0.89
Lean Mass (Females)													
Gillen et al. [19]	8	42.8 ± 5.5	43.3 ± 5.5	0.08 (0.32)	−0.54 to 0.70	8	43.5 ± 8.2	44.1 ± 7.8	0.07 (0.32)	−0.55 to 0.68	0.01 (0.47)	−0.91 to 0.94	0.98
Schoenfeld et al. [20]	10	45.9 ± 6.7	45.4 ± 6.1	−0.07 (0.29)	−0.64 to 0.50	10	46.3 ± 3.8	46.1 ± 4.3	−0.05 (0.29)	−0.61 to 0.52	0.05 (0.43)	−0.79 to 0.89	0.90
Mean Effect	-	-	-	0.01 (0.21)	−0.42 to 0.42	-	-	-	0.01 (0.21)	−0.41 to 0.42	0.04 (0.32)	−0.59 to 0.66	0.91

Statistical significance accepted as $p \leq 0.05$; % = Percentage; CI = Confidence interval. Data are mean ± SD. Statistical significance accepted as $p \leq 0.05$.

Table 3. Study risk of bias *.

Study	Random Sequence Generation (Selection Bias)	Allocation Concealment (Selection Bias)	Blinding Participants and Personnel (Performance Bias)	Blinding of Outcome Assessment (Detection Bias)	Incomplete Outcome Data (Attrition Bias)	Selective Reporting (Reporting Bias)
De Bock et al. [18]	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk
Gillen et al. [19]	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk
Schoenfeld et al. [20]	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk
Van Proeyen et al. [21]	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk
Van Proeyen et al. [22]	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk

* Risk of bias in individual studies was assessed using the Cochrane risk of bias tool [13].

6. Discussion

To the best of the authors' knowledge, this is the first systematic review and meta-analysis to investigate the effects of overnight-fasted exercise versus fed exercise on weight loss and body composition. The data shows minimal changes in body mass and composition following aerobic exercise interventions in both fasted and fed states. Furthermore, performing exercise in a fasted state did not influence weight loss or changes in lean and fat mass. These findings support the notion that weight loss and fat loss from exercise is more likely to be enhanced through creating a meaningful caloric deficit over a period of time, rather than exercising in fasted or fed states. However, caution is warranted when interpreting the findings due to the limited number of studies and hence insufficient data. Hence, future well-controlled longitudinal studies are required in cohorts of healthy adults to confirm and extend our findings.

A common rationale for undertaking fasted exercise is to increase the oxidation of fatty acids as a source of fuel during an exercise bout, thus creating a larger negative net fat balance compared fed exercise, translating to greater losses of body fat. However, although acute exercise in the fasted state has been shown to result in greater fat oxidation than exercise performed in a fed state [9], the research is currently equivocal as to whether or not this influences 24 h energy expenditure [24,25]. Also, there is evidence of a differential sex effect on fat oxidation in a fasted state [26]. Based on findings from the present review it seems that fasted compared to fed exercise does not increase the amount of weight loss and fat mass loss. An explanation for the disparity between the acute studies showing increased fat oxidation following fasted exercise and the review findings could be due to a compensatory decrease in fat oxidation in the post-exercise period once a meal is consumed [27].

Based on the minimal weight loss found for the studies included in this review, it can be argued that the interventions were not adequate for achieving significant weight loss. Previously it was thought that lower intensity exercise, conducted in the "fat-burning" zone, was superior for weight loss when compared to high intensity exercise. This theory was based on the fact that higher intensity exercise elicits an acutely lower level of fat oxidation [28]. In the present review one of five studies involved high intensity interval training (HIIT) which may have affected weight loss [19], whereas the other studies involved moderate intensity continuous training (MICT). However, similar energy expenditure over 24 h has been observed following HIIT and MICT [29]. Furthermore, recent systematic reviews and meta-analyses have shown that HIIT and MICT can induce similar improvements in body adiposity, with HIIT possibly being a more "time-efficient" exercise strategy [30,31]. Although, as seen in the present review, when HIIT or MICT are performed on their own without any dietary intervention, it is unlikely that clinically meaningful weight loss (>5% reduction [32]) in body mass and body fat can be achieved unless performed at very high volumes [33].

