Acute exercise and subsequent energy intake: a meta-analysis

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Highlights

- A meta-analysis of energy intake responses to acute exercise was performed
- Absolute energy intake is unchanged after exercise, suggesting minimal compensation
- Relative energy intake indicates an exercise-induced energy deficit
- Aerobic exercise may be best for inducing energy deficits with minimal compensation

Abstract

The precise magnitude of the effect of acute exercise on subsequent energy intake is not well understood. Identifying how large a deficit exercise can produce in energy intake and whether this is compensated for, is important in design of long-term exercise programs for weight loss and weight maintenance. Thus, this paper sought to review and perform a meta-analysis on data from the existing literature. Twenty-nine studies, consisting of 51 trials, were identified for inclusion. Exercise duration ranged from 30 – 120 min at intensities of 36 – 81% VO_2max, with trials ranging from 2 – 14 hr, and *ad libitum* test meals offered 0 – 2 hr post-exercise. The outcome variables included absolute energy intake and relative energy intake. A random effects model was employed for analysis due to expected heterogeneity. Results indicated that exercise has a trivial effect on absolute energy intake (n = 51; ES = 0.14, 95% CI: -0.005 to 0.29) and a large effect on relative energy intake (creating an energy deficit, n = 45; ES = - 1.25, 95% CI: -1.50 to -1.00). Despite variability among studies, results suggest that exercise is effective for producing a short-term energy deficit and that individuals tend not to compensate for the energy expended during exercise in the immediate hours after exercise by altering food intake.

Keywords: exercise; appetite; energy intake; exercise-induced anorexia; meta-analysis; systematic review

Abbreviations: EI = energy intake; REI = relative energy intake; EE = exercise energy expenditure; AG = acylated (active) ghrelin; PA = physical activity; RT = resistance training; ES = effect size; AUC = area-under-the-time-curve; BMI = body mass index

1. Introduction

Regular physical activity (PA) is an important component of overall health. PA is well known to improve cardiorespiratory fitness, blood pressure, and body composition, which are all negatively correlated with the risks of chronic disease (King et al. 2009b). PA also plays a role in body weight regulation through its effects on energy expenditure and energy intake, providing a potential disruption to the energy balance equation (Martins, Morgan, & Truby 2008). Despite this, the topic of how exercise precisely impacts energy intake and appetite regulation is quite controversial (Bilski et al. 2009) and constantly evolving. Because exercise creates an energy deficit that may perturb homeostasis and hormone levels, the effects of exercise on energy intake are of interest.

It is known that the weight loss responses to exercise interventions are mixed. Some individuals show a marked weight loss and reduction in energy intake during an exercise intervention while others have been shown to lose less weight because of an increase in subjective feelings of hunger and, consequently, energy intake (King et al. 2008). It has been proposed that the mechanisms of exercise-induced weight loss may be related to changes in perceptions of hunger and satiety in response to an exercise bout, and that these changes may be caused by exercise-induced fluctuations of hormones related to energy balance and appetite regulation (Martins, Truby, & Morgan 2007; Martins, Morgan, & Truby 2008; Bilski et al. 2009; King et al. 2009a). Acute exercise bouts tend to suppress of acylated ghrelin levels, a hormone that stimulates energy intake, while increasing levels of some satiety hormones such as peptide YY (PYY) and glucagon-like peptide 1 (GLP-1) (Ueda 2009a & 2009b; King et al. 2010a; King et al. 2011a; Larson-Meyer et al. 2012).

The term “exercise-induced anorexia” was introduced to describe the reduction of perceived hunger that may be observed for a period of time after intense exercise (Blundell et al. 2003). Numerous studies, utilising intense exercise, have shown transient decreases in hunger after exercise (Pomerleau et al. 2004; Broom et al. 2007, 2009). However, it has been reported that changes in hunger do not always correlate with decreased food intake after exercise. Some authors have reported increased (Pomerleau et al. 2004; Martin et al. 2007; Shorten et al. 2009), no difference (King et al. 2010b; Balaguera-Cortes et al. 2011), or decreased (Ueda et al. 2009a; Ueda et al. 2009b) energy intake at test meals offered 30 or more minutes post-exercise. Interestingly, data from acute exercise studies tends to report a much greater suppression of hunger, energy intake, and acylated ghrelin than data from long-term (chronic exercise interventions > 8 weeks) studies (Martins, Morgan, & Truby 2008; Hopkins, King, & Blundell 2010). This disassociation between acute and chronic exercise responses is likely due to compensation, whereby an increase in energy intake in response to exercise training or a decrease in spontaneous non-exercise physical activity occurs.

Given the somewhat mixed findings, it is important to systematically determine how acute bouts of exercise impact subsequent energy intake. Hence, the purpose of this study was to perform a meta-analysis to determine the efficacy of acute exercise for reducing energy intake. Understanding the influence of exercise mode, duration, and intensity will help to clarify the role of exercise in the manipulation of body composition via changes in post-exercise energy intake. Additionally, the results may help to inform future long-term weight management trials by describing those characteristics of acute exercise tasks that result in the greatest energy deficits.

2. Methods

2.1 Study selection and inclusion criteria

Major research databases (PubMed, Scopus, EBSCOHost, Google Scholar, Academic Search Premier, ScienceDirect, & SpringerLink) were searched up through July 2012. Keyword searches were performed for “exercise”, “physical activity”, “energy expenditure”, "energy intake", "appetite", "hunger", and "food intake". Potential studies were identified by examining the abstracts and full-text copies were obtained if they met the initial criteria of evaluating energy intake in response to an acute exercise bout. Guidelines from the recent PRIMSA Statement were followed in preparation of this paper, including a checklist for reporting systematic reviews and meta-analyses (Liberati et al. 2009).

Participants were required to be healthy, non-smoking individuals (lean and/or obese), without a history of chronic disease and lacking contraindications to exercise. Selection criteria were not limited by study duration or time between end-exercise and a test meal; however, studies were excluded if the monitoring of energy intake continued for more than 24 hours post-exercise. Study selection was also not limited by a set intensity or duration of the exercise bout, nor was inclusion constrained by exercise modality. All studies were required to have a control condition for inclusion and were required to employ trial randomisation. The control condition was required to be the same as the exercise condition with regards to protocol, minus the exercise bout. Studies needed a standardised measure of energy intake, such as an *ad libitum* test meal (either a homogenous meal or a buffet-style meal). In this situation, food was presented in controlled conditions, under observation, and participants were instructed to eat until they were full; hence removing errors associated with self-reported energy intake (Jeacocke & Burke 2010). Some studies reported blinding participants to the true purpose of the study (i.e. measuring energy intake), but since the interventions were exercise bouts, investigators were not blinded. Studies were included if published in peer-reviewed journals, or were available as conference proceedings, theses, and dissertations. These were all considered for inclusion to minimise the risk of publication bias, which can occur if only published studies are included, since studies with larger effect sizes are more likely to be published in the peer-reviewed literature (Liberati et al. 2009).

2.2 Exclusion criteria

Studies were excluded from further analysis if they did not measure or report absolute and/or relative energy intake. In the event that a study reported energy intake data in graphical form and/or did not report a standard deviation, the corresponding author was contacted to request the raw data for synthesis. Studies were excluded if the author(s) could not be contacted for exact values (n = 1). Studies that examined environmental factors had their data extracted for control and normal/neutral exercise conditions only (Shorten et al. 2009; Wasse et al. 2012; Kelly et al. 2012).

2.3 Data synthesis

Once studies were obtained, they were assessed for quality by two authors using established criteria (Physiotherapy Evidence Database-PEDro, http://www.pedro.org.au/english/downloads/pedro-scale/), and the following data were extracted: absolute energy intake (in kcals or kJ), gross exercise energy expenditure (ExEE), relative energy intake [(Exercise REI = absolute EI – gross ExEE; Control REI = absolute EI – gross EE at rest (where reported)], sample size, subject characteristics, and exercise intervention information. All studies were generally of high quality.

In studies that reported energy intake/expenditure values in kilocalories, data were converted to kilojoules (1 kcal = 4.1868 kJ). Standard error of the measurement (SEM) was converted to standard deviation (SD). All descriptive data are reported as ranges with median values.

