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REVIEW ARTICLE

Prevention and treatment of childhood and adolescent obesity: a systematic review of meta-analyses

Theodora Psaltopoulou[1] · Stamatios Tzanninis[2] · Ioannis Ntanasis-Stathopoulos[3] · George Panotopoulos[4] · Myrto Kostopoulou[1] · Ioannis-Georgios Tzanninis[2] · Anastasia Tsagianni[5] · Theodoros N. Sergentanis[1]

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Abstract

Background The goal of this systematic review is to synthesize the published meta-analyses assessing the role of nutritional, behavioral and physical activity factors/interventions on the prevention or treatment of pediatric and adolescent obesity.

Methods An online search was conducted in PubMed (end-of-search: September 30, 2015); English-language meta-analyses pooling observational and/or interventional studies examining weight-related indices on children and adolescents were included.

Results Sixty-six meta-analyses corresponding to more than 900,000 children and adolescents were retrieved. The majority of meta-analyses included interventional studies most of which referred to mixed or combined interventions, including components such as diet, physical activity and sedentary behavior reduction. Discrepancies between meta-analyses on observational and interventional studies were noted. Combined interventions including physical activity and nutritional modifications seemed to represent the most effective means for tackling childhood obesity.

Conclusions Synthesis of interventional or observational evidence may yield discrepant results. The combination of enhanced physical activity and improved nutrition emerged as a promising intervention in the fight against childhood/adolescent obesity. However, further research is needed about the most effective multidimensional prevention strategy.

Keywords Childhood obesity · Diet · Meta-analysis · Physical activity · Systematic review

Introduction

According to the World Health Organization, overweight and obesity are defined as the abnormal and the excessive fat accumulation, respectively, that may impair health [1]. A child or adolescent is considered overweight if it is above the 85th percentile and obese if it is above the 95th percentile [2]. Childhood and adolescence obesity has skyrocketed during the latest decades and has become extremely prevalent in the developed world leading to a modern "obesity epidemic" [3]. Four out of ten children in North America, in Europe, and almost three out of ten in the western Pacific were predicted to have abnormally high weight by 2010 [4]. Childhood obesity is associated with various morbidities later in life such as adulthood obesity [5] and diabetes mellitus [6]. The subsequent health consequences [7–9] including the increased mortality risk [10] are currently considered among the major public health challenges [2, 7, 11].

To tackle this progressing problem, a great number of trials, meta-analyses and systematic reviews have been

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✉ Theodora Psaltopoulou
tpsaltop@med.uoa.gr

1 Department of Hygiene, Epidemiology and Medical Statistics, School of Medicine, National and Kapodistrian University of Athens, 75, M. Asias Str, 115 27 Athens, Greece

2 Department of Medicine, University Hospital Southampton NHS Foundation Trust, Southampton, UK

3 Department of Clinical Therapeutics, School of Medicine, National and Kapodistrian University of Athens, Athens, Greece

4 Hellenic Association for the Study of Obesity, Metabolism and Eating Disorders (HASOMED), Athens, Greece

5 Division of Internal Medicine, University of Pittsburgh Medical Center (UPMC), Pittsburgh, PA, USA

published. Many interventions including diet, increase in physical activity and behavioral modifications have been proposed either separately or combined [12, 13]. Given that high quality metaanalyses play a central role in shaping "level A" grades of recommendations [14], the present systematic review focuses especially on the published meta-analyses that summarized observational and/or interventional evidence on nutritional, physical activity and behavioral factors regarding the prevention and/or treatment of childhood and adolescent obesity. Drug interventions were beyond the scope of the present study.

Methods

Search strategy and eligibility of studies

The present systematic review was performed following the guidelines of the PRISMA statement [15]; the PRISMA Checklist is provided as supplementary material. A systematic search was conducted in PubMed (end-of-search: September 30, 2015) using the following search algorithm: (child OR childhood OR children OR adolescent OR adolescents OR puberty OR pubertal) AND (obese OR obesity OR overweight OR "body mass") AND (diet OR dietary OR nutrition OR nutritional OR eating OR food OR foods OR protein OR proteins OR lipid OR lipids OR fat OR fats OR macronutrient OR macronutrients OR micronutrient OR micronutrients OR vitamin OR vitamins OR milk OR dairy OR fruit OR fruits OR vegetable OR vegetables OR meat OR poultry OR fish OR grain OR grains OR legumes OR juice OR breakfast OR dinner OR water OR alcohol OR beverage OR beverages OR coffee OR tea OR chocolate OR sweet OR sweets OR exercise OR "physical activity" OR sedentary) AND (meta-analysis OR meta-analyses OR "systematic review"). A detailed list of nutritional terms was included due to the anticipated heterogeneity of nutritional terminology that is applied across the studies in contrast to studies regarding physical activity. Studies pertaining exclusively to behavioral changes were anticipated to be included in the search results since the vast majority of behavioral interventions concern either dietary modifications or physical activity or sedentary life interventions. Subsequently, the reference lists of the retrieved articles were searched in a "snowball procedure", to include further eligible articles in this review.

Inclusion criteria were as follows: (1) the study had to be a meta-analysis published in English language; (2) meta-analyses synthesizing interventional as well as observational studies were deemed eligible; (3) the study subjects or a fraction of them should be children and adolescents according to the age range definition provided by each study separately and there should be a specific subgroup analysis for this age range; (4) if the intervention/exposure was multifactorial, it should include at least a modification of one diet-related or physical activity-related factor. These included also behavioral modifications on parents/children aiming at nutrition/dietary modifications of children, increase in physical activity and sedentary life reduction; (5) the outcome should pertain to the prevention or treatment of obesity [in terms of weight change, body mass index (BMI), *Z* scores, overweight/obesity status, fat mass reduction, central obesity]. Although we acknowledge the inherent limitations of assessing each of the abovementioned obesity indices separately, we opted to include all the relevant studies to provide a more complete overview of the available evidence and formulate enhanced directions for future research. Proxy outcomes such as eating habits, quantity of meals, etc., were not included; (6) meta-analyses examining surgical or drug-related interventions for obesity were not included. Two reviewers (ST and MK) independently performed the selection of studies; in case of disagreement, final decision was reached by team consensus.

Data extraction and effect estimates

The extraction of data comprised the first author's name, publication year, description of the population, time frame and eligibility criteria regarding the studies included in each meta-analysis, type and description of the intervention/exposure as well as the corresponding outcomes, number of studies/subjects, and the results of each meta-analysis. Effect estimates yielded by random effects models were preferred over the fixed-effect ones, due to the superiority of the first in accommodating the heterogeneity. Studies describing provision of meals or implementation of specific physical activity programs were referred to as "actual" interventions, whereas studies concerning behavioral or educational interventions were allocated in the corresponding subcategory. Regarding physical activity interventions, "actual" were considered those interventions pertaining to specific exercise programs implementation such as those in the context of the school curriculum, whereas the remaining interventions such as the family-based ones were included in the behavioral and educational groups.

If the required data for the review were not readily available in the published article, the corresponding authors were contacted twice (a reminder e-mail was sent after the first e-mail). Two reviewers (ST and MK) independently performed data abstraction, and, in case of disagreement, final decision was reached by team consensus.

Results

Description of eligible studies

The flowchart describing the subsequent steps of the selection of eligible studies is presented as a

Supplementary Fig. 1. Through the algorithm, 933 articles were retrieved, among which 711 were considered irrelevant to the present topic and 154 were relevant but were not meta-analyses. Four studies [16–19] were excluded due to overlap with more updated articles by the same research teams [20–23]. In particular, a Cochrane meta-analysis [16] was updated [21] in 2009, a report by Wang et al. [17] overlapped with a newer study by the same team [20], the Cochrane report [18] by Langford et al. overlapped with a newer article [22] and the study by Collins et al. [19] was excluded due to overlap with another more recent study [23] by the same authors. One meta-analysis was excluded due to language [24], one due to insufficient data regarding children and adolescents [25] and another one because it was a letter to the editor [26]. Two corresponding authors replied and provided further data for their studies [27, 28]. After adding five articles from the snowball procedure [29–33], 66 articles were finally included in the review [20–23, 27–88].

Dietary factors and interventions (Table 1, Supplementary Table 1)

Meta-analyses including only non-interventional studies

Increased dietary energy density (DED) is a relatively new parameter associated with obesity [89]. It is calculated by dividing total food energy (kJ) by total food weight (g) excluding beverages. A meta-analysis [41] of six cross-sectional studies including 6800 children in the age group of 4–11 years showed a marginal positive correlation between DED and children's fat mass index (FMI = fat mass in kg/height in m^2) [change in FMI = 0.064, 95% confidence interval (CI) 0.01–0.11, $P = 0.013$]. However, the results became statistically non-significant when they were adjusted for internal and external biases.

The impact of meal frequency on childhood obesity has been the topic of two meta-analyses [28, 46]. Hammons et al. [46] analyzed eight studies with 44,016 children and suggested that having three or more family-shared meals per week reduced the possibility of a child becoming obese by 12% in comparison with those that consumed less than three family meals per week. Similar results came up from Kaisari et al. [28] who investigated the total number of meals/eating episodes consumed on a daily basis on 18,849 children and adolescents. An inverse association between eating frequency and overweight/obesity status emerged, increased eating frequency, as compared with the lowest category, was associated with 22% lower likelihood of being overweight/obese [log(odds ratio) = − 0.24, 95% CI − 0.41 to − 0.06].

Meta-analyses including interventional studies with actual interventions

Two meta-analyses [23, 27] pooling the effects of dietary randomized controlled trials (RCTs) concluded that diet alone could produce significant weight loss and reduce many obesity-related outcomes in children and adolescents. These effects were observed among children above 5 years of age and adolescents. Collins et al. [23] found that these outcomes were not only reduced [standardized mean difference (SMD) = − 1.82, 95% CI − 2.40 to − 1.23, $P < 0.001$], but also the result could be maintained during the follow-up, to a lesser extent (SMD = − 0.64, 95% CI − 0.89 to − 0.39, $P < 0.001$). However, some dietary interventions with active components did not achieve statistically significant results [22, 45], others' results were marginally clinically significant [47] and some meta-analyses had a limited number of included studies to provide a safe conclusion [88].

