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Is adherence to the Mediterranean diet associated with healthy habits and physical fitness? A systematic review and meta-analysis including 565 421 youths

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Abstract

The relationship between adherence to the Mediterranean diet (MD), physical activity (PA), sedentary behaviour and physical fitness levels has been analysed in several studies; however, there is mixed evidence among youth. Thus, this study aimed to meta-analyse the associations between adherence to the MD, PA, sedentary behaviour and physical fitness among children and adolescents. Three databases were systematically searched, including cross-sectional and prospective designs with a sample of healthy youth aged 3–18 years. Random effects inverse-variance model with the Hartung–Knapp–Sidik–Jonkman adjustment was used to estimate the pooled effect size (correlation coefficient (*r*)). Thirty-nine studies were included in the meta-analysis, yielding a total of 565 421 youth (mean age, 12·4 years). Overall, the MD had a weak-to-moderate positive relationship with PA (*r* 0·14; 95 % CI 0·11, 0·17), cardiorespiratory fitness (*r* 0·22; 95 % CI 0·13, 0·31) and muscular fitness (*r* 0·11; 95 % CI 0·03, 0·18), and a small-to-moderate negative relationship with sedentary behaviour (*r* –0·15; 95 % CI –0·20, –0·10) and speed–agility (*r* –0·06; 95 % CI –0·12, –0·01). There was a high level of heterogeneity in all of the models ($I^2 \geq 75$ %). Overall, results did not remain significant after controlling for sex and age (children or adolescents) except for PA. Improving dietary habits towards those of the MD could be associated with higher physical fitness and PA in youth, lower sedentary behaviours and better health in general.

Key words: Healthy diet: Muscular fitness: Cardiorespiratory fitness: Children: Sedentary behaviour

The Mediterranean diet (MD) is derived from the traditional dietary habits of people living around the Mediterranean basin[1]. because it is linked to major health and nutrition benefits, a substantial body of scientific evidence has demonstrated the importance of the MD in preventing a number of chronic non-communicable diseases and maintaining good health over the entire lifespan[2].

Despite the well-known benefits of the MD, current lifestyle changes characterised by a high consumption of processed food, sugar, soda and meat products (i.e. Western dietary pattern) have become a growing public health concern and are a major contributory factor to the global epidemic of obesity[3,4]. Another factor related to obesity and associated health conditions is the increase in sedentary behaviours, such as increasing time spent on watching television, playing video games and using the Internet and reductions in physical activity (PA)[5] and physical fitness levels[6]. In this regard, evidence suggests that food habits of youth are strongly influenced by several factors such as healthy lifestyles[1] and physical fitness[7,8] in a complex interactive manner.

Childhood and adolescence are critical periods in life for the adoption of lifestyle habits that are likely to persist into

Abbreviations: CRF, cardiorespiratory fitness; MD, Mediterranean diet; PA, physical activity.

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adulthood. Because many chronic diseases that manifest in adulthood stem from childhood[9], it is important to establish healthy habits early in life. Also, healthy behaviours do not act in isolation, and the effects of multiple healthy lifestyle behaviours may be greater than the sum of their individual impacts[10]. For this reason, the relationship between adherence to the MD, PA, sedentary behaviours and different parameters of physical fitness has been analysed in several studies, but inconsistent results have been reported, and a meta-analytic understanding of how the MD adherence contributes to healthy habits and physical fitness in youth remains unknown. Thus, the aim of the present systematic review and meta-analysis was to synthesise the evidence regarding these relationships and to quantify their associations in children and adolescents.

Methods

The present systematic review and meta-analysis was developed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and was registered in the International Platform of Registered Systematic Review and Meta-analysis Protocols (registration number: INPLASY202040032). The entire process from literature selection to data extraction was performed independently by two researchers (A. G.-H. and Y. E.). Any disagreements were resolved through consultation with a third researcher (R. R.-V.).

Selection criteria

To be eligible for inclusion in the meta-analysis, studies needed to meet the following criteria (using PICOS criteria): (i) participants: generally healthy population aged 3 up to 18 years (mean age); (ii) exposure: MD measured using the KIDMED test (Mediterranean Diet Quality Index); (iii) comparisons: exposed *v.* non-exposed youths; (iv) outcomes: PA, sedentary behaviour and physical fitness and (v) study design: cross-sectional and prospective cohort studies. The first and second reviewer (A. G.-H. and Y. E.) assessed the full-text articles for eligibility. If a single study assessed different sedentary behaviours (e.g. television watching, computer use, sitting time), all effect sizes were extracted.

Search strategy

Two investigators (A. G.-H. and Y. E.) systematically searched MEDLINE, Embase and SPORTDiscus electronic databases for articles, from inception to March 2020. We used variations of the terms MD (e.g. Mediterranean, diet, adherence), children and adolescents (e.g. child, children, adolescent, adolescents, youth), PA (e.g. active, exercise, physical inactivity), sedentary behaviour (e.g. sitting time, screen time, screen media, electronic media, Internet use, computer use, mobile phone use, television watching, video game) and physical fitness (e.g. cardiorespiratory fitness (CRF), aerobic fitness, muscular fitness, muscular strength) (online Supplementary material 1). Searching was restricted to published articles in the English and Spanish languages.

Data collection process and data items

The extracted data from the articles meeting the selection criteria included the following information: (i) study characteristics (the first author's name, publication year, enrolment year, study location, sample size, study design); (ii) participants' information (sex and age); (iii) measurement details (method of MD, PA, sedentary behaviours and physical fitness assessments) and (iv) analysis and study results (adjusted variables, outcome of interest and main results). We requested from the study authors any effect sizes that were missing from the original published papers.

