Impact of Resistance Training on Energy Intake and Appetite Regulation for Obese or Overweight Individuals: A Systematic Literature Review

Qiang Wang[1], Soh Kim Geok[2*], Wan Ying Gan[3], He Sun[4], Sheng Yao Luo[5]

Abstract
Individuals experiencing obesity or overweight conditions frequently encounter difficulties in managing their appetite. The sustained practice of resistance training over an extended duration presents a potential avenue for regulating appetite among this demographic. Despite the extensive examination of long-term resistance training in existing literature, a consensus on pertinent issues remains elusive, necessitating a comprehensive review. This paper aims to evaluate empirical studies examining alterations in energy intake and appetite among obese or overweight individuals engaging in prolonged resistance training regimens. Information was gathered from databases including EBSCOhost, Science Direct, PubMed, and Web of Science. Search queries were executed on Google Scholar and other sources, utilizing key terms pertinent to energy intake (or appetite), resistance training, and overweight (or obesity) for identifying relevant studies. A comprehensive evaluation of 38 full-text articles was conducted, resulting in the inclusion of eight articles in the review. The PEDro scale was utilized to assess bias and completeness risk, with no exclusion of any articles during this process. The impact of resistance training on energy intake in overweight or obese individuals was observed through sessions lasting 35–45 minutes conducted twice a week over a nine-month period. The exercise significantly influenced parameters such as energy intake, glucose levels, leptin concentrations, Homeostatic Model Assessment of Insulin Resistance (HOMA-IR), Neuropeptide Y (NPY), and adiponectin. However, no significant effects were noted on perceived fullness and hunger, ghrelin PP, or PYY. Resistance training has the potential to impact energy intake and appetite regulation in overweight or obese individuals. Further research is warranted, particularly in exploring its effects on female and adolescent populations, implementing a sample size calculation strategy, conducting comparisons across three intensities, and undertaking a comprehensive analysis of relevant variables.
Keywords: Resistance Training, Energy Intake, Appetite, Overweight, Obese.

1. Introduction

Obesity is delineated as an outcome arising from an excess of energy. Augmented dietary energy intake does not confer advantages in terms of heightened energy expenditure (Jéquier, 2002). As elucidated by Jéquier (2002), energy expenditure encompasses basal metabolism, thermogenesis, and physical activities. Notably, physical activities serve as a particularly diverse variable, given that individuals experiencing overweight or obesity tend to participate in significantly reduced physical activity, in contrast to their generally elevated dietary intake (Suzuki, Jayasena, & Bloom, 2012; Thedinga, Zehl, & Thiel, 2021).

Physical activity plays a crucial role in the intricate regulation of energy balance. Research has shown a connection between energy balance and physiological cues related to food intake (Hameed et al., 2017; Zhang et al., 2015), with some studies indicating that sports can induce satiety (Cook & Schoeller, 2011; Hubner, Boron, & Koehler, 2021). Moreover, investigations have suggested that brief interventions can elevate energy expenditure, while sustained exercise regimens may also influence appetite dynamics (Hopkins, King, & Blundell, 2010; Martins, Morgan, & Truby, 2008). Consequently, researchers advocate for a multifaceted approach for weight management in overweight and obese individuals, encompassing a reduction in dietary intake, augmentation

[1] Department of Sport Studies, Faculty of Educational Studies, Universiti Putra Malaysia, Serdang, 43400, Malaysia.
Email: gs58624@student.upm.edu.my (Q.W.)
[2] Department of Sport Studies, Faculty of Educational Studies, Universiti Putra Malaysia, Serdang, 43400, Malaysia.
* Corresponding author: kims@upm.edu.my (S.K.G.)
[3] Department of Nutrition and Dietetics, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, Serdang, 43400, Malaysia.
Email: wanying@upm.edu.my (W.Y.G.)
[4] Department of Sport Studies, Faculty of Educational Studies, Universiti Putra Malaysia, Serdang, 43400, Malaysia.
Email: 1669978178@qq.com (H.S.)
[5] Department of Sport Studies, Faculty of Educational Studies, Universiti Putra Malaysia, Serdang, 43400, Malaysia.
Email: gs59031@student.upm.edu.my (S.Y.L.)

of physical activity, and the identification of effective training strategies for weight loss (Hill, 2006). Additionally, efforts are directed towards diminishing energy intake and enhancing the perception of fullness (Hetherington et al., 2013).

Resistance training, a distinctive exercise modality, impacts dietary intake and various physical activities (Avila et al., 2010; Bales et al., 2012; Halliday et al., 2014; Hunter et al., 2015; Tulloch et al., 2013). Interventions in resistance (Marinik et al., 2014) training have demonstrated a sustained reduction in reported energy, carbohydrates, total sugar, fruit and vegetable, and sugar intake over three months (Halliday et al., 2014). Its efficacy and safety across age groups, with a particular emphasis on encouraging young adults to engage, have been established (Malina, 2006). Moreover, studies indicate positive outcomes of resistance training on the well-being of obese or overweight children and adolescents (Shaibi et al., 2006; Yu et al., 2005). Furthermore, research reveals that resistance training at varied intensities significantly diminishes appetite-related physiological indices in obese or overweight elderly individuals after six months (Fatouros et al., 2005).

Food intake comprises three distinct phases. The initial phase, termed the ingestive phase, is characterized by the sensation of hunger. The second phase, known as the prandial phase, corresponds to the consumption of food until the point of satiety. Subsequently, the postprandial period is marked by the sensation of satiety (Jéquier, 2002). The Cascade hypothesis (of appetite) (Chambers, 2016) posits that experienced hunger and fullness can be elucidated by caloric intake at the psychological level. In contrast, the traditional glucostatic theory suggests that diminished blood glucose levels trigger meal consumption (Joseph et al., 2011). However, the regulation of food intake is a facet of a intricate system involving physiological communication across the body (Murphy & Bloom, 2006), categorized as either orexigenic (appetite-stimulating) or anorectic (appetite-suppressing) (Sobrino Crespo et al., 2014). Notable physiological indices governing appetite include total ghrelin, Neuropeptide Y (NPY) (an orexigenic molecule), insulin, leptin, pancreatic polypeptide (PP), peptide tyrosine tyrosine (PYY), and adiponectin (anorectic molecule) (Guelfi, Donges, & Duffield, 2013; Kim & Kim, 2020). Researchers have investigated the influence of resistance exercise on these physiological indices, with each indicator associated with a distinct mechanism of action (Cawthorn et al., 2014). Additionally, certain studies have explored the effect of resistance training on the leptin resistance index through the Homeostatic Model Assessment of Insulin Resistance (HOMA-IR) approach (Cândido et al., 2021). Resistance training is anticipated to reduce the energy intake of sedentary overweight or obese individuals by suppressing orexigenic molecules, augmenting anorectic molecules, and diminishing the HOMA-IR index (Benite-Ribeiro, Putt, & Santos, 2016; Carnier et al., 2013; Shakiba et al., 2019).

Despite the existing literature on resistance training's effects on energy intake and appetite regulation, empirical evidence specific to its impact on overweight or obese individuals is insufficient. Consequently, there is a need to systematically evaluate the scientific evidence regarding the potential benefits and risks of resistance training in this population. This systematic review aims to assess published research on the influence of resistance training on energy intake or appetite regulation among overweight or obese individuals.

