**Article:**

Thivel, D, Rumbold, PL, King, NA et al. (2016) Acute post-exercise energy and macronutrient intake in lean and obese youth: a systematic review and meta-analysis. International Journal of Obesity, 40 (10). pp. 1469-1479. ISSN: 0307-0565

https://doi.org/10.1038/ijo.2016.122

# Acute post-exercise energy and macronutrient intake in lean and obese youth: a systematic review and meta-analysis

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**Running title**: Nutritional response to exercise in youth

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**Abstract**

**Aim.** This review aims to determine if acute exercise affects subsequent energy and macronutrients intake in obese and non-obese children and adolescents.

**Methods.** Databases were searched between January 2015 and December 2015 for studies reporting energy and/or macronutrients intake immediately after an acute exercise and control condition, in children and adolescents. From the initial 118 references found, 14 were included for subsequent analysis after screening representing 31 acute exercise conditions that varied in intensity, duration and modality.

**Results.** One study found increased energy intake after exercise, seven decreased and 23 revealed no change. The meta-analysis revealed a significant effect of acute exercise on intake in obese but not in lean youth by a mean difference of -0.430 (95% CI = -0.703 to -0.157, p=0.002) displaying low heterogeneity ($I^2$ = 0.000; Q = 5.875; $d_f$ = 9, p=0.752). The analysis showed that intense exercise only reduces intake in obese children (no intensity effect in lean). Unchanged macronutrients intake was reported in nine studies as opposed to three which found modified lipids, protein and/or carbohydrate intake.

**Conclusion.** While acute exercise does not affect energy intake in lean, it appears to reduced food intake in obese youth when intense, without altering the macronutrients composition of the meal.

***Key words.*** Exercise; energy intake; macronutrient consumption, pediatric

**Abbreviations**

EI – Energy Intake
EE – Energy Expenditure
ES – Effect Size
REI – Relative Energy Intake
ExEE – Exercise-induced Energy Expenditure
CHO – Carbohydrates
RCT – Randomized Controlled Trial
CCK – Cholecyctokinin
GLP-1 – Glucagon-Like Peptide 1
PYY – Peptide YY

## Introduction

Based on the worldwide increasing rates of pediatric overweight and obesity, the energy balance regulation, particularly the relationships between energy intake (EI) and energy expenditure (EE), are currently of major interest. Although the respective implications of physical activity and EI in the control of energy balance have been long considered independently, this approach seems today too simplistic.

About 60 years ago, it was considered that energy consumption was regulated with such flexibility that an increase in physical activity-induced energy expenditure would be immediately compensated for by an increase in food intake (1). Mayer et al. (1956) however demonstrated that the relationship between EE and EI could be reversed during habitual activities favoring very low level of EE such as sedentary behaviors (1).

Studies exploring the impact of acute exercise or chronic physical activity programs on nutritional adaptations have been conducted (2, 3). Despite the large numbers of studies that have been conducted in adults, the question of how exercise precisely affects EI and appetite control remains controversial (4). In their recent meta-analysis based on 29 studies, Schubert et al. (2014) revealed that adults do not compensate for the EE induced by acute exercise by increasing their food intake (5). Furthermore, Donnelly and collaborators (2014) also failed (in a systematic review) to identify any consistent evidence to suggest that increased physical activity (or exercise) modifies energy or macronutrient intake in adults (6). It is acknowledged that individual responses to exercise with regards to energy homeostasis have been found to be variable thus making it difficult to make firm conclusions (3).

This question has been investigated less frequently in children and adolescents with the first study of its kind that has been conducted in 2004 and that explored post-exercise EI responses in lean 10 years old girls (7). In this study, the authors identified no detectable increase in EI in the short term, following exercise of either low (50% $\dot{V}O_{2peak}$) or high (75% $\dot{V}O_{2peak}$) intensity (7). Since then, studies have been conducted in both lean and obese children and adolescents, examining the role of exercise (or physical activity induced EE) duration, modality, frequency or intensity on subsequent energy and macronutrient intake. For example, in 2009, Nemet and collaborators identified that EI was decreased after 1 hour of resistance training and remained unchanged after 1 hour of aerobic exercises or swimming in lean pre-pubertal children while the swimming session was the only condition that led to an increased food consumption in overweight ones (8). More recently, Thivel et al. (2014) examined the effect of pubertal adolescents' body mass on post-exercise EI and identified that obese youth only modify (decrease) their EI after intensive exercise (>70% $\dot{V}O_{2max}$) (9). Since the available evidence in youth remains scarce and sometimes equivocal, it is difficult to state whether or not acute exercise affects subsequent food consumption. In addition, there is an important heterogeneity in the methodologies used (time interval between exercise and meal; exercise characteristics; participants characteristics, etc.). For detailed review see Thivel et al., 2012 (10).