Risk of bias in individual studies

The Quality Assessment Tool for Observational Cohort and Cross-sectional Studies was used to evaluate the risk of bias[11]. The checklist comprised fourteen items for longitudinal research, of which only eleven could be applied to cross-sectional studies. Each item of methodological quality was classified as 'yes', 'no' or 'not reported'.

Summary measures

We chose the correlation coefficient (r) as the main effect size for the present meta-analysis. Effect sizes reported by studies were standardised regression coefficients (β), unstandardised regression coefficients (beta), standardised mean differences (Cohen's d) and OR. We converted all of these estimates to correlations according to their corresponding formulas[12–14]. If adjusted and unadjusted effect sizes were provided, we selected adjusted. Correlation coefficients were entered along with the corresponding standard errors or sample size, and the software was set to produce pooled r values with 95 % CI using a random effects inverse-variance model with the Hartung–Knapp–Sidik–Jonkman adjustment. The pooled effect size for r was classified as small (≤0·10), moderate (0·10–0·37) or large (≥0·37)[15]. All analyses were performed using the admetan routine[16] within version 16.1 of STATA (STATA Corp.). A P value of <0·05 was considered a threshold for statistical significance.

Synthesis of results

For each meta-analysis, heterogeneity across studies was calculated using the total variance (Q), the df and the inconsistency index (I^2)[17], considering I^2 values of <25, 25–75 and ≥75 % as small, moderate and high heterogeneity, respectively[18]. Sensitivity analysis was performed to determine whether any single study with extreme findings had an undue influence on the overall results.

Risk of bias across studies

In the different meta-analyses performed, small-study effect bias was assessed using the extended Egger's regression test[19].

Additional analysis

We identified potential moderator variables *a priori*. The variables were sex and age (children <12 years and adolescents ≥12 years of mean age), by stratifying meta-analyses by each of these factors.

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Results

Study selection

In total, thirty-nine studies met the inclusion criteria and were included in the systematic review and meta-analysis[10,20–57]. The reasons for exclusion based on full text are reported as online Supplementary material 2. The PRISMA flow diagram illustrating the number of studies excluded at each stage of the systematic review and meta-analysis is shown in Fig. 1.

Study characteristics

A total of thirty-nine studies reported endpoints, and details of these are listed in Table 1. Most of the studies were cross-sectional in nature except for two that included a prospective design (however, we used only data from baseline)[23,43]. The studies involved a total sample of 565 421 youth with ages between 8 and 17 years (mean age, 12·4 years). All studies included males and females (51 and 49 %, respectively). Sample sizes across studies ranged from 298[35] to 335 810 participants[20].

Seventeen studies included participants from Spain[21–24,26,28,31,32,34,35,38,40,44,53,55–57], eight from Greece[20,25,36,37,41,47,51], four from Italy[10,33,49,50] and one from Chile[45], Croatia[54], Iceland[27], Estonia[29] and Lithuania[42]. Two studies were multi-national (Lithuania and Serbia[46], Colombia and Portugal[52]).

Measurements

Nine of the thirty-nine studies in the systematic review reported PA through several instruments[22,26,32,33,36,37,50,51] (e.g. the Moderate-to-Vigorous Physical Activity Screening Measure), fifteen used validated questionnaires like the Physical Activity Questionnaire for Children[21,23,25,34,38,45] or adolescents[10,53], the International Physical Activity Questionnaire[24,39,40,42,44,46], the Krece Plus test[35] and accelerometry[56].

Regarding screen time, most studies reported data on overall screen media time or frequency, mainly television viewing, computer use and video game playing. Four studies used sitting time[46,50,54,56] as sedentary behaviour.

Finally, components of physical fitness used were the CRF[21,27–29,31,38,45,51,52,57], muscular fitness[27–31,38,45,51,52,57] and