2. Materials and Methods

This systematic review adhered to the established guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009) and was duly registered with the International Platform of Registered Systematic Review and Meta-analysis Protocols (INPLASY) under the registration code INPLASY202210090.

2.1 Literature Search Strategy

The pertinent literature for this review was sourced from databases such as EBSCOHOST, Science Direct, PubMed, and Web of Science. Additionally, relevant articles from Google Scholar and other references were considered for inclusion. Established systematic reviews were consulted to ascertain related keywords and synonyms, which were subsequently incorporated into the following search queries: "resistance training" OR "resistance exercise" OR "strength training" OR "strength exercise" OR "weight training" OR "weight lifting" AND "appetite" OR "hunger" OR "food intake" OR "food consumption" OR "energy intake" OR "intake energy" OR "Calorie intake" OR "intake calorie" AND "obesity" OR "overweight" OR "fat" OR "obese" OR "unhealthy weight" OR "high BMI." These terms were employed to investigate the impact of resistance training on appetite regulation and energy intake among individuals classified as obese or overweight. The search was confined to papers published between January 1, 1980, and August 23, 2022.

2.2 Eligibility Criteria

2.2.1. Inclusion Criteria

i. The participants in the study must have had a history of being overweight or obese.

ii. The intervention should involve a minimum of 10 participants.
iii. The independent variable consisted of resistance training, delineated by varying intensity levels categorized as high, medium, low, or other.
iv. The article incorporates experimental research, including randomized controlled trials (RCTs), comparison trials, and single-group trials, owing to the robust empirical evidence.
v. The intervention duration should be a minimum of four weeks, as participants engaged in resistance training for less than 28 days did not demonstrate neuromuscular adaptation. Consequently, the outcomes may not significantly influence the relevant physiological indices of the body (Smith et al., 2019).
vi. Evaluate the effects of resistance training on energy intake and appetite regulation in obese or overweight individuals, with a focus on categorizing at least one of the outcomes.
vii. Scholarly papers with standardized peer review published in full-text format within academic journals.

2.2.2. Exclusion Criteria

i. Participants must be free from any underlying medical conditions and should not be undergoing any pharmacological treatment.
ii. Participants should not have engaged in structured exercise training or adhered to a specific diet within the preceding three months.
iii. The intervention should not impose constraints on energy intake or mandate the consumption of supplements.
iv. Resistance training should not be incorporated as a component of the regimen in the resistance training group. For instance, studies featuring a single intervention group involving both resistance and aerobic training simultaneously would be excluded.
v. The reporting and control of the resistance training intervention are inadequately documented.

2.3 Study Selection

Search results, comprising pertinent papers, were imported into Mendeley reference software to remove duplicates. Two independent reviewers conducted initial screening by assessing titles and abstracts, eliminating irrelevant or unmatched publications. The second screening involved a thorough examination of the full texts of potential articles based on predetermined inclusion and exclusion criteria. In cases of disagreement, a third reviewer facilitated consensus. Among 38 full-text articles assessed, eight met the inclusion criteria and were incorporated into the review.

2.4 Data Extraction and Quality Assessment

Upon completion of the data search, pertinent details were extracted from relevant articles in the subsequent format: (1) Author, title, publication year; (2) sample size; (3) participant demographics (including gender, age, weight); (4) research design; (5) intervention characteristics (comprising intensity, frequency, and duration); (6) measurement approach; and (7) research findings.
One author systematically transcribed the data into the standardized form, and a second author verified the accuracy of the data. Subsequently, the Physiotherapy Evidence Database (PEDro) scale was employed to appraise the comprehensive quality of the retained eight records (Bales et al., 2012; Fatouros et al., 2005; Guelfi et al., 2013; Halliday et al., 2017; Kim & Kim, 2020; Lau et al., 2010; Onambélé-Pearson, Breen, & Stewart, 2010; Shaw, Shaw, & Brown, 2010). Two independent reviewers conducted the majority of the processes, with a third reviewer resolving differences. The PEDro scale (www.pedro.org.au), known for excellent validity and reliability, assessed the experimental methodology quality in constructing the systematic review (Maher et al., 2003). Each manuscript underwent evaluation according to 11 criteria related to the scientific rigor of the methodology, with criteria 2–11 being assigned a score of 0 or 1 point. However, the overall score did not supersede the eligibility conditions, as it was deemed indicative of external validity. Consequently, articles were assigned a score ranging from 0 to 10 based on the number of criteria fulfilled by the study methodology (10 indicating excellent internal validity and 0 denoting poor internal validity).

3. Results

The search yielded 132 results, with 35 duplicate articles manually removed. Subsequent filtering through title and abstract examination led to the exclusion of 59 papers for various reasons: lack of relevance to the subject (n = 42), categorized as a review or book (n = 4), absence of full text (n = 6), and the intervention featuring energy intake restrictions or regular additional supply (n = 7). Full-text reviews of the remaining 38 potentially relevant papers resulted in the exclusion of 30 additional papers for reasons including subjects not being overweight or obese, insufficient sample size (n = 8), subjects being patients (n = 8), subjects undergoing diet or not previously sedentary (n = 3), absence of single resistance training (n = 5), lack of intervention (n = 3), and no examination of energy intake or perceived appetite (n = 3). Ultimately, eight full-text articles were selected for inclusion in this review.

3.1 Study Quality Assessment

Table 1 presents an evaluation of the study quality using the PEDro criteria. The data indicates that the included papers demonstrated an average standard, with none satisfying all the PEDro quality criteria. All studies detailed their eligibility criteria, baseline group comparability, intergroup comparisons, point measures, and variability. Notably, there were no indications of allocation concealment, subject blinding, therapist blinding, assessor blinding, or intention-to-treat analyses across the studies. However, six studies disclosed the use of random assignment (Bales et al., 2012; Fatouros et al., 2005; Halliday et al., 2017; Kim & Kim, 2020; Onambélé-Pearson et al., 2010; Shaw et al., 2010), and three studies reported follow-up assessments (Fatouros et al., 2005; Guelfi et al., 2013; Lau et al., 2010). Blinding of subjects, therapists, and assessors was challenging due to the nature of exercise training interventions in the included studies. However, addressing these limitations in future research could enhance overall research quality. The eight articles evaluated in this study received scores of 4 or 5 on the PEDro scale, indicating good quality and satisfactory publications. No studies were excluded based on their PEDro scale scores, and the inter-rater reliability was excellent (94.1%).

