High Adherence to the Mediterranean Diet is Associated with Higher Physical Fitness in Adults: a Systematic Review and Meta-Analysis

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ABSTRACT

Although prior research has synthesized the relationships between the Mediterranean diet (MD) and components of physical fitness (PF) in adults, they are limited and inconclusive. This study aimed to synthesize the associations between high (compared with low) MD adherence and PF levels with each of its components (cardiorespiratory, motor, and musculoskeletal) in adulthood. We conducted a systematic search in 5 databases from inception to January 2022. Observational studies and randomized controlled trials were included. Pooled odds ratios (ORs) and effect sizes (Cohen *d* index) with their 95% CIs were calculated via a random effects model. A total of 30 studies were included (19 cross-sectional in young, middle-aged, and older adults; 10 prospective cohort in older adults; and 1 randomized controlled trial in young adults) involving 36,807 individuals (mean age range: 20.9–86.3 y). Pooled effect sizes showed a significant cross-sectional association between higher MD adherence scores (as a continuous variable) and overall PF ($d = 0.45$; 95% CI: 0.14, 0.75; $I^2 = 91.0\%$, $n = 6$). The pooled ORs from cross-sectional data showed that high adherence to MD was associated with higher cardiorespiratory fitness (OR: 2.26; 95% CI: 2.06, 2.47; $I^2 = 0\%$, $n = 4$), musculoskeletal fitness (OR: 1.26; 95% CI: 1.05, 1.47; $I^2 = 61.4\%$, $n = 13$), and overall PF (OR: 1.44; 95% CI: 1.20, 1.68; $I^2 = 83.2\%$, $n = 17$) than low adherence to MD (reference category: 1). Pooled ORs from prospective cohort studies (3- to 12-y follow-up) showed that high adherence to MD was associated with higher musculoskeletal fitness (OR: 1.20; 95% CI: 1.01, 1.38; $I^2 = 0\%$, $n = 4$) and overall PF (OR: 1.14; 95% CI: 1.02, 1.26; $I^2 = 9.7\%$, $n = 7$) than low adherence to MD (reference category: 1). Conversely, no significant association was observed between MD and motor fitness. High adherence to MD was associated with higher PF levels, a crucial marker of health status throughout adulthood. This trial was registered at PROSPERO as CRD42022308259. *Adv Nutr* 2022;13:2195–2206.

Statement of Significance: This is the first systematic review and meta-analysis to provide a comprehensive picture of the associations between adherence to the Mediterranean diet and physical fitness levels with each of its components (cardiorespiratory, motor, and musculoskeletal) in adulthood.

Keywords: adulthood, healthy diet, Mediterranean diet adherence, Mediterranean foods, aerobic capacity, motor skills, muscular strength

Introduction

Physical fitness (PF) is a critical determinant of health throughout adulthood (1). The core components of overall PF include cardiorespiratory fitness (CRF) (i.e., the functional capacity of the cardiovascular and respiratory systems during sustained physical activity), motor fitness (MF) (i.e., motor skills such as agility or speed), and musculoskeletal fitness (MSF) (i.e., muscle abilities such as flexibility or muscular strength) (2). These health-related PF components categorize the set of attributes related to a person's ability to perform physical activities, facilitating the development of practical and public health recommendations according to each component (3). Adults of any age have the trainability capacity to increase PF levels, which is vital for short- and long-term health status (4). In fact, higher PF was associated with improved health prognosis (5, 6) and reduced mortality (1, 7) in young, mid-, and old life.

 Adv Nutr 2022;13:2195–2206; doi: https://doi.org/10.1093/advances/nmac104.

Nutrition has received increasing attention as one of the most potent, feasible, and safest strategies to extend the time in which health status and functional capacity are maintained (8, 9). In this context, the Mediterranean diet (MD) appears to be a robust scientific concept (10) associated with favorable health outcomes over the entire life span (11). Some evidence has suggested that the MD could have a positive impact on PF (12), mainly because the synergistic effect of its food features—olive oil as the principal source of fat; high consumption of fruits, herbs, legumes, nuts, olives, seeds, spices, vegetables, and whole grain cereals; moderate consumption of eggs, fish or seafood, dairy products (preferably low in fat), red wine, and white meat; and occasional consumption of red or processed meat and sweets (carbonated beverages, pastries, sugar) (13, 14)—leads to high-quality nutrient intake [i.e., rich in unsaturated fatty acids (especially monounsaturated), essential amino acids, and antioxidant capacity (from carotenoids, phenolic compounds, trace elements, and vitamins)] (15), which in turn promotes greater PF (16). Moreover, the concept of MD incorporates lifestyle and cultural elements (e.g., adequate rest, conviviality, regular physical activity; preference for fresh, local, seasonal, and traditional foods) that should be considered to contribute to the nutritional benefits of this healthy and sustainable food matrix (10, 14).

Syntheses of the available evidence on MD–PF relationships among adults are limited and inconclusive. Most systematic reviews analyzing the associations between MD patterns and PF levels during adulthood (12, 17–20) are mainly focused on musculoskeletal impairment outcomes (i.e., frailty, mobility disability, sarcopenia) rather than PF components (19, 20). However, some of them did not specifically analyze adherence to the MD (17–19), did not perform meta-analysis (17–20), and were based on few cross-sectional and prospective cohort studies (n = 2–5), showing mixed results on PF components (12, 17–20). The only meta-analysis on MD and PF components showed that high MD adherence was cross-sectionally associated with MF in older adults, although inconsistent results were found regarding MSF parameters (12). Considering this body of evidence, a systematic review and meta-analysis remain lacking to address whether adherence to the MD is associated with each PF component (CRF, MSF, MF) in observational and interventional studies throughout adulthood. Therefore, this study was aimed at synthesizing the cross-sectional, prospective observational (i.e., from cohort studies), and interventional [i.e., from randomized controlled trials (RCTs)] associations between high (compared with low) MD adherence and PF levels in the adult population.