Meta-analyses including interventional studies with behavioral and/or educational interventions

Nutritional education alone [36] yielded a mean BMI reduction of 0.33 kg/m^2 (95% CI − 0.55 to − 0.11) in a meta-analysis including eight RCTs and 8451 participants. Despite that, the majority of dietary behavioral modification studies did not show any statistically significant effect on various weight-related outcomes [40, 44, 48, 80, 83, 84].

Meta-analyses including both interventional and non-interventional studies

Forshee et al. [51] found a very weak association between the sugar-sweetened beverages' (SSB) consumption and children and adolescents BMI [effect size (ES) = 0.017 kg/m^2 change in BMI (95% CI − 0.009 to 0.044) during the time period defined by the study for each serving per day change in SSB consumption]. Another meta-analysis [58] with the same topic indicated that SSBs could cause weight gain: one daily serving of SSBs could lead to a 0.06-unit increase in BMI (95% CI 0.02–0.10) over a year's period, and a 0.07-unit increase in BMI (95% CI 0.01–0.12) over the time period of each study, whereas replacing SSBs with non-caloric beverages could induce a reduction in BMI of about 0.34 kg/m^2 (95% CI − 0.50 to − 0.18). However, another meta-analysis [42] did not find any correlation between dietary sugars and children's BMI/BMI-*Z* score.

High frequency of cereal consumption [43] seemed to be associated with lower BMI and BMI-*Z* scores (ES = − 1.13 units; 95% CI − 0.81 to − 1.46, $P < 0.0001$) and may halve the possibility of becoming overweight.

Another meta-analysis [71] regarding the efficacy of nutritional school programs and policies including children

Table 1 Characteristics and main results of the eligible meta-analyses regarding dietary factors and interventions

Author (year)	Description of the population, age (y)	Time frame	Topic (exposure/intervention—outcome)	Description of intervention/exposure	Number of studies included	Number of subjects included	Main results
Only non-interventional studies							
Hammons et al. (2011) [46]	2.8–17.3	No year restrictions	Frequency of shared family mealtimes—weight change	Number of family members present for the meal Frequency of regular family dinners	8	44,016	Pooled OR = 0.88 (95% CI 0.81–0.97)
Kaisari et al. (2013) [28]	2–19	Until 10/2011	Eating frequency—overweight/obesity status	Self-reported questionnaires; 24-h dietary recalls	11	18,849	log(OR) for increased eating frequency = − 0.24 (95% CI − 0.41 to − 0.06)
Wilks et al. (2011) [41]	4–11	Up to 01/09/2008	Dietary energy density—change in FMI	Food diaries, 24 h recalls or a food frequency questionnaire or by 7 day weighed food diaries	6	6800	Change in FMI of 0.064 kg/m^2 (95% CI 0.01–0.11, $P = 0.013$)
			Dietary energy density—change in FMI	Adjusted for internal and external bias	6	6800	Change in FMI = 0.17 kg/m^2 (95% CI − 0.11 to + 0.45; $P = 0.24$)
Only interventional studies–actual interventions							
Clark (2015) [27]	6–18	01/01/1980–31/01/2014	Diet only (therapeutic effect)—body mass (kg)	Diet: manipulation of macronutrients and reduced calories Physical activity: aerobic, endurance, strength/resistance exercise or combinations	32	3523	ES = − 1.56 (95% CI − 1.95 to − 1.17)
			Diet only (therapeutic effect)—fat mass (kg)				ES = − 3.32 (95% CI − 3.51 to − 2.62)
			Diet only (therapeutic effect)—fat-free mass (kg)				ES = − 0.49 (95% CI − 1.07 to 0.095)
			Diet only (therapeutic effect)—BMI (kg/m^2)				ES = − 2.44 (95% CI − 2.91 to − 1.98)
Collins et al. (2007) [23]	Children < 18	1975–2003	Nutritional/dietary advice interventions–weight-related outcomes post-intervention	The most commonly used diet was the traffic light diet or variations of it. The weight-related outcomes of the interventions were BMI, BMI percentile, % overweight for age, waist measurements and body composition	8	646	SMD = − 1.82 (95% CI − 2.40 to − 1.23), $P = 0.00001$
			Nutritional/dietary advice interventions—weight-related outcomes after a period of follow-up		4	268	SMD = − 0.64 (95% CI − 0.89 to − 0.39), $P = 0.00001$

Table 1 (continued)

Author (year)	Description of the population, age (y)	Time frame	Topic (exposure/intervention—outcome)	Description of intervention/exposure	Number of studies included	Number of subjects included	Main results
Hooper et al. (2015) [88]	12–17	Up to 11/2014	Reduced fat diet versus usual fat diet—change in BMI	Exposures for cohort studies: total fat intake, in grams or as a percentage of dietary energy intake, had to be assessed at baseline and related to a measure of body fatness, or change in body fatness, at least a year later	1	191	WMD = −1.50 (95% CI −2.45 to −0.55), $P = 0.0020$
Katz et al. (2008) [47]	3–18	1966–10/2004	Single nutrition intervention—body weight	Nutrition intervention	1	644	SMD = 0.39 (95% CI 0.23–0.56, $P < 0.05$)
Langford et al. (2015) [22]	4–18	Up to April 2013	Nutrition—BMI	The World Health Organization Health Promoting School (WHO HPS) framework	1	843	WMD = −0.04 (95% CI −0.28 to +0.20), $P = 0.74$
			Nutrition—BMI-*Z* score		1	843	WMD = −0.01 (95% CI −0.09 to +0.07), $P = 0.80$
Luckner et al. (2012) [45]	0–18	Up to 6/11/2008	Nutrition—BMI (FEM)	Interventions that promote healthy weight (defined as reduction in BMI or percentage body fat) in general populations	1	103	WMD = −0.14 (95% CI −0.55 to 0.27)
Only interventional studies—behavioral or/and educational interventions							
Friedrich et al. (2012) [44]	4–19	1998–08/2010	Intervention programs using nutritional education—BMI (FEM)	Physical activity and nutritional education interventions such as encouragement of healthy dietary habits through presentations and didactic materials or interventions	2	3524	SMD = −0.03 (95% CI −0.10 to 0.04)
Kamath et al. (2008) [40]	2–18	Until 02/2006	Dietary modifications—BMI	Dietary interventions = interventions focused on increasing healthy dietary behaviors and/or decreasing unhealthy dietary behaviors	7		SMD = −0.04 (95% CI −0.16 to +0.08)
McGovern et al. (2008) [48]	2–18	Until 02/2006	Diet only—body weight	Reduced glycemic load (carbohydrates < 50 g), 2 diet counseling sessions	6	259	Pooled effect across all diets = −0.22 (95% CI −0.56 to +0.11)

Table 1 (continued)

Author (year)	Description of the population, age (y)	Time frame	Topic (exposure/intervention—outcome)	Description of intervention/exposure	Number of studies included	Number of subjects included	Main results
Peirson et al.[a] (2015) [83]	Children < 18	01/2010–08/2013	Diet—BMI, BMI-Z score	Behavioral modifications included diet, exercise, and social support or lifestyle strategies alone or in combination, aiming at weight gain prevention and lasting for at least 12 wk	15	11,568	SMD = –0.08 (95% CI –0.17 to + 0.01)
Peirson et al.[b] (2015) [84]	2–18 with BMI > 85th percentile	10/06/2008–28/08/2013	Behavioral interventions (diet only)—BMI, BMI-Z score	Behavioral interventions included diet, exercise, lifestyle strategies	2	270	SMD = –0.36 (95% CI –0.65 to –0.06)
Silveira et al. (2013) [36]	5–18	Until 05/2012	School-based nutrition education—BMI	Educational games, classroom activities, school nutrition policy, parental involvement, social marketing and environmental changes	8	8451	ES = − 0.33 (95% CI − 0.55 to − 0.11), $P = 0.003$
van Hoek et al. (2014) [80]	3–8; overweight or obese	Up to 04/2012	Nutritional education: very low intensity—BMI-Z score	Nutritional education as part of a multidisciplinary approach	2	103	ES = − 0.46 (95% CI − 0.94 to + 0.02)
Both non-interventional and interventional studies							
de la Hunty et al. (2013) [43]	Children < 18	1990–2012	Breakfast cereal consumption—BMI, BMI-Z scores	Measurement of cereal consumption: 7-d weighed intakes, diet history, 7-d food record, 14-d food diaries, yearly 3-d food record, 24-h recall + frequency of RTEC consumption, semi-quantitative FFQ	9	20,119	ES = –1.13 units (95% CI –0.81 to –1.46), $P < 0.0001$
			Breakfast cereal consumption—BMI, BMI-Z scores	After removal of the study with the largest effect size	8	19,516	ES = – 0.98 units (95% CI –1.29 to –0.66), $P < 0.0001$
			Breakfast cereal consumption—prevalence of obesity		7	16,811	The risk of overweight was reduced by 10% and up to 50% when consuming breakfast cereals regularly
Dror (2014) [76]	2–19	01/01/1966–01/08/2013	Dairy consumption (children + adolescents)—adiposity	24 h or 48 h diet recall, parental interview about the type of milk consumed, 3-d food records, NHANES 1999–2004, FFQ	22		ES = − 0.07 (95% CI − 0.32 to + 0.18), $P = 0.59$
			Dairy consumption (adolescents only)—adiposity				ES = − 0.26 (95% CI − 0.38 to − 0.14), $P < 0.0001$

Table 1 (continued)