Table 1

Summary of Methodological Quality Assessment Scores

Reference	Eligibility criteria	Randomisation	Concealment of allocation	Group similar in baseline	Blind participants	Blind therapists	Blind assessors	Follow-ups	Intention for treating analysis	Group comparisons	Point measures and variability	Final PEDro value
Onambélé-Pearson et al. (2010)	1	1	0	1	0	0	0	0	0	1	1	4
Guelfi et al. (2013)	1	0	0	1	0	0	0	1	0	1	1	4
Halliday et al. (2017)	1	1	0	1	0	0	0	0	0	1	1	4
Fatouros et al. (2005)	1	1	0	1	0	0	0	1	0	1	1	5
Lau et al. (2010)	1	0	0	1	0	0	0	1	0	1	1	4
Bales et al. (2012)	1	1	0	1	0	0	0	0	0	1	1	4
Shaw et al. (2010)	1	1	0	1	0	0	0	0	0	1	1	4
Kim and Kim (2020)	1	1	0	1	0	0	0	0	0	1	1	4

3.2 Participant Characteristics

The studies selected for this review comprised a total of 432 participants distributed across 19 study groups, as outlined in Table 2. The average number of participants in each group was 23, with the experimental group having a minimum of 12 study participants (Fatouros et al., 2005; Onambélé-Pearson et al., 2010). The experimental group with the largest sample size consisted of 65 participants (Halliday et al., 2017). All studies provided information on the gender, age, and weight of the participants. Four articles included either both genders or exclusively male participants (Bales et al., 2012; Fatouros et al., 2005; Guelfi et al., 2013; Halliday et al., 2017; Kim & Kim, 2020; Lau et al., 2010; Onambélé-Pearson et al., 2010; Shaw et al., 2010). Meanwhile, two articles specifically involved elderly participants (Onambélé-Pearson et al., 2010), and four articles recruited middle-aged adults for their study (Guelfi et al., 2013; Halliday et al., 2017; Kim & Kim, 2020; Shaw et al., 2010). One article included both ordinary adults and the elderly (Bales et al., 2012), while only one article focused on teenagers (Lau et al., 2010). Six articles considered overweight and obese individuals (Bales et al., 2012; Fatouros et al., 2005; Guelfi et al., 2013; Halliday et al., 2017; Lau et al., 2010; Onambélé-Pearson et al., 2010), and two studies each were relevant to single overweight or obese populations (Kim & Kim, 2020; Shaw et al., 2010).

Table 2

Study Characteristics

Study	Sample				Intervention			Outcome		
	Sample Size	Age (Year)	Gender	Weight	Study Design	RT Intensity	Session Duration, Length, and Frequency of Intervention	Energy Intake	Perceive Appetite	Appetite-Related Physiological Index
Onambélé-Pearson et al. (2010)	30	LI 76 ± 3, HI 69 ± 6	M + F	Overweight or obese BMI = 28.79 ± 4.14 (LI), 26.37 ± 3.84 (HI)	NON-RCT Comparative trials, Two RT	LI 40%, HI, 80% 1RM	1 hour/day, thrice weekly for 12 weeks	N/A	N/A	**Glucose** in LI → (−2.3±4.9%); in HI ↑ (16.1 ± 4.1%). **Insulin** in LI →, (3±7.5%); in HI → (6±6.6%). **NPY** in LI ↓ (-13.7%); in HI ↓ (-27.3%).
Guelfi et al. (2013)	33	49 ± 7	M	Overweight or obese BMI = 30.8 ± 4.2	RCT, one RT, one AT and one CG	HI 75% - 85% 1RM	40 – 60 mins 1 day, 3 times a week for 12 weeks.	N/A	**Perceived hunger** → (28.9%) **Perceived fullness** → (30.3%) By VAS	**Ghrelin** →(0%). **PP** →(-42.9%). **Leptin**↓ (-14.3%). **PYY** →(0%). **Glucose** →(1.7%). **Insulin** →(0%).
Halliday et al. (2017)	129	59.5 ± 5.5,	M + F	Overweight or obese BMI = 32.9 ± 3.8 (25 – 39.9)	NON-RCT Comparative trials, two RT	Same, but no mentioned intensity	35 – 45 mins/ day, twice a week for 15 months	**Total kilocalories** in 3 months → (-3.3%); in 6 months ↓ (-4.2%); in 9 months → (-3.7%). A 3-day, 24-hour food record	N/A	N/A
Fatouros et al. (2005)	50	CG 69.8 ± 5.1, LI 71.1 ± 3.6, MI 69.7 ± 3.8, HI 70.8 ± 2.8, 65 - 78	M	Overweight or obese BMI= 28.7 – 30.2	RCT three RT and one CG	LI 45 - 50%, MI 60 - 65%, HI 80 - 85% 1RM	60 mins/day, thrice weekly for six months	N/A	N/A	**Leptin**in LI ↓ (-3.3%); in MI ↓ (-2.2%); in HI ↓ (-19.6%); HI << in LI or MI. **adiponectin**in LI → (13.8%), in MI ↑ (21.7%); in HI → (61.4%, P=0.06). **Glucose** in LI ↓ (-2.8%); in MI ↓ (-4.2%), in HI ↓ (-6.5%) among groups = **HOMA-IR**in LI ↓ (-3.0%); in MI ↓ (-5.0%); in HI ↓ (-25.4%); HI << LI or MI
Lau et al. (2010)	18	12.45 ± 1.77	M + F	Overweight or obese BMI = 30.5 ± 4.9	NON-RCT, single-group trial	HI 70% - 85% 1RM	1 hour/day, thrice weekly for six weeks	N/A	N/A	**Leptin**→(-12.9%, P=0.09). **Glucose** ↑ (4.3%). **Insulin** →(-8.2%).

Bales et al. (2012)	117	49.0, 18 - 70	M + F	Overweight or obese BMI =30.3 (27.9 – 33.0)	NON-RCT, comparative trials, one RT, one AT and one AT/RT	No mentioned intensity	Thrice weekly for nine months	**Total kilocalories** → (-9.0%, p=0.073) By 3-day, 24- hour food record; **Total kilocalories** → (-4.0%) By Food frequency questionnaires (FFQ)	N/A	N/A
Shaw et al. (2010)	28	28.58	M	Obese Body fat percentage = 26.83 ± 1.52	RCT, one RT and one CG	No mentioned intensity	Thrice weekly for eight weeks	**Total kilocalories** → (-16.6%) By 3-day, 24- hour food record	N/A	N/A
Kim and Kim (2020)	27	RT 51.79 ± 8.22 AT 50.15 ± 5.84 30 – 64	M	Overweight BMI = 27.39 ± 1.87	NON-RCT, comparative trials, one RT and one AT	LI 50% 1RM	90 mins/day, thrice weekly for 12 weeks	**Total kilocalories** → (-2.7%) By 3-day, 24- hour food record	N/A	**Glucose** →(1.1%). **HOMA-IR** → (-3.7%).

RT, resistance training; AT, aerobic training; CG, control group; M, male; F, female; BMI, body mass index; RCT, Randomized Controlled Trial; NON-RCT, non-randomized controlled trial; 1RM, one-repetition maximum; LI, low intensity resistance training; MI, moderate intensity resistance training; HI, high intensity resistance training; VAS, visual analogue scales; ↑ indicates significant increase; ↓ indicates significant decrease; → indicates no significant difference;≫ indicates significantly higher than others;<< indicates significantly lower than others; and N/A indicates not available.