2.4 Meta-analysis procedures

Upon data extraction, all data were entered into software designed specifically for meta-analyses (Comprehensive Meta Analysis, version 2; Biostat, Englewood, NJ). The data inputted included the sample sizes, absolute energy intakes for the control and exercise conditions with their respective SDs, relative energy intakes with their respective SDs, and mean differences between control and exercise trials. The software calculated the standardised difference in means to determine Cohen's *d* for each study; additionally, Hedge's *g* was used to account for potential bias due to the small sample sizes in the reviewed studies. Overall effect sizes (ES) were calculated using a random-effects model that accounts for true variation in effects occurring from study to study, as well as random error within a single study. The random effects model was chosen over a fixed-effect model because experimental factors such as exercise energy expenditure and assessment of energy intake had wide variation, and a random-effects model better accounts for these variations during analysis (Conger et al. 2011). In accordance with Cohen (1992), we interpreted effect sizes of < 0.2 as trivial, 0.2 – 0.3 as small, 0.5 as moderate, and > 0.8 as large (Cohen 1992). A negative effect size value indicates that exercise *decreased* energy intake while a positive effect size indicates that exercise *increased* energy intake.

Heterogeneity was calculated as Cochrane's Q and the I^2 index by the software. Values of 25%, 50%, and 75% were used for the I^2 analysis of heterogeneity, and correspond to low, moderate, and high heterogeneity, respectively (Higgins et al. 2003). For Cochrane's Q, significant heterogeneity is known to exist when the Q value exceeds the degrees of freedom (d_f) of the estimate (Huedo-Medina et al. 2006). Sensitivity analyses were conducted by excluding one study at a time to examine if results were driven by any one study.

To assess whether differences in experimental design could explain the variation in ES between the studies, we performed sub-group meta-analyses and/or meta-regressions (method-of-moments model), as has been performed previously (Warren et al. 2010; Conger et al. 2011). This analysis included meta-regressions of continuous data, such as energy expenditure of exercise, exercise duration, exercise intensity, body mass index, and number of meals post-exercise. Sub-group meta-analyses were conducted for categorical data, such as exercise mode, fed state, (men, women, or both), and fitness level. Because not all studies reported VO_2max values of participants, studies were searched for descriptive information. Fitness levels were defined as follows: low (sedentary or < 1 hr/wk of moderate exercise), moderate (1 – 3 hr/wk), and high (> 3 hr/wk).

Publication bias was assessed utilising funnel plots, as previously described (Supplementary Figures 1 & 2; Warren et al. 2010; Conger et al. 2011). If there is no publication bias, studies should be distributed evenly around the mean ES because of random sampling error. The trim-and-fill correction described by Duval and Tweedie was used to assess bias (Duval & Tweedie 2000). This technique allows for the computation and inclusion of potentially missing studies to create symmetry about the overall mean ES.

Statistical significance was set at $p < 0.05$ in a Z-test analysis. The Z-tests were utilised to examine if ES were significantly different from zero.

3. Results

3.1 Overview

Figure 1 presents the decision tree of study selection. In total, 29 studies were included in the meta-analysis. All studies, except one dissertation, were published in peer-reviewed, scientific journals. In summary, the experimental trials within the studies were conducted over the course of several hours, and generally began with either a standardised breakfast meal (providing either an absolute amount of energy or a set relative amount of CHO, set as $g \bullet kg^{-1}$ body mass) or a bout of exercise. After the exercise bout, participants were given access to *ad libitum* buffet meals one or more times, depending on the length of the trial.

[Insert Figure 1 here]

Studies on acute exercise and energy intake are summarised in Table 1. Multiple studies utilised more than one category of participants: normal vs. overweight, lean vs. obese, active vs. inactive, and runners vs. walkers (George & Morganstein 2003; Ueda et al. 2009a; Jokisch, Coletta, & Raynor 2011; Larson-Meyer et al. 2012); different exercise intensities (King et al.1994; Imbeault et al. 1997; Erdmann et al. 2007; Ueda et al. 2009b); fed-state/supplement use (Hubert, King, & Blundell 1998; Deighton et al. 2012; Melby et al. 2002; Ballard et al. 2009); or different types of exercise (Laan et al. 2010; Balaguera-Cortes et al. 2011). Therefore, these studies were reported as two trials. When accounting for differences, this raised the total number of trials to 51, each with an exercise and control condition. In summary, all studies (n = 29; 51 trials) reported absolute energy intake and 26 (45 trials) reported relative energy intake (or REI was able to be calculated from data presented). Twenty-three of the 51 trials utilised cycling as the mode of exercise, 13 utilised running, 9 utilised walking, 5 utilised resistance training, and 1 utilised swimming. Twenty-eight of 51 trials were conducted 1 – 3.5 hr post-prandially (median = 1.75 hr), while the remaining 23 trials were conducted after an 8 – 10 hr fast. Approximately half of the trials reported the energy value of the pre-exercise meal (n = 15), which ranged from 880 – 2400 kJ (median = 2000 kJ).

3.2 Subject demographics and exercise intervention characteristics

The majority of participants (n = 584) were men (n = 359; 61.5 %), with BMI and VO_2max values between 19.8 – 37.2 kg•m^{-2} (median = 22.85 kg•m^{-2}) and 34 – 63 mL•kg^{-1}•min^{-1} (median = 49.7 mL•kg^{-1}•min^{-1}), respectively. Aerobic exercise interventions ranged from 30 – 120 min at an intensity between 35 – 81% VO_2max (medians = 60 min and 70% VO_2max). Resistance exercise interventions were between 35 – 90 min at intensities of 10 – 12 repetition maximum (protocols summarised in Table 1). Gross energy expended during the exercise bouts ranged from 335 – 6500 kJ (median = 1890 kJ). There was a median of 11 participants per study (range = 7 – 21).

3.3 Changes in energy intake

Change in absolute energy intake was trivial (an increase of 201 kJ with the exercise compared to the control trial), with 28 trials showing a change in EI of ± 400 kJ, 17 showing an increase of more than 400 kJ, and 6 showing a decrease of more than 400 kJ. A large decrease in relative energy intake after exercise (1640 kJ) was observed, with 41 studies showing a fall of more than 500 kJ and 4 showing a minimal change (± 300 kJ). The length of the trials was between 2 – 14 hours (median = 3.25 hr). Test meals were offered 0 – 2 hr post-exercise; if subsequent meals were presented, they were 4 – 5 hr apart. The number of meals offered ranged from 1 – 4.

[Insert Table 1 here]

3.4 Meta-analysis

3.4.1 Effect size and moderator variables for the absolute EI analysis

Effect size for absolute energy intake, as calculated from *ad libitum* test meals following an acute bout of exercise, ranged from -2.38 to 2.40 (n = 51). Results of the meta-analysis indicated a trivial mean effect of exercise on absolute energy intake favouring control (ES = 0.14, 95% CI = -0.005 to 0.29; Figure 2). However, this was not statistically different from zero (p = 0.059). Heterogeneity among these studies was low (I^2 = 37.2 %; Q

= 79.64, $d_f = 50$, $p = 0.005$). Sensitivity analysis showed minor shifts only, and these shifts did not impact overall significance of the mean effect.

Data from the analyses of moderator variables are presented in Table 2. The only moderator to impact variation in effect sizes was participant fitness levels. The analysis indicated that studies with participants of moderate and low fitness had negative effect sizes, i.e. exercise suppressed energy intake. For individuals of high fitness, the opposite trend was observed. Effect sizes of studies with individuals of moderate ($p = 0.028$) and high ($p < 0.001$) fitness levels were significantly different from zero, while those with participants of low fitness were not ($p = 0.199$).

Inspection of the funnel plot (Supplementary Figure 1) of standard error by the ES showed a symmetrical distribution, suggesting minimal publication bias. This suggests that the results of the model are valid, and that additional data would not significantly alter the result.