Materials and Methods

The systematic review and meta-analysis were conducted in accordance with the 2020 PRISMA guidelines (21) and the Cochrane Collaboration handbook (22). The study protocol was registered in PROSPERO (CRD42022308259) and has been published elsewhere (23). The literature search, data extraction, and risk-of-bias assessment were independently performed by 2 researchers (BB-P and JB-S) with any disagreements resolved by a third researcher (AEM).

Search strategy and study selection

The systematic search was conducted in the following databases from inception until 31 January 2022: MEDLINE–PubMed (January 1975), Cochrane CENTRAL (March 1982), Scopus (July 1974), SPORTDiscus (June 1993), and Web of Science (January 1972). The full detailed search strategy for each database is presented in **Supplemental Table 1**. All identified studies were pooled into a single database, and duplicate articles were excluded via Mendeley Manager (version 1.19.8). Next, studies that clearly did not address the MD–PF relationship were first excluded by title and abstract. In a second step, the remaining studies were analyzed by reading the full text to determine whether they met the eligibility criteria.

Eligibility criteria

To be included, studies retrieved from the peer-reviewed literature had to meet the following inclusion criteria according to the PI(E)COS strategy:

- Participants: general adult population (≥18 y)
- Intervention or exposure: for observational studies, high MD adherence according to the overall score of different scales (e.g., 9-point MD scale, 14-point MD scale) and to their specific elements (foods and nutrients); for RCTs, a treatment strategy directly related to the MD (e.g., dietary advice or cooking workshops)
- Comparison: for observational studies, low adherence to the MD; for RCTs, control condition as a non-MD strategy (e.g., habitual diet or usual care)
- Outcome: PF components, including CRF (maximal or submaximal aerobic capacity), MF (agility, balance, or speed), and MSF (flexibility; maximal, endurance, explosive, or isokinetic strength) measured by standardized tests;
- Study design: observational studies (cross-sectional, case–control, and prospective/retrospective cohort) or RCTs

Moreover, studies were excluded if they reported on the following: *1*) only data for populations with specific activities

This work was supported by the University of Castilla-La Mancha and cofinanced by the European Social Fund under grant 2020-PREDUCLM-16746; the National Agency for Research and Innovation under grant POS_EXT_2020_20_1_165371; the Spanish Ministry of Education, Culture and Sport under grant FPU 19/00167; and the Spanish Ministry of Education, Culture and Sport under Beatriz Galindo contract BEAGAL18/00093. The funders played no role in the study design, the data collection or analysis, the decision to publish, or the preparation of the manuscript. The conclusions and interpretations provided, based on the scientific data reviewed, are those of the authors and not of the public funding agencies of the study.
Author disclosures: The authors report no conflicts of interest.
Supplemental Tables 1–10, Supplemental Material, and Supplemental Figures 1–9 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/advances/.
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Abbreviations used: CRF, cardiorespiratory fitness; MD, Mediterranean diet; MF, motor fitness; MSF, musculoskeletal fitness; PF, physical fitness; RCT, randomized controlled trial.

(e.g., elite athletes); *2*) diet in terms of single-nutrient intake, food items, or food groups; *3*) neuromusculoskeletal impairment as the outcome (i.e., frailty, sarcopenia, and physical disability); *4*) PF measured exclusively by self-report; *5*) duplicate data published in another included study; and *6*) noneligible publications, such as qualitative studies, conference or meeting abstracts, preprints, editorials, and letters to the editor.

Data extraction

The following data were extracted from the included studies: name of the first author and year of publication, country, study design, sample size, participant information (sex, age, high MD adherence, and health condition), diet assessment, MD assessment instrument and cutoff score for high MD adherence, specific MD elements (foods and nutrients), PF components, main results, and statistical methods and covariates used.

Risk-of-bias assessment

The Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (24) and the Risk of Bias tool for crossover trials (25) were used to evaluate the risk of bias of observational studies and RCTs, respectively. Assessment details of the risk-of-bias rating are synthesized in the **Supplemental Material** (Risk of Bias Appendix).

Data synthesis and statistical analysis

For meta-analysis, MD intervention compared with control condition (for RCTs) and higher compared with lower MD adherence (for observational studies) as exposures were considered to compare their association with overall PF levels and, where possible, separately with each PF component (CRF, MF, and MSF; outcomes). The results of the studies were synthesized narratively, and a meta-analysis was performed when at least 4 studies addressed the same outcome (26). In the meta-analysis, ORs and 95% CIs were calculated according to the estimator used in each study (means, ORs, standardized regression coefficients, and unstandardized regression coefficients) by applying the appropriate formula (27–30). We conducted separate meta-analyses depending on the study design. Pooled ORs were estimated with the DerSimonian and Laird random effects method (31). Associations between adherence to the MD as a categorical variable (high compared with low adherence as the reference category) and PF levels as categorical and continuous variables were combined in forest plots according to PF components. Heterogeneity among studies was assessed with the I^2 statistic, categorized as not important (0%–30%), moderate (30%–60%), substantial (60%–75%), or considerable (75%–100%) (22). Additionally, the corresponding P values for I^2 were considered (32).