3.3 Interventions Characteristics

The intervention characteristics of the eight included studies were documented across the following dimensions:

i. Intervention Duration: Three interventions were conducted within a 12-week cycle (Guelfi et al., 2013; Kim & Kim, 2020; Onambélé-Pearson et al., 2010). Individual articles reported intervention periods of 15 months, nine months, six months, nine weeks, and eight weeks (Bales et al., 2012; Fatouros et al., 2005; Halliday et al., 2017; Lau et al., 2010; Shaw et al., 2010).

ii. Workout Duration: Six studies specified the duration for each workout (Fatouros et al., 2005; Guelfi et al., 2013; Halliday et al., 2017; Kim & Kim, 2020; Lau et al., 2010; Onambélé-Pearson et al., 2010), with three workouts lasting 60 minutes (Fatouros et al., 2005; Lau et al., 2010; Onambélé-Pearson et al., 2010). The workout durations ranged from 40–60 minutes, 35–45 minutes, and 90 minutes, with one study having an unspecified duration (Halliday et al., 2017; Kim & Kim, 2020; Onambélé-Pearson et al., 2010).

iii. Training Frequency: All eight studies reported training frequency, with seven having a frequency of three times per week (Bales et al., 2012; Fatouros et al., 2005; Guelfi et al., 2013; Kim & Kim, 2020; Lau et al., 2010; Onambélé-Pearson et al., 2010; Shaw et al., 2010). One study conducted training twice weekly (Halliday et al., 2017).

iv. Study Design: Three articles employed formal Randomized Controlled Trials (RCT) (Fatouros et al., 2005; Guelfi et al., 2013; Shaw et al., 2010), and four articles used comparative trials without a control group (Halliday et al., 2017; Kim & Kim, 2020; Onambélé-Pearson et al., 2010). Only one research study had an experimental group with a single-group trial (Lau et al., 2010).

v. Resistance Training Intensity: Among the eight articles, five detailed the intensity of resistance training (Fatouros et al., 2005; Guelfi et al., 2013; Kim & Kim, 2020; Lau et al., 2010; Onambélé-Pearson et al., 2010). Two articles exclusively included a high-intensity group (Lau et al., 2010; Onambélé-Pearson et al., 2010), one article featured only a low-intensity (50%) group (Kim & Kim, 2020), and one article had two groups with different intensities (40%, 80%) (Onambélé-Pearson et al., 2010). Another article included all three intensity groups (low: 45–50%, moderate: 60–65%, and high: 80–85%) (Fatouros et al., 2005), while one article featured two similar groups without reporting the intensity (Halliday et al., 2017). Two articles had a single group without a specified intensity (Bales et al., 2012; Shaw et al., 2010).

3.4. Measurements

3.4.1. Energy Intake and Appetite Measurement

Four studies documented energy intake through a combination of 3-day food records and 24-hour diet recall interviews (Bales et al., 2012; Hameed et al., 2017; Kim & Kim, 2020; Shaw et al., 2010). In contrast, one study utilized the Block 1998 revision of health habits and a Food Frequency Questionnaire (FFQ) (Bales et al., 2012). Notably, only one study focused on subjective appetite sensations, assessed using visual analogue scales (VAS), among overweight and obese individuals (Guelfi et al., 2013).

3.4.2. Endocrine Measurement

Certain studies evaluated endocrine factors linked to appetite, encompassing measurements of glucose (Fatouros et al., 2005; Guelfi et al., 2013; Kim & Kim, 2020; Lau et al., 2010; Onambélé-Pearson et al., 2010), total ghrelin (Guelfi et al., 2013), Neuropeptide Y (NPY) (Onambélé-Pearson et al., 2010), insulin (Guelfi et al., 2013; Lau et al., 2010; Onambélé-Pearson et al., 2010), leptin (Fatouros et al., 2005; Guelfi et al., 2013; Lau et al., 2010), pancreatic polypeptide (PP) (Guelfi et al., 2013), peptide tyrosine tyrosine (PYY) (Guelfi et al., 2013), adiponectin (Fatouros et al., 2005), and Homeostatic Model Assessment of Insulin Resistance (HOMA-IR) (Fatouros et al., 2005; Kim & Kim, 2020). All blood samples were collected using vacutainers.

3.5 Outcomes

3.5.1 Impact of Resistance Training on Perceived Appetite and Energy Intake for Obese or Overweight individuals

With the exception of four studies, all measured at least one parameter related to energy intake (Table 2), and one article employed two methods for energy intake measurement (Bales et al., 2012). Among the five outcomes associated with energy intake, a statistically significant improvement was observed in one intervention (-4.2%, $p = 0.015$) (Halliday et al., 2017). One study showed non-significant differences, but with a substantial effect size change at $p < 0.10$ (-9%, $p = 0.073$) (Bales et al., 2012). The remaining three outcomes were significant at $p > 0.1$ (Bales et al., 2012; Kim & Kim, 2020; Shaw et al., 2010). Only one article addressed subjective appetite sensations, specifically perceived hunger 120 minutes after a meal and fullness indices before a meal, without reporting statistical changes or significant differences between pre- and post-tests.

3.5.2 Impact of Resistance Training on Appetite Related Physiological Index for Obese or Overweight Individuals

All studies, excluding three (Fatouros et al., 2005; Guelfi et al., 2013; Kim & Kim, 2020; Lau et al., 2010; Onambélé-Pearson et al., 2010), assessed at least one appetite-related physiological parameter influenced by resistance training (Table 2).

Significantly Different Physiological Indexes:

3.5.2.1 Glucose

In five articles, glucose alterations were reported across eight groups, with significant differences observed in five groups (16.1%—−6.5%, $p < 0.05$) (Fatouros et al., 2005; Lau et al., 2010; Onambélé-Pearson et al., 2010). The post-test data of the remaining three groups in the three articles did not show significant differences compared to the pre-test results (Guelfi et al., 2013; Kim & Kim, 2020; Onambélé-Pearson et al., 2010). Among the four groups subjected to high-intensity resistance training (with the same intensity), statistically significant differences were identified in the glucose index of three groups before and after the training (Fatouros et al., 2005; Lau et al., 2010; Onambélé-Pearson et al., 2010).

Three articles documented significant changes in opposing directions (increase or decrease) for three groups subjected to high-intensity training: 16.1% (Onambélé-Pearson et al., 2010), 4.3% (Lau et al., 2010), and −6.5% (Halliday et al., 2017). In contrast, only one group participating in moderate-intensity resistance training reported significant changes (−4.2%, $p < 0.05$) (Fatouros et al., 2005). Among the three groups subjected to low-intensity resistance training (Fatouros et al., 2005; Kim & Kim, 2020; Onambélé-Pearson et al., 2010), only one group demonstrated a statistically significant difference (−2.8%, $p < 0.05$) (Fatouros et al., 2005), while the remaining groups did not exhibit significant outcomes (Kim & Kim, 2020; Onambélé-Pearson et al., 2010). In the same article, the analysis of different intensity groups indicated a statistically significant difference in the high-intensity group (16.1%, $p = 0.001$), while there was no statistical difference in the low-intensity group (Onambélé-Pearson et al., 2010). Conversely, one article revealed no significant differences between high, moderate, and low-intensity groups (Fatouros et al., 2005).

3.5.2.2 Leptin

Leptin levels were assessed in three studies, encompassing a total of five groups (Fatouros et al., 2005; Guelfi et al., 2013; Lau et al., 2010). One study demonstrated a statistically significant difference (−14.3%, $p = 0.028$) in the leptin index following resistance training (Guelfi et al., 2013). In another study, although there was no significant difference before and after resistance training, the p-value remained below 0.1 (−12.9%, $p = 0.09$) (Lau et al., 2010). Furthermore, significant differences in leptin levels were observed in all low, medium, and high-intensity groups in a separate study (−3.3%, −2.2%, and −19.6%, respectively, all $p < 0.01$), with the leptin of the high-intensity group being significantly lower than that of the other groups ($p < 0.001$) (Fatouros et al., 2005).

3.5.2.3 HOMA-IR

Two articles presented the HOMA-IR index findings in four groups among the five hormone-related articles (Fatouros et al., 2005; Kim & Kim, 2020). In one article, a significant difference was reported across low, moderate, and high-intensity groups (−25.4%, −5%, and −3%, $p < 0.05$), with the high-intensity group exhibiting a lower index compared to the other groups ($p < 0.05$) (Fatouros et al., 2005). Conversely, the other article indicated no significant difference in HOMA-IR for the low-intensity group (Kim & Kim, 2020).