[Insert Figure 2 here]

3.4.2 Effect size and moderator variables for the relative EI analysis

Effect sizes for relative energy intake, calculated as previously described, ranged between -5.63 to -0.034 (n = 45). The meta-analysis revealed a large mean effect favouring exercise (ES = -1.23, 95% CI = -1.47 to -0.98; Figure 3), and this was significantly different from zero ($p < 0.001$). Heterogeneity among these studies was moderate ($I^2 = 68.1\%$; $Q = 137.95$, $d_f = 44$, $p < 0.0001$). Sensitivity analysis showed minor shifts only, and these shifts did not impact overall significance of the mean effect.

Data from the analyses of moderator variables are presented in Table 2. Exercise mode significantly impacted the variation of the studies, with a significant difference between groups ($p = 0.001$). The effect sizes for cycling, running, and walking were all significantly different from zero ($p < 0.002$); however, swimming ($p = 0.213$) and resistance training ($p = 0.201$) were not. Furthermore, as with absolute energy intake, differences in fitness levels significantly influenced the variation of the effect sizes. The effect sizes of studies with individuals of low ($p = 0.014$) and moderate ($p < 0.001$) fitness were significantly different from zero, and these effect sizes were larger than the effect sizes for studies with participants of high fitness ($p < 0.001$). Finally, the number of meals offered post-exercise also influenced the variation of the effect size results – as the number of meals offered increased, the effect size moved towards positive values.

Inspection of the funnel plot (Supplementary Figure 2) of standard error by the ES showed a disproportion of studies to the left of the mean, favouring exercise. If symmetry was to be brought about the mean using the trim and fill correction (Duval & Tweedie 2000), approximately 10 studies would need to be found with positive effect sizes. These studies would moderate the ES slightly to -0.95 (95% CI = -1.21 to -0.69), which is still significantly different from zero ($p < 0.001$). This suggests that even if the studies favouring control were found, the results of the model are still valid.

[Insert Figure 3 here]

[Insert Table 2 here]

4. Discussion

The impact of acute exercise on energy intake has been examined by many studies in the literature, but data are relatively equivocal and have not been previously collated. The purpose of this study was to perform a meta-analysis to determine the efficacy of acute exercise for reducing energy intake. Despite considerable variability in protocol and analytical methods between the studies, there was no meaningful change in absolute energy intake in response to an acute bout of exercise (~200 kJ). By examining relative energy intake, the energy expended during the exercise bout can be accounted for, and this allows the calculation of a prospective energy deficit and the magnitude to which individuals may compensate for exercise energy expenditure through a change in energy intake. For the 45 studies in this meta-analysis that reported relative energy intake, participants compensated for the energy expended during exercise by ~14 %. Net energy consumed in response to exercise was only 260 kJ. This suggests that the energy loss created by exercise is only being partially compensated for by a change in energy intake; such a deficit may have significant implications for weight management if it continues to occur over long periods of time.

An effect of exercise intensity on variation among the studies was not observed in the present meta-analysis. This is likely because most studies were relatively homogenous in their intensity. While the range was wide (35-80% VO_2max), 26 of the 51 trials were at intensities between 70-80% VO_2max. Thus, this may have prevented study intensities from significantly predicting variability in the effect sizes. It is known that exercise at intensities above 70% VO_2max appears to produce transient (~1-2 hr) reduction in perceived hunger (King et al. 1994). However, this is not always associated with a reduced energy intake. For example, studies from the laboratory of Stensel (King et al. 2010a, 2011a; Deighton et al. 2012; Wasse et al. 2012) all show an acute suppression of hunger after high-intensity (> 70% VO_2max) exercise, but with minor or no changes in absolute energy intake.

Another variable that could have impacted the variation of studies is the energy expenditure from exercise. A large range of ExEE values were observed in the reviewed studies, with the highest bout being approximately 20 times greater than the lowest bout. Interestingly, there was no significant impact of this wide variance in ExEE on the variation of the studies. Despite this, if the missing 10 studies needed to ensure symmetry for REI were found and imputed, this may change the predictive value of ExEE as a moderator variable – that is, ExEE may become a stronger predictor of the heterogeneity among the studies, as would be expected from simply examining the range of data. Furthermore, not all studies measured ExEE via indirect calorimetry. Thus, the studies that estimated ExEE may have over- or underestimated the energy expended during exercise, which might explain ExEE's non-significant impact on heterogeneity.

The timing of energy intake must also be carefully considered when examining the changes in energy intake post-exercise. In approximately half the studies, participants exercised following a prolonged fasted state, whereby they arrived after an overnight fast (8 – 12 hr). Additionally, because the energy content of the pre-exercise meals varied considerably in the remaining studies, it is difficult to precisely determine whether impacts on energy intake are due to a satiety effect resulting from a pre-exercise meal or exercise itself, although Deighton et al. (2012) observed significant decreases in energy intake after exercise in a fed state compared to a fed control trial. Additionally, the studies examining relative energy intake were found to be influenced by the number of meals offered post-exercise. The meta-regression indicated that as more meals were offered, the energy deficit caused by exercise decreased. This notion supports the data suggesting that exercise has a transient effect on appetite suppression, i.e. "exercise-induced anorexia" (King et al. 1994, 1996).

Exercise mode was found to significantly influence relative energy intake. For example, most studies involving exercises requiring greater metabolic and mechanical demands (potentially causing muscle damage and greater muscle loading, i.e. running) tend to show a more potent transient suppression of hunger levels as opposed to methods like cycling (Broom et al. 2007; King et al. 2010a). The running studies had the highest energy expenditure (~3230 kJ) and longest duration during exercise (60 min). However, despite large energy expenditures, absolute EI was only slightly higher in the meal(s) following exercise (CON: 7535 kJ v. EX: 7909 kJ). Consequently, relative EI was substantially lower (CON: 7323 kJ v. EX: 4669 kJ). This may be caused by an inhibition of some hormones which are secreted by the gut (such as ghrelin) as well as altered gastric motility due to altered splanchnic blood flow (Broom et al. 2007). Nevertheless, the data from the running studies suggest that individuals do not substantially compensate in response to acute running. Future research will need to address energy intake responses to lower intensities in less trained individuals.

Studies utilising cycling as an exercise modality were of shorter duration (cycling ~50 min v. ~60 min running), and had half the energy expenditure of the running studies (~1700 kJ). There were minimal differences in absolute energy intake for the cycling studies (CON: 4105 kJ v. EX: 3869 kJ); thus, a substantial deficit in relative energy intake was incurred (CON: 4271 kJ v. EX: 2575 kJ). Energy intake responses to more intense and intermittent cycling bouts, such as high-intensity interval training, still need to be addressed. There is a relative dearth of variety within the cycling studies, so much still needs to be determined regarding variations of intensity, rest intervals, and duration. This is particularly true since HIT programs are gaining acceptance as alternatives to continuous, moderate intensity exercise in clinical populations (Astorino & Schubert 2012).

Data from the walking studies report small or no differences in absolute energy intake (CON: 5201 kJ v. EX: 5454 kJ) and either no changes in relative intake or a significant decrease (CON: 6430 kJ v. EX: 5490 kJ) after ~56 minutes of walking incurring a median EE of ~1400 kJ (Imbeault et al. 1997; George & Morganstein 2003; Tsofliou et al. 2003; Pomerleau et al. 2004; King et al. 2010a; Unick et al. 2010; Larson-Meyer 2012b). These data indicate that moderate intensity walking exercise has the potential for producing negative energy balances over time. Further research is needed to examine how food intake would respond to multiple shorter walks compared to one extended walking bout, since this is more likely to reflect daily physical activity patterns (Donnelly et al. 2009). This is an important area for future research because it is known individuals do not need to accrue all their exercise at one time to achieve significant health benefits (i.e. walking a dog twice a day for 30 minutes) (Jakicic & Otto 2006; Jakicic & Davis 2011).