There have been two narrative reviews in which the impact of acute exercise on subsequent EI in children and adolescents has been explored (10, 11). Although the reviews highlight the important design diversity found in the literature, they suggest that post-exercise EI is not associated with the volume of energy expended during an acute exercise (11). Those reviews highlighted that the characteristics of the exercise (such as intensity and duration) are key factors influencing feeding behavior following exercise in paediatric populations (10). However they both failed in drawing a clear conclusion on the impact of acute exercise on adolescents' food intake. Therefore, the purpose of this systematic review and meta-analysis is to identify and evaluate studies that have employed robust study designs to determine the impact of acute exercise on energy and macronutrient intake in lean and obese children and adolescents.

## Methods

*Database searching*

The following electronic bibliographic databases were searched: MEDLINE, EMBASE, CINAHL psycINFO, SPORTDiscus and SocINDEX. All searches were conducted from January 2015 and December 2015. Keyword searches were performed for "Exercise", "physical activity", "energy expenditure", "energy intake", "food intake", "appetite", "hunger", "children" and "adolescents". Titles and abstracts of potentially relevant articles were screened. Full text articles were screened in duplicate for inclusion in the review and any discrepancies were collectively discussed by the authors. All the selected references were then extracted to the Endnote software. The PRISMA guidelines were followed for the preparation of this paper (12).

*Study eligibility*

*Inclusion criteria*. To be included in the analysis, studies had to enroll lean, overweight or obese children or adolescents (5-to-18 years old). The participants had to be non-smoking individuals, to be free of any medications affecting the control of energy intake and appetite or exercise contraindications. To be included, the studies had to assess post exercise EI, at the meal immediately following exercise. There was no exclusion criterion for the exercise characteristics (intensity, duration, modality, etc.). All studies were required to include a control condition and to use an appropriate trial randomization approach (13). The post exercise meal presented to the children and adolescents had to be in the laboratory (i.e. not free-living EI). There was no exclusion criterion for the type (e.g., buffet, single meal) of *ad libitum* meal provided. Published peer-reviewed studies, conference proceedings, theses and dissertations were eligible.

*Exclusion criteria.* Studies were excluded for further analysis if they did not report absolute or relative EI. When data were presented in a graphical form without mean or standard deviation (SD) indicated, the corresponding author of the work was contacted to obtain complementary data. If the corresponding author did not answer or declined the query, studies were excluded.

*Data synthesis.* After a first selection based on the title of the papers, a second author independently assessed the papers' eligibility based on titles. Each authors had to code papers as "yes" or "no" or "maybe" for eligibility. Once this first round of selection was completed (based on title only), any disagreement was discussed and a common decision taken. The same procedure was followed a second time based on the abstract of the previously selected papers. Any disagreement regarding eligibility for inclusion was discussed and a consensus made among co-authors. Computer files were developed containing the selected papers at each stage of the selection, and made available to all the co-authors. By the end of the study selection process (as described above), all the references were classified in the EndNote reference management software (Endnote X4, Thomson Reuters, NYC, USA). Any issue encountered by an author when extracting the data was discussed collectively and a consensus was agreed to harmonize the extraction process. For every paper under consideration, an extraction sheet was completed in order to collect the following data: sample size, sex of the sample (or sex repartition), age, EI, macronutrient intake, EE, exercise modality, exercise intensity, exercise duration. All the extraction sheets were then saved in a dedicated folder. The flow diagram presented in Figure 1 illustrates the selection/inclusion/exclusion process.