3.5.2.4 NPY

Out of the five articles focusing on appetite hormones, only one addressed Neuropeptide Y (NPY) (Onambélé-Pearson et al., 2010). The resistance training interventions, both of low and high intensity, detailed in this article exhibited significant differences in NPY levels before and after the experiment (low intensity: −13.7%, $p = 0.026$; high intensity: −27.3%, $p = 0.044$). However, the article did not provide details on whether significant differences existed between the two intensity groups.

3.5.2.5 Adiponectin

Among the five articles focusing on appetite hormones, only one provided adiponectin results for three distinct intensity levels of resistance training (Fatouros et al., 2005). The adiponectin index of the medium-intensity group exhibited a significant difference before and after the intervention (21.7%, $p = 0.03$). Both the high and low-intensity groups did not show significant differences, although the effect size for high intensity was notably large at $p < 0.1$ (61.4%, $p = 0.06$).

Non-Significantly Different Physiological Index:

3.5.2.6 Insulin

Insulin evaluation was incorporated in all studies, except for two, within the five related articles (Guelfi et al., 2013; Lau et al., 2010; Onambélé-Pearson et al., 2010). Furthermore, findings from three articles encompassing four groups indicated no significant differences in pre and post-test insulin levels for both the high-intensity and low-intensity groups.

3.5.2.7 Ghrelin, PP, and PYY

Among the five articles focusing on appetite hormones, only one addressed active Ghrelin, PP, & PYY (Guelfi et al., 2013). The outcomes revealed no significant difference in active Ghrelin, PP, and PYY levels among obese or overweight individuals before and after high-intensity resistance training (75%–85%).

4. Discussion

4.1 Impact of Resistance Training on Energy Intake for Obese or Overweight Individuals

One of the four energy intake articles demonstrated a significant difference before and after resistance training, while another article showed a relatively significant difference. Thus, the actual relationship between resistance training and appetite cannot be determined conclusively. Additionally, one article recorded significantly different results after nine months of resistance training, while another group with the same duration had a relatively significant outcome. Two articles, with resistance training durations of eight and 12 weeks, did not report any significant findings. Consequently, resistance training may impact appetite after at least nine months.

The article exhibiting a significant and relatively significant difference included both genders, while the two articles without a significant difference comprised only male participants, suggesting a potentially more pronounced effect of resistance training on female appetite. The article reporting significantly different findings had a training frequency of twice a week, whereas the one with a relatively significant difference and the two without significant differences involved thrice-weekly training sessions. Hence, the higher frequency of resistance training may contribute to the lack of significant findings. Furthermore, articles with significant results implemented a training period of 35–45 minutes per session, whereas a study conducting 90-minute resistance training sessions reported no significant findings. Therefore, the extended training sessions may have contributed to the absence of positive results.

Two studies yielding either significant or relatively significant results involved both obese and overweight individuals. Conversely, two articles exclusively examining obese or overweight individuals did not present any significant findings. Consequently, the impact of resistance training on energy intake for the combined weight population may be more substantial than studies solely focusing on obese or overweight individuals. Moreover, articles demonstrating significant or relatively significant differences did not specify the training intensity, while those reporting no significant findings involved low-intensity resistance training. Therefore, future research is suggested to explore moderate or high-intensity training lasting at least nine months, twice a week with 35–45 minutes per session, and to discern the differential impacts on various genders (males and females) and sample populations (obese or overweight individuals).

4.2 Impact of Resistance Training on Perceived Appetite of Overweight Individuals

One article examined subjective appetite changes following a 12-week high-intensity resistance training program. Perceived appetite, encompassing perceived hunger and fullness, did not exhibit significant differences. However, the actual indices of perceived hunger and fullness displayed substantial changes, with effect sizes of 28.9% and 30.3%, respectively. Therefore, resistance training could significantly impact the perceived hunger and fullness of obese and overweight individuals under specific conditions. The study analysis suggests that the lack of significant differences may be attributed to the relatively short experimental period (12 weeks compared to 9 months of energy intake) or insufficient single training duration (40 minutes compared to 45 minutes of energy intake).

This article exclusively examines high-intensity resistance training at 75%–85%, without comparing with low and medium-intensity resistance training. Additionally, the study sample comprises only males within the adult age range, excluding the elderly and teenagers. Consequently, the findings can only establish a relationship between resistance training and subjective appetite under these specific conditions. Overall, the limited number of studies in this domain precludes a comprehensive understanding of the relationship between resistance training and perceived appetite due to insufficient literature. Nevertheless, future research on subjective hunger and satiety is recommended, considering the significant influence of resistance training on energy intake.

4.3 Impact of Resistance Training on Appetite Related Physiological Index for Obese or Overweight Individuals

4.3.1 Glucose

Multiple articles featured experimental groups with varying intensities, totalling eight groups across five articles. Significant differences were observed in three out of the five articles, with five out of the eight groups exhibiting significantly different outcomes. This suggests a strong correlation between resistance training and glucose, necessitating further research for validation. Among the five articles, two studies included elderly participants, and one involved adolescent. Three of these studies reported significantly different findings, while the two studies involving adults did not yield significant results. Consequently, glucose levels in the younger and older populations may be more influenced by resistance training. Among the three articles with significant findings, two incorporated both males and females in the sample population, while the two articles without significant differences exclusively included males. Consequently, resistance training may exert a more pronounced effect on female glucose levels compared to males. Additionally, only one of the four groups engaging in high-intensity resistance training reported no significant findings for intensity resistance training. This strongly suggests that high-intensity resistance training likely has a significant impact on glucose levels. However, there were inconsistencies in glucose levels among the three high-intensity resistance training groups with significant findings, as some reported an increase while others observed a decrease. Therefore, further research is recommended to explore the impact of training intensity on glucose levels.

In studies on the elderly, high-intensity resistance training had a more favorable impact on glucose levels among females (effect size 16.1%) compared to males (effect size −6.5%). For the elderly, high-intensity resistance training showed a significant effect (effect size 16.1%), while for teenagers, the effect size was 4.3%, indicating a more substantial impact among the elderly than teenagers. Medium-intensity resistance training in one study reported a significant decrease in glucose levels, but further research is needed to validate this finding due to limited literature support. Low-intensity resistance training did not show significant differences in glucose levels in three studies, suggesting it may not strongly affect glucose levels. One study reported significant differences between low and high-intensity groups, while others did not observe significant changes across different intensity levels. Therefore, further exploration is essential to understand the impact of resistance training on glucose levels. In summary, resistance training significantly reduces energy intake and affects glucose levels. Hence, the glucostatic theory (Krishnan et al., 2019) was substantiated in this review, demonstrating a positive correlation between glucose levels and energy intake.

4.3.2 Leptin

Two of the three articles demonstrated a significant effect of resistance training on leptin in four groups, while the third did not observe any significant difference. The age range of the four study groups with significant differences included adults and the elderly, whereas the group with no significant difference involved teenagers. Therefore, the relatively low impact of resistance training on leptin in teenagers warrants further investigation. Additionally, the four groups with significant differences in leptin levels consisted solely of males, and the only article with no significant difference included both males and females. This suggests that the absence of a significant finding may be attributed to the potentially unfavourable influence of resistance training on leptin in females. Furthermore, the intervention period for the two articles with significant outcomes was 12 weeks and six months, while the study lasting six weeks did not yield significant results. Hence, an intervention period of less than 12 weeks may not significantly impact leptin levels.