Resistance exercise also showed similar patterns to the other exercise modes, although deficits in relative EI were attenuated. Because the assumptions of indirect calorimetry are violated during resistance exercise, the energy expenditure of RT is difficult to precisely quantify (Ballard et al. 2009; King 2010). The average estimated EE for the RT studies was ~1400 kJ, with the trials lasting ~65 minutes (Ballard et al. 2009; King 2010; Laan et al. 2010; Balaguera-Cortes et al. 2011). Absolute energy intake showed a larger difference than other modes of exercise (CON: 6292 kJ v. EX: 6802 kJ). Relative energy intake showed a smaller deficit compared to running and cycling, but was similar to walking (CON: 6743 kJ v. EX: 5758 kJ). While resistance training is important for many aspects of health, it does not appear to be as effective at inducing an acute energy deficit when compared to running and cycling. However, it is possible that the influences and benefits of resistance training on body composition may not be detectable over an acute period of time.

Clear differences in appetite and energy intake are evident between men and women (Hagobian et al. 2009; Hagobian & Braun 2010). However, the meta-regression in the present study showed no impact of sex on the variation of the results for absolute energy intake. For studies that included both men and women (Erdmann et al. 2007; Martin et al. 2007; Laan et al. 2010), the effect size was large and was nearly significantly different from zero (ES = 0.64; $p = 0.054$). Why this was observed when there was no effect of sex alone is not clear at this time, but is likely due to differences in methods. The studies of Erdmann et al. and Laan et al. utilised comparatively low energy expenditure bouts (350 – 1500 kJ), and the test meal was administered 15 – 30 mins post-EX, which may have been too short for any latent exercise-induced hunger suppression to occur. For example, King et al. (1996) reported a significant delay (5 min) in female participants after exercise compared to control when requesting an *ad libitum* meal. Furthermore, King (2010b) found that male participants requested an *ad libitum* meal ~80 min post-exercise; this was ~35 min longer than the time at which food was requested in the control condition.

With regards to differences among individuals, both analyses indicated that individuals of lower fitness (moderate & low) were more responsive to the anorexic effects of exercise. This is not surprising, as it has been argued for over 40 years that individuals who are more physically active more accurately regulate their energy expenditure (Mayer & Thomas 1967; Jokisch, Coletta, & Raynor 2011). This is supported by the recent results of Jokisch and colleagues, who compared active and inactive college-aged males matched for age and body composition. These authors found that in response to an acute bout of exercise, active individuals compensated for about 23% of the energy expended while the inactive individuals actually had a negative compensation of -35.5% (Jokisch, Coletta, & Raynor 2011). This negative compensation suggests that the anorexic effects of exercise were more potent in these inactive individuals. These data are supported by longer-term studies reporting improvements in energy regulation in previously sedentary individuals after regular exercise (Martins, Truby, & Morgan 2007).

Despite the evidence presented in this paper, it is reasonably well known that weight loss during longer-term exercise interventions is less than would be expected (Hall et al. 2012). It has been estimated that complete compensation for large daily perturbations in energy balance (~5000 kJ) would take between 2-4 weeks (Stubbs et al. 2004). As discussed, some individuals change their dietary intake in response to exercise, which could impact upon energy balance (Hall et al. 2012); furthermore, evidence has shown that exercise without concomitant energy restriction is not very effective for weight loss, particularly in women (Jakicic & Otto 2006). Several theories exist regarding why individuals do not lose as much weight during the course of an exercise program, and these include dietary compensation for exercise-induced energy expenditure (King et al. 2008) and a potential change in macronutrient preferences immediately post-exercise in some participants for sweet, high-fat foods (Finlayson et al. 2012), and these behavioural changes in eating patterns could abolish the energy deficit incurred during exercise. It has also been suggested that in response to an exercise-based intervention, energy intake may not increase *per se*, but rather a compensation in physical activity levels occurs – that is, PA levels outside of the exercise program decrease (Hall et al. 2012). It is also unknown if genetics or some other cause leads some individuals to adapt to continuous exercise-induced energy deficits (losing weight) while others compensate (gaining or maintaining weight). Further research is needed to provide definitive conclusions on other forms of exercise, such water-based modes of exercise, individual differences, and hormonal markers related to energy balance and appetite, such as acylated ghrelin and PYY. The best methods to identify and combat compensation in long-term studies also need to be addressed. A final limitation of the present study is the acute nature of the cited literature. Acute studies can provide excellent mechanistic data and can accurately account for how changes in hormonal status, substrate turnover, and cognitive function impact energy intake post-exercise, but this monitoring period generally does not extend beyond 12-14 hr. Furthermore, this model does not factor in body composition changes, since changes in body composition would take weeks or longer to be noticeable. Hence, little is known about effects of exercise on energy intake from 24 hrs to a few weeks. Studies addressing at-risk populations, utilising more modest intensities, are also needed to determine if the overall effects documented in the present meta-analysis also exist in those individuals.

5. Conclusions

The present meta-analysis demonstrates that exercise does not increase or decrease the absolute energy intake following an exercise task. Consequently, exercise is likely to cause acute reductions in energy balance because energy intake during subsequent meals is not increased to match the energy expended during exercise. The energy expended during an exercise bout is likely the main determinant of this deficit; thus aerobic exercise bouts, which require greater metabolic demands, appear to be more effective than resistance training in the short-term. Results of the present meta-analysis also indicate that individuals of lesser fitness are more likely to experience an anorexic effect of exercise, at least in the initial hours following an exercise bout.

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Study	Participants	Intervention	Meal(s)	Energy Intake (kJ)	
				Absolute EI	Relative EI
King et al. 1994a	12 men BMI = 24.2 kg/m^2 (SD NR)	60 min cycle @ ~30% VO_2max	Ad lib meal available from 15 min post-EX; participants permitted to start when hungry	CON: 6448 ± 1306 EX: 6904 ± 1405	CON: 6217 ± 1305 EX: 5401 ± 1440
King et al. 1994a-1	As above	30 min cycle @ ~70% VO_2max	As above	CON: 6448 ± 1306 EX: 6443 ± 1779	CON: 6217 ± 1305 EX: 5020 ± 1817
King et al. 1994b	12 men BMI = 23.2 ± 2.2 kg/m^2	30 min cycle @ ~70% VO_2max	Ad lib meal available from 15 min post-EX; participants permitted to start when hungry	CON: 5845 ± 2253 EX: 6356 ± 2282	CON: 5644 ± 2253 EX: 5116 ± 2290
King et al. 1994b-1	As above	60 min cycle @ ~70% VO_2max	As above	CON: 5845 ± 2253 EX: 5979 ± 2223	CON: 5644 ± 2253 EX: 3722 ± 2144*
King et al. 1996	13 women BMI = 21.9 ± 1.6 kg/m^2	50 min cycle @ ~70% VO_2max followed by low-fat/high-carb meal	Ad lib meal available from 15 min post-EX; participants permitted to start when hungry	CON: 2730 ± 549 EX: 2998 ± 506	CON: 2529 ± 646 EX: 1537 ± 397*
King et al. 1996-1	As above	50 min cycle @ ~70% VO_2max followed by high-fat/low-carb meal	As above	CON: 4484 ± 782 EX: 4886 ± 996	CON: 4283 ± 811 EX: 3010 ± 844*
Imbeault et al. 1997	11 men	2050 kJ EE walking @ 35%	Standard breakfast 3.5 hr pre-	CON: 6593 ± 1988	CON: 6593 ± 1988

	BMI = 23.2 ± 2.3 kg/m^2	VO_2max (~70 min)	EX Ad lib meal 15 min post-EX	EX: 7387 ± 1724	EX: 5719 ± 2227
Imbeault et al. 1997-1	As above	2050 kJ EE running @ 75% VO_2max (~35 min)	As above	CON: 6593 ± 1988 EX: 6623 ± 1996	CON: 6593 ± 1988 EX: 4796 ± 1446*
King et al. 1997	8 men BMI = 22.4 ± 1.8 kg/m^2	50 min treadmill run @ 70% HR_{max}	Free living choice remainder of day	CON: 12,154 ± 2453 EX: 12,481 ± 2085	CON: 12,154 ± 2453 EX: 7495 ± 1080*
Hubert et al. 1998	11 women BMI = 21.5 ± 1.1 kg/m^2	40 min cycling @ 70% VO_2max	Exercise followed by low-energy breakfast (~270 kJ) + ad lib lunch 3 hr post-EX	CON: 3182 ± 783 EX: 2843 ± 1076	CON: 3182 ± 783 EX: 1516 ± 892*
Hubert et al. 1998-1	As above	As above	Exercise followed by standard high-energy breakfast (~2100 kJ) + ad lib lunch 3-hr post-EX	CON: 2525 ± 821 EX: 2495 ± 900	CON: 2525 ± 821 EX: 1168 ± 716*
Melby et al. 2002	13 women BMI = 21.6 ± 0.2 kg/m^2	2160 kJ EE cycling @ 65% VO_2max (~75 min) CHO supplementation during exercise (~750 kcals)	Ad lib meal 90 min post-EX, free choice overnight assessed by diet logs	CON: 5383 ± 913 EX: 5723 ± 912	CON: 5383 ± 913 EX: 3565 ± 885*
Melby et al. 2002-1	As above	As above, but without CHO	As above	CON: 7046 ± 1164	CON: 7046 ± 1164