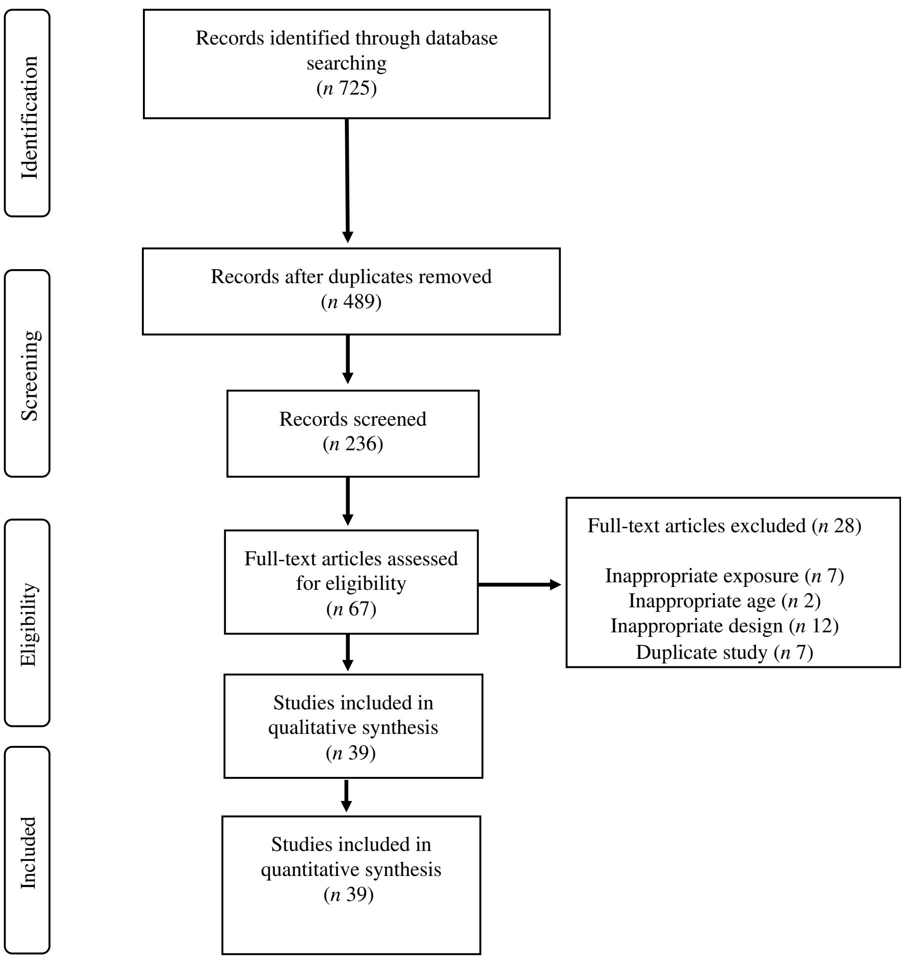

Fig. 1. Study selection.

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Table 1. Characteristics of the studies

Authors	Sample	Girls	Mean age (years)	Age range (years)	Location	Type of PA	Type of sedentary behaviour	Physical fitness component	Risk of bias
Agostinis-Sobrinho *et al.*[46]	2477	1320	14·3		Colombia and Portugal	–	–	CRF, muscular fitness	9
Arcila-Agudelo *et al.*[42]	1177	621	11·8		Spain	Light PA, vigorous PA	–	–	9
Arnaoutis *et al.*[20]	335 810	163 539	9·9		Greece	Total PA	Television watching, computer use and playing video games	–	6
Arriscado *et al.*[31]	321	158	11·7		Spain	Total PA	–	CRF	7
Bawaked *et al.*[52]	1639	790	10·1		Spain	Total PA	Television watching, computer use and playing video games	–	12
Bibiloni *et al.*[53]	1961	1022		12–17	Spain	Total PA	–	–	9
Cabañas-Sánchez *et al.*[50]	1197	600	12·1		Spain	Moderate-to-vigorous PA	Television watching, computer use and playing video games	CRF, muscular fitness and motor ability	7
Chacón-Cuberos *et al.*[47]	1059	527	15·2		Spain	Total PA	–	–	7
Farajian *et al.*[54]	4786	2426	10·9		Greece	Total PA	–	–	8
Fauquet *et al.*[55]	1502	647	14·1		Spain	Total PA	Television watching and computer use	–	8
Galan-Lopez *et al.*[56]	387	178	13·5		Iceland	–	–	CRF, muscular fitness and motor ability	7
Galan-Lopez *et al.*[57]	917	500	14·8		Spain	–	–	CRF, muscular fitness and motor ability	8
Galan-Lopez *et al.*[21]	413	265	15·1		Estonia	–	–	CRF, muscular fitness and motor ability	7
García-Hermoso *et al.*[22]	1140	346	10·0		Chile	–	–	Muscular fitness	8
Grao-Cruces *et al.*[23]	1988	983	13·9		Spain	–	–	CRF, muscular fitness and motor ability	6
Grao-Cruces *et al.*[24]	1897	941	13·9		Spain	Moderate-to-vigorous PA	Television watching, computer use and doing homework	–	7
Grosso *et al.*[25]	1135	508	13		Italy	PA level	–	–	7
Kontogianni *et al.*[28]	1305	617	11·5		Greece	Leisure-time PA	Television watching, computer use and playing video games	–	8
Lazarou *et al.*[29]	1140	637	10·7		Greece	PA and time in sports	Television, video or DVD watching, computer use and playing video games	–	9
López-Gil *et al.*[30]	370	166	8·7		Spain	Total PA	–	CRF, muscular fitness and motor ability	6
Magriplis *et al.*[32]	4580	2336	10·9		Greece	Total PA	–	–	7
Manzano-Carrasco *et al.*[51]	1676	470	11·1		Spain	–	–	CRF, muscular fitness	6
Martínez *et al.*[33]	1231	NR		12–17	Spain	Total PA	–	–	9
Mazaraki *et al.*[34]	365	153	13·8		Greece	Time in sports	Television watching	–	7
Mieziene *et al.*[35]	1863	957		14–18	Lithuania	Total PA	–	–	7
Monjardino *et al.*[36]	1264	673	13		Portugal	Sports activities	–	–	10
Moral García *et al.*[37]	648	330	13·8		Spain	Total PA	–	–	8
Muros *et al.*[38]	515	255	10·6		Chile	Total PA	Television, video or DVD watching, computer use and playing video games	CRF and muscular fitness	6
Novak *et al.*[39]	3071	1622		14–18	Lithuania and Serbia	Total PA	Sitting time	–	7

Table 1. (*Continued*)