In the context of overweight or obese individuals, the influence of resistance training on leptin appears to be modulated by factors such as age, gender, and the duration of intervention. Notably, resistance exercise was associated with reduced leptin levels and a concurrent decrease in the energy intake of obese and overweight individuals, establishing a correlation between human leptin concentration and appetite. Contrary to the expected elevation of leptin levels with decreased energy intake, as suggested by its role as an anorectic hormone (Ranđelović & Jevtović-Stoimenov, 2021), the literature demonstrates otherwise. This discrepancy is attributed to the phenomenon of leptin resistance observed in individuals with a high BMI (Izquierdo et al., 2019).

4.3.3 HOMA-IR

Differences were noted in HOMA-IR outcomes between two studies. One study, focusing on older adults, showed a significant impact, whereas a study involving adult men found no significant changes. This suggests that resistance training may have a greater sensitivity to HOMA-IR in older adults compared to adult men. Additionally, the absence of an obese population in one study group might explain the lack of significant findings, indicating that resistance training effects on the overweight population may be less pronounced than in obese individuals. Furthermore, a six-month intervention period yielded significant outcomes in three intensity groups, while a 12-week intervention showed no significant effects. This suggests that a shorter intervention period may not influence HOMA-IR, but further research is required to confirm this hypothesis. Notably, a study with 60 minutes per session reported significant findings, contrasting with the non-significant results in the group with 90 minutes per session, indicating that an extended training duration may result in an insignificant impact on HOMA-IR.

In general, the literature indicates that resistance training has a significant effect on reducing the energy intake of overweight and obese individuals. While the insulin mechanism posits that insulin, concentration decreases with increased energy intake (Schneider et al., 2021), empirical evidence suggests that resistance training does not significantly influence insulin levels. This lack of significant impact on insulin levels may be attributed to insulin resistance. Moreover, the calculations based on the HOMA suggest that resistance training significantly mitigates insulin resistance in three groups.

4.3.4 Others

One study investigated the effect of resistance training on NPY, revealing significant differences before and after both high-intensity and low-intensity resistance training. This suggests a potential correlation between 12-week high or low-intensity resistance training and NPY in overweight or obese elderly individuals. Overall, resistance exercise demonstrates the ability to significantly reduce NPY concentration and may potentially decrease the energy intake of overweight and obese individuals under specific conditions.

Adiponectin was studied in one article, revealing significant differences in the moderate-intensity resistance training group after six months. This suggests a positive correlation between adiponectin and moderate-intensity resistance training in overweight or obese older adults. The substantial effect size in the high-intensity group underscores its potential impact. In summary, resistance training has the potential to enhance the adiponectin index, reflecting its effectiveness in reducing energy intake among overweight or obese individuals.

No significant differences were observed in insulin levels among four groups in three studies that implemented low and high-intensity resistance training thrice weekly. Additionally, one study investigating the effects of resistance training on Ghrelin, PP, and PYY found no significant findings. Hence, further research is imperative to clarify the influence of resistance training on these specified factors.

5. Limitations

This review presents a comprehensive examination of the influence of resistance training on appetite regulation and energy intake in individuals classified as obese or overweight. However, certain limitations have been acknowledged within this paper.

i. The chosen studies exclusively featured male participants or both genders, lacking exclusive exploration of the female population. The training parameters applied to males or both genders may not be directly transferable to overweight or obese females, as gender-related differences exist in evaluating certain appetite indices.

Previous research has indicated that females exhibit heightened sensitivity to overfeeding and macronutrient alterations, resulting in more pronounced changes in appetite sensation ratings and subsequent energy intake compared to males (Bédard et al., 2015). Moreover, studies with significant findings predominantly focused on overweight or obese adults or elderly individuals, with only one article addressing teenagers. The training characteristics and frequency applicable to adults or the elderly may not be directly relevant to overweight or obese teenagers due to age-related variations in energy intake, potentially impacting research outcomes (Okubo et al., 2006).

ii. The chosen studies did not provide information on sample size calculations. Determining the sample size is influenced by various factors, encompassing the study's overarching objectives, sample risk considerations, and permissible sampling error. Inappropriately small or large sample sizes can have implications for the overall quality of the study. Notably, an inaccurate approach to sample size computation has the potential to introduce bias into the study results.

iii. Solely one study conducted a comparison among low, moderate, and high-intensity resistance training. The majority of studies reported on only one or two intensities or did not explicitly specify the training intensity. Previous research has indicated that distinct intensities can impact glucose, leptin, adiponectin, and HOMA-IR. However, the comprehensive assessment of diverse energy intakes, perceived appetite, and other crucial physiological indices across different training intensity groups was absent, resulting in a lack of completeness in the findings.

iv. Most articles only reported on one of the three variables: energy intake, perceived appetite, and appetite-related physiological index. Few studies investigated two of the three variables, and none explored all three factors. Without simultaneous consideration of all three variables, accurate examination of their relationship is not feasible. Additionally, appetite changes are intricate and linked to various physiological indices. The review's eight articles omitted crucial appetite-related physiological indices like Ghrelin, CCK, orexin or hypocretin, and obestatin. Without the inclusion of all essential physiological indices, a correct analysis of the reasons behind changes in energy intake and perceived appetite is not possible. Furthermore, the effect of subjective appetite does not consistently align with the effect on energy intake, necessitating further research.

v. The available research has highlighted several factors influencing human energy intake or appetite, grounded in diverse theories such as the Glucostatic Theory (blood glucose concentration), Lipostatic Theory (fat metabolism), Aminostatic Theory (protein intake), thermostatic theory (ambient temperature), Hepatostatic Theory (liver metabolism), and Ischymetric Theory (metabolic rate). Numerous studies have shown that various forms of exercise can significantly impact energy intake and appetite regulation both in the short and long term (Beer et al., 2020; Shakiba et al., 2019). However, no existing theory provides a comprehensive explanation for the specific relationship between a particular form of exercise, including resistance training, and long-term appetite regulation. Consequently, individuals may encounter challenges in utilizing exercise for appetite control and weight loss.

6. Conclusion and Implications

According to current literature, resistance training can impact the energy intake of overweight or obese individuals when performed for 35–45 minutes, twice a week, over a nine-month period with medium or high intensity, specifically for obese or overweight women. The intervention influences glucose, Leptin, HOMA-IR, NPY, and adiponectin but does not affect perceived appetite, Ghrelin, PP, and PYY. Further research is needed, particularly including females and teenagers, employing appropriate sample size strategies, comparing three intensities, and analysing comprehensive variables. Studies should strive to establish an overarching relationship between resistance training and energy intake or appetite, leading to the development of more practical theories for exercise and diet interpretation in the future. Incorrect exercise choices by individuals with high BMI may otherwise lead to increased appetite and weight gain.

Acknowledgments

The authors sincerely thank the Department of Sport Studies, Faculty of Educational Studies, Universiti Putra Malaysia (UPM), and searching strategy assistance from the librarians at UPM.

Funding

This study was supported by the Educational Reform Project Fund of the Jiangxi Provincial Department of Education, China (grant number JXJG-18-48-4).

Conflicts of Interest

The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

SohKim Geok conceived the presented idea. Qiang Wang and Wan Ying Gan developed the protocol. All authors carried out writing, editing, and preparation of the manuscript. All authors approved the final version of the manuscript and agreed with the authors' presentation order.