				EX: 7134 ± 1314	EX: 4976 ± 1287*
George & Morganstein 2003	12 women BMI = 22 ± 1 kg/m^2	60 min treadmill walk @ 60% HR$_{max}$	Standard breakfast 90-150 min pre-EX Ad lib meal 30 min post-EX	CON: 1846 ± 859 EX: 1503 ± 536	NR
George & Morganstein 2003-1	12 overweight women BMI = 28 ± 1 kg/m^2	As above	As above	CON: 2374 ± 1101 EX: 2198 ± 724	NR
Tsofliou et al. 2003	10 obese women BMI = 37.2 ± 6.5 kg/m^2	30 min walking @ ~72% HR$_{max}$	Ad lib dinner 1 hr post-EX	CON: 3032 ± 900 EX: 2860 ± 900	NR
Pomerleau et al. 2004	13 women BMI = 22.2 ± 2.4 kg/m^2	350 kcals EE @ 40% VO$_2$max (~65 min, LOW) treadmill walking	Standard breakfast 90 min pre-EX Ad lib lunch 60 min post-EX Ad lib dinner 6.5 hr post-EX Snack bags 4.5 and 9 hr post-EX	CON: 9567 ± 2495 LO: 10,040 ± 1809	CON: 9567 ± 2495 LO: 8826 ± 1821
Pomerleau et al. 2004-1	As above	350 kcals EE @ 70% VO$_2$max (~40 min, HI) treadmill walking	As above	CON: 9567 ± 2495 HI: 10,802 ± 2215	CON: 9567 ± 2495 HI: 9487 ± 2211
Erdmann et al. 2007	7 men & women (2, 5)	30 min cycling @ 50 W	Ad lib meal 15 min post-EX	CON: 1721 ± 217	CON: 1721 ± 217

	BMI = 21.4 ± 0.8			EX: 1825 ± 375	EX: 1467 ± 375
Erdmann et al. 2007-1	As above	30 min cycling @ 100 W	As above	CON: 1721 ± 217 EX: 1758 ± 262	CON: 1721 ± 217 EX: 1041 ± 262*
Erdmann et al. 2007-2a	7 men & women (4, 3) BMI = 22.1 (SD not reported)	30 cycling min @ 50W	As above	CON: 2350 ± 135 EX: 1992 ± 412	CON: 2350 ± 135 EX: 1634 ± 412*
Erdmann et al. 2007-2b	As above	60 min cycling @ 50W	As above	CON: 2350 ± 135 EX: 2386 ± 497	CON: 2350 ± 135 EX: 1669 ± 497*
Erdmann et al. 2007-2c	As above	120 min cycling @ 50 W	As above	CON: 2350 ± 135 EX: 3248 ± 511*	CON: 2350 ± 135 EX: 1814 ± 511
Martins et al. 2007	12 men & women (6, 6) BMI = 22.0 ± 3.2 kg/m^2	60 min cycling @ 65% HR_{max}	Standard breakfast 60 min pre-EX Ad lib lunch 60 min post-EX	CON: 3190 ± 1055 EX: 3822 ± 1520*	CON: 2366 ± 946 EX: 1763 ± 1264*
Ballard et al. 2009	21 men BMI= 24.8 ± 3.3 kg/m^2	80 min RT 4 sets of 8 exercises, 3 min between sets 3 sets of 10 reps @ 70% 1-RM, 1 set of 55% 1-RM to	Standard breakfast 2.5 hr pre-EX CHO condition – participants consumed ~1250 kJ of CHO beverage during EX	CON: 5238 ± 1842 EX: 5430 ± 1453 -EI from buffet meal only-	CON: 6494 ± 1874 EX: 4794 ± 1412* REI = (CHO consumed during exercise) + (buffet) –

		fatigue	Ad lib lunch 2 hr post-EX		(ExEE)
Ballard et al. 2009-1	As above	As above	Standard breakfast 2.5 hr pre-EX PLA condition – no CHO supplementation Ad lib lunch 2 hr post-EX	CON: 5238 ± 1342 EX: 5723 ± 1269 -EI from buffet meal only-	CON: 6494 ± 1876 EX: 3828 ± 1194* REI = (CHO consumed during exercise) + (buffet) – (ExEE)
Shorten et al. 2009	11 men BMI = 24.1 ± 2.3 kg/m^2	40 min treadmill running @ 70% VO$_2$max	Ad lib meal ~35 min post-EX	CON: 3744 ± 1566 EX: 5193 ± 1998*	CON: 3744 ± 1566 EX: 2818 ± 1718
Ueda et al. 2009a	7 obese men BMI = 30.0 ± 3.1 kg/m^2	60 min cycling @ 50% VO$_2$max	Standard breakfast 70 min pre-EX Ad lib lunch 60 min post-EX	CON: 3952 ± 737 EX: 2571 ± 374*	CON: 2770 ± 641 EX: -387 ± 468*
Ueda et al. 2009a-1	7 men BMI = 22.4 ± 2.4 kg/m^2	As above	As above	CON: 3509 ± 476 EX: 2899 ± 488*	CON: 2648 ± 487 EX: 822 ± 453*
Ueda et al. 2009b	10 men BMI = 22.5 ± 1 kg/m^2	30 min cycling @ 75% VO$_2$max (HI)	Standard breakfast 60 min pre-EX Ad lib lunch 60 min post-EX	CON: 3930 ± 922 HI:3059 ± 1156*	NR

Ueda et al. 2009b-1	As above	30 min cycling @ 50% VO$_2$max (MOD)	As above	CON: 3930 ± 922 MOD: 3342 ± 1091*	NR
King 2010	10 men BMI = 23.6 ± 2.2 kg/m^2	90 min RT 3 sets, 12 reps @ 80% 12-RM of 10 exercises 3 min between sets	Standard breakfast 60 min pre-EX Ad lib meals 1 and 4 hr post-EX Diet log overnight	CON: 12,418 ± 3627 EX: 13,543 ± 2334	CON: 12,418 ± 3311 EX: 12,535 ± 2062
King et al. 2010a	9 men BMI = 23.6 ± 1.2 kg/m^2	90 min treadmill running @ 70% VO$_2$max	Ad lib meals 1 hr, 4 hr, and 8.5 hr post-EX Diet log overnight	CON: 17,191 ± 3432 EX: 17,606 ± 4152	CON: 17,191 ± 3432 EX: 12,282 ± 3756*
King et al. 2010b	14 men BMI = 23.4 ± 2.2 kg/m^2	60 min self-paced “brisk walking” (7.0 ± 0.4 km/hr; 45 ± 7.5% VO$_2$max)	Ad lib meals 30 mins and 4 hrs post-EX	CON: 9212 ± 2200 EX: 9384 ± 2466	CON: 9212 ± 2200 EX: 7548 ± 1979*
Laan et al. 2010	19 women & men (10, 9) BMI = 22.5 ± 1.8 kg/m^2	35 min cycling @ 70% HRR	Ad lib meal 30 min post-EX	CON: 3282 ± 373 EX: 3756 ± 402*	CON: 3282 ± 373 EX: 2541 ± 394*
Laan et al. 2010-1	As above	35 min RT 2 sets of 10 reps @ 70% 1-	Ad lib meal 30 min post-EX	CON: 3282 ± 373 EX: 3868 ± 398*	CON: 3282 ± 373 EX: 3533 ± 381