Authors	Sample	Girls	Mean age (years)	Age range (years)	Location	Type of PA	Type of sedentary behaviour	Physical fitness component	Risk of bias
Obradovic Salcin *et al.*[48]	260	126		5–6	Croatia	Total PA in the home environment	Sitting time	–	9
Papadaki & Mavrikaki[40]	525	316	14·7		Greece	–	Television/DVD watching and playing video games	–	6
Peng *et al.*[41]	5268	2978		11–19	Israel	PA and time in sports	Television, videos and listening to music	–	9
Pino-Ortega *et al.*[49]	349	156	9·9		Spain	–	–	CRF, muscular fitness and motor ability	7
Roccaldo *et al.*[43]	1740	840	8·8		Italy	–	Television watching and computer use	–	8
Rosa Guillamón *et al.*[26]	520	301	12·8		Spain	Total PA	–	–	5
Rosa Guillamón *et al.*[27]	298	159	9·5		Spain	Outdoor active play	–	–	4
Rosi *et al.*[10]	409	187	12·5		Italy	Total PA	–	–	8
Santomauro *et al.*[44]	1127	506	16·8		Italy	Time in sports	Sitting time	–	7
Tambalis *et al.*[45]	177 091	89 288	11·1		Greece	–	–	CRF, muscular fitness and motor ability	6

PA, physical activity; CRF, cardiorespiratory fitness.

speed–agility[27–29,31,38,51] measured with the EUROFIT[51,55] or ALPHA fitness battery[27–29,31,38,45,56,57] tests (Table 1).

Risk of bias within studies

All thirty-nine studies met at least four criteria and were considered to have moderate methodological quality. The average score was 7·5/14·0 (online Supplementary material 3).

Synthesis of results

Figs. 2–6 show the synthesis of results. There was a weak-to-moderate direct relationship between adherence to the MD and PA (r 0·14; 95 % CI 0·11, 0·17; I^2 88·6), CRF (r 0·22; 95 % CI 0·13, 0·31; I^2 95·7) and muscular fitness (r = 0·11; 95 % CI 0·03, 0·18; I^2 95·4), and a weak-to-moderate negative relationship with sedentary behaviour (r –0·15; 95 % CI –0·20, –0·10; I^2 97·3) and speed–agility (r –0·06; 95 % CI –0·12, –0·01; I^2 84·2).

The results remained significant after controlling for sex and age (children or adolescents) in PA (Table 2). Also, there was a significant slightly higher correlation between adherence to the MD and sedentary behaviour in children (r –0·21; 95 % CI –0·29, –0·12; I^2 96·5) and CRF in adolescents (r 0·30; 95 % CI 0·12, 0·47; I^2 96·5).

Publication bias and sensitivity analysis

Funnel plots and the Egger asymmetry test indicated statistically significant publication bias for PA (effect size = 1·75; 95 % CI 0·58, 2·91; P < 0·001), sedentary behaviour (effect size = 5·22; 95 % CI 3·24, 7·32; P < 0·001) and CRF (effect size = 3·38; 95 % CI 1·48, 5·27; P = 0·002) (online Supplementary material 4).

Finally, sensitivity analyses were carried out by sequentially removing one study from the data set to elucidate the influence of individual studies on the analysis. Results remained consistent across all deletions.

Discussion

To our knowledge, the present systematic review and meta-analysis is the first to synthesise the evidence on the cross-sectional associations between adherence to the MD, PA, sedentary behaviour and physical fitness levels in children and adolescents. Our analyses showed small-to-moderate positive relationships between adherence to the MD, PA, CRF and muscular fitness and a negative relationship with sedentary behaviours and speed–agility. Overall, the meta-analysis indicates that youths with higher adherence to the MD are more likely to be physically active, fit and have a less sedentary lifestyle. However, the findings should be interpreted while keeping in mind the heterogeneity between studies in the associations, exposure and outcomes assessment and publication bias.

A recent review by Iaccarino Idelson *et al.*[1] suggested a positive association between adherence to the MD and PA levels. In this line, our meta-analytic findings suggest a moderate direct association between them, independent of sex and age. One might speculate about four possible hypotheses underlying the relationships between the two behaviours: (i) it is possible that MD adherence influences PA by allowing those youths