Data Availability Statement

The dataset and codes used in the current study are available from the corresponding author upon reasonable request.

References

Avila, J. J., Gutierres, J. A., Sheehy, M. E., Lofgren, I. E., & Delmonico, M. J. (2010). Effect of moderate intensity resistance training during weight loss on body composition and physical performance in overweight older adults. *European Journal of Applied Physiology, 109*, 517-525. https://doi.org/10.1007/s00421-010-1387-9

Bales, C. W., Hawk, V. H., Granville, E. O., Rose, S. B., Shields, T., Bateman, L., Willis, L., Piner, L., Slentz, C. A., & Houmard, J. A. (2012). Aerobic and Resistance Training Effects on Energy Intake: The Strride AT/RT Study: Exercise Training Effects on Energy Intake. *Medicine and Science in Sports and Exercise, 44*(10), 2033-2039. https://doi.org/10.1249/mss.0b013e318259479a

Bédard, A., Hudon, A.-M., Drapeau, V., Corneau, L., Dodin, S., & Lemieux, S. (2015). Gender Differences in the Appetite Response to a Satiating Diet. *Journal of Obesity, 2015*, 140139. https://doi.org/10.1155/2015/140139

Beer, N. J., Dimmock, J. A., Jackson, B., & Guelfi, K. J. (2020). Exercise-related factors that influence post-exercise energy intake: A psychological perspective. *Journal of Science and Medicine in Sport, 23*(11), 1068-1073. https://doi.org/10.1016/j.jsams.2020.05.017

Benite-Ribeiro, S. A., Putt, D. A., & Santos, J. M. (2016). The effect of physical exercise on orexigenic and anorexigenic peptides and its role on long-term feeding control. *Medical Hypotheses, 93*, 30-33. https://doi.org/10.1016/j.mehy.2016.05.005

Cândido, A. P. C., Geloneze, B., Calixto, A., Vasques, A. C. J., Freitas, R. N. d., Freitas, S. N. d., & Machado-Coelho, G. (2021). Adiponectin, HOMA-adiponectin, HOMA-IR in children and adolescents: Ouro Preto study. *Indian Journal of Pediatrics, 88*, 336-344. https://doi.org/10.1007/s12098-020-03444-3

Carnier, J., de Mello, M. T., Ackel-D́Elia, C., Corgosinho, F. C., da Silveira Campos, R. M., de Lima Sanches, P., Masquio, D. C. L., Júnior, C. R. B., de Piano Ganen, A., & Martins, A. C. (2013). Aerobic training (AT) is more effective than aerobic plus resistance training (AT+ RT) to improve anorexigenic/orexigenic factors in obese adolescents. *Appetite, 69*, 168-173. https://doi.org/10.1016/j.appet.2013.05.018

Cawthorn, W. P., Scheller, E. L., Learman, B. S., Parlee, S. D., Simon, B. R., Mori, H., Ning, X., Bree, A. J., Schell, B., & Broome, D. T. (2014). Bone marrow adipose tissue is an endocrine organ that contributes to increased circulating adiponectin during caloric restriction. *Cell Metabolism, 20*(2), 368-375. http://dx.doi.org/10.1016/j.cmet.2014.06.003

Chambers, L. (2016). Food texture and the satiety cascade. *Nutrition Bulletin, 41*(3), 277-282. https://doi.org/10.1111/nbu.12221

Cook, C. M., & Schoeller, D. A. (2011). Physical activity and weight control: conflicting findings. *Current Opinion in Clinical Nutrition & Metabolic Care, 14*(5), 419-424. https://doi.org/10.1097/mco.0b013e328349b9ff

Fatouros, I. G., Tournis, S., Leontsini, D., Jamurtas, A. Z., Sxina, M., Thomakos, P., Manousaki, M., Douroudos, I., Taxildaris, K., & Mitrakou, A. (2005). Leptin and adiponectin responses in overweight inactive elderly following resistance training and detraining are intensity related. *The Journal of Clinical Endocrinology & Metabolism, 90*(11), 5970-5977. https://doi.org/10.1210/jc.2005-0261

Guelfi, K. J., Donges, C. E., & Duffield, R. (2013). Beneficial effects of 12 weeks of aerobic compared with resistance exercise training on perceived appetite in previously sedentary overweight and obese men. *Metabolism, 62*(2), 235-243. https://doi.org/10.1016/j.metabol.2012.08.002

Halliday, T. M., Davy, B. M., Clark, A. G., Baugh, M. E., Hedrick, V. E., Marinik, E. L., Flack, K. D., Savla, J., Winett, S., & Winett, R. A. (2014). Dietary intake modification in response to a participation in a resistance training program for sedentary older adults with prediabetes: Findings from the Resist Diabetes study. *Eating Behaviors, 15*(3), 379-382. https://doi.org/10.1016/j.eatbeh.2014.04.004

Halliday, T. M., Savla, J., Marinik, E. L., Hedrick, V. E., Winett, R. A., & Davy, B. M. (2017). Resistance training is associated with spontaneous changes in aerobic physical activity but not overall diet quality in adults with prediabetes. *Physiology & Behavior, 177*, 49-56. https://doi.org/10.1016/j.physbeh.2017.04.013

Hameed, S., Patterson, M., Dhillo, W. S., Rahman, S. A., Ma, Y., Holton, C., Gogakos, A., Yeo, G. S., Lam, B. Y., & Polex-Wolf, J. (2017). Thyroid hormone receptor beta in the ventromedial hypothalamus is essential for the physiological regulation of food intake and body weight. *Cell Reports, 19*(11), 2202-2209. http://dx.doi.org/10.1016/j.celrep.2017.05.066

Hetherington, M. M., Cunningham, K., Dye, L., Gibson, E. L., Gregersen, N. T., Halford, J. C. G., Lawton, C. L., Lluch, A., Mela, D. J., & Van Trijp, H. C. M. (2013). Potential benefits of satiety to the consumer: scientific considerations. *Nutrition Research Reviews, 26*(1), 22-38. https://doi.org/10.1017/S0954422413000012

Hill, J. O. (2006). Understanding and addressing the epidemic of obesity: an energy balance perspective. *Endocrine Reviews, 27*(7), 750-761. https://doi.org/10.1210/er.2006-0032

Hopkins, M., King, N. A., & Blundell, J. E. (2010). Acute and long-term effects of exercise on appetite control: is there any benefit for weight control? *Current Opinion in Clinical Nutrition & Metabolic Care, 13*(6), 635-640. https://doi.org/10.1097/mco.0b013e32833e343b

Hubner, S., Boron, J. B., & Koehler, K. (2021). The effects of exercise on appetite in older adults: a systematic review and meta-analysis. *Frontiers in Nutrition, 8*, 734267. https://doi.org/10.3389/fnut.2021.734267

Hunter, G. R., Fisher, G., Neumeier, W. H., Carter, S. J., & Plaisance, E. P. (2015). Exercise training and energy expenditure following weight loss. *Medicine and Science in Sports and Exercise, 47*(9), 1950-1957. https://doi.org/10.1249/mss.0000000000000622

Izquierdo, A. G., Crujeiras, A. B., Casanueva, F. F., & Carreira, M. C. (2019). Leptin, obesity, and leptin resistance: where are we 25 years later? *Nutrients, 11*(11), 2704. https://doi.org/10.3390/nu11112704