*Synthesis of the Results*. Tables were composed on a priori established columns chosen collectively by the authors (Reference; Population; Exercise Characteristics; Meal Characteristics; Energy Intake; macronutrients consumption). A table for all studies related to lean children and adolescents (Table 1) and overweight/obese children and adolescents (Table 2) were developed. In some instances duplicate study citations appear in both Tables 1 and 2 as the studies in question employed both lean and overweight/obese children and/or adolescents. Studies were ranked in the tables according to the publication year (from the oldest to more recent). All EI and EE values were converted to kilocalories (kcal).

*Risk of Bias in Individual studies*. Risk of bias was independently evaluated by two authors using the Cochrane risk of bias tool (13). Risk of bias was assessed for: selection bias; performance bias; detection bias; attrition bias; reporting bias. Any discrepancies in bias coding were resolved by a third reviewer (Table 3). Studies were not excluded on the basis of risk of bias.

**Meta-analysis procedure**

The data were compiled into software designed specifically for meta-analyses (Comprehensive Meta-Analysis, version 2; Biostat, Englewood, NJ). Data included: sample size, absolute EI for the exercise and control sessions as well as their respective SDs, body mass and exercise intensity. Intensity was defined as follows: Low intensity: <50% maximal capacities; moderate intensity: 50-69% maximal capacities; and intensive exercise: ≥70% maximal capacities. Two of the authors extracted the studies independently and any disagreement was discussed and a common decision taken. Studies were selected if they met all the inclusion criteria previously detailed and if their design was judge satisfactory (13). The mean standardized differences were calculated by the software to determine Cohen's d for each study and Hedge's g was used to account for potential bias of small sample sizes. 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 single studies. This random effects model was preferred over a fixed-effect approach as some experimental parameters such as the measurement of EI had wide variation, which is better considered with the random-effects model during analysis (14).
Since only one of the included studies reported relative EI, and none provided results for EE, only absolute energy intake was considered in the meta-analysis. The effect sizes were interpreted according to Cohen (1992) such as <0.2 as trivial, 0.2–0.3 as small, 0.5 as moderate, and >0.8 as large (15). A negative effect size value indicates that exercise decreased energy intake while a positive effect size indicates that exercise increased energy intake. Cochrane's Q and the $I^2$ index were used to calculate Heterogeneity with 25%, 50% and 75% respectively indicating low, moderate and high heterogeneity according to the $I^2$ analysis (16) and a Cochrane's Q value above the degree of freedom (df) to attest for a significant heterogeneity (17). To test sensitivity and whether results were driven by any one study, the analyses were conducted by excluding one study at a time. Subgroup meta-analysis and/or meta-regression were also performed to test whether differences in methodologies could explain the variation in ES between trials (14, 18). This analysis included meta-regressions of EI as a continuous variable and sub-group meta-analyses were conducted for categorical data such as exercise intensity and body mass status. Funnel plots were used to assess publication bias (14, 18), in absence of 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 (2000) was used to assess bias (19), which give the possibility to compute and include 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 used to examine if ES were significantly different from zero.

## Results

The initial database search identified 163 studies and 15 additional studies were also identified (book of abstracts, conference proceedings, dissertations, and ongoing data). Following the removal of duplicate studies, 118 studies were identified. After review of titles and abstracts, 79 studies were excluded and after close consideration of the inclusion criteria 14 studies were finally considered for analysis (as detailed in Figure 1). The Table 3 details the risk of bias analysis.

*Population characteristics*

Of the 14 studies considered in the final part of the analysis, five included lean participants only (7, 20-23) and five included overweight/obese ones only (24-28). Four studies enrolled both lean and obese subjects (8, 9, 29, 30).

Overall, the studies selected included sample sizes ranging from 10 (27) to 22 (8), with subsamples of lean ranging from nine (9) to 22 (8) and from seven (25) to 22 (8) in obese.

The selected studies enrolled participants from 9.1 ± 0.6 (8) to 16.1 ± 0.3 years old (23). Studies involving lean individuals only used an age range from 9.4 ± 0.3 y (8) to 16.1 ± 0.3 y (23); while studied enrolling obese individuals only present an age ranged from 9.1 ± 0.6 y (8) to 14.5 ± 0.8 years old (28).

*Exercise characteristics*

Altogether, the 14 studies included compared 31 different exercise conditions (all study characteristics taken together) with control sessions.