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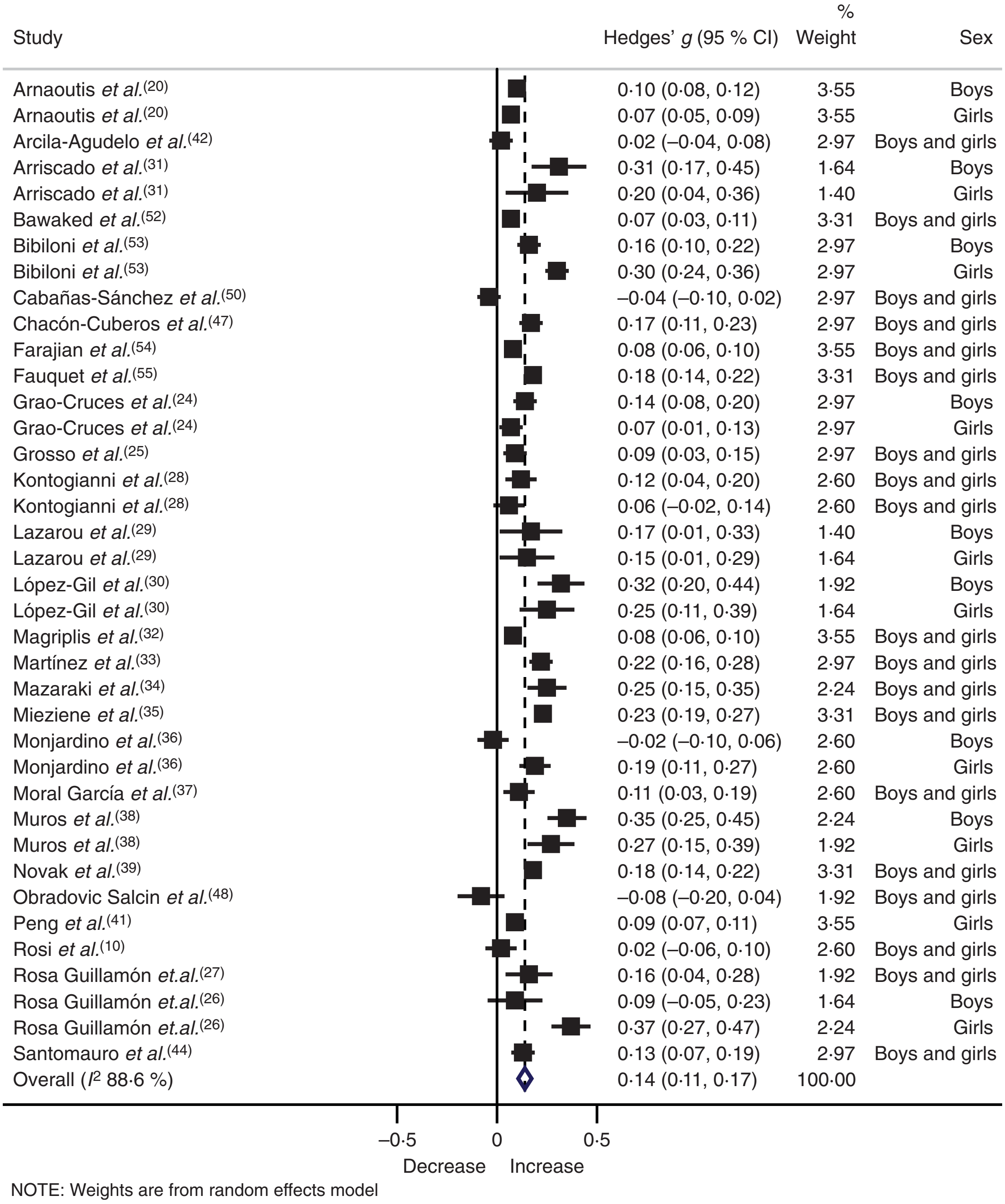

Fig. 2. Forest plot showing the correlation of Mediterranean diet adherence and physical activity for each study. Squares represent pooled effect size for each subgroup analysis, and the diamond represents the overall pooled effect size.

who eat properly to be more physically active by providing them with the necessary nutrients[58]. For example, it has been reported that the higher energy expenditure of active children and adolescents requires higher intake of essential nutrients[59], which requires a higher consumption of carbohydrates, vitamins and quality proteins, all provided by adequate MD adherence; (ii) better eating habits seem to be linked with some personality traits such as self-efficacy and self-regulation, which is a motive to get more involved in PA among children and adolescents[60]; (iii) specific behavioural and environmental factors such as the school environment and the influence of peer groups often result in the clustering of behavioural habits, meaning that youths who are more active tend to develop other healthy habits such as consuming a healthy diet[61] and (iv) both behaviours and their relationship could be linked to the family environment[54]. With respect to the latter, there is some evidence to indicate the importance of parental education in the healthy eating choices of their children[42]. Likewise, it has been determined that socio-economic status is one of the most important determinants of both MD adherence[1] and PA among young people[62].

With respect to sedentary behaviour, our analysis showed that higher adherence to the MD was related to lower sedentary lifestyle, usually assessed as screen time and predominantly television viewing and computer use. These relationships have been