Jéquier, E. (2002). Pathways to obesity. *International Journal of Obesity, 26*(2), S12-S17. https://doi.org/10.1038/sj.ijo.0802123

Joseph, R. J., Alonso-Alonso, M., Bond, D. S., Pascual-Leone, A., & Blackburn, G. L. (2011). The neurocognitive connection between physical activity and eating behaviour. *Obesity Reviews, 12*(10), 800-812. https://doi.org/10.1111/j.1467-789X.2011.00893.x

Kim, B., & Kim, S. (2020). Influences of resistance versus aerobic exercise on physiological and physical fitness changes in previously inactive men with obesity: A prospective, single-blinded randomized controlled trial. *Diabetes, Metabolic Syndrome and Obesity, 13*, 267-276. https://doi.org/10.2147/dmso.s231981

Krishnan, S., Witbracht, M., Thomas, A., Adams, S., Van Loan, M., Horn, W., Laugero, K., & Keim, N. (2019). Evaluating the Glucostatic Theory of Appetite Using an Acute Buffet Meal Challenge (P08-008-19). *Current Developments in Nutrition, 3*, 3131098. https://doi.org/10.1093/cdn/nzz044.P08-008-19

Lau, P. W. C., Kong, Z., Choi, C.-r., Clare, C. W., Chan, D. F. Y., Sung, R. Y. T., & Leung, B. W. C. (2010). Effects of short-term resistance training on serum leptin levels in obese adolescents. *Journal of Exercise Science & Fitness, 8*(1), 54-60. https://doi.org/10.1016/S1728-869X(10)60008-1

Maher, C. G., Sherrington, C., Herbert, R. D., Moseley, A. M., & Elkins, M. (2003). Reliability of the PEDro scale for rating quality of randomized controlled trials. *Physical Therapy, 83*(8), 713-721. https://doi.org/10.1093/ptj/83.8.713

Malina, R. M. (2006). Weight training in youth-growth, maturation, and safety: an evidence-based review. *Clinical Journal of Sport Medicine, 16*(6), 478-487. https://doi.org/10.1097/01.jsm.0000248843.31874.be

Marinik, E. L., Kelleher, S., Savla, J., Winett, R. A., & Davy, B. M. (2014). The Resist Diabetes trial: rationale, design, and methods of a hybrid efficacy/effectiveness intervention trial for resistance training maintenance to improve glucose homeostasis in older prediabetic adults. *Contemporary Clinical Trials, 37*(1), 19-32. https://doi.org/10.1016/j.cct.2013.11.006

Martins, C., Morgan, L., & Truby, H. (2008). A review of the effects of exercise on appetite regulation: an obesity perspective. *International Journal of Obesity, 32*(9), 1337-1347. https://doi.org/10.1038/ijo.2008.98

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Group*, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Annals of Internal Medicine, 151*(4), 264-269. https://doi.org/10.7326/0003-4819-151-4-200908180-00135

Murphy, K. G., & Bloom, S. R. (2006). Gut hormones and the regulation of energy homeostasis. *Nature, 444*(7121), 854-859. https://doi.org/10.1038/nature05484

Okubo, H., Sasaki, S., Hirota, N., Notsu, A., Todoriki, H., Miura, A., Fukui, M., & Date, C. (2006). The influence of age and body mass index on relative accuracy of energy intake among Japanese adults. *Public Health Nutrition, 9*(5), 651-657. https://doi.org/10.1079/PHN2005894

Onambélé-Pearson, G. L., Breen, L., & Stewart, C. E. (2010). Influence of exercise intensity in older persons with unchanged habitual nutritional intake: skeletal muscle and endocrine adaptations. *Age, 32*, 139-153. https://doi.org/10.1007/s11357-010-9141-0

Ranđelović, M., & Jevtović-Stoimenov, T. M. (2021). Leptin: From Appetite Suppression to Autoimmunity. *Facta Universitatis, Series: Medicine and Biology, 22*(2), 34-38. https://doi.org/10.22190/FUMB191004017R

Schneider, E., Martin, E., Thomas, J. M., Hallschmid, M., Lee, M., Rotshtein, P., Dourish, C. T., Higgs, S., & Spetter, M. (2021). Intranasal insulin decreases palatable food intake, increases satiety and enhances positive mood in women with obesity. *Appetite, 157*, 104891. http://dx.doi.org/10.1016/j.appet.2020.104891

Shaibi, G. Q., Cruz, M. L., Ball, G. D., Weigensberg, M. J., Salem, G. J., Crespo, N. C., & Goran, M. I. (2006). Effects of resistance training on insulin sensitivity in overweight Latino adolescent males. *Medicine and Science in Sports and Exercise, 38*(7), 1208-1215. https://doi.org/10.1249/01.mss.000227304.88406.0f

Shakiba, E., Sheikholeslami-Vatani, D., Rostamzadeh, N., & Karim, H. (2019). The type of training program affects appetite-regulating hormones and body weight in overweight sedentary men. *Applied Physiology, Nutrition, and Metabolism, 44*(3), 282-287. https://doi.org/10.1139/apnm-2018-0197

Shaw, B. S., Shaw, I., & Brown, G. A. (2010). Relationship between resistance training and self-reported habitual macronutrient and energy intake. *South African Journal for Research in Sport, Physical Education and Recreation, 32*(2), 109-116. https://hdl.handle.net/10520/EJC108925

Smith, C. M., Housh, T. J., Hill, E. C., Keller, J. L., Anders, J. P. V., Johnson, G. O., & Schmidt, R. J. (2019). Variable resistance training versus traditional weight training on the reflex pathway following four weeks of leg press training. *Somatosensory & Motor Research, 36*(3), 223-229. https://doi.org/10.1080/08990220.2019.1659238

Sobrino Crespo, C., Perianes Cachero, A., Puebla Jimenez, L., Barrios, V., & Arilla Ferreiro, E. (2014). Peptides and Food Intake. *Frontiers in Endocrinology, 5*, 58. https://doi.org/10.3389/fendo.2014.00058

Suzuki, K., Jayasena, C. N., & Bloom, S. R. (2012). Obesity and appetite control. *Journal of Diabetes Research, 2012*, 824305. https://doi.org/10.1155/2012/824305

Thedinga, H. K., Zehl, R., & Thiel, A. (2021). Weight stigma experiences and self-exclusion from sport and exercise settings among people with obesity. *BMC Public Health, 21*, 565. https://doi.org/10.1186/s12889-021-10565-7

Tulloch, H., Sweet, S. N., Fortier, M., Capstick, G., Kenny, G. P., & Sigal, R. J. (2013). Exercise facilitators and barriers from adoption to maintenance in the diabetes aerobic and resistance exercise trial. *Canadian Journal of Diabetes, 37*(6), 367-374. https://doi.org/10.1016/j.jcjd.2013.09.002

Yu, C. C. W., Sung, R. Y. T., So, R. C. H., Lui, K.-C., Lau, W., Lam, P. K. W., & Lau, E. M. C. (2005). Effects of strength training on body composition and bone mineral content in children who are obese. *The Journal of Strength & Conditioning Research, 19*(3), 667-672. https://doi.org/10.1519/14994.1

Zhang, G., Hasek, L. Y., Lee, B.-H., & Hamaker, B. R. (2015). Gut feedback mechanisms and food intake: a physiological approach to slow carbohydrate bioavailability. *Food & Function, 6*(4), 1072-1089. https://doi.org/10.1039/C4FO00803K