Author (year)	Description of the population, age (y)	Time frame	Topic (exposure/intervention—outcome)	Description of intervention/exposure	Number of studies included	Number of subjects included	Main results
Forshee et al. (2008) [51]	Children < 19	1966–10/2006	Sugar-sweetened beverages (SSBs) consumption—BMI (FEM)	Quantities of SSBs consumed	10	15,679	ES = 0.004 kg/m^2 (95% CI − 0.006 to 0.014) change in BMI for each serving per day change in SSB consumption
			SSBs' consumption—BMI (REM)		10	15,679	ES = 0.017 (95% CI − 0.009 to 0.044) change in BMI for each serving per day change in SSB consumption
			Serving of SSB—BMI change over time		10	15,679	ES = 0.03 (95% CI − 0.01 to 0.07) change in BMI per serving of SSB, $P = 0.001$
Malik et al. (2013) [58]	0–18	1947–03/2013	1-Serving/d increase in sugar-sweetened beverages—1-y changes in BMI (REM)	One daily serving increment of SSBs (each additional daily 12-oz serving of SSBs over a 1-y period)	7	16,004	Increase in BMI by 0.06 kg/m^2 (95% CI 0.02–0.10)
			1-Serving/d increase in sugar-sweetened beverages—1-y changes in BMI (FEM)		7	16,004	Increase in BMI by 0.05 kg/m^2 (95% CI 0.03–0.07), $P = 0.002$
			1-Serving/d increase in SSBs during the time period of each study—changes in BMI (REM)		15	25,745	Increase in BMI by 0.07 kg/m^2 (95% CI 0.01–0.12)
			1-Serving/d increase in SSBs during the time period of each study—changes in BMI (FEM)		15	25,745	Increase in BMI by 0.16 kg/m^2 (95% CI 0.15–0.16)
			RCTs (intervention reducing sugar-sweetened beverages versus control)—BMI (REM)		5	2772	WMD = − 0.17 kg/m^2 (95% CI − 0.39 to + 0.05)
			RCTs (intervention reducing sugar-sweetened beverages versus control)—BMI (FEM)		5	2772	WMD = − 0.12 kg/m^2 (95% CI − 0.22 to − 0.20), $P = 0.003$
Te Morenga et al. (2012) [42]	Children	Up to 12/2011	Increase of dietary sugars—BMI, BMI-*Z* score	Participants in the ad libitum studies were advised to decrease or increase sugars, or foods and drinks containing sugars without strict attempt at weight control	5	12,317	OR = 1.55 (95% CI 1.32–1.82)
			Decrease of dietary sugars—BMI, BMI-*Z* score		5	2968	ES = 0.09 (95% CI -0.14 to + 0.32), $P < 0.01$

Table 1 (continued)

Author (year)	Description of the population, age (y)	Time frame	Topic (exposure/intervention—outcome)	Description of intervention/exposure	Number of studies included	Number of subjects included	Main results
Williams et al. (2013) [71]	4–11	Up to 06/2011	School Breakfast Program (SBP) intervention—BMI, BMI-SDS	SBP according to the latest Dietary Guidelines for Americans; more whole grains offered zero grams of trans fat per portion and appropriate calories, more fruit, sodium reduction	5	23,684	WMD = −0.08 (95% CI: −0.14, −0.02), P = 0.007
			National School Lunch Program (NSLP) intervention—BMI-SDS	NSLP increased availability of fruits, vegetables, and whole grains in the school menu; age-appropriate meals; gradual sodium reductions	4	22,889	WMD = +0.04 (95% CI −0.19, +0.27), P = 0.001
			Other diet-related policies—BMI-SDS	Removing low nutrient, energy-dense foods, fried potato products, desserts and whole or 2% milk from cafeterias, available fruits and vegetables, children being prevented from eating any food at break periods and attending a school with a nutrition policy	4	3147	WMD = −0.02 (95% CI −0.07, +0.02), P = 0.954

OR odds ratio, *CI* confidence interval, *FMI* fat mass index, *BMI* body mass index, *ES* effect size, *WMD* weighted mean difference, *SMD* standardized mean difference, *FEM* fixed effects model, *RTEC* ready-to-eat cereals, *FFQ* food frequency questionnaire, *NHANES* National Health and Nutrition Examination Survey, *REM* random effects model

4–11 years old did not show any significant results, except for the implementation of the School Breakfast Program according to the Dietary Guidelines for Americans [weighted mean difference (WMD) = −0.08 (95% CI −0.14 to −0.02)]; however, the results suffered from a significant degree of heterogeneity among the pooled studies. Finally, no association was found between dairy product consumption and adiposity-related outcomes in children [76]; nevertheless, an inverse relation appeared (ES = −0.26, 95% CI −0.38 to −0.14, $P < 0.0001$) in adolescents.

Physical activity-related factors and interventions (Table 2, Supplementary Table 2)

No pure observational meta-analyses were yielded by the search strategy. Regarding interventional approaches, the results are summarized below.

Physical activity: actual interventions

Various exercise intensities and modalities (e.g., aerobic, resistance or a combination of both) have been shown to positively affect body composition [33] by reducing body fat [61, 63, 77] while increasing fat-free mass [59]. Furthermore, body fat percentage was reduced to a greater extent when aerobic activity was combined with resistance exercise (ES = 1.20 ± 0.35, 95% CI 0.34–2.10) than when aerobic activity was implemented alone (ES = 0.58 ± 0.31, 95% CI 0.18–0.90), it was also inversely correlated with the intensity of the program [59] (low intensity ES = 0.97 ± 0.33, 95% CI 0.31–1.90 vs high intensity ES = 0.29 ± 0.10, 95% CI 0.01–0.35). Body fat percentage reduction might be maintained for a significant period of time [60] (ES after 1 year follow-up = 0.84 ± 0.51; 95% CI 0.22–0.94).

Physical activity could often reduce fat mass per se [27, 48, 68, 70] but, on the other hand, the effect on lean mass was not always statistically significant [65, 68, 70, 79]. Physical activity alone often did not have a notable effect on BMI in pediatric and adolescent populations [44, 48, 64, 71, 72, 78]. Only few meta-analyses indicated a significant BMI reduction [22, 57, 79], while others showed that exercise and especially resistance exercise could even increase it [27, 59, 68]. As for absolute body weight, the results were mixed as well. There was absolute weight loss in two meta-analyses [47, 79], whereas some showed that physical activity could cause weight gain [27, 47, 59] especially when resistance training was included [68] and others showed no effect at all [27, 61, 63, 73]. Two meta-analyses referred to waist circumference but the results were not statistically significant [68, 79]. Furthermore, it has to be noted that most of the eligible meta-analyses in this category reported on studies whose participants were above 4 years old; thus the results should be extrapolated with caution to younger ages.

Physical activity: behavioral and/or educational interventions

The meta-analysis of Katz et al. [47] showed diversity between the effects of behavioral interventions targeting increase in physical activity. In populations including both sexes, there was an increase in absolute weight in kilograms (SMD = 1.87, 95% CI 1.31–2.42); in girls' population, absolute weight slightly fell (SMD = −0.38, 95% CI −0.74 to −0.02), whereas in boys' population it was not affected significantly (SMD = −0.14, 95% CI −0.17 to 0.44). Luckner et al. [45] investigated the effects of exercise-promoting educational interventions in the general population which significantly reduced both BMI (WMD = −0.15, 95% CI −0.34 to 0.04) and body fat percentage (WMD = −0.7, 95% CI −1.05 to −0.31) in subjects up to 18 years old. It should be noted, however, that such physical activity interventions based solely on behavioral/educational modification often failed to elicit significant results [40, 83] and, in addition, the number of eligible studies included in some of the meta-analyses was very limited [47, 80, 84].

Combination of physical activity and dietary interventions (Table 3—upper panels, Supplementary Table 3)

Two meta-analyses [32, 59] including participants aged above 5 years found that interventions combining diet and exercise yielded a better outcome when compared to exercise-only interventions or a no-intervention group. However, the same combination was not proven to be superior to diet alone [38]. Resistance training alone or added to diet increased lean body mass over a period of 4 months compared to diet only (pooled difference = 0.44 kg, 95% CI 0.04–0.84), and reduced body fat percentage more, in comparison with diet-only interventions (pooled difference = −2.73%; 95% CI −4.38 to −1.09) [38]. In turn, Clark [27] showed that the combination of diet with resistance and endurance exercise could cause a remarkable decrease in fat mass and in BMI among children older than 5 years and adolescents.

School-based combined interventions were also effective in reducing multiple obesity-related indices [56] ($r = 0.128$, 95% CI 0.126–0.171, $P < 0.001$) and especially BMI according to Lavelle et al. [57] (overall BMI reduction = −0.17 kg/m^2, 95% CI −0.29 to −0.06, $P < 0.001$) and Wang et al. [20] (overall BMI reduction = −0.30 kg/m^2, 95% CI −0.45 to −0.15). School-based combined interventions also reduced absolute body weight in kilograms [47] in mixed boys' and girls' populations (SMD = −0.29 kg, 95% CI −0.45 to −0.14, $P = 0.0002$).