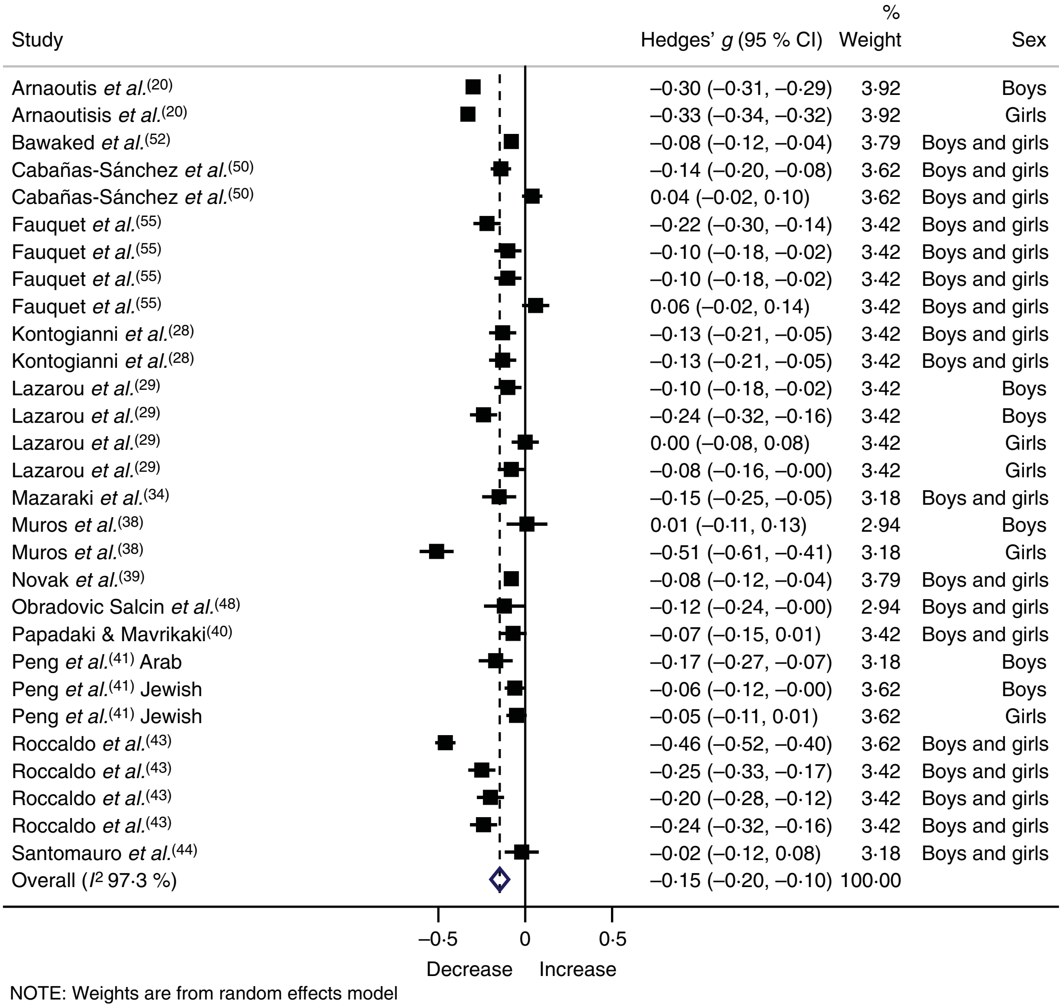

Fig. 3. Forest plot showing the correlation of Mediterranean diet adherence and sedentary behaviours for each study. Squares represent pooled effect size for each subgroup analysis, and the diamond represents the overall pooled effect size.

reiterated by other authors, suggesting that children with healthy eating habits, assessed with the question 'Do you think this child typically eats healthy meals?', are engaged in fewer sedentary behaviours[63]. There are several possible explanations for this result: (i) screen time viewing, mainly television use, is inversely related to healthy foods such as fruits and vegetables and is positively associated with a higher intake of energy-dense snacks and drinks, fast foods, total energy intake and energy from fat in youth[64]; (ii) television viewing and exposure to food advertising are connected, in a positive manner, to unhealthy food habits in children and adolescents[65]. In this context, some authors disagree between television and computer sedentarism, suggesting that using personal computers involves lower nutritional risk, as hands are usually engaged and therefore not free for the consumption of unhealthy foods[66]. In contrast to these earlier findings, our meta-analysis showed similar relationship between MD and television (r –0·14; 95 % CI –0·22, –0·05) and computer use (r –0·19; 95 % CI –0·33, –0·05) (data not shown).

Our study also shows that adherence to the MD is significantly associated with higher CRF, muscular fitness and speed–agility levels. These results are similar to those reported by several studies which used other eating habits questionnaires[7,8]. An example of this is the study carried out by Thivel *et al.*[7] who reported that CRF and muscular fitness in French schoolchildren were associated with healthy eating habits. In a similar case in ten European cities, the authors suggested that adolescents who skipped breakfast were less likely to achieve elevated CRF measurements in comparison with those who consumed breakfast[8]. According to this, it could be proposed that a well-balanced diet, providing adequate energy sources throughout the day, rich in all essential nutrients and natural antioxidants, low in saturated fat, and based on an abundant consumption of fruits, vegetables, legumes, fish, nuts and olive oil, would yield great benefits on physical fitness during childhood and adolescence[20].

Practice implications

Improving dietary habits towards those of the MD could be associated with higher physical fitness and PA in youth, lower sedentary behaviours[67] and better health in general. Under-