Studies have shown that consumption of food prior to exercise increases the thermic effect of the bout, thus leading to greater energy expenditure post-exercise compared to exercise in a fasted state [34–36], therefore suggesting that fed compared to fasted exercise may be more efficacious for weight loss. Also, an acute bout of fasted compared to fed exercise has been shown to result in a significantly greater loss in muscle protein [37], which may lead to a significant loss of lean mass if this practice is performed over week or months. However, even in the absence of exercise which is shown to improve the net muscle–protein balance [38,39], lean mass can be preserved during short duration fasting (<24 h) over short periods of time (≤ 8 weeks) [40]. This is in agreement with the findings from this review of no differences in lean mass for females between the fasted and fed exercise conditions. An explanation for the preservation of lean mass during short duration fasts may be due to increases in daily protein intake so that net muscle–protein balance is maintained [4]. Other possible mechanisms include increases in anabolic hormones such as growth hormone to stimulate greater muscle protein synthesis [41] and increased utilization of ketone bodies for fuel, thus suppressing skeletal muscle breakdown [42].

There are several limitations that should be taken into account when interpreting the results of this review. Firstly, there were only five studies that met the inclusion criteria for this review. Of these

studies, all involved body mass analysis; however only two studies (involving females) included % body fat and lean mass analyses. Therefore, this will impact on the ability to generalize the precise effects of overnight-fasted exercise versus fed exercise on weight loss and body composition. Secondly, the majority of participants in the included studies were trained, therefore it is possible that their response to the fasted versus fed exercise interventions may have been different to the untrained participants. However, trained and untrained participants have similar metabolic responses to acute exercise in both the fasted and fed state, with the exception of low intensity exercise [43]. While the authors of this review are unaware of any research directly comparing training status in a chronic or long-term fasting and fed model, if the response is similar to the acute response, an effect of training status may not be apparent. Also, based on evidence of a differential sex effect on fat oxidation in a fasted state [26], it did not seem prudent to combine males and females for the body mass analysis. However, we are confident this did not confound the combined analysis as there were similar negligible differences between the interventions for males ($ES = 0.02$) and females ($ES = 0.05$).

Findings from this review are also limited due to the heterogeneity between dietary interventions, such as the macronutrient composition, quantity, and timing of meals between participants and groups may have influenced the findings of this review. Three studies provided supervised meals or take-home meal packages [18,21,22], however one of these diets was a hypercaloric high-fat diet [21] which would, in theory, alter the body composition responses to the exercise intervention. Conversely, one study provided a customized diet plan, tracked via a daily online food diary, aimed at eliciting weight loss [20]. Three studies utilized food diaries, implemented three days per week, with no other nutritional controls. One study provided a standardized breakfast on training days, with the recommendation to continue with regular dietary habits for the duration of the study [19]. As such, given that some studies intended to implement either a caloric surplus or deficit, and that others intended for diets to be isocaloric and did not have strict nutritional controls in place, it is impossible to be sure that diet has not had an influence on the outcome of this analysis. However, based on the similar intra-group effect sizes (trivial to small) for all studies, it seems unlikely that heterogeneity between dietary interventions influenced the findings of this review.

7. Practical Applications

Our review of a small number of studies does not support the use of fasted exercise for weight loss and positive changes in body composition. Furthermore, our findings also suggest there is no detrimental effect on body mass and body composition with utilizing this practice. Future research studies on this topic should use interventions of larger exercise volumes and durations to allow significant changes in weight loss and body composition. Also, for future-fasted versus fed exercise studies, the dietary habits of participants need to be well controlled. This could be achieved through prescribing participants specific diets and monitoring their compliance at regular time points throughout the intervention (e.g., three-day weighed food record or iPhone app). Acutely, fasted exercise has been shown to increase fat oxidation and the subsequent use of fatty acids as a fuel source, potentially inducing improvements in insulin sensitivity which may have important implications for type 2 diabetes and insulin-resistant patients [44]. Until further research on this topic is performed, it appears individuals can participate in whichever form of exercise that they prefer in either fasted or fed states when targeting improvements in body composition.

Author Contributions: Daniel Hackett was involved in search strategy, study selection, data extraction, risk of bias scoring, statistical analysis, and manuscript write up. Amanda D. Hagstrom was involved in study selection, data extraction, risk of bias scoring, and manuscript write up.

Conflicts of Interest: The authors declare no conflict of interest.