		RM of 5 exercises 1 min between sets			
O'Donoghue, Fournier, & Guelfi 2010	9 men BMI = 22.4 ± 1.6 kg/m^2	45 min running @ 75% VO$_2$max	3 ad lib meals over ~14 hours Ad lib breakfast 15 min post-EX, lunch 5 hr post-EX, dinner 10.5 hr post-EX	CON: 19,975 ± 5909 EX: 21,145 ± 4507	CON: 19,975 ± 5909 EX: 18,314 ± 3988
Unick et al. 2010	19 pre-menopausal, overweight women BMI = 32.5 ± 4.3 kg/m^2	~45 min treadmill walking @ 70-75% HR$_{max}$	Ad lib meal 60 min post-EX	CON: 2309 ± 1026 EX: 2297 ± 1201	CON: 2111 ± 1215 EX: 828 ± 1112*
Balaguera-Cortes et al. 2011	10 men BMI = 23.7 ± 2.0 kg/m^2	45 min treadmill running @ 70% VO$_2$max	Ad lib meal 30 min post-EX	CON: 5283 ± 1342 EX: 5516 ± 1558	CON: 5027 ± 1531 EX: 2698 ± 1140‡
Balaguera-Cortes et al. 2011-1	10 men BMI = 23.7 ± 2.0 kg/m^2	45 min RT 3 sets of 12 reps or to failure of 8 exercises 1 min between sets	Ad lib meal 30 min post-EX	CON: 5283 ± 1342 EX: 5441 ± 1503	CON: 5027 ± 1531 EX: 4101 ± 830‡
Jokisch et al. 2011	10 inactive men BMI = 23.0 ± 1.9	45 min cycling @ 65-75% HR$_{max}$	Ad lib meal 60 min post-EX	CON: 4497 ± 1968 EX: 3915 ± 929*	CON: 4497 ± 1968 EX: 2609 ± 1918*

Jokisch et al. 2011-1	10 active men BMI = 23.9 ± 1.5	As above	As above	CON: 4258 ± 1662 EX: 4643 ± 1629	CON: 4258 ± 1662 EX: 1909 ± 1591
King et al. 2011a	12 men BMI = 22.8 ± 1.4 kg/m^2	90 min treadmill running @ 70% VO$_2$max	Standard meals 30 min and 3.25 hr post-EX Ad lib meal 8 hr post-EX (ad lib EI reported)	CON: 4004 ± 1479 EX: 4343 ± 2262	NR
King et al. 2011b	14 men BMI = 23.2 ± 2.2 kg/m^2	60 min intermittent swimming [6x (7 min swim/3 min rest)]	Standard breakfast 60 min pre-EX Ad lib meals 2 and 6.5 hr post-EX	CON: 9161 ± 2690 EX: 9749 ± 3027	CON: 9163 ± 2694 EX: 7828 ± 2896*
Vatansever-Ozen et al. 2011	10 men BMI = 22.0 ± 0.4 kg/m^2	105 min treadmill running @ 50% VO$_2$max + 15 min @ 70% VO$_2$max	Ad lib meal 60 min post-EX	CON: 8194 ± 2169 EX: 8587 ± 2889	CON: 7210 ± 2177 EX: 3081 ± 2935*
Deighton et al. 2012 (Fasted trial)	12 men BMI = 22.9 ± 2.1 kg/m^2	60 min treadmill running @ 70% VO$_2$max	Standard breakfast 30 min post-EX Ad lib meals 4.5 hr and 8.5 hr post-EX	CON: 13,452 ± 2682 EX: 13,652 ± 2385	CON: 13,451 ± 2682 EX: 10,406 ± 2289*
Deighton et al. 2012-1 (Fed trial)	Same as above	Same as above, but standard breakfast 2.5 hr pre-EX	Standard breakfast 2.5 hr pre-EX	CON: 13,452 ± 2682 EX: 12,929 ± 2933	CON: 13,451 ±2682 EX: 9699 ± 2866*

			Ad lib meals 4.5 and 8.5 hr post-EX		
Kelly et al. 2012	10 men BMI = 23.9 ± 2.1 kg/m^2	45 min treadmill running @ 70% VO_2max	Ad lib meal 30 min post-EX	CON: 4773 ± 1730 EX: 5195 ± 1742	CON: 4339 ± 1686 EX: 1541 ± 911*
Larson-Meyer et al. 2012	9 female runners BMI = 19.8 ± 1.0 kg/m^2	60 min treadmill running @ 70% VO_2max	Standard breakfast 90 min pre-EX Ad lib meal 2 hr post-EX	CON: 2011 ± 529 EX: 2034 ± 768	CON: 1188 ± 505 EX: -812 ± 862*
Larson-Meyer et al. 2012-1	10 female walkers BMI = 22.1 ± 3.4 kg/m^2	60 min treadmill walking @ 70% VO_2max	Same as above	CON: 2305 ± 680 EX: 2612 ± 582*	CON: 1532 ± 769 EX: 531 ± 820*
Wasse et al. 2012	10 men BMI = 24.8 ± 2.4 kg/m^2	60 min treadmill running @ 70% VO_2max	Standard meal 60 min post-EX Ad lib meal 4.5 hr post-EX	CON: 7535 ± 2112 EX: 7909 ± 2599	CON: 7435 ± 2324 EX: 4542 ± 2448

Table 1: Effects of acute exercise on absolute and relative energy intake.

* = significantly different from Control (as reported within studies; $p < 0.05$) ‡ = Calculated by authors of the present study

Divide kilojoule values by 4.1868 to calculate kilocalories.

HRR = Heart Rate reserve HR_{max} = Max heart rate BMI = Body mass index CON = resting control trial EX = exercise trial

ExEE = exercise energy expenditure CHO = carbohydrate RT = resistance training NR = not reported

Moderator variable	$p^{\#}$	**Comparison**
		Absolute EI
Exercise mode	0.669	Cycling (n = 23, ES = 0.04, 95% CI: -0.26 to 0.33)
		Running (n = 13, ES = 0.16, 95% CI: -0.08 to 0.4)
		Walking (n = 9, ES = 0.09, 95% CI: -0.18 to 0.35)
		Resistance training (n = 5, ES = 0.49, 95% CI: -0.04 to 1.01)
		Swimming (n = 1, ES = 0.21, 95% CI: -0.54 to 0.95)
Sex	0.227	Men (n = 29, ES = 0.05, 95% CI: -0.11 to 0.22)
		Women (n = 14, ES = 0.11, 95% CI: -0.11 to 0.32)
		Both (n = 8, ES = 0.64, 95% CI: -0.01 to 1.29)
Fed state	0.84	Fed (n = 29, ES = 0.12, 95% CI: -0.09 to 0.34)
		Fasted (n = 22, ES = 0.15, 95% CI: -0.04 to 0.35)
Fitness Level	0.005	Low fitness (n = 6, ES = -0.22, 95% CI: -0.56 to 0.12)
		Moderate fitness (n = 5, ES = -0.70, 95% CI: -1.33 to -0.08)
		High fitness (n = 40, ES = 0.29, 95% CI: 0.16 to 0.43)
Exercise EE	0.657	Meta-regression of ExEE vs. ES (slope = -0.00003, 95% CI: -0.00015 to 0.00010)
Exercise Duration	0.289	Meta-regression of ExDur vs. ES (slope = 0.00399, 95% CI: -0.00338 to 0.01135)
Exercise Intensity	0.212	Meta-regression of ExInt vs. ES (slope = 0.009, 95% CI: -0.00531 to 0.02314)
Body Mass Index	0.118	Meta-regression of BMI vs. ES (slope = -0.042, 95% CI: -0.0936 to 0.0106)

Number of Meals Post-EX	0.816	Meta-regression of number of meals vs. ES (slope = 0.0238, 95% CI: -0.1764 to 0.2245)