Combined interventions with or without family participation might reduce multiple obesity-related outcomes

Table 2 Characteristics and main results of the eligible meta-analgarding physical activity-related factors and interventions

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
Actual interventions							
Atlantis et al. (2006) [61]	Children < 18; overweight	1966–2004	Exercise—percent of body fat (REM)	≥ 1 exercise or physical activity treatment arm either in isolation or as an adjunct	9	369	SMD = − 0.4 (95% CI − 0.7 to − 0.1), $P = 0.006$
			Exercise—percent of body fat	After removing 3 studies with low- frequency exercise	6		SMD = − 0.6 (95% CI − 0.8 to − 0.3), $P < 0.001$
			Exercise—percent of body fat	After removing 2 studies which included weight training	7		SMD = − 0.5 (95% CI − 0.8 to − 0.1), $P = 0.003$
			Exercise—body weight (REM)		11	334	WMD = − 2.7 (95% CI − 6.1 to + 0.8), $P = 0.07$
			Exercise—body weight	After removing 6 studies with low-frequency exercise	5		WMD = − 4.9 kg (95% CI − 9.1 to − 0.7), $P = 0.01$
			Exercise—body weight	After removing 4 studies which included weight training	7		WMD = − 3.1 kg (95% CI − 6.1 to − 0.1 kg), $P = 0.02$
			Exercise—central obesity-related outcomes (FEM)		4	156	SMD = − 0.2 (95% CI − 0.6 to + 0.1), $P = 0.07$
Beets et al. (2009) [33]	Children < 18	1980–02/2008	Physical activity—body composition	Physical activity: reports of bodily movement related to moderate physical activity Body composition: BMI, %fat, waist circumference, fat mass, fat-free mass, skinfold thickness	10	3150	ES = 0.075 (95% CI 0.03 to 0.12)
Cesa et al. (2014) [78]	6–12	Up until 06/2013	Physical activity—BMI	Any physical activity program lasting ≥ 6 mon, with ≥ 150 min per wk as compared to a less intensive program or no intervention	9	10,355	ES = − 0.02 (95% CI − 0.16 to + 0.13), $P = 0.83$
Clark (2015) [27]	6–18	January 1980–January 2014	Endurance exercise only (therapeutic effect)—body mass (kg)	Aerobic exercise at various intensities, endurance or strength/resistance exercise or combinations	32	3523	ES = − 0.40 (95% CI − 0.93 to + 0.13)

Table 2 (continued)

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
			Resistance exercise only (therapeutic effect)—body mass (kg)				ES = −0.63 (95% CI −1.33 to 0.06)
			All exercise (therapeutic effect)—body mass (kg)				ES = −3.16 (95% CI −3.46 to −2.86)
			Endurance exercise only (therapeutic effect)-fat mass (kg)				ES = −0.49 (95% CI −0.87 to −0.11)
			Resistance exercise only (therapeutic effect)—fat mass (kg)				ES = −1.02 (95% CI −1.66 to −0.38)
			All exercise (therapeutic effect)—fat mass (kg)				ES = −5.45 (95% CI −6.03 to −4.87)
			Endurance exercise only (therapeutic effect)—fat-free mass (kg)				ES = 0.48 (95% CI −0.05 to 1.02)
			Resistance exercise only (therapeutic effect)—fat-free mass (kg)				ES = 0.54 (95% CI 0.20 to 0.88)
			All exercise (therapeutic effect)—fat-free mass (kg)				ES = 0.23 (95% CI −0.08 to 0.54)
			Endurance exercise only (therapeutic effect)—BMI (kg/m^2)				ES = −0.86 (95% CI −1.34 to −0.40)
			Resistance exercise only (therapeutic effect)—BMI (kg/m^2)				ES = 0.57 (95% CI −0.95 to 2.08)
			All exercise (therapeutic effect)—BMI (kg/m^2)				ES = 5.07 (95% CI 4.49 to 5.65)
Dobbins et al. (2013) [67]	6–18	Until 10/2011	School-based interventions—BMI (secondary outcome)	The interventions were targeted primarily within the school setting. The interventions were implemented by a variety of professionals or parents	32	27,567	ES = −0.55 (95% CI −1.0 to −0.1)
Friedrich et al. (2012) [44]	4–19	1998–08/2010	Physical activity—BMI (FEM)	Physical activity interventions	5	4172	SMD = −0.02 (95% CI −0.08 to +0.04), P = 0.46
Garcia-Hermoso et al. (2014) [77]	6–18	Up to September 2013	Aerobic exercise—changes in %body fat (secondary outcome)	Aerobic exercise only	8	327	ES = −0.35 (95% CI −0.57 to −0.13), P = 0.002

Table 2 (continued)

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
Guerra et al. (2013) [72]	6–18	April 2009–September 2012	School-based physical activity—BMI	Interventions included: skipping, dance, resistance training, endurance training circuits, games, recreational athletics, various sports	11	4273	ES = − 0.02 (95% CI − 0.13 to + 0.17), $P = 0.8$
			School-based physical activity—BMI	Stratification by the methodological quality of the studies	8	3869	ES = − 0.03 (95% CI − 0.15 to + 0.21), $P = 0.7$
			School-based physical activity (studies' duration > 9 mon)—BMI		6	2745	ES = 0.005 (95% CI − 0.25 to + 0.24), $P = 0.9$
Harris et al. (2009) [64]	5–18	1966–2008	School-based physical activity interventions—BMI	Fitness sessions, increased intensity of physical activity, decreased inactive time during physical education, high-impact, weight-bearing exercise sessions, aerobic exercise sessions, strength training sessions	20	13,003	WMD = –0.05 (95% CI –0.19 to + 0.10)
Kelley and Kelley (2008) [63]	5–19	1955–2007	Exercise programs—body weight (kg)	Cycle ergometry, walking, jogging, aerobic dance types of activities or a combination of ≥ 3 of the following: walking, jogging, aerobic dance, cycle ergometry, games, and other activities	10		Mean ± standard error of the mean = 1.1 ± 1.5 (95% CI − 1.9 to + 4.0)
			Exercise programs—body fat percentage		5		Mean ± standard error of the mean = − 2.1 ± 0.5 (95% CI − 3.0 to − 1.2)
Kelley et al. (2014) [79]	2–18	01/1990–12/2012	Physical exercise—BMI-Z score	The exercise program for 4 wk or more for 43 min per session for > 16 wk	10	835	ES = − 0.06 (95% CI -0 09 to -0 03), $P < 0.001$
			Physical exercise—body weight (kg)		6	474	ES = − 0.74 (95% CI − 1.18 to − 0.30), $P < 0.001$
			Physical exercise—BMI		8	562	ES = − 0.47 (95% CI − 0.86 to − 0.08), $P = 0.02$
			Physical exercise—fat mass (kg)		5	426	ES = − 0.65 (95% CI − 1.15 to − 0.16), $P < 0.01$
			Physical exercise—body fat%		9	759	ES = − 0.96 (95% CI − 1.43 to − 0.50), $P < 0.001$

Table 2 (continued)

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
			Physical exercise—fat-free mass (kg)		5	148	ES = − 0.07 (95% CI − 0.62 to + 0.48), $P = 0.79$
			Physical exercise—waist circumference		3	377	ES = + 0.27 (95% CI − 2.08 to + 2.62), $P = 0.82$
			Physical exercise—waist-to-hip ratio		2	100	ES = − 0.03 (95% CI − 0.09 to + 0.04), $P = 0.48$
Langford et al. (2015) [22]	4–18	Up to April 2013	Physical activity—BMI	The World Health organization Health Promoting School (WHO HPS) framework	3	1430	WMD = − 0.38 (95% CI − 0.73 to − 0.03), $P = 0.032$
Lavelle et al. (2012) [57]	Children < 18	Up to 21/02/2011	Physical activity—BMI	All of the interventions were conducted on school premises. The duration of the intervention ranged from 1 mon to 6 y, and the maximum length of follow-up was 6 y	11		ES = − 0.13 (95% CI − 0.22 to − 0.04)
LeMura et al. (2002) [59]	5–17	1960–2001	Exercise programs—percentage of body fat	The interventions used exercise as a mode of training (e.g., walking, jogging, cycle ergometry, high repetition resistance exercise, and combinations) and lasted > 3 wk	17		ES = 0.70 ± 0.35 (95% CI + 0.21 to + 1.1)
			Exercise programs—fat-free mass		11		ES = 0.50 ± 0.38; (95% CI + 0.03 to + 0.57)
			Exercise programs—body mass		20		ES = 0.34 ± 0.18; (95% CI + 01 to + 0.46)
			Exercise programs—BMI		19		ES = 0.76 ± 0.55; (95% CI + 0.24 to + 1.7)
			Low intensity of exercise (60–65%)—percentage of body fat		8		ES = 0.97 ± 0.33 (95% CI 0.31 to 1.9)
			Moderate intensity of exercise (66–70%)—percentage of body fat		8		ES = 0.65 ± 0.19 (95% CI 0.27 to 1.1)
			High intensity of exercise (> 71%)—percentage of body fat		8		ES = 0.29 ± 0.10 (95% CI 0.01 to 0.35)
			Duration of exercise ≤ 30 min—percentage of body fat		8		ES = 0.57 ± 0.21 (95% CI 0.14 to 0.71), $P < 0.03$

Table 2 (continued)

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
			Duration of exercise > 30 min—percentage of body fat		9		ES = 0.95 ± 0.27 (95% CI 0.29 to 1.7), $P < 0.03$
			Aerobic exercise only—percentage of body fat		20		ES = 0.58 ± 0.31 (95% CI 0.18 to 0.90)
			Aerobic plus resistance exercise—percentage of body fat		8		ES = 1.20 ± 0.35 (95% CI 0.34 to 2.10)
			Duration of exercise program ≤ 10 wk—percentage of body fat		10		ES = 0.70 ± 0.40 (95% CI 0.36 to 1.1)
			Duration of exercise program > 10 wk—percentage of body fat		9		ES = 0.76 ± 0.30 (95% CI 0.38 to 1.4)
			Exercise only—percentage of body fat		15		ES = 0.36 ± 0.18
Maziekas et al. (2003) [60]	4–17	1960–2001	Exercise intervention (all kinds) immediately—percentage of body fat	Walking, jogging, cycle ergometry, high repetition resistance exercise, and combinations and lasted for ≥ 8 wk	8	236	ES = 1.04 ± 0.35 (95% CI 0.41 to 1.6)
			Exercise intervention (all kinds) after 1 y—percentage of body fat		8	236	ES = 0.84 ± 0.51 (95% CI 0.22 to 0.94)
McGovern et al. (2008) [48]	2–18	Until February 2006	Physical activity only—BMI and %overweight	Physical activity interventions	11	433	ES = − 0.02 (95% CI − 0.21 to + 0.18), $P = 0.49$
			Physical activity only—body fat mass		6	257	ES = − 0.52 (95% CI − 0.73 to − 0.30), $P < 0.00001$
			Physical activity only—overall		17	690	ES = − 0.24 (95% CI − 0.42 to − 0.06), $P = 0.009$
Nogueira et al. (2014) [70]	5–17	Up to 08/2012	Exercise—whole body fat mass	Jumps and nonimpact exercises and aerobic exercise or jumping and circuit training, general moderate-to-vigorous circuit training and combination for 30–80 min, two to five times per week. Control: usual physical education classes	8	1053	SMD = − 0.248 (95% CI − 0.406 to − 0.089)
			Exercise—whole-body lean mass		9	1124	SMD = 0.159 (95% CI − 0.076 to + 0.394)