Type/modalities of training varied to a great extent. Nine studies used cycling as an exercise modality (7, 9, 22-28, 30). Treadmill exercise was used in two studies (20, 29); aerobic games, swimming and resistance exercises used in one study (8), and collective games used in two studies with Rumbold et al. using Netball (21) and Thivel et al. using rugby (23).

Exercise durations ranged from 15 min (20, 29) to 60 min (23) in lean individuals and from 15 min (29) to 59 ± 6 min (26) in obese individuals.

Exercise intensities ranged from 50% $\dot{V}O_2max$ (7) to 75% $\dot{V}O_2max$ (7, 9, 22, 23) in lean children and adolescents, and from 40% $\dot{V}O_2max$ (26) to 75% $\dot{V}O_2max$ (9, 26, 27) in obese ones.

Of the 14 studies included in the analysis, only two did not report the exercise-induced energy expenditure (9, 22). In studies using lean participants, the gross exercise-induced energy expenditure ranged from 57 ± 3 kcal (20) to 549 ± 3 kcal (23) and from 63 ± 7 kcal (29) to 358 ± 3 kcal (28) in samples with obese participants.

*Test meal characteristics*

All the studies included in the present analysis proposed *ad libitum* buffet meals. The buffets were provided 30 minutes (9, 20, 22-30) to 80 minutes (7) after exercise. While most of the studies provided buffet meals composed of a range of foods, two studies used single-item foods such as pizzas (20, 29) and pasta (21).

*Total Energy Intake*

Of the 31 different exercise conditions tested, one study found a significantly higher energy intake after exercise (8) and 7 found a significant reduction of energy intake after exercise (7-9, 24-26, 31) and 23 reported no difference (7-9, 20-23, 25, 26, 28-30). None of the studies involving lean participants observed an increased in EI after exercise. However, a significant decrease in food consumption was observed twice (7, 8) and no difference was observed 16 times (7-9, 20-23, 29, 30). Among obese individuals, only Nemet et al. observed a significant increase in EI after exercise (8), 5 studies found decreased post-exercise EI (9, 24-26, 31), and 7 found no changes (8, 25, 26, 28-30).

Only one study reported relative EI (REI=EI-ExEE) and failed to find any differences between long duration (45 min) and short duration (15 min) exercise compared with a control session in lean boys and girls (20).

*Macronutrients intake*

Nine out of the 14 studies included reported macronutrient intakes (9, 22-26, 28, 30, 31), 4 in lean children (9, 22, 23, 30) and 7 in obese (9, 24-26, 28, 30, 31).

Three out of the 4 studies providing results in lean individuals reported no change in macronutrient intake after exercise compared with a control session (9, 22, 30). Only Thivel et al. found a statistically significant increase in the intake of energy-derived from fat after a bout of cycling in adolescent males (no modification of the energy ingested derived from protein or CHO; (23)). In obese adolescents; 6 studies revealed no significant change in macronutrients intake after an acute bout of exercise (9, 24-26, 28, 30) and one reported a significant increase in energy-derived from protein and fat, and a significant reduction of the energy intake derived from CHO (31).

***Meta-Analysis***

*Effect of acute exercise on absolute energy intake in adolescents (lean + OW/OB):* The effect size ranged from -1.051 to 0.895 (n=25). Results of the meta-analysis revealed a mean effect size of exercise to reduce EI of -0.188 (95% CI = -0.644 to 0.268, p= 0.418; Figure 2A). Results for heterogeneity among these studies were as follow: $I^2$ = 31.347; Q = 34.958; $d_f$ = 24, p=0.069.

Table 4 details the meta-analysis results in lean and overweight youth according to exercise intensity (Low, moderate and high), highlighting a significant effect of intensive exercise only on subsequent energy intake (decrease) in overweight/obese youth (p=0.001), as shown by the Figure 2B.

## Discussion

The effect of acute exercise on energy intake has been widely explored and discussed in adults for the last 20 years (3, 5, 6). Recently, the interest around this question in pediatric population emerged (10). A growing number of studies has been published during the last decade addressing this issue in lean and obese children and adolescents. Data appear relatively equivocal and it remains unclear whether or not acute exercise affects EI in youth. The purpose of this study was to systematically review the available literature in this field and to perform a meta-analysis to determine the efficacy of acute physical exercise for reducing EI in children and adolescents.