References

- Clark, J.E. Diet, exercise or diet with exercise: Comparing the effectiveness of treatment options for weight-loss and changes in fitness for adults (18–65 years old) who are overfat, or obese; systematic review and meta-analysis. *J. Diabetes Metab. Disord.* **2015**, *14*, 1–28.
- Forbes, G.B. Lean body mass-body fat interrelationships in humans. *Nutr. Rev.* **1987**, *45*, 225–231. [[CrossRef](#)] [[PubMed](#)]
- Hall, K.D. Body fat and fat-free mass inter-relationships: Forbes's theory revisited. *Br. J. Nutr.* **2007**, *97*, 1059–1063. [[CrossRef](#)] [[PubMed](#)]
- Longland, T.M.; Oikawa, S.Y.; Mitchell, C.J.; Devries, M.C.; Phillips, S.M. 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*, 738–746. [[CrossRef](#)] [[PubMed](#)]
- Phillips, B.; D'Orso, M. *Body for Life: 12 weeks to mental and physical strength*; Harper Collins: New York, NY, USA, 1999.
- Goldhamer, A.; Lisle, D.; Parpia, B.; Anderson, S.V.; Campbell, T.C. Medically supervised water-only fasting in the treatment of hypertension. *J. Manip. Physiol. Ther.* **2001**, *24*, 335–339. [[CrossRef](#)] [[PubMed](#)]
- Sweileh, N.; Schnitzler, A.; Hunter, G.; Davis, B. Body composition and energy metabolism in resting and exercising muslims during ramadan fast. *J. Sports Med. Phys. Fit.* **1992**, *32*, 156–163.
- Maughan, R.J.; Fallah, J.; Coyle, E.F. The effects of fasting on metabolism and performance. *Br. J. Sports Med.* **2010**, *44*, 490–494. [[CrossRef](#)] [[PubMed](#)]
- Vieira, A.F.; Costa, R.R.; Macedo, R.C.; Coconcelli, L.; Kruel, L.F. Effects of aerobic exercise performed in fasted v. Fed state on fat and carbohydrate metabolism in adults: A systematic review and meta-analysis. *Br. J. Nutr.* **2016**, *116*, 1153–1164. [[CrossRef](#)] [[PubMed](#)]
- Gropper, S.S.; Smith, J.L. *Advanced Nutrition and Human Metabolism*; Cengage Learning: Belmont, CA, USA, 2012.
- Jeukendrup, A.E. Regulation of fat metabolism in skeletal muscle. *Ann. N. Y. Acad. Sci.* **2002**, *967*, 217–235. [[CrossRef](#)] [[PubMed](#)]
- Liberati, A.; Altman, D.G.; Tetzlaff, J.; Mulrow, C.; Gotzsche, P.C.; Ioannidis, J.P.; Clarke, M.; Devereaux, P.J.; Kleijnen, J.; Moher, D. The prisma statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. *PLoS Med.* **2009**, *6*, e1000100. [[CrossRef](#)] [[PubMed](#)]
- Higgins, J.P.; Green, S. *Cochrane Handbook for Systematic Reviews of Interventions*; John Wiley & Sons: Chichester, UK, 2011; pp. 8.1–8.43.
- Ugille, M.; Moeyaert, M.; Beretvas, S.N.; Ferron, J.M.; van den Noortgate, W. Bias corrections for standardized effect size estimates used with single-subject experimental designs. *J. Exp. Educ.* **2014**, *82*, 358–374. [[CrossRef](#)]
- Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed.; Elsevier Science: Burlington, MA, USA, 2013; pp. 25–27.
- Higgins, J.P.; Thompson, S.G.; Deeks, J.J.; Altman, D.G. Measuring inconsistency in meta-analyses. *BMJ* **2003**, *327*, 557–560. [[CrossRef](#)] [[PubMed](#)]
- Begg, C.B.; Mazumdar, M. Operating characteristics of a rank correlation test for publication bias. *Biometrics* **1994**, *50*, 1088–1101. [[CrossRef](#)] [[PubMed](#)]
- De Bock, K.; Derave, W.; Eijnde, B.O.; Hesselink, M.K.; Koninckx, E.; Rose, A.J.; Schrauwen, P.; Bonen, A.; Richter, E.A.; Hespel, P. Effect of training in the fasted state on metabolic responses during exercise with carbohydrate intake. *J. Appl. Physiol.* **2008**, *104*, 1045–1055. [[CrossRef](#)] [[PubMed](#)]
- Gillen, J.B.; Percival, M.E.; Ludzki, A.; Tarnopolsky, M.A.; Gibala, M.J. Interval training in the fed or fasted state improves body composition and muscle oxidative capacity in overweight women. *Obesity* **2013**, *21*, 2249–2255. [[CrossRef](#)] [[PubMed](#)]
- Schoenfeld, B.J.; Aragon, A.A.; Wilborn, C.D.; Krieger, J.W.; Sonmez, G.T. Body composition changes associated with fasted versus non-fasted aerobic exercise. *J. Int. Soc. Sports Nutr.* **2014**, *11*, 54. [[CrossRef](#)] [[PubMed](#)]
- Van Proeyen, K.; Szlufcik, K.; Nielens, H.; Pelgrim, K.; Deldicque, L.; Hesselink, M.; Van Veldhoven, P.P.; Hespel, P. Training in the fasted state improves glucose tolerance during fat-rich diet. *J. Physiol.* **2010**, *588*, 4289–4302. [[CrossRef](#)] [[PubMed](#)]