Table 2 (continued)

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
Schranz et al. (2013) [68]	Children < 18	Up to 30/01/2013	Resistance training (RCTs and NRCTs)—body weight	Resistance training only Resistance training + aerobic training only Resistance training + diet + other interventions	23		SMD = 0.14 (95% CI + 0.01 to + 0.27)
			Resistance training (UCTs)—body weight		15		SMD = 0.18 (95% CI + 0.04 to + 0.32)
			Resistance training (RCTs and NRCTs)—BMI		22		SMD = 0.16 (95% CI + 0.01 to + 0.30)
			Resistance training (UCTs)—BMI		16		SMD = 0.32 (95% CI + 0.18 to + 0.45)
			Resistance training (RCTs and NRCTs)—waist girth		13		SMD = 0.36 (95% CI + 0.17 to + 0.55)
			Resistance training (UCTs)—waist girth		2		SMD = 0.12 (95% CI − 0.30 to + 0.55)
			Resistance training (RCTs and NRCTs)-percentage of body fat		17		SMD = 0.24 (95% CI + 0.09 to + 0.39)
			Resistance training (UCTs)-percentage of body fat		19		SMD = 0.53 (95% CI + 0.40 to + 0.66)
			Resistance training (RCTs and NRCTs)-fat mass		12		SMD = 0.20 (95% CI -0.01 to + 0.41)
			Resistance training (UCTs)-fat mass		9		SMD = 0.42 (95% CI + 0.19 to + 0.65)
			Resistance training (RCTs and NRCTs)-lean/fat-free mass		17		SMD = 0.05 (95% CI − 0.11 to + 0.22)
			Resistance training (URCTs)-lean/fat-free mass		10		SMD = 0.14 (95% CI − 0.05 to + 0.33)
Vasques et al. (2014) [56]	Children < 19	2000–2011	School- and after-school-based intervention programs—weight-related outcomes	Interventions aimed to increase the levels of physical activity by adapting the school curriculum and providing an effective increase in time spent in physical activity and sport practices, both at school and during leisure time	52	28,236	Overall: $r = 0.068$ (95% CI: 0.058 to 0.079), $P < 0.001$
			Physical activity—weight-related outcomes		17		$r = 0.029$ (95% CI 0.003 to 0.055), $P = 0.027$

Table 2 (continued)

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
			Minimal frequency of physical activity—weight-related outcomes		19		$r = 0.029$ (95% CI 0.007 to 0.050), $P = 0.008$
			Moderate frequency of physical activity—weight-related outcomes		22		$r = 0.080$ (95% CI 0.064 to 0.096), $P < 0.001$
			High frequency of physical activity—weight-related outcomes		12		$r = 0.077$ (95% CI 0.044 to 0.109), $P < 0.001$
Wilks et al. (2011) [65]	4–11	01/2000–09/2008	Physical activity—fat mass/ fat-free mass/ fat percentage	Physical activity	6	586	Correlation = − 0.04 (95% CI − 0.22 to + 0.14)
			Physical activity—fat mass/ fat-free mass/ fat percentage	Internal + external bias adjusted	6	586	Correlation = − 0.01 (95% CI − 0.18 to + 0.16)
Williams et al. (2013) [71]	4–11	Up to 06/2011	Physical activity-related policies—BMI-SDS	Policies according to the National Association for Sport and Physical Education guidelines	6		WMD = − 0.01 (95% CI − 0.04, + 0.01), $P = 0.977$
Behavioral or/and educational interventions							
Kamath et al. (2008) [40]	2–18	Until 02/2006	Physical activity interventions—BMI	Interventions aiming at increasing physical activity		32,003	SMD = + 0.01 (95% CI − 0.06 to + 0.08)
Katz et al. (2008) [47]	3–18	1966–10/2004	Physical activity (boys + girls)—body weight	Physical activity increase			SMD = 1.87 (95% CI 1.31 to 2.42)
			Physical activity (girls)—body weight		1		SMD = − 0.38 (95% CI − 0.74 to − 0.02)
			Physical activity (boys)—body weight		1		SMD = − 0.14 (95% CI − 0.17 to + 0.44)
Luckner et al. (2012) [45]	0–18	Up to 06/11/2008	Physical activity—BMI (REM)	Physical activity increase	10	2927	WMD = − 0.15 (95% CI − 0.34 to 0.04)
			Physical activity—body fat % (REM)		6	1989	WMD = − 0.7 (95% CI − 1.05 to − 0.31)
Peirson et al.[a] (2015) [83]	0–18	01/2010–08/2013	Behavioral interventions (exercise only)—BMI, BMI-Z score	Physical activity increase ≥ 12 wk	18	15,902	SMD = –0.08 (95% CI − 0.16 to 0.00), $P < 0.001$
Peirson et al.[b] (2015) [84]	2–18	10/06/2008–28/08/2013	Behavioral interventions (exercise only)—BMI, BMI-Z score	Physical activity increase	1	322	SMD = –0.43 (95% CI –0.65 to –0.21)

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Table 2 (continued)

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
van Hoek et al. (2014) [80]	3–8	Up to 04/2012	Physical activity education: high intensity (> 75 h)—BMI-Z score	Important components in treatment programs are dietary and physical activity, education and behavioral therapy	2	166	ES = − 0.31 (95% CI − 0.88 to + 0.27)

CI confidence interval, *BMI* body mass index, *ES* effect size, *WMD* weighted mean difference, *SMD* standardized mean difference, *REM* random effects model, *FEM* fixed effects model, *RCTs* randomized controlled trials, *NRCTs* non randomized controlled trials, *UCTs* uncontrolled trials, *URCTs* unclear randomized controlled trials

such as BMI, percentage of overweight or body fat percentage [48]. The largest effect size was observed in young children between 2 and 8 years old (ES = − 0.70, 95% CI − 1.00 to − 0.40). It has to be noted that among the included studies only this meta-analysis by McGovern et al. provided subgroup analyses according to different age groups (2–8 and 9–18 years old). Interestingly, combined lifestyle interventions produced significant results irrespective of the age group.

School-based behavioral interventions which improved dietary habits and increased physical activity were effective both in preventing weight gain [83] (reduction on BMI/BMI-*Z* score = − 0.10, 95% CI − 0.17 to − 0.03, $P < 0.001$) and in causing weight loss [84] (BMI/BMI-*Z* score reduction = − 1.09 units, 95% CI − 1.84 to − 0.34, $P < 0.001$). Similar effectiveness in BMI reduction [44] was observed by combining nutritional education and physical exercise in students' population (SMD = − 0.37 kg/m^2, 95% CI − 0.63 to − 0.12, $P < 0.01$). However, three meta-analyses [22, 40, 73] showed ineffectiveness on BMI alone and another one [71] in BMI-SDS (standard deviation score) reduction by combining the aforementioned interventions.

Combination of physical activity or diet plus another intervention (Table 3—lower panels, Supplementary Table 3)

Three meta-analyses [45, 59, 74] investigated the potential of combining diet or physical activity plus another intervention. LeMura et al. [59], who included parental and family behavioral interventions in addition to exercise among participants older than 4 years, found a significant boost to the body fat percentage reduction compared to the one caused by exercise alone. Luckner et al. [45] examined two combinations, namely education plus physical activity, as well as education plus diet, but neither combination elicited statistically significant difference in BMI and body fat percentage. The combination of sedentary behavior reduction combined with exercise [74] induced mild changes in BMI (ES = − 0.089, 95% CI − 0.202 to 0.025, $P = 0.125$). The pooled results [74] of the combinations of sedentary behavior reduction with either diet or physical activity or both produced an overall BMI reduction of 0.073 kg/m^2 (95% CI − 0.135 to − 0.011, $P = 0.021$).

Sedentary behavior reduction interventions (Table 4, Supplementary Table 4)

The search strategy did not yield any pure observational meta-analyses. Regarding interventional approaches,

Table 3 Characteristics and results of the eligible meta-analyses regarding a combination of physical activity and dietary interventions or physical activity/dietary intervention and another intervention

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
Physical activity and dietary interventions							
Clark (2015) [27]	6–18	01/1980–01/2014	Physical exercise, dietary modification—body mass, BMI, fat mass, fat-free mass	Diet: manipulation of macronutrients and reduced calories Physical activity: aerobic exercise at various intensities, endurance or strength/resistance exercise or combinations	32	3523	Detailed below
			Diet + endurance exercise (therapeutic effect)—body mass (kg)				ES = − 7.28 (95% CI − 8.26 to − 6.30)
			Diet + endurance + resistance exercise (therapeutic effect)—body mass (kg)				ES = 4.81 (95% CI 4.04 to 5.588)
			Diet + endurance exercise (therapeutic effect)—fat mass (kg)				ES = − 11.95 (95% CI − 13.8 to − 10.09)
			Diet + endurance + resistance exercise (therapeutic effect)—fat mass (kg)				ES = − 10.85 (95% CI − 12.54 to − 9.16)
			Diet + endurance exercise (therapeutic effect)—fat-free mass (kg)				ES = − 0.91 (95% CI − 1.40 to − 0.41)
			Diet + endurance + resistance exercise (therapeutic effect)—fat-free mass (kg)				ES = − 0.805 (95% CI − 1.32 to − 0.29)
			Diet + endurance exercise (therapeutic effect)—BMI (kg/m^2)				ES = 9.63 (95% CI − 11.14 to − 8.12)
			Diet + endurance + resistance exercise (therapeutic effect)—BMI (kg/m^2)				ES = − 8.79 (95% CI − 10.42 to − 7.16)
Epstein et al. (1999) [32]	7–13	01/1966–11/1998	Diet plus exercise programs vs diet alone programs vs no intervention—obesity-related outcomes	Aerobic exercise at various frequencies and intensities. Obesity-related outcomes included percent overweight, percent body fat, body weight	6		SMD = 0.45