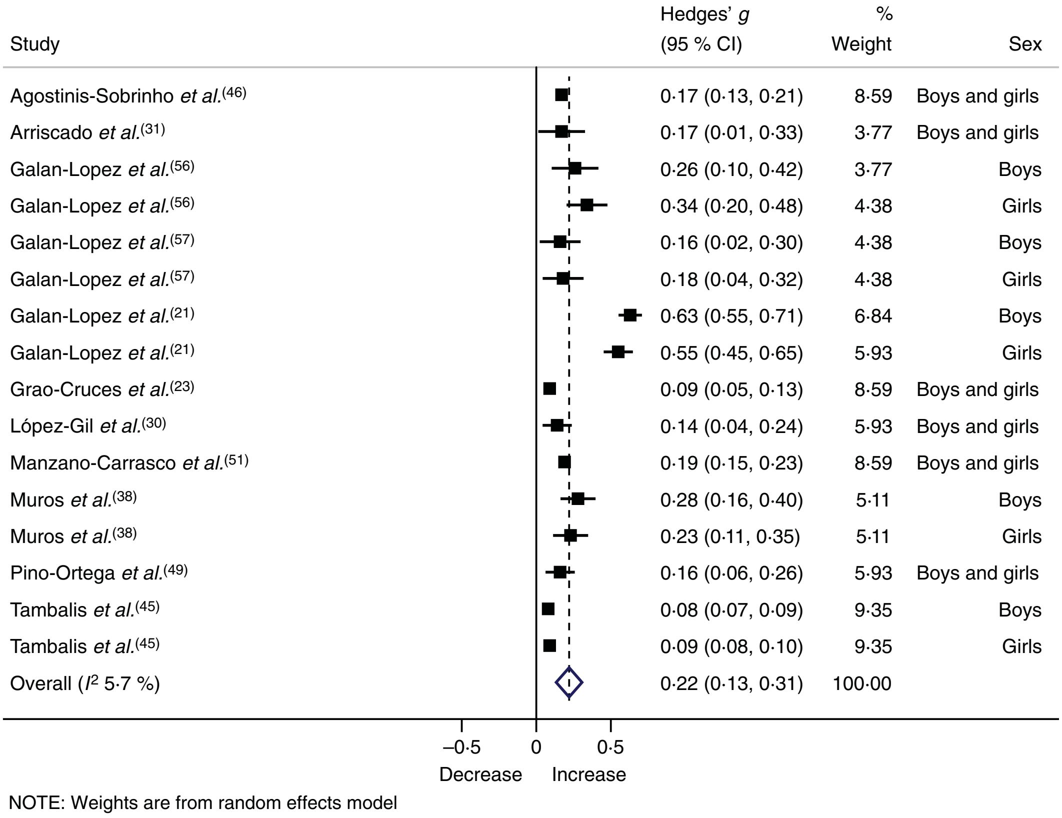

Fig. 4. Forest plot showing the correlation of Mediterranean diet adherence and cardiorespiratory fitness for each study. Squares represent pooled effect size for each subgroup analysis, and the diamond represents the overall pooled effect size.

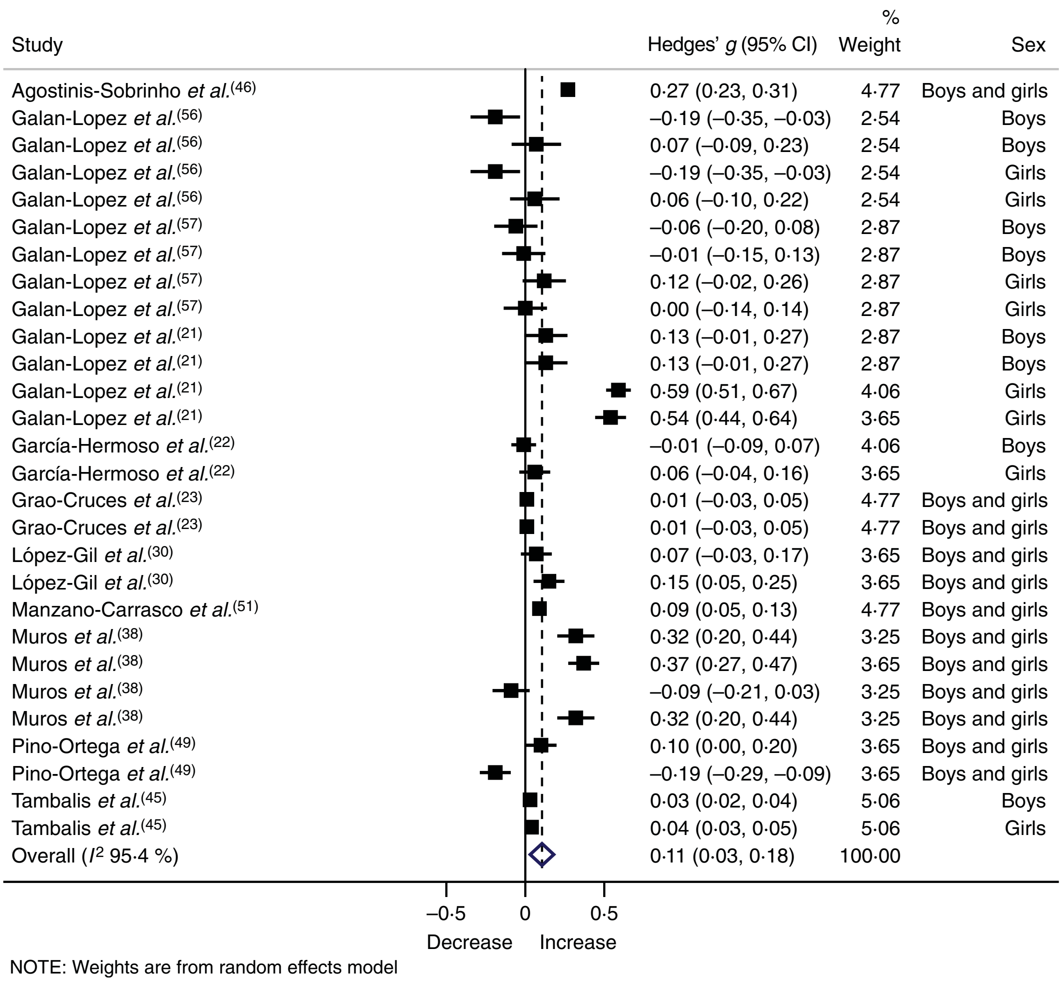

Fig. 5. Forest plot showing the correlation of Mediterranean diet adherence and muscular fitness for each study. Squares represent pooled effect size for each subgroup analysis, and the diamond represents the overall pooled effect size.