		Relative EI
Exercise mode	0.002	Cycling (n = 21, ES = -1.53, 95% CI: -1.90 to -1.17)
		Running (n = 12, ES = -1.40, 95% CI: -1.78 to -1.02)
		Walking (n = 6, ES = -0.65, 95% CI: -1.02 to -0.27)
		Resistance training (n = 5, ES = -0.57, 95% CI: -1.45 to 0.30)
		Swimming (n = 1, ES = -0.48, 95% CI: -1.23 to 0.27)
Sex	0.529	Men (n = 26, ES = -1.12, 95% CI: -1.40 to -0.83)
		Women (n = 11, ES = -1.42, 95% CI: -1.88 to -0.96)
		Both (n = 8, ES = -1.31, 95% CI: -2.2 to -0.43)
Fed state	0.403	Fed (n = 24, ES = -1.13, 95% CI: -1.50 to -0.76)
		Fasted (n = 21, ES = -1.33, 95% CI: -1.60 to -1.06)
Fitness level	0.000	Low fitness (n = 3, ES = -2.11, 95% CI: -3.79 to -2.45)
		Moderate fitness (n = 9, ES = -1.78, 95% CI: -2.39 to -1.18)
		High fitness (n = 33, ES = -1.06, 95% CI: -1.33 to -0.80)
Exercise EE	0.138	Meta-regression of ExEE vs. ES (slope = -0.00015, 95% CI: -0.00036 to 0.00005)
Exercise Duration	0.636	Meta-regression of ExDur vs. ES (slope = -0.00284, 95% CI: -0.01459 to 0.00891)
Exercise Intensity	0.309	Meta-regression of ExInt vs. ES (slope = -0.01175, 95% CI: -0.0344 to 0.01091)
Body Mass Index	0.912	Meta-regression of BMI vs. ES (slope = 0.00711, 95% CI: -0.11827 to 0.13248)
Number of Meals Post-EX	0.0318	Meta-regression of number of meals vs. ES (slope = 0.34181, 95% CI: 0.02969 to 0.65394)

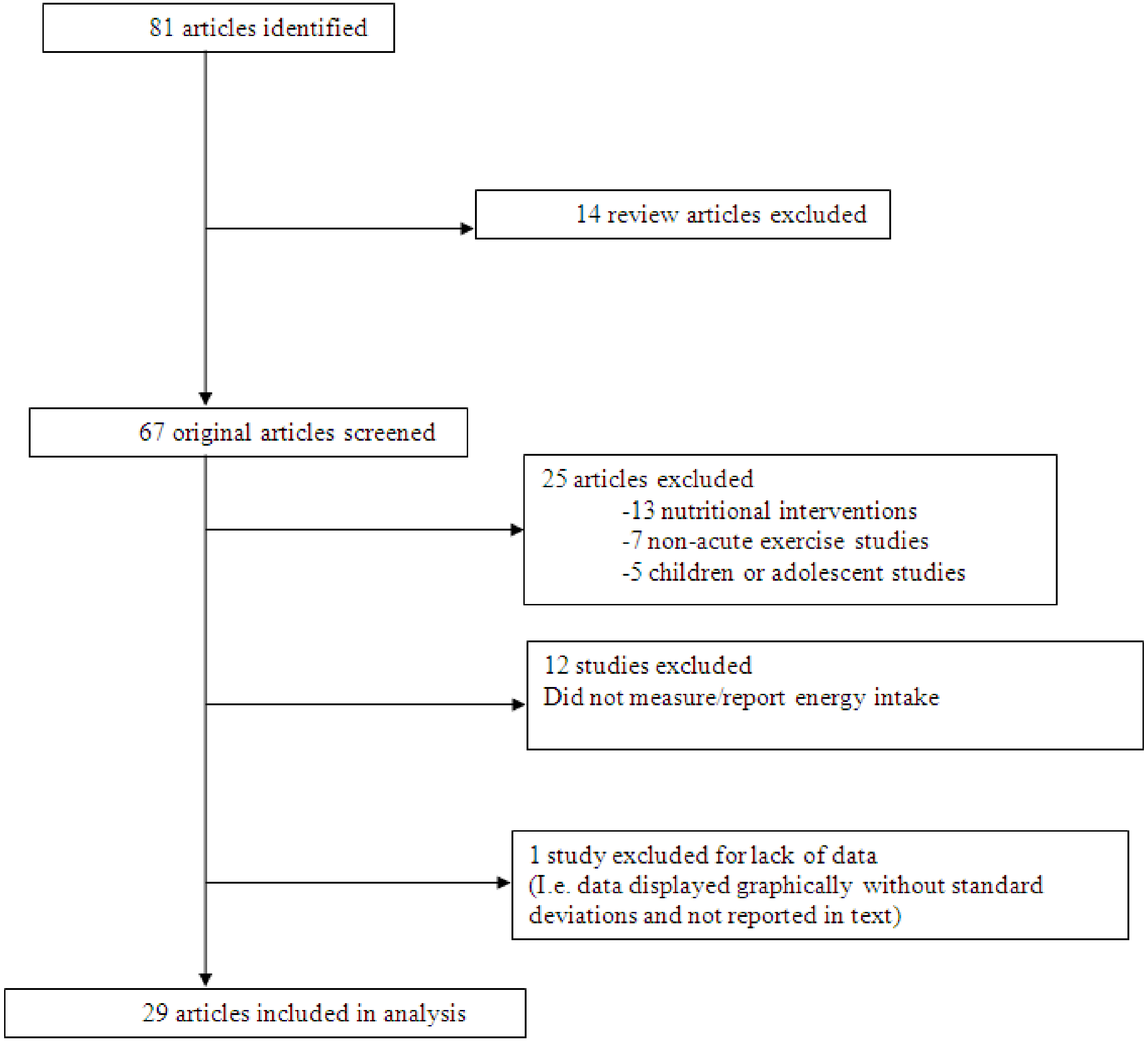
Table 2: Summary of Moderator variable analysis for the two meta-analyses by sub-group and meta-regression

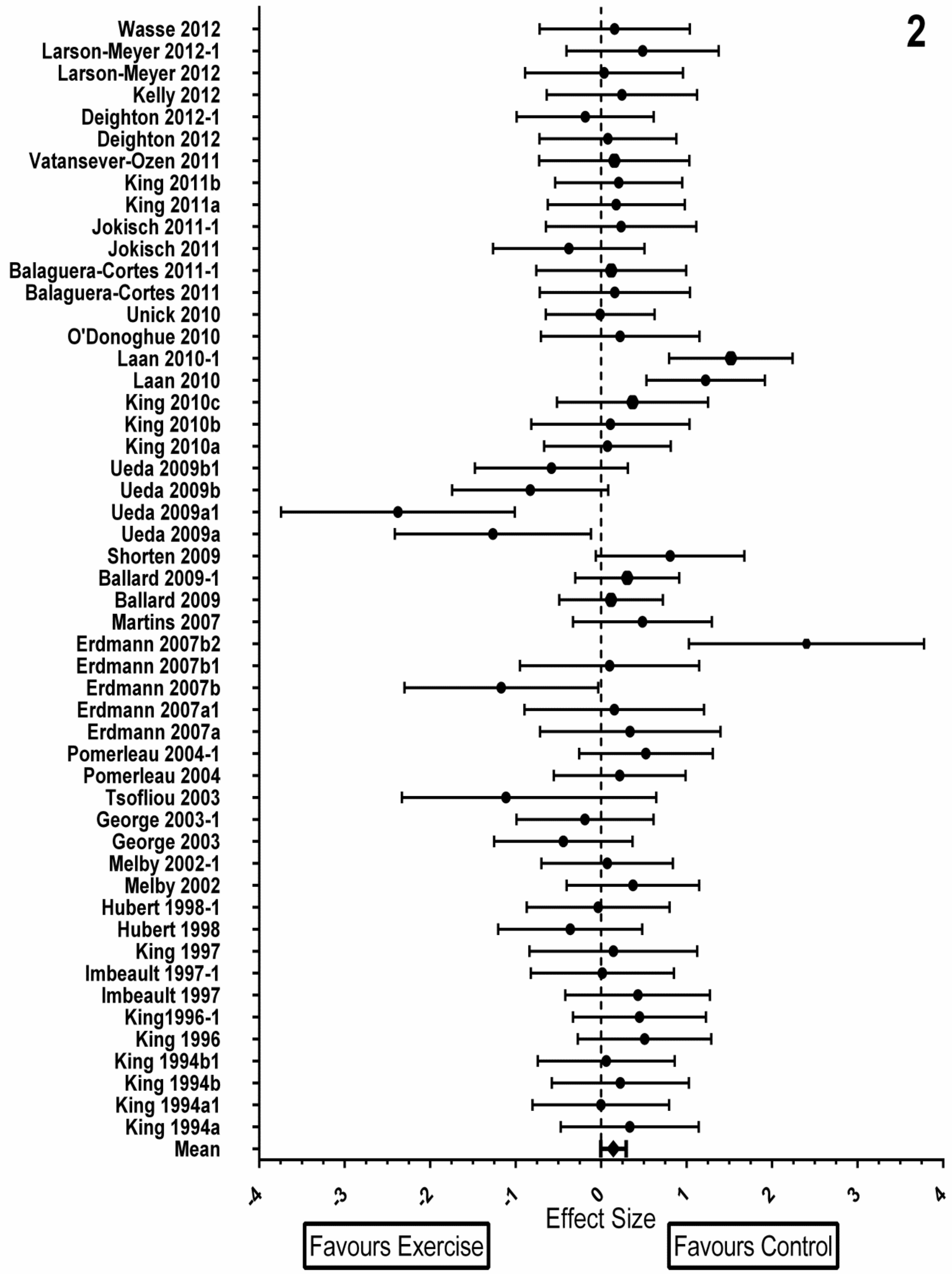
#Test for statistical difference between moderator sub-group and meta-regression (see text for explanations)