Table 3 (continued)

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
Friedrich et al. (2012) [44]	4–19	1998–08/2010	Nutritional education + physical activity—BMI (REM)	Physical activity and nutritional education interventions such as encouragement of healthy dietary habits through presentations and didactic materials or interventions with school meals and cafeterias	16	9997	SMD = −0.37 (95% CI −0.63 to −0.12), $P < 0.01$
Guerra et al. (2014) [73]	6–18	Up to 30 September 2012	School-based physical activity plus nutritional education interventions—BMI	Increasing fruits and vegetables availability, parental support, vigorous exercise plus health and nutrition education plus behavior modification, family homework lessons, classroom curriculums, ecological-level strategies, multimedia intervention delivered by interactive CD-ROM, multi-component interventions, behavioral interventions, academic bouts	38	28,870	ES = −0.03 (95% CI −0.09 to +0.04), $P = 0.4$
			School-based physical activity plus nutritional education interventions with duration < 1 school year (9 mon)—BMI		19	7604	ES = −0.04 (95% CI −0.14 to +0.06)
			School-based physical activity plus nutritional education interventions with duration > 1 school year (9 mon)—BMI		22	21,266	ES = −0.02 (95% CI −0.10 to +0.07)

Table 3 (continued)

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
Ho et al. (2013) [38]	Children < 18	1975–2010	Diet plus exercise intervention vs diet-only intervention (overall)—weight loss and BMI	Dietary Interventions: calorie restriction approach, with energy levels ranging from 900 to 1800 kcal/d and aiming at limiting added sugar consumption and increasing dietary fiber intake Exercise Interventions: supervised training sessions with variety in type of exercise and intensity. All studies except one provided at least 70 min of exercise per wk and 1 school-based program provided a total of 6 h of indoor exercise per wk	9	519	WMD = − 0.06 (95% CI: − 0.14 to + 0.26), $P = 0.55$
			Diet plus aerobic exercise intervention vs diet-only intervention-weight loss, BMI		4	109	WMD = − 0.24 (95% CI − 0.62 to + 0.14), $P = 0.21$
			Diet-only intervention vs diet plus resistance exercise intervention—weight loss, BMI		3	178	WMD = − 0.40 (95% CI − 0.71 to − 0.08), $P = 0.01$
			Diet plus combined aerobic and resistance exercise intervention vs diet-only intervention-weight loss, BMI		3	232	WMD = − 0.10 (95% CI − 0.45 to + 0.26), $P = 0.59$
			Resistance exercise intervention vs diet-only intervention-body fat%		5		Pooled difference = − 0.50% (95% CI − 0.94 to − 0.06)
			Diet plus exercise intervention vs diet-only intervention-body fat% (1 y follow-up)		2		Pooled difference = − 2.73% (95% CI − 4.38 to − 1.09)
Kamath et al. (2008) [40]	2–18	Until 02/2006	Combined lifestyle (overall)—BMI	Increase of physical activity, and implementing healthier dietary habits or avoiding unhealthy dietary habits	34	32,003	ES = − 0.02 (95% CI − 0.06 to + 0.02)

Table 3 (continued)

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
			Combined lifestyle interventions (dietary + physical activity)—BMI				SMD = −0.03 (95% CI −0.07 to +0.01)
			Long trials—BMI				SMD = −0.04 (95% CI −0.08 to 0.00)
			Short trials—BMI				SMD = +0.06 (95% CI −0.02 to +0.15)
Katz et al. (2008) [47]	3–18	1966–10/2004	Combination intervention (boys + girls)—body weight (REM)	Parents, teachers and students were actively involved in the implemented strategies	8	10,752	SMD = −0.29 (95% CI −0.45 to −0.14), $P = 0.0002$
			Combination intervention (girls)—body weight (REM)		3	1807	SMD = −0.53 (95% CI −1.37 to +0.30)
			Combination intervention with family/parent component—body weight (REM)		4	2459	SMD = −0.20 (95% CI −0.41 to 0.00), $P = 0.05$
Langford et al. (2015) [22]	4–18	Up to April 2013	Physical activity + nutrition—BMI	The World Health Organization Health Promoting School (WHO HPS) framework	8	13,628	WMD = −0.11, 95% CI −0.24 to +0.02), $P = 0.097$
			Physical activity + nutrition—BMI-*Z* score		7	11,184	WMD = 0.00 (95% CI −0.04 to +0.03), $P = 0.84$
Lavelle et al. (2012) [57]	Children < 18	Up to 21 February 2011	Physical activity + nutrition—BMI	All of the interventions were conducted on school premises. The duration of the intervention ranged from 1 mon to 6 y, and the maximum length of follow-up was 6 y. Studies used physical activity or education or combinations of interventions	19		ES = −0.17 (95% CI −0.29 to −0.06), $P < 0.001$
LeMura et al. (2002) [59]	5–17	1960–2001	Exercise + diet—%body fat	The interventions used exercise as a mode of training and lasted for at least 3 wk, along with diet interventions	7		ES = 0.33 ± 0.20

Table 3 (continued)

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
McGovern et al. (2008) [48]	2–18	Until 02/2006	Diet plus physical activity (targeting family only)—BMI, %fat, %overweight	Lifestyle interventions included any treatment strategy aimed at changing the diet and/or activity level of overweight children that targeted the participant directly or through their family, school, or community	11	514	ES = −0.64 (95% CI −0.88 to −0.39), $P < 0.00001$
			Diet plus physical activity (targeting children only)—BMI, %fat, %overweight		12	662	ES = −0.17 (95% CI −0.40 to −0.05)
			Diet plus physical activity (family vs children)—BMI, %fat, %overweight		2	55	ES = −0.64 (95% CI −1.80 to +0.52), $P = 0.13$
			Combined lifestyle intervention (2–8 y)—BMI, %body fat, %overweight		2	193	ES = −0.70 (95% CI −1.00 to −0.40), $P < 0.00001$
			Combined lifestyle intervention (9–18 y)—BMI, %body fat, %overweight		10	278	ES = −0.49 (95%CI: −0.81 to −0.18), $P = 0.002$
			Combined lifestyle intervention (all ages)—BMI, %body fat, %overweight		12	471	ES = −0.54 (95% CI −0.78 to −0.29), $P < 0.0001$
Peirson et al.[a] (2015) [83]	Children < 18	01/2010–08/2013	Diet + exercise—BMI, BMI-*Z* score	Interventions aimed at weight gain prevention and they lasted for at least 12 wk	26	14,923	SMD = −0.10 (95% CI −0.17 to −0.03), $P < 0.001$
Peirson et al.[b] (2015) [84]	2–18; overweight or obese	10/06/2008–28/08/2013	Behavioral interventions (diet + exercise)—BMI, BMI- *Z* score	Behavioral interventions included diet, exercise, lifestyle strategies	6	684	SMD = −1.09 (95% CI −1.84 to −0.34), $P < 0.001$
Vasques et al. (2014) [56]	Children < 19	2000–2011	School- and after-school-based intervention programs—weight-related outcomes	Interventions aimed to (1) increase the levels of physical activity, (2) change the diet of children in schools or at home	52	28,236	Overall: $r = 0.068$ (95% CI 0.058 to 0.079), $P < 0.001$
			Physical activity + nutrition-weight-related outcomes		12		$r = 0.128$ (95% CI 0.126 to 0.171), $P < 0.001$
Wang et al. (2015) [20]	2–18	Until 11 August 2012	Diet + physical activity in school setting—BMI-*Z* score	The interventions involved a modification of diet and physical activity	5	9203	WMD = −0.05 (95% CI −0.10 to −0.01), $P = 0.002$
			Diet + physical activity in school setting—BMI		9	5828	WMD = −0.30 (95% CI: −0.45 to −0.15), $P < 0.001$

Table 3 (continued)

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
			Diet + physical activity in school setting with a home-based component—BMI		8	4850	WMD = −0.25 (95% CI −0.68 to +0.17)
Williams et al. (2013) [71]	4–11	Up to 06/2011	Combined policies—BMI-SDS	Policies with both diet and physical activity-related components	5		WMD = 0.00 (95% CI −0.47 to +0.47)
Physical activity or dietary interventions plus another intervention							
LeMura et al. (2002) [59]	5–17	1960–2001	Exercise + behavioral modification—percentage of body fat	Exercise as a mode of training > 3 wk. Behavioral: the family to support exercise, offered classes on variations of caloric and nutrient intake, and encouraged participation in spontaneous over sedentary activities	6		ES = 0.63 ± 0.16
Liao et al. (2014) [74]	Children < 18	Up to July 2012	Sedentary behavior reduction + physical activity—BMI	Components to reduce sedentary behaviors. Active control groups: some non-obesity prevention-related information; control groups: usual-programming or assessment-only	10	2805	ES = −0.089 (95% CI −0.202 to +0.025), $P = 0.125$
Luckner et al. (2012) [45]	0–18	Up to 06/11/2008	Physical activity + education—BMI (REM)	Physical activity, education, nutrition, reduction of sedentary behavior	21	8399	WMD = −0.17 (95% CI −0.34 to 0.00)
			Education + nutrition—BMI (REM)		2	1695	WMD = −0.04 (95% CI −0.25 to 0.17)

CI confidence interval, *BMI* body mass index, *ES* effect size, *WMD* weighted mean difference, *SMD* standardized mean difference, *SDS* standard deviation score, *REM* random effects model the reduction of sedentary lifestyle has been purported to aid weight loss and prevent or treat obesity through many direct and indirect ways. Seven meta-analyses [45, 47, 48, 66, 74, 85, 86] with a sedentary behavior reduction arm were identified. Screen time and sitting time reduction [74] did not produce statistically significant reduction in BMI (ES = − 0.154, 95% CI − 0.354 to 0.045, $P = 0.129$). Another meta-analysis [66] combining multiple behavioral interventions reduced the target population's BMI by 0.25 kg/m^2 (95% CI − 0.40 to − 0.09, $P = 0.002$). Other meta-analyses [45, 85] indicated a BMI reduction up to 0.89 kg/m^2 (95% CI − 1.67 to − 0.11) but absolute body weight [48] was not affected. Finally, reducing screen time specifically in children 4–12 years old did not seem to affect BMI [86]. It should be noted that the included studies reporting on screen time reduction did not provide detailed information about what behaviors were substituted for that time, thus the effect of confounders could not be extensively determined.