22. Van Proeyen, K.; Szlufcik, K.; Nielens, H.; Ramaekers, M.; Hespel, P. Beneficial metabolic adaptations due to endurance exercise training in the fasted state. *J. Appl. Physiol.* **2011**, *110*, 236–245. [[CrossRef](#)] [[PubMed](#)]
23. Stonehouse, W.; Wycherley, T.; Luscombe-Marsh, N.; Taylor, P.; Brinkworth, G.; Riley, M. Dairy intake enhances body weight and composition changes during energy restriction in 18–50-year-old adults—a meta-analysis of randomized controlled trials. *Nutrients* **2016**, *8*, 394. [[CrossRef](#)] [[PubMed](#)]
24. Paoli, A.; Marcolin, G.; Zonin, F.; Neri, M.; Sivieri, A.; Pacelli, Q.F. Exercising fasting or fed to enhance fat loss? Influence of food intake on respiratory ratio and excess postexercise oxygen consumption after a bout of endurance training. *Int. J. Sport Nutr. Exerc. Metab.* **2011**, *21*, 48–54. [[CrossRef](#)] [[PubMed](#)]
25. Shimada, K.; Yamamoto, Y.; Iwayama, K.; Nakamura, K.; Yamaguchi, S.; Hibi, M.; Nabekura, Y.; Tokuyama, K. Effects of post-absorptive and postprandial exercise on 24 h fat oxidation. *Metabolism* **2013**, *62*, 793–800. [[CrossRef](#)] [[PubMed](#)]
26. Henderson, G.C.; Alderman, B.L. Determinants of resting lipid oxidation in response to a prior bout of endurance exercise. *J. Appl. Physiol.* **2014**, *116*, 95–103. [[CrossRef](#)] [[PubMed](#)]
27. Melanson, E.L.; MacLean, P.S.; Hill, J.O. Exercise improves fat metabolism in muscle but does not increase 24-h fat oxidation. *Exerc. Sport Sci. Rev.* **2009**, *37*, 93–101. [[CrossRef](#)] [[PubMed](#)]
28. Romijn, J.A.; Coyle, E.F.; Sidossis, L.S.; Gastaldelli, A.; Horowitz, J.F.; Endert, E.; Wolfe, R.R. Regulation of endogenous fat and carbohydrate metabolism in relation to exercise intensity and duration. *Am. J. Physiol.* **1993**, *265*, E380–E391. [[PubMed](#)]
29. Skelly, L.E.; Andrews, P.C.; Gillen, J.B.; Martin, B.J.; Percival, M.E.; Gibala, M.J. High-intensity interval exercise induces 24-h energy expenditure similar to traditional endurance exercise despite reduced time commitment. *Appl. Physiol. Nutr. Metab.* **2014**, *39*, 845–848. [[CrossRef](#)] [[PubMed](#)]
30. Keating, S.E.; Johnson, N.A.; Mielke, G.I.; Coombes, J.S. A systematic review and meta-analysis of interval training versus moderate-intensity continuous training on body adiposity. *Obes. Rev.* **2017**. [[CrossRef](#)] [[PubMed](#)]
31. Wewege, M.; Berg, R.; Ward, R.; Keech, A. The effects of high-intensity interval training vs. Moderate-intensity continuous training on body composition in overweight and obese adults: A systematic review and meta-analysis. *Obes. Rev.* **2017**, *18*, 635–646. [[CrossRef](#)] [[PubMed](#)]
32. Stevens, J.; Truesdale, K.P.; McClain, J.E.; Cai, J. The definition of weight maintenance. *Int. J. Obes.* **2006**, *30*, 391–399. [[CrossRef](#)] [[PubMed](#)]