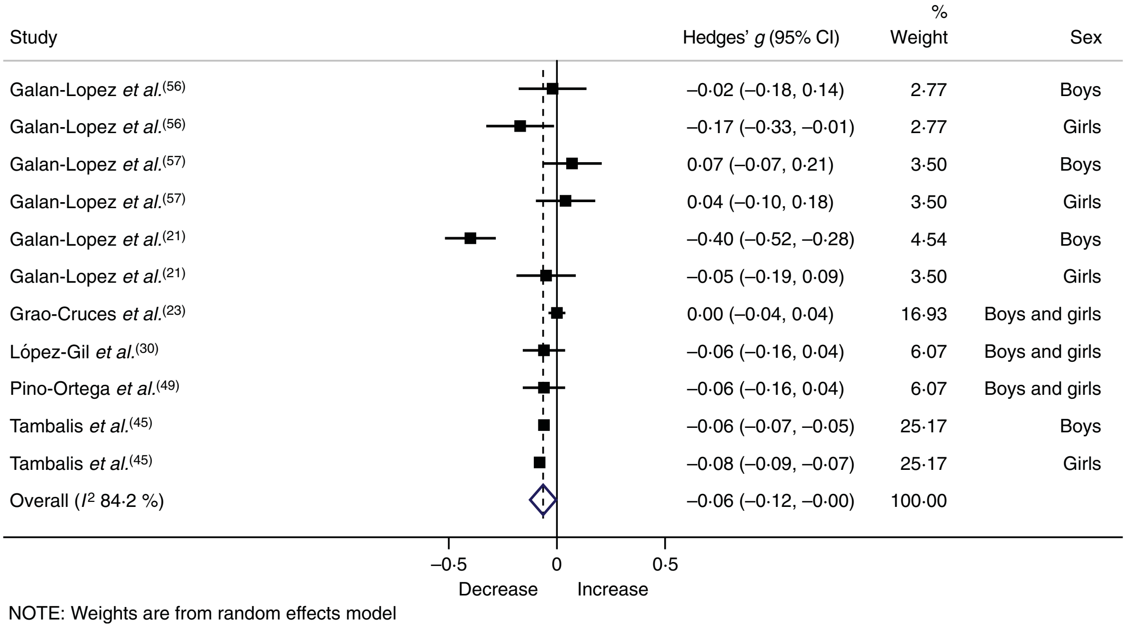

Fig. 6. Forest plot showing the correlation of Mediterranean diet adherence and speed–agility (lower values represent higher performance) for each study. Squares represent pooled effect size for each subgroup analysis, and the diamond represents the overall pooled effect size.

Table 2. Subgroup analysis of the association between adherence to the Mediterranean diet and physical activity, sedentary behaviour and physical fitness components according to sex and age
(Correlation coefficients (*r*) and 95 % confidence intervals)

	Studies (*n*)	*r*	95 % CI	*P*	I^2
Boys					
Physical activity	8	0·19	0·08, 0·29	0·005	85·4
Sedentary behaviours	4	–0·15	–0·30, 0·00	0·056	78·7
CRF	3	0·34	–0·06, 0·73	0·072	94·1
Muscular fitness	5	0·02	–0·06, 0·09	0·630	52·9
Speed–agility	4	–0·11	–0·43, 0·22	0·381	91·6
Girls					
Physical activity	10	0·21	0·11, 0·18	0·001	90·7
Sedentary behaviours	4	–0·19	–0·46, 0·07	0·117	96·1
CRF	4	0·32	0·04, 0·62	0·036	88·4
Muscular fitness	5	0·16	–0·07, 0·38	0·147	97·6
Speed–agility	4	–0·07	–0·17, 0·03	0·103	31·6
Children					
Physical activity	12	0·14	0·07, 0·21	<0·001	84·1
Sedentary behaviours	7	–0·21	–0·29, –0·12	<0·001	96·5
CRF	5	0·19	0·15, 0·23	<0·001	0
Muscular fitness	7	0·07	–0·01, 0·14	0·063	89·8
Speed–agility	4	–0·06	–0·10, –0·04	0·004	76·2
Adolescents					
Physical activity	18	0·14	0·10, 0·19	<0·001	87·7
Sedentary behaviours	8	–0·08	–0·13, –0·04	0·001	76·2
CRF	5	0·30	0·12, 0·47	0·005	96·5
Muscular fitness	4	0·12	–0·03, 0·26	0·105	94·8
Speed–agility	4	–0·08	–0·23, 0·07	0·268	87·1

CRF, cardiorespiratory fitness.

standing the behaviours associated with adherence to MD in the young population could be essential for the appropriate, specific design of public health interventions that will contribute to early adoption of healthy habits to reduce the impact of Western dietary patterns.

Limitations and strengths

To the best of our knowledge, this is the first study to determine the association between the MD and healthy habits among children and adolescents, including a total of 562 764 youth in the analyses.

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The present meta-analysis has some limitations. First, the cross-sectional design of the included studies prevents causal inferences and can be more susceptible to biases (e.g. selection bias, information bias, etc.). Reverse causality could also be true. However, a prospective study included in our meta-analysis confirms results on PA and sedentary behaviours[23]. Second, in most studies, PA, dietary habits and sedentary time were self-reported and could potentially be subject to socially desirable reporting bias. Also, the included studies measured PA, sedentary behaviours and physical fitness using a wide variety of different tools. Third, most of the studies did not consider potential confounding factors such as socio-economic status and/or parental education. Finally, the results indicate publication bias for PA, sedentary behaviour and CRF. However, due to between-study heterogeneity, we are unable to conclude whether the asymmetry in the plot is due to heterogeneity between studies or publication bias[68].

In conclusion, our findings have significant implications for the understanding of how MD is related to behavioural outcomes among youth. In general, it seems that lifestyle factors could interact with each other synergistically. The lack of experimental and prospective studies found in our meta-analysis suggests that the overall body of evidence is weak and further research is needed.

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Supplementary material

For supplementary materials referred to in this article, please visit https://doi.org/10.1017/S0007114520004894

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