Other methodological considerations for data collection and analysis should be noted. According to a previous meta-analysis (33), studies in which MD adherence was analyzed as a continuous score (i.e., no categorical high compared with low MD adherence was presented) were excluded from the calculation of the ORs to provide more homogeneous results and accurate quantification of associations between high MD adherence and PF levels. For studies analyzing MD adherence as a continuous score, effect sizes and 95% CIs were calculated for each observed correlation and regression coefficient with the Cohen *d* index (28, 30, 34, 35). A pooled effect size was estimated with the DerSimonian and Laird random effects method (31).

Moreover, if the studies presented adjustment models, the results of the fully adjusted model were selected. When studies presented results stratified by sex groups separately and where >1 measure was used for the exposure or for the same PF component, we combined the respective measures to calculate a single pooled OR for each study. In those cases where studies stratified the level of MD adherence into group percentiles, high MD adherence was defined as the highest group and low MD adherence as the lowest group. In prospective cohort studies reporting results for >1 follow-up length, the longest period was selected. Furthermore, prospective cohort studies reporting baseline associations between MD adherence and PF levels were included in the cross-sectional meta-analyses.

Subgroup analyses were performed according to geographic location (Mediterranean region compared with non-Mediterranean region), adult age group (older compared with young or middle-aged), and scale used to assess adherence to the MD (9-point MD scale compared with other scales). Random effects meta-regressions were performed considering the following sample characteristics as continuous independent variables in the model: sex (percentage women), age (mean years), BMI (mean kg/m^2), health status (percentage of ≥1 chronic diseases), current smoker (percentage), and total energy intake (mean kilocalories per day). Moreover, sensitivity analyses were conducted to evaluate the robustness of the summary estimates by removing each study one by one. Additional analyses were carried out by combining the measurements of the PF components (CRF, MF, and MSF) into a single pooled OR (overall PF) for each study. Finally, publication bias was assessed with Egger's regression asymmetry test (36) and by evaluating funnel plots through visual inspection when ≥10 studies were included in the meta-analysis to distinguish chance from real asymmetry (37).

All statistical analyses were performed in Stata/SE software (version 15.0; StataCorp).

Results

Study selection

A total of 3631 studies were considered for title–abstract review after removal of duplicates, of which 80 were fully assessed for eligibility and 50 were excluded for various reasons (**Supplemental Table 2**). Thirty studies were included in the systematic review: 19 cross-sectional (38–56), 10 prospective cohort (57–66), and 1 RCT (67) (**Supplemental Figure 1**).

Study characteristics

Table 1 and **Supplemental Table 3** summarize the characteristics of the studies. The studies were conducted between 2011 (59) and 2021 (44, 50, 51, 55, 58, 65). Twenty-two studies were conducted with older adults (38, 39, 41, 44–49, 53, 55–66). Five cross-sectional (44, 47, 48, 53, 54) and 3 prospective cohort (63–65) studies analyzed adherence to the MD as a continuous score. The insufficient number of prospective cohort studies (n < 4) (63–65) estimating associations between MD adherence as a continuous score and PF levels did not allow meta-analysis. The crossover RCT compared two 4-d dietary interventions (MD compared with Western diet) based on verbal and written instructions for each diet (i.e., following the recommended dietary goals through general meal plans for the MD and the Western diet), separated by a washout period from 9 to 16 d (67). Insufficient RCTs addressing the same outcome did not allow meta-analysis regarding this study design (67).

Participants

The studies included 36,807 adults from Mediterranean (38, 39, 41, 43, 46–48, 51, 52, 54, 55, 57, 59, 60, 63) and non-Mediterranean (40, 42, 44, 45, 49, 50, 53, 55, 56, 58, 61, 62, 64–67) countries. The mean age ranged from 20.9 (43) to 86.3 (41) y. Six studies (39, 44, 48–50, 53) analyzed participants with specific health conditions, such as autosomal dominant polycystic kidney disease (50), obesity (44, 48, 49), and type 2 diabetes mellitus (39, 44, 53).

Exposure: MD

MD was calculated via the 9-point MD scale (68) in 12 studies (38–40, 42, 57–62, 64, 66) and the 14-point MD scale (69) in 9 studies (43, 44, 47–49, 53–55, 67). The specific MD index items analyzed were butter and cream (47), cereals (51), commercial sweets and confectionery (47), fish (51, 55), fish and seafood (47, 53), legumes (47, 55), nuts (47), olive oil (47, 51), red meat (47, 51, 55), soda drinks (47), sofrito sauce (47), vegetables and fruits (47, 51, 61), and wine (47).

Outcome: PF

CRF was assessed with 6-min walking test (39, 46, 48), maximal or submaximal bicycle or treadmill ergometry test (42, 51, 64, 67), and 20-m shuttle run test (43, 54). MF was measured with the Short Physical Performance Battery derived from gait speed, functional performance of lower limbs, and standing balance (41, 44, 49, 53, 55, 59–61, 63) and the gait speed test (38, 45, 46, 52, 57, 58, 61, 62, 65, 66). MSF was evaluated with the handgrip strength test (40, 43–47, 49, 50, 52–57, 61–63, 65, 67).

Risk-of-bias assessment

According to the Quality Assessment Tool (24), cross-sectional studies scored between 5 and 8 points (36.8% were rated good quality and 63.2% poor quality), and prospective cohort studies scored between 9 and 11 points (20% were rated good quality and 80% fair quality). The 4 criteria where most of the articles lacked information were sample size justification, varying levels of exposure, repeated exposure assessment, and outcome blinding of the assessors to the participants' exposure status (**Supplemental Table 4**). The RCT (67) was rated as having "some concerns" according to the Risk of Bias tool for crossover trials (25) (**Supplemental Figure 2**).