The present paper systematically reviewed fourteen original publications that questioned the effect of acute exercise on subsequent energy intake in children and adolescents, with lean participants taking part in 9 of these studies (7-9, 20-23, 29, 30) where 9 included overweight/obese participants (8, 9, 24-26, 28-31). Although cycling was the most common exercise mode, there was variability in the exercise modalities between the selected studies. For example running, cycling, resistance exercises, swimming, rugby and netball (7, 9, 22-26, 28, 30, 31). In addition to variability in modality, exercise durations ranging from 15 to 60 minutes, exercise-induced energy expenditures from 57 to 549 kcal and exercise intensities from 40% to 75% of the participants' maximal capacities were also highly variable between trials.

This systematic review reveals methodological heterogeneities in all components of the study designs. Indeed, the meal type and exercise to meal interval also varied. Although all the included studies proposed *ad libitum* buffet-type meal, the time interval between the exercise bout and the meal varied from 30 minutes (9, 20, 22-26, 28-31) to 80 minutes (7). Difference in timing between the exercise and the subsequent meal was shown to influence EI (32). In addition, most of the proposed buffets excluded preferred items based on food preference questionnaires while some studies used single items such as pizzas (20, 29) or pasta (21) that can represent highly palatable foods for some children. Given the limited number of studies, analyses based on timing and EI protocols were not addressed specifically, but they would warrant further investigation.

The 14 included studies represent a total of 31 different exercise sessions where *ad libitum* EI has been studied after an acute bout of exercise. The present systematic exploration showed that of those 31 exercise conditions, 7 found a significant reduction in EI (7-9, 24-26, 28, 31), only one found increased EI (8) and the large majority (n=23) reported no difference (7-9, 20-23, 25, 26, 28-30). The absence of post-exercise energy consumption modification observed in the majority of the included studies is aligned with the results of our meta-analysis performed on the whole sample, showing no significant effect of acute exercise on energy intake (Figure 2A). However, the analysis also shows that 16 of the 23 experimental conditions showing no change in post-exercise food intake were performed in lean youth (7-9, 20-23, 29, 30). This suggests that body composition or body weight influences the outcome.

Indeed, when considering obese children and adolescents separately, the results are much more ambiguous, with one study showing increased intake (8), 5 showing a decrease (9, 24-26, 31), and 7 showing no difference (8, 25, 26, 28-30). Although our meta-analysis approaches found no significant effect of acute exercise in lean youth, it shows significantly reduced post-exercise food ingestion in obese (Figure 2B). Yet it has already been suggested that changes in post-exercise energy intake are not associated with the volume of energy expenditure-induced by exercise in children and adolescents (11, 26), the intensity of exercise seems to be a key factor (26, 29).

The publications systematically reviewed here proposed a range of intensities form 40% to 75% of the participants' individual maximal capacities. Subgroup meta-analysis were then performed questioning the effect of exercise intensity on subsequent energy intake, by classifying the studies as follows: i) low intensity: <50% maximal capacities; ii) moderate intensity: between 50% and 70% of the maximal capacities; iii) and intensive exercise: >70% maximal capacities. Although the meta-analysis confirmed that an acute bout of exercise (whatever its intensity) does not affect the subsequent *ad libitum* energy intake in lean children and adolescents, intensive exercise (but not moderate or low intensity exercises) has been shown to significantly reduce post-exercise food consumption in obese youth. This confirms what was previously suggested by narrative reviews (10) based on strongly designed RCT comparing isoenergetic low and high intensity exercises and showing decreased energy intake only after the intensive exercise (26). This is also in line with results obtained in adults where intensive exercise has been shown to decrease energy intake in lean and overweight/obese subjects compare to exercises of lower intensities (33, 34). According to the authors, this intensity-dependent reduction in energy intake was explained by significantly higher post-exercise concentrations of some anorexigenic gastro-peptides such as CCK and GLP-1 (33).