Diet, physical activity and a third component: multidimensional interventions (Table 5, Supplementary Table 5)

There were four meta-analyses [45, 56, 74, 80] which provided results of multidimensional interventions (namely three or more interventions) on obesity-related outcomes.

Luckner et al. [45] showed that the combination of physical activity, education and nutrition resulted in a small reduction in BMI in six studies including 10,257 subjects (mean difference = − 0.10, 95% CI − 0.16 to − 0.04), but it did not reduce body fat percentage. Similarly, the combination of physical activity, lifestyle modification and nutrition in the school and after-school intervention programs [56] produced a small positive effect on various weight-related outcomes ($r = 0.047$, 95% CI 0.023–0.070, $P < 0.001$) in children and adolescents up to 19 years old. No effect was observed [74] by the combination of sedentary behavior reduction, physical exercise and nutrition.

Lastly, physical exercise combined with diet and behavioral therapy [80] reduced BMI-*Z* score in eleven studies with 1015 children 3–8 years old by 0.25 BMI-*Z* score units (95% CI − 0.36 to − 0.14) but the heterogeneity was high ($I^2 = 100\%$), and, thus, the reliability of the results is rather questionable, taking into consideration the limitations of BMI use in young ages.

Meta-analyses collectively reporting on "any" type of interventions (Supplementary Table 6)

Meta-analyses collectively reporting on school-based interventions

Many mixed interventions were organized within a school environment. A meta-analysis [30] of nineteen RCTs including 9302 children showed that school-based interventions with dietary and/or physical activity components could reduce the incidence of obesity by 26%, while classroom activities and physical education by 27%. Mixed programs conducted both during and after school hours [56] were associated with very small reductions in various weight-related outcomes, but they were all statistically significant. School-based obesity prevention [29] and treatment [57] programs managed to lower BMI and BMI-*Z* scores in 31,059 students and in 36,579 students, respectively. Educational programs [37] reduced waist circumference by 3.21 cm (95% CI − 6.34 to − 0.07) and BMI by 0.86 kg/m^2 (95% CI − 1.59 to − 0.14). Other mixed multi-interventional studies were only mildly effective [55] in obesity prevention or not effective at all [52, 82] in reducing indices such as BMI. However, these results should be interpreted with caution due to the inherent limitations of using BMI among children and adolescents. School nutritional education plus physical activity [73] failed to reach statistical significance in a large meta-analysis with 47 studies and 41,634 participants.

Meta-analyses collectively reporting on behavioral or/and educational interventions

Two meta-analyses [83, 84] conducted by Peirson et al. had multiple behavioral modification arms. Such modifications such as diet, exercise, social support or lifestyle strategies, alone or in combination [83], resulted in a small-scale reduction in BMI/BMI-*Z* score in 56,342 children and adolescents (ES = − 0.07, 95% CI − 0.10 to − 0.03), in BMI alone (ES = − 0.09 kg/m^2, 95% CI − 0.16 to − 0.03) and in the prevalence of overweight and obesity (relative risk = 0.94, 95% CI 0.89–0.99). The meta-analysis of behavioral treatment of obesity [84] yielded clinically greater results. The overall reduction of BMI/BMI-*Z* score reached 0.54 units (95% CI − 0.73 to − 0.36).

Joint analyses of studies assessing nutritional education combined with either behavioral therapy or physical activity education provided as a very low-intensity intervention [80] did not seem to affect BMI-*Z* score in overweight/obese young children aged 3–8 years. On the other hand, lifestyle modification [53] did reduce various obesity-related outcomes in older overweight/obese children and adolescents up to 19 years old.

Table 4 Characteristics and main results of the eligible meta-analyses regarding sedentary behavior reduction interventions. All meta-analyses were based on the synthesis of behavioral interventional studies

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
Katz et al. (2008) [47]	3–18	1966–10/2004	TV reduction intervention—body weight	Family, teacher and students participated in behavioral interventions	1	198	SMD = 0.35 (95% CI 0.06–0.63)
Liao et al. (2014) [74]	Children < 18	Up to 07/2012	Sedentary behavior reduction—BMI	Components to reduce sedentary behaviors. Active control groups: some non-obesity prevention-related information; control groups: usual-programming or assessment-only	5	389	ES = − 0.154 (95% CI − 0.354 to + 0.045), $P = 0.129$
Luckner et al. (2012) [45]	0–18	Up to 06/11/2008	TV and other—BMI (REM)	Interventions that promote healthy weight such as physical activity, education, nutrition, reduction of sedentary behavior	8	3962	WMD = − 0.27 (95% CI − 0.40 to − 0.13)
			TV and other—body fat percentage		1	459	WMD = + 0.08 (95% CI − 0.68 to + 0.84)
McGovern et al. (2008) [48]	2–18	Until February 2006	Reduced sedentary behavior—body weight	TV watching time reduction, increased physical activity	3	114	ES = + 0.02 (95% CI − 0.35 to + 0.39), $P = 0.91$
Tremblay et al. (2011) [85]	5–17	1806–2010	Reduction of sedentary behaviors—BMI	Exposures of sedentary behaviors included those obtained via direct and self-reported methods	4	326	WMD = − 0.89 (95% CI − 1.67 to − 0.11), $P = 0.03$
van Grieken et al. (2012) [66]	0–18	1990–2011	Sedentary behavior reduction (single + multiple behavioral interventions)—BMI	Sedentary behavior included screen time activities and behaviors such as listening to music, reading, "sitting around doing nothing" or talking on the phone	14	5197	WMD = − 0.25 (95% CI − 0.40 to − 0.09), $P = 0.002$
			Sedentary behavior reduction (single behavioral interventions)—BMI		6	624	WMD = − 0.41 (95% CI − 1.03 to + 0.22), $P = 0.2$
			Sedentary behavior reduction (multiple behavioral interventions)—BMI		8	4573	WMD = − 0.24 (95% CI − 0.47 to − 0.01), $P = 0.04$
Wahi et al. (2011) [86]	3.9–11.7	1982–21/04/2011	Interventions aimed at reducing screen time in children—BMI	Interventions included a reduction of screen time	6	769	SMD = − 0.10 (95% CI − 0.28 to + 0.09), $P = 0.32$

CI confidence interval, *BMI* body mass index, *ES* effect size, *WMD* weighted mean difference, *SMD* standardized mean difference, *REM* random effects model

Active behavioral interventions [31] yielded positive effects in all comparisons versus the control or education-only groups. In the same way, combinations of behavioral modification with additional components [62] such as cognitive ones or parental participation were better than behavioral interventions without additional components. Furthermore, mixed behavioral interventions [87] were effective against obesity when parents were also participants, even optionally (WMD = 0.30, SE = 0.11, $P = 0.027$).

A collective analysis on various modalities of family behavioral treatment [50] indicated mild reductions in various weight-related outcomes among children 5–12 years old. Solely educational interventions [45] did induce BMI reduction in 5667 children 0–18 years old (ES = − 0.18 kg/m^2, 95% CI − 0.30 to − 0.05), but they did not affect body fat percentage (ES = 0.13, 95% CI − 0.04 to + 0.3).

Meta-analyses collectively reporting on "lifestyle" interventions without further specification

A Cochrane meta-analysis [21] pooled the results of seventeen RCTs including 5230 children regarding the effects of various lifestyle interventions on BMI or BMI-SDS). The intervention groups showed greater reductions than the control ones in almost all measurements conducted both after 6 and 12 months of follow-up.

Another Cochrane meta-analysis [75] including only a few studies with lifestyle modifications did not affect obesity in children between 3 and 18 years old.

A larger scale meta-analysis [54] of thirty-seven studies with 27,946 children up to 18 years old underscored this protective effect of lifestyle programs on BMI/BMI-*Z* score (SMD = − 0.15 kg/m^2, 95% CI − 0.21 to − 0.09).

A collective analysis on various "lifestyle" interventions [49] suggested that they could effectively cause weight loss in kilograms (ES = − 0.95, 95% CI − 0.79 to − 1.11) in middle-school/pre-teen children younger than 16 years old and reduce BMI [69] by − 0.08 kg/m^2 (95% CI − 0.16 to − 0.01, $P = 0.02$). However, effectiveness was not observed in older children and teenagers [39], but we should note that in this study participants were aged up to 22 years old that poses limitations in the interpretation of the results.

A meta-analysis [34] specifically targeting US (United States) minority children aged 6–19 years old did not reveal any effectiveness of one-component or multiple component interventions.

Discussion

Addressing separately interventional and non-interventional evidence, this systematic review highlights the discrepancies between meta-analyses pooling these two types of studies. Indeed, this notion has been the base of a vivid debate in the field of childhood obesity epidemiology [90]. Among the factors and interventions that were examined in the published meta-analyses, the combination of enhanced physical activity and improved nutrition emerged as a promising, effective intervention against childhood/adolescent obesity. A variety of multidimensional interventions have also been examined in the literature, nevertheless, the optimal scheme remains to be shaped in the future.

The combination of physical activity and diet was proven an effective tool against obesity regarding both prevention [83] and treatment [84], according to evidence stemming from interventional studies. It was commonly implemented within school settings in the synthesized meta-analyses [20, 47, 56, 57]. This combination may improve numerous metabolic outcomes, causing mild weight loss [38, 91], preserving lean mass and protecting from weight regain that may appear when diet is implemented alone [92]. When the intervention targeting physical activity and diet was based on a behavioral approach, the findings of relevant meta-analyses were rather conflicting with protective [44, 83, 84] or neutral results [22, 40, 71, 73]. On the other hand, results derived from combining physical exercise or diet with a second component like education or sedentary behavior reduction were associated with smaller effect sizes [45, 59, 74].