MD and PF associations

Systematic review.

The results of the studies in the systematic review, not in the meta-analysis, are displayed in **Supplemental Table 5**. The prospective associations between higher MD continuous scores and PF levels provided mixed results, with studies showing significant (63) and nonsignificant (64, 65) improvements. Concerning the RCT, a 4-d MD intervention as compared with a 4-d Western diet reported significant increases in CRF and no significant changes in MSF (67).

When studies analyzed MD-specific elements, higher consumption of fish and seafood (53), nuts (47), and vegetables and fruits (47, 51, 61) and lower consumption of butter and cream, commercial sweets and confectionery, red meat, and soda drinks (47) were significantly associated with higher PF, specifically for CRF (51), MF (53, 61), and MSF (47). Meanwhile, other studies showed no significant association between consumption of cereals (51), fish (47, 51, 55), legumes (47, 55), olive oil (47, 51), red meat (51), and wine (47) and PF levels, specifically for CRF (51), MF (55), and MSF (47, 55). Finally, 1 study showed that higher consumption of red meat was significantly associated with higher MSF (55).

Meta-analysis.

The meta-analysis comparing high and low MD adherence included 16 studies with cross-sectional data (38–43, 45, 46, 49, 51, 52, 55, 56, 59, 61, 66) in 29,866 adults (mean age range: 20.9–86.3 y) and 7 prospective cohort studies (57–62, 66) in 6912 older adults (mean age range: 67.8–74.6 y). Moreover, 5 cross-sectional studies (44, 47, 48, 53, 54) reporting adherence to the MD as a continuous score in 695 adults (mean age range: 20.9–71.7 y) were included in a second meta-analysis.

The pooled ORs from cross-sectional associations (**Figure 1**) showed that high adherence to MD was statistically associated with higher CRF (OR: 2.26; 95% CI: 2.06, 2.47; $I^2 = 0\%$; $n = 4$), MSF (OR: 1.26; 95% CI: 1.05, 1.47; $I^2 = 61.4\%$, $n = 13$), and overall PF (OR: 1.44; 95% CI: 1.20, 1.68; $I^2 = 83.2\%$, $n = 17$) when compared with low adherence to MD (reference category: 1). Moreover, the association between high (compared with low) MD adherence and MF was not statistically significant (OR: 1.27; 95% CI: 0.96, 1.58; $I^2 = 52.9\%$, $n = 10$). The pooled ORs from prospective cohort associations (**Figure 2**) showed that high adherence to MD was statistically associated with higher MSF (OR: 1.20; 95% CI: 1.01, 1.38; $I^2 = 0\%$, $n = 4$) and overall PF (OR: 1.14; 95% CI: 1.02, 1.26; $I^2 = 9.7\%$, $n = 7$) than low adherence to MD (reference category: 1). Moreover, the association between high (compared with low) MD adherence and MF

TABLE 1 Main characteristics of the studies included in the systematic review and meta-analysis

Studies			Participants			Exposure		Outcome		
Reference	Country	Design	Women, *n* (%)	Age, y, mean ± SD or range	haMD, %	Dietary assessment	MD scale/cutoff score for haMD	CRF test	MF test	MSF test
Baker (2019) (67)	Spain	RCT (4 d)	11 (64)	28.0 ± 3.0	—	DH, 3- and 4-d DR	MEDAS/—	5-km treadmill ergometer	—	VHJ, WAn
Barrea (2019) (47)	Italy	Cross-sectional	84 (100)	71.7 ± 5.5	26.2	DH, 7-d DR	MEDAS/≥10	—	—	HGS
Bibiloni (2017) (46)	Spain	Cross-sectional	380 (54.9)	55–80	24.9	FFQ	MP/—	6-min walk	30-m gait speed	Arm curl, HGS, chair stands
Bollwein (2013) (45)	Germany	Cross-sectional	192 (64.6)	83.0 ± 4.0	23.9	FFQ	aMED/≥6	—	4.6-m gait speed	HGS
Buchanan (2021) (44)[1]	Australia	Cross-sectional	87 (33.3)	71.2 ± 8.2	—	—	MEDAS/≥10	—	SPPB	HGS
			65 (66.1)	68.7 ± 5.6						
Cervo (2021) (65)	Australia	Prospective cohort (3 y)	794 (0.0)	81.1 ± 4.5	—	DH, 4-d DR	MEDI-LITE/—	—	6-m gait speed	HGS
Chan (2019) (64)	China	Prospective cohort (7 y)	1235 (39.1)	70.4 ± 4.2	—	FFQ	MDS, MIND/—	Maximal bicycle ergometry	—	—
Cobo-Cuenca (2019) (43)	Spain	Cross-sectional	310 (65.2)	20.9 ± 2.5	24.0	FFQ	MEDAS/≥9	20-m shuttle run	—	HGS, SLJ
Cuenca-García (2014) (42)[2]	US	Prospective cohort (11.6 y)	12,449 (23.3)	46.2 ± 10.1	17.4	3-d DR	MDS/>7	Maximal treadmill ergometry	—	—
Fougère (2016) (41)	Italy	Cross-sectional	304 (59.5)	86.3 ± 6.8	—	—	MSDPS/—	—	SPPB	—
Gallucci (2019) (63)	Italy	Prospective cohort (3 y)	190 (56.8)	83.8 ± 4.5	—	—	MSDPS/—	—	SPPB	HGS
Huang (2021) (62)	Japan	Prospective cohort (3 y)	666 (56.5)	69.4 ± 4.4	—	FFQ	MDS/—	—	5-m gait speed	HGS
Isanejad (2018) (61)[3]	Finland	Prospective cohort (3 y)	503 (100)[4]	67.8 ± 1.8	15.7	3-d DR	MDS/≥7	—	10-m gait speed, 30-s leg stance, SPPB	HGS, knee extension, chair stands
Jin (2017) (60)	Italy	Prospective cohort (9 y)	906 (55.3)	74.0 ± 6.7	—	FFQ	MDS/—	—	SPPB	—
Kelaiditi (2016) (40)[1]	UK	Cross-sectional	2570 (100)	48.3 ± 12.7	—	FFQ	MDS/≥6	—	—	NPR
			949 (100)	59.1 ± 9.3						HGS
Kim (2019) (56)	Korea	Cross-sectional	3675 (53.5)	72.6 ± 0.2	41.7	24-h recall survey	aMED/—	—	—	HGS
Marcos-Pardo (2020) (48)	Spain	Cross-sectional	62 (—)	62.7 ± 8.02	50.0	—	MEDAS/—	6-min walk	—	—
Marcos-Pardo (2021) (55)	Finland, Ireland, Italy, Spain	Cross-sectional	1880 (51.6)	65.4 ± 8.5	34.4	—	MEDAS/≥7	—	SPPB	HGS
Martín-Espinosa (2020) (54)	Spain	Cross-sectional	310 (65.2)	20.9 ± 2.5	24.0	FFQ	MEDAS/>9	20-m shuttle run	—	HGS