33. Donnelly, J.E.; Blair, S.N.; Jakicic, J.M.; Manore, M.M.; Rankin, J.W.; Smith, B.K. 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*, 459–471. [[CrossRef](#)] [[PubMed](#)]
34. Davis, J.M.; Sadri, S.; Sargent, R.G.; Ward, D. Weight control and calorie expenditure: Thermogenic effects of pre-prandial and post-prandial exercise. *Addict. Behav.* **1989**, *14*, 347–351. [[CrossRef](#)]
35. Goben, K.W.; Sforzo, G.A.; Frye, P.A. Exercise intensity and the thermic effect of food. *Int. J. Sport Nutr.* **1992**, *2*, 87–95. [[CrossRef](#)] [[PubMed](#)]
36. Lee, Y.S.; Ha, M.S.; Lee, Y.J. The effects of various intensities and durations of exercise with and without glucose in milk ingestion on postexercise oxygen consumption. *J. Sports Med. Phys. Fit.* **1999**, *39*, 341–347.
37. Lemon, P.W.; Mullin, J.P. Effect of initial muscle glycogen levels on protein catabolism during exercise. *J. Appl. Physiol. Respir. Environ. Exerc. Physiol.* **1980**, *48*, 624–629. [[PubMed](#)]
38. Carraro, F.; Stuart, C.A.; Hartl, W.H.; Rosenblatt, J.; Wolfe, R.R. Effect of exercise and recovery on muscle protein synthesis in human subjects. *Am. J. Physiol. Endocrinol. Metab.* **1990**, *259*, E470–E476.
39. Sheffield-Moore, M.; Yeckel, C.; Volpi, E.; Wolf, S.; Morio, B.; Chinkes, D.; Paddon-Jones, D.; Wolfe, R. Postexercise protein metabolism in older and younger men following moderate-intensity aerobic exercise. *Am. J. Physiol. Endocrinol. Metab.* **2004**, *287*, E513–E522. [[CrossRef](#)] [[PubMed](#)]
40. Klempel, M.C.; Kroeger, C.M.; Varady, K.A. Alternate day fasting (ADF) with a high-fat diet produces similar weight loss and cardio-protection as ADF with a low-fat diet. *Metabolism* **2013**, *62*, 137–143. [[CrossRef](#)] [[PubMed](#)]
41. Ho, K.Y.; Veldhuis, J.D.; Johnson, M.L.; Furlanetto, R.; Evans, W.S.; Alberti, K.G.; Thorner, M.O. Fasting enhances growth hormone secretion and amplifies the complex rhythms of growth hormone secretion in man. *J. Clin. Investig.* **1988**, *81*, 968–975. [[CrossRef](#)] [[PubMed](#)]

42. Nair, K.S.; Welle, S.L.; Halliday, D.; Campbell, R.G. Effect of beta-hydroxybutyrate on whole-body leucine kinetics and fractional mixed skeletal muscle protein synthesis in humans. *J. Clin. Investig.* **1988**, *82*, 198–205. [[CrossRef](#)] [[PubMed](#)]
43. Bergman, B.C.; Brooks, G.A. Respiratory gas-exchange ratios during graded exercise in fed and fasted trained and untrained men. *J. Appl. Physiol.* **1999**, *86*, 479–487. [[PubMed](#)]
44. Hansen, D.; De Strijcker, D.; Calders, P. Impact of endurance exercise training in the fasted state on muscle biochemistry and metabolism in healthy subjects: Can these effects be of particular clinical benefit to type 2 diabetes mellitus and insulin-resistant patients? *Sports Med.* **2017**, *47*, 415–428. [[CrossRef](#)] [[PubMed](#)]



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