Adding a third component to the combination of physical activity and diet generated significant results in some weight-related indices [45, 56, 74, 80], but effect sizes were often small. The explanation may be small number of included studies in the subgroup analyses [45, 80], high degree of heterogeneity [45, 80] and lack of methodological rigor [56]. Therefore, the optimal combination that would further boost the effectiveness remains an issue under investigation.

Interesting nutritional aspects associated with childhood obesity emerged from our review. Regarding interventional meta-analyses with actual dietary interventions, there were conflicting results; since some [23, 27] found significant and durable positive effect on weight-related indices, but others did not [22, 45]. Dietary behavioral modification did not seem to have any effect on obesity-related outcomes [40, 44, 48, 80, 83, 84]. This may be due to methodological issues regarding the length of follow-up, characteristics of the target population and the intensity [40, 48] of the intervention, as well as the subjects' compliance [44].

When interventional studies were pooled with non-interventional ones, the findings should be examined critically. Forshee et al. published a meta-analysis [51] which found that SSBs had almost no effect on BMI of children and adolescents. This study was challenged [26, 93] on the ground that it had not taken into account the amount of calories of the SSBs and the phenomenon of underreporting. A similar meta-analysis [58] clearly indicated their replacement with

Table 5 Characteristics and main results of the eligible meta-analyses regarding a combination of diet, physical activity and a third component: multidimensional interventions

Author (year)	Description of the population, age (y)	Time frame of eligible studies	Topic (exposure/intervention—outcome)	Detailed description of intervention	Number of studies included	Number of subjects included	Main results
Liao et al. (2014) [74]	Children < 18	Up to July 2012	Sedentary behavior reduction + physical activity + diet—BMI	Components to reduce sedentary behaviors. Active control groups: some non-obesity prevention-related information; control groups: usual-programming or assessment-only	10	3851	ES = − 0.060 (95% CI − 0.154 to + 0.034), $P = 0.214$
Luckner et al. (2012) [45]	0–18	Up to 06/11/2008	Physical activity + education + nutrition—BMI (REM)	Physical activity, education, nutrition, reduction of sedentary behavior	6	10,257	WMD = − 0.1 (95% CI − 0.16 to − 0.04)
			Physical activity + education + nutrition—body fat% (REM)		2	1517	WMD = + 0.42 (95% CI − 0.54 to + 1.38)
van Hoek et al. (2014) [80]	3–8	Up to 04/2012	Dietary and physical activity education and behavioral therapy—BMI-*Z* score	Important components in treatment programs are dietary and physical activity, education and behavioral therapy	11	1015	ES = –0.25 (95% CI − 0.36 to − 0.14)
			Multicomponent: very low intensity (< 10 h)—BMI-*Z* score		5	956	ES = − 0.08 (95% CI − 0.13 to − 0.03)
			Multicomponent: moderate (26–75 h) or high (> 75 h) intensity—BMI-*Z* score		2	101	ES = − 0.46 (95% CI − 0.53 to − 0.39)
Vasques et al. (2014) [56]	Children < 19	2000–2011	School-based and after-school-based intervention programs—weight-related outcomes (BMI, BMI-*Z* scores, percentile BMI, overweight/obesity)	Interventions aimed to (1) increase the levels of physical activity, (2) change the diet of children and (3) reduce sedentary activities	52	28,236	$r = 0.068$ (95% CI 0.058 to 0.079), $P < 0.001$
			Physical activity + lifestyle + nutrition—weight-related outcomes		11		$r = 0.047$ (95% CI 0.023 to 0.070), $P < 0.001$

CI confidence interval, *BMI* body mass index, *ES* effect size, *WMD* weighted mean difference, *REM* random effects model non-SSBs results in weight loss. Interestingly, dietary sugars per se showed no effect on children's BMI and BMI-*Z* score according to a synthesis of interventional and non-interventional studies [42]. Milk and dairy product consumption was effective only in adolescent populations regarding the reduction in BMI/BMI-*Z* scores, and this was attributed to the molecular ingredients of milk as well as methodological issues [76]. Cereals consumed in breakfast may affect body weight by increasing energy expenditure through the day and reducing appetite, but it should be noted that the large number of included observational studies prevents the establishment of a causational relation and gives ground to many forms of bias [43].

Regarding meta-analyses on non-interventional studies, two of them [28, 46] found an inverse association between the frequency of family-shared meals and the risk of obesity. Overall, families that ate five or more meals together had children who were 25% less likely to encounter nutritional issues than children who ate only one meal with their families [46], while increased eating frequency was associated a 24% lower likelihood of being overweight/obese [28]. This phenomenon may be explained by the fact that such persons are more likely to develop healthy eating behaviors [94]. Observational studies regarding dietary energy density showed a positive association with weight gain; nevertheless, the effect of external and internal bias was considerable [41].

An interesting remark on the topic of nutritional meta-analyses would be that many interventional studies did not reach either clinical or statistical significance in their results; however, observational studies had much more prominent effects. This phenomenon has been underscored in terms of the effectiveness of breakfast in obesity-related indices [90]. In this context, an ongoing debate about the reliability of results of non-interventional studies, compared to those of interventional ones, has been triggered.

No observational studies were found regarding the impact of physical activity on obesity-related outcomes. As for interventional studies, physical activity seems to be mildly to highly effective in improving body composition [33], especially resistance exercise, by reducing body fat [48, 59, 70] and simultaneously increasing lean mass [59]. A direct effect of the latter is that BMI and body weight may not be affected by PA or they can even increase [27, 68]. Nonetheless, a considerable number of actual interventional studies and/or part of their subgroup analyses did not manage to prove the effectiveness of physical activity [40, 44, 61, 64, 65, 68, 71, 73, 78]. Similarly, indirect increase of physical activity through purely educational and behavioral interventions did not produce significant results either [40, 83]. Several reasons may pertain to this, such as RCTs of severely low methodological quality included in the meta-analyses [40], high level of heterogeneity [45, 47], limited number of studies available [80], mixed populations of overweight/obese and non-overweight children and adolescents [83], as well as inadequate description of the interventions [40]. Finally, it should be highlighted that other reviews [95-97], as well as a review of meta-analyses [98] about physical activity in childhood obesity, have shown similar results.

Sedentary lifestyle has been positively correlated with body fatness in young people by both reducing energy expenditure and increasing energy intake [47]. Indeed, several meta-analyses showed a reduction in BMI via sedentary behavior reduction interventions [45, 66, 85], but the effects were rather limited. Also, some others did not produce a significant effect [48, 74, 86].

It is noticeable that there were numerous meta-analyses which presented interventions and outcomes regarding "any" type of interventions collectively. Longer duration [23, 30, 47, 55] and better structure [49] seemed to augment their effectiveness, as well as parental participation [87]. On the other hand, the heterogeneity and the various conditions, under which the interventions were organized, provided different results, many of which were not statistically significant [30, 34, 39, 52, 62, 82]. From a methodological point of view, many of these meta-analyses presented a pooled effectiveness of various interventions grouped together, assessing an overall performance; this is a rather crude approach which does not allow the comparative evaluation of the heterogeneous group of adopted interventions. Other methodological concerns were conduction of completers' analyses instead of intention-to-treat analyses [31], lack of clear description of the intervention [80], unclear assessment of risk of bias [83] and very high heterogeneity [84].

Such collective analyses of various interventional programs were very frequent in school-based studies, as it is easier to try multiple interventions within a school setting [47, 55]. Despite their popularity and anticipated effectiveness, however, aspects such as study type, duration, intervention type, number of intervention components and cost-efficacy need to be taken into account during the planning and structuring of such meta-analyses. In these terms, several school-based studies did not elicit either statistically [52, 73] or clinically [29, 56] significant results, especially in their subgroup analyses. The ideal combination of interventions to be implemented in school-based settings remains elusive.

Purely behavioral and educational interventions also had mixed results, either significant [50, 53, 62, 87] or marginally significant [45, 80, 83, 84]. However, this should not discourage their possible assessment because control groups receiving no intervention at all presented with gain weight and BMI increase [31].

Meta-analyses were exclusively used in our qualitative analysis since their results are considered to constitute highly reliable pieces of evidence [99]. Guidelines by various Expert Panels, have been issued; these guidelines have highlighted a variety of effective points in the prevention of childhood obesity, such as eating more frequently, including parents in the intervention programs, increasing exercise, decreasing caloric intake and decreasing screen time [100-103]. However, the strict adherence of participants to the intervention programs represents a major obstacle regarding their effective implementation.

The search strategy included a variety of possible ways of fighting childhood and adolescent obesity. However, methodological concerns and possible publication bias should be kept in mind. Moreover, some meta-analyses included several subgroup analyses based on a limited number of studies. It should be also highlighted that subgroup analyses according to the age of the participants were not universally available in the included meta-analyses; therefore, this aspect should be addressed in future studies to reveal potential differentiations in the outcomes and determine the most effective, age-adapted interventions. Furthermore, a very commonly used outcome, namely BMI, is not always reliable in pediatric populations, as well as in tall and thin persons and those with high percentage of muscle mass, since it does not precisely reflect body composition [87]. Children and adolescents can have rapid changes in linear growth and, thus, changes in BMI cannot be safely attributed exclusively to an implicated external parameter. Therefore, studies should ideally report also results regarding the percentage change of body fat to provide a more robust description of the effects of the implemented intervention. Thus, the interpretation and generalization of the reported outcomes restricted to BMI should be extremely cautious.

In conclusion, synthesis of interventional or observational evidence may provide different results. Our findings confirm that the combination of increased physical activity and improved nutrition are currently utilized mainstream interventions against childhood/adolescent obesity. However, further research is needed to identify the most effective age-specific multi-dimensional prevention strategy.

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