(*Continued*)

TABLE 1 (*Continued*)

Studies			Participants			Exposure		Outcome		
Reference	Country	Design	Women, *n* (%)	Age, y, mean ± SD or range	haMD, %	Dietary assessment	MD scale/cutoff score for haMD	CRF test	MF test	MSF test
McClure (2019) (53)	Australia	Cross-sectional	87 (33.3)	71.2 ± 8.2	—	FFQ	MEDAS, aMED/≥10, ≥6	—	SPPB	HGS
Milaneschi (2011) (59)[3]	Italy	Prospective cohort (9 y)	935 (55.6)[5]	74.1 ± 6.8	29.3	FFQ	MDS/≥6	—	SPPB	Knee extension
Mohseni (2017) (52)	Iran	Cross-sectional	250 (100)	57.7 ± 6.2	33.3	FFQ	MP/—	—	4-m gait speed	HGS
Payandeh (2021) (51)	Iran	Cross-sectional	270 (56.3)	36.5 ± 13.1	24.2	FFQ	Med-DQI/≥7	Maximal treadmill ergometry	—	—
Ryu (2021) (50)	Korea	Cross-sectional	68 (60.3)	57.1 ± 10.5	—	FFQ	aMED/—	—	—	HGS
Saadeh (2021) (58)	Sweden	Prospective cohort (12 y)	1686 (57.6)	69.0 ± 8.1	30.8	FFQ	MDS/—	—	6- or 2.4-m gait speed	Chair stands
Shahar (2012) (66) [3]	US	Prospective cohort (8 y)	2225 (49.9)	74.6 ± 2.8	5.1	FFQ	MDS/≥6	—	20-m gait speed	—
Stanton (2019) (49)	Australia	Cross-sectional	65 (63.1)	68.7 ± 5.6	35.4	—	MEDAS/≥6	—	SPPB	HGS
Talegawkar (2012) (57)	Italy	Prospective cohort (6 y)	690 (51.7)	73.0 ± 6.2	27.4	FFQ	MDS/≥6	—	4-m gait speed	HGS
Tepper (2018) (39)	Israel	Cross-sectional	117 (39.3)	70.6 ± 6.5	26.5	FFQ	MDS/≥5	6-min walk	—	—
Zbeida (2014) (38)	Israel	Cross-sectional	2791 (49.3)	71.3 ± 7.8	14.2	24-h recall survey	MDS/≥6	—	6-m gait speed	Knee extension

aMED, alternate Mediterranean diet; CRF, cardiorespiratory fitness; DH, diet history; DR, dietary registration; haMD, high adherence to the Mediterranean diet; HGS, handgrip strength; MD, Mediterranean diet; MDS, Mediterranean Diet Score; MEDAS, Mediterranean Diet Adherence Screener; Med-DQI, Mediterranean Dietary Quality Index; MEDI-LITE, Literature-Derived Mediterranean Diet; MF, motor fitness; MIND, Mediterranean–DASH Intervention for Neurodegenerative Delay Diet; MP, Mediterranean Pattern; MSDPS, Mediterranean-Style Dietary Pattern Score; MSF, musculoskeletal fitness; NPR, Nottingham Power Rig; RCT, randomized controlled trial; SLJ, standing long jump; SPPB, Short Physical Performance Battery; VHJ, vertical height jump; WAn, Wingate Anaerobic.

[1]Data from 2 samples.

[2]Only cross-sectional data were included in the meta-analysis.

[3]Cross-sectional data were also included in the meta-analysis.

[4]Among the participants in the cross-sectional analyses, 253 had available data at the 3-y follow-up.

[5]Among the participants in the cross-sectional analyses, 486 had available data at the 9-y follow-up.

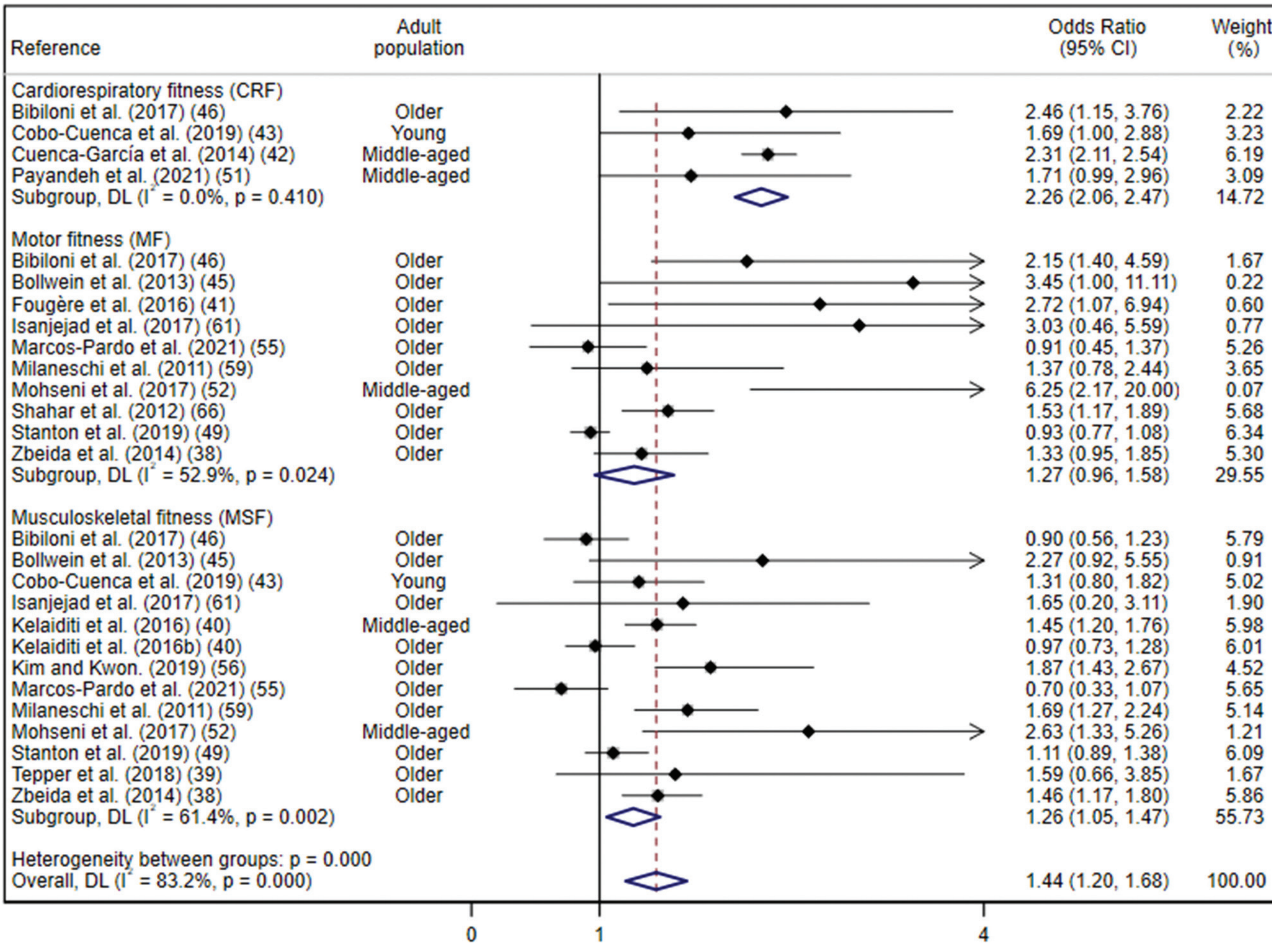

FIGURE 1 Forest plot for the cross-sectional associations between high adherence to the Mediterranean diet and physical fitness components in adults of all ages.

was not statistically significant (OR: 1.17; 95% CI: 0.95, 1.38; $I^2 = 36.5\%$, $n = 7$). Finally, the pooled effect sizes between higher MD adherence scores (as a continuous variable) and overall PF (**Figure 3**) showed a significant cross-sectional association ($d = 0.45$; 95% CI: 0.14, 0.75; $I^2 = 91.0\%$, $n = 6$).

Subgroup analyses and meta-regressions

Subgroup analyses are displayed in **Supplemental Table 6** and **Supplemental Figures 3** and **4**. The pooled estimates for the cross-sectional subgroup analyses were similar to the main pooled OR for overall PF in the Mediterranean and non-Mediterranean regions, in older adults and in young or middle-aged adults, and when MD adherence was assessed by the 9-point MD scale and by other MD indices. Moreover, high (compared with low) MD adherence and PF levels were statistically significant for MF in the Mediterranean region and for CRF and MSF in the Mediterranean and non-Mediterranean regions. Concerning the prospective cohort studies, the pooled estimates for subgroup analyses were similar to the main pooled ORs for MF and overall PF in the Mediterranean region. Additionally, meta-regression models showed that none of the variables considered (sex, age, BMI, health status, current smoker, and total energy intake) influenced the relationship between high (compared with low) MD adherence and PF levels for the cross-sectional or prospective cohort models (**Supplemental Table 7**).

Sensitivity analyses

Sensitivity analyses for the cross-sectional estimates (**Supplemental Table 8**) showed that the association between high (compared with low) MD adherence and MF became significant after excluding the studies by Marcos-Pardo et al. (55) and Stanton et al. (49). The pooled ORs for CRF, MSF, and overall PF were not modified when removing each study one by one. Sensitivity analyses for the prospective cohort estimates (**Supplemental Table 9**) showed that the association between high (compared with low) MD adherence and MSF was no longer significant after excluding the study performed

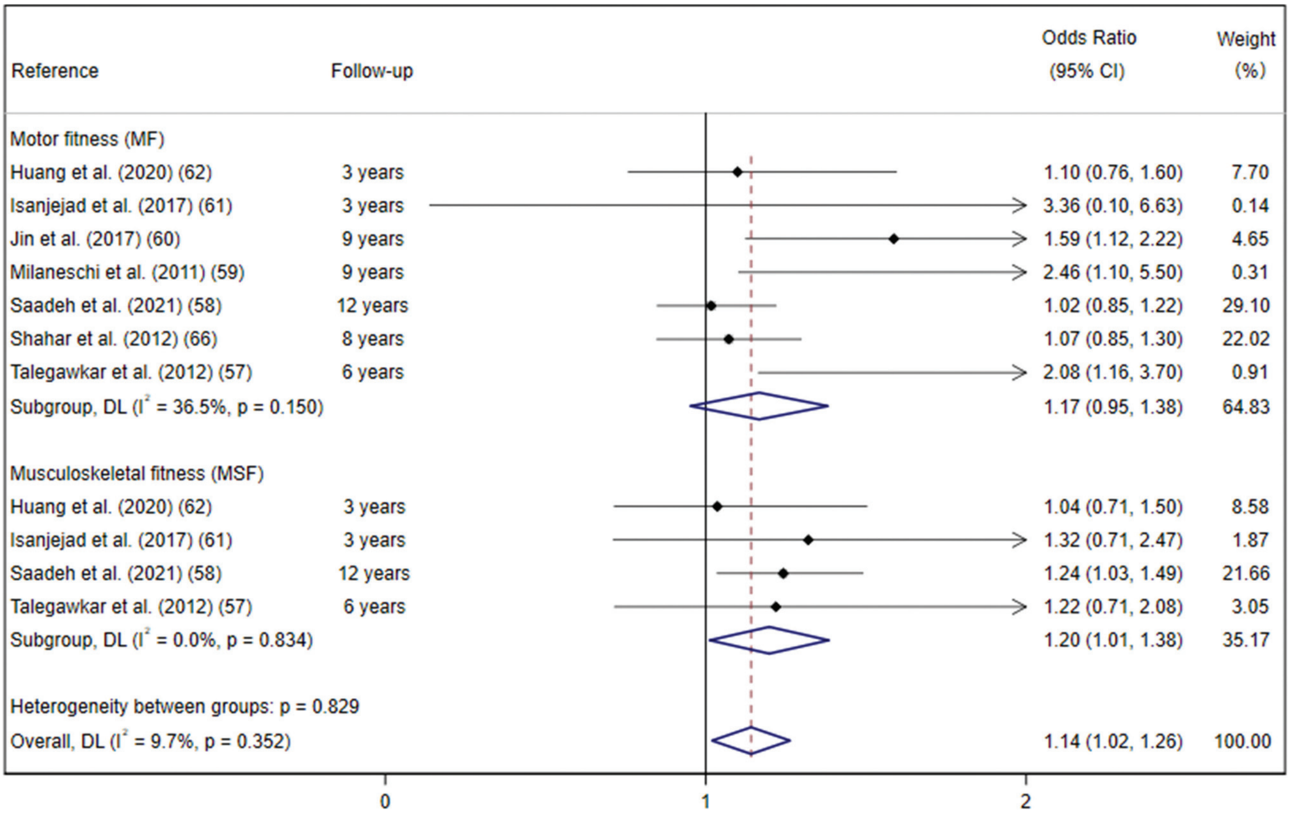

FIGURE 2 Forest plot for the prospective cohort associations between high adherence to the Mediterranean diet and physical fitness components in older adults.

by Saadeh et al. (58). Moreover, the association between high (compared with low) MD adherence and overall PF was no longer significant after excluding the studies conducted by Jin et al. (60), Saadeh et al., and Talegawkar et al. (57). The pooled ORs for MF were not modified when removing each study one by one. Finally, after combining measurements for all PF components from each study, cross-sectional and prospective cohort estimates showed that the association between high (compared with low) MD adherence and overall PF remained significant (**Supplemental Figures 5** and **6**).

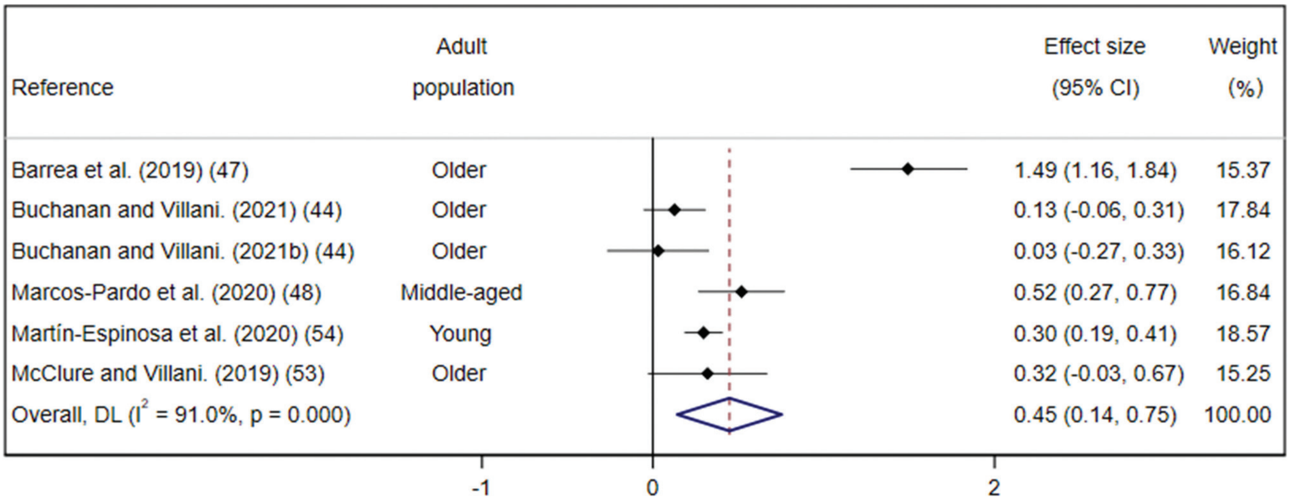

FIGURE 3 Forest plot for the cross-sectional association between higher Mediterranean diet adherence scores (as a continuous variable) and overall physical fitness in adults of all ages.

Publication bias

According to Egger's test and funnel plot asymmetry, publication bias was found for MF in the cross-sectional analysis (**Supplemental Table 10** and **Supplemental Figures 7–9**).

Discussion

This systematic review and meta-analysis synthesized the relationships between adherence to the MD and PF components (cardiorespiratory, motor, and musculoskeletal) in adulthood. Our results support a significant positive association between high (compared with low) MD adherence and PF levels in cross-sectional studies specifically for CRF, MSF, and overall PF in adults of all ages. Furthermore, the improvement in PF among those with higher MD adherence was observed in prospective cohorts (3- to 12-y follow-up), specifically for MSF and overall PF, but only older adults were included in these studies. No significant association was observed between MD adherence and MF. Sex, age, BMI, health status, current smoking status, and total energy intake did not influence the strength of these associations.

Thus far, the available evidence regarding associations between high (compared with low) MD adherence and PF levels among adults has been inconclusive (12, 17, 18). Previous systematic reviews included a limited number of observational studies and showed mixed results in CRF (18) and MSF (12) in late adulthood. Regarding other plant-based dietary patterns (MD can be considered mainly, but not exclusively, a plant-based food matrix) (10), a recent systematic review reported a positive trend in associations between a vegetarian or vegan dietary pattern and PF levels, although the evidence is scarce and does not allow drawing consistent conclusions (70). Our results extend knowledge by providing a comprehensive picture of MD–PF associations in adulthood, pointing out that adults of all ages with high MD adherence have greater CRF, MSF, and overall PF levels than their counterparts with low MD adherence. These findings suggest the potential role of following the MD, which is associated with higher levels of PF, thus reducing the risk of critical outcomes such as mortality (1, 5–7).

Subgroup analyses showed that high cross-sectional adherence to the MD was associated with higher PF levels in Mediterranean and non-Mediterranean countries (for MSF and overall PF). However, changes were observed in the MF component according to geographic region. Indeed, high (compared with low) MD adherence was cross-sectionally and prospectively associated with higher MF only in countries from the Mediterranean region. A potential explanation is the influence of the Mediterranean lifestyle (e.g., adequate rest, regular practice of moderate physical activity, social support), which contributes to the effectiveness of high MD adherence (71). While this applies to all PF factors (71), according to our results, it may play a key role in the motor component. MF parameters (e.g., speed or balance), whose results were reported by the studies in older adults, are complex neuromuscular tasks that could require greater neurocognitive demands than measures of CRF and MSF in late adulthood (72). Therefore, MF improvements in older adults may require the whole structure of the Mediterranean lifestyle and not just MD adherence to improve their condition. The influence of this demographic characteristic needs to be confirmed because of the lack of studies to draw consistent conclusions.

Significant heterogeneity was observed in some of the pooled analyses and was explored in the subgroup and meta-regression analyses based on participant characteristics. Although sex, age, BMI, chronic diseases, smoking status, and total energy intake have been identified as factors related to MD adherence (73), the results of the meta-regressions did not confirm that the relationship between high (compared with low) MD adherence and PF levels could be influenced by these factors. Additionally, data from subgroup analyses suggest that geographic position could be a source of heterogeneity. This may be related to the variability of other factors in assessing the MD–PF relationships not available for the present analyses, such as inconsistencies in food and nutrient intakes in MD adherence (74) or country-typical food products and customs (75).

Different mechanisms have been proposed to explain the effects of MD on PF. Optimal concentrations of nutrients linked to high MD adherence, such as advanced glycation end products (76), carotenoids (77), n-3 polyunsaturated fatty acids (78), polyphenolic compounds (79), trace elements (80), and vitamins (81), have been associated with greater benefits on PF status. Notably, the main elements of the Mediterranean food matrix (extra virgin olive oil, fresh fruits and vegetables, legumes, nuts, red wine, seeds, and whole grain cereals) include a wide variety of antioxidant molecules that can influence the MD–PF links, such as carboxymethyl-lysine, coenzyme Q10, creatine, flavonoids, hydroxytyrosol, lycopene, oleocanthal, selenium, spermidine, vitamins D and E, α-linolenic acid, β-carotene, and others (82, 83). Evidence suggests that these components are rich in antioxidant compounds and contribute to PF development through different pathways, such as reduced reactive oxygen species (84) and proinflammatory cytokine expression (85), which drive important signaling events in PF status (86, 87). The results of our systematic review showed inconsistent results regarding specific MD elements, mainly because studies analyzing MD adherence in conjunction with specific foods and PF status are scarce. However, preliminary evidence showed positive associations between high consumption of vegetables and fruits and higher PF levels (47, 51, 61).

Two main strengths of this study were identified. First, to date, this is the first systematic review and meta