None of the studies included for analysis here assessed appetite-regulating hormones. We found only one study that simultaneously measured post-exercise energy intake and appetite-hormones in obese adolescents to date (35). In their work Prado and colleagues asked 9 obese girls to perform a 30-minute treadmill exercise set at their ventilatory threshold; leptin and $PYY_{3-36}$ concentrations were assessed as well as appetite feelings, before, 30 minutes and 150 minutes post-exercise (35). Although leptin concentrations were not modified, which is not surprising since this adipokine is mainly involved in the long term control of energy intake, the authors observed a significant increase in circulating $PYY_{3-36}$ concentrations 30 minutes after exercise. Although the authors concluded that an acute bout of intensive exercise favors a transient anorexigenic effect in obese adolescent girls (35), they used a 24-hr diary record to assess self-reported energy intake, which limits their interpretations and conclusion (36).

Although the post-exercise modifications of appetite-regulating hormones are mainly mentioned to explain these different nutritional responses between lean and obese children and adolescents, neurocognitive factors should also be considered. Some recent studies effectively pointed out the role of weight status and body composition on the neural control of energy intake, with higher neural responses to food cues observed in overweight/obese youth compared with lean once (37, 38).

Interestingly, an acute exercise has been recently showed to decrease the neural response to food stimuli in obese adolescent boys, which was accompanied by a reduce food intake at the following meal (39), which is not observed in lean adolescents (ongoing data).

No meta-analysis was performed in this work to determine the impact of acute exercise on macronutrients intake because only a few studies assessed macronutrient repartition at a meal that follows acute exercise in children and adolescents. However, the systematic review indicated that children and adolescents do not alter the macronutrient composition of their meal in response to acute exercise (9, 22, 24-26, 28, 30). Only 2 reported a change in fat (23, 31) or protein and CHO (31). This has obviously to be interpreted with caution and further studies assessing post-exercise macronutrient intake are obviously needed.

Similarly, absolute post-exercise energy intake only was considered for analysis in this work since only one study reported relative energy intake (REI=EI-ExEE) (20) and the other included studies did not clearly indicate exercise- and/or resting-induced energy expenditure.

Several other important limitations have to be considered when interpreting the present analysis. First, the important heterogeneity revealed by our systematic approach regarding the methodologies used. While the literature is limited on this topic, studies use a large range of exercise modalities or intensities making any comparison difficult. This is also true when it comes to the characteristics of the meal with a wide range of delays between the end of the exercise and the weighted meal between trials or the composition of the meal. As previously highlighted, there is a need for more standardized procedures between research teams to allow comparison between studies (10, 40). The most critical limitation might be the lack of powered studies to detect significant effect of acute exercise, with studies enrolling from 7 to 22 participants in their groups. Finally, the lack of data regarding the important inter-individual variability in the energy intake response to exercise in children and adolescents must be considered here. Although this variability has been highlighted in adults in response to acute exercise (41), it has been only discussed in response to chronic physical activity in obese adolescent boys (42) and acute analysis must be performed in the future.

**Conclusion**

The present systematic review and meta-analysis reveals that an acute bout of exercise, when performed at high intensity (above 70% of individual capacities) favors reduced energy consumption in obese children and adolescents without altering the qualitative composition of the meal (in terms of macronutrient repartition). Since several methodological limitations have been highlighted, and particularly an important heterogeneity in the methods employed, additional well-controlled trials specially designed and powered to detect post-exercise energy intake modification in youth have to be encouraged. Future studies should consider energy expenditure by providing relative energy intake and absolute results, and report the energy consumed derived from each macronutrient relatively to total energy consumed (in percentage of total energy intake). Finally, although studying the effect of acute exercise on subsequent food consumption in children and adolescents is recent, it seems today necessary to explore the physiological mechanisms involved.

**Acknowledgements**

TD as the first author initiated the paper and wrote the first version of the manuscript. BP and TD were in charge of the statistical analysis. TD, RPL, MEM, NK and BJE led the writing process and helped in the redaction of the paper. The authors have no conflict of interest to declare.

**Conflict of Interest**: The authors have no conflicts of interest to disclose. The authors have no financial relationships relevant to this article to disclose.

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**Figure legends**

**Figure 1.** Flow diagram of the description of the screening, selection and inclusion process

**Figure 2.** (A) Effect size forest plot for absolute energy intake in both lean and obese youth (mean ± 95% confidence intervals); (B) Effect size forest plot for absolute energy intake in obese youth, depending on the exercise intensity (mean ± 95% confidence intervals).