Figure 1: Decision tree of study selection

Figure 2: Effect size forest plot for absolute energy intake (means ± 95% confidence intervals)

Figure 3: Effect size forest plot for relative energy intake (means ± 95% confidence intervals)


81 articles identified
14 review articles excluded
67 original articles screened
25 articles excluded
-13 nutritional interventions
-7 non-acute exercise studies
-5 children or adolescent studies
12 studies excluded
Did not measure/report energy intake
1 study excluded for lack of data
(I.e. data displayed graphically without standard deviations and not reported in text)
29 articles included in analysis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Larson-Meyer 2012
Kelly 2012
Deighton 2012-1
Deighton 2012
Vatansever-Ozen 2011
King 2011b
King 2011a
Jokisch 2011-1
Jokisch 2011
Balaguera-Cortes 2011-1
Balaguera-Cortes 2011
Unick 2010
O'Donoghue 2010
Laan 2010-1
Laan 2010
King 2010c
King 2010b
King 2010a
Ueda 2009b1
Ueda 2009b
Ueda 2009a1
Ueda 2009a
Shorten 2009
Ballard 2009-1
Ballard 2009
Martins 2007
Erdmann 2007b2
Erdmann 2007b1
Erdmann 2007b
Erdmann 2007a1
Erdmann 2007a
Pomerleau 2004-1
Pomerleau 2004
Tsofliou 2003
George 2003-1
George 2003
Melby 2002-1
Melby 2002
Hubert 1998-1
Hubert 1998
King 1997
Imbeault 1997-1
Imbeault 1997
King1996-1
King 1996
King 1994b1
King 1994b
King 1994a1
King 1994a
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-3
-2
-1
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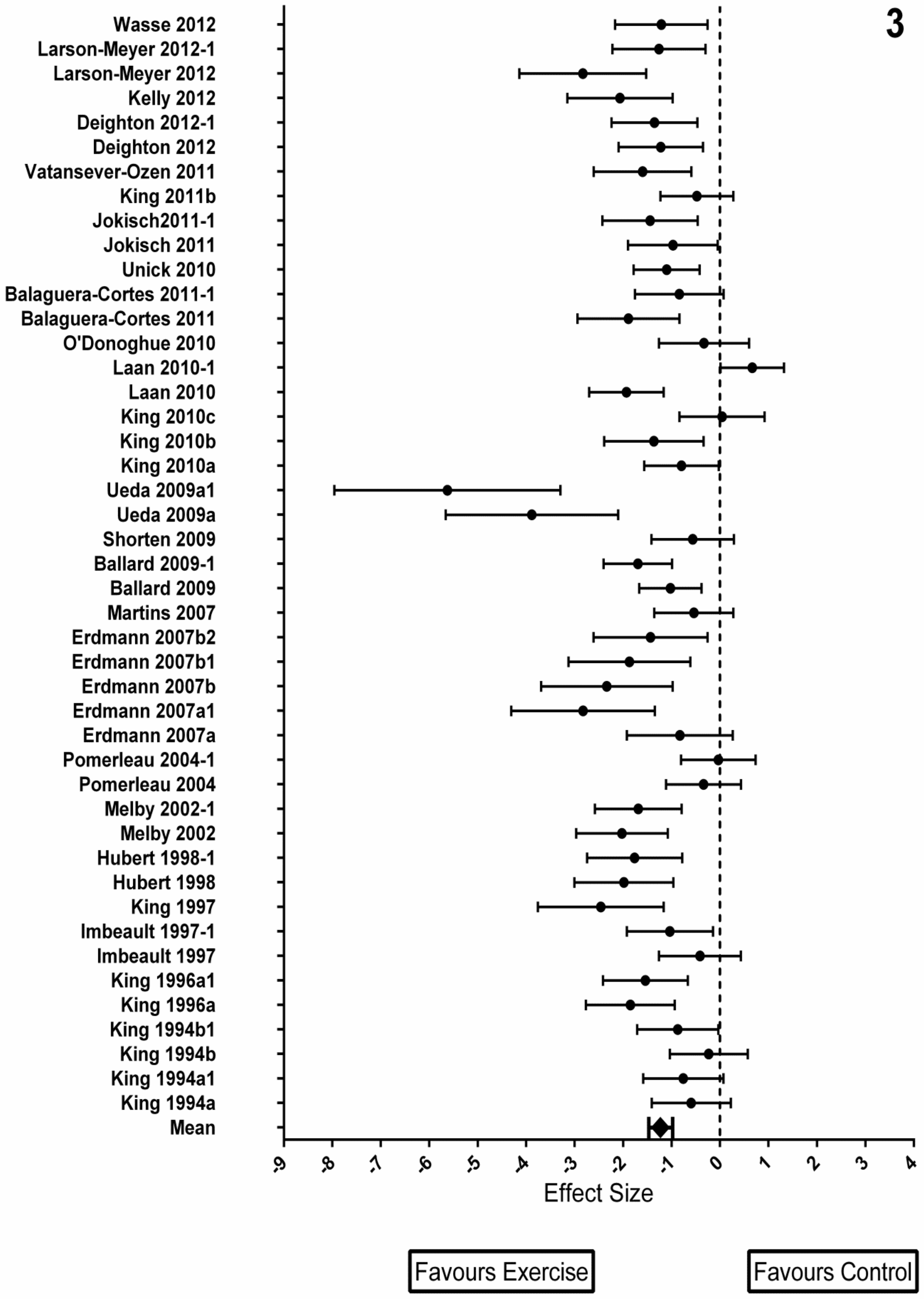
4
Effect Size
Favours Exercise
Favours Control


3
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Larson-Meyer 2012-1
Larson-Meyer 2012
Kelly 2012
Deighton 2012-1
Deighton 2012
Vatansever-Ozen 2011
King 2011b
Jokisch2011-1
Jokisch 2011
Unick 2010
Balaguera-Cortes 2011-1
Balaguera-Cortes 2011
O'Donoghue 2010
Laan 2010-1
Laan 2010
King 2010c
King 2010b
King 2010a
Ueda 2009a1
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Shorten 2009
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Ballard 2009
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Erdmann 2007b
Erdmann 2007a1
Erdmann 2007a
Pomerleau 2004-1
Pomerleau 2004
Melby 2002-1
Melby 2002
Hubert 1998-1
Hubert 1998
King 1997
Imbeault 1997-1
Imbeault 1997
King 1996a1
King 1996a
King 1994b1
King 1994b
King 1994a1
King 1994a
Mean
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
Effect Size
Favours Exercise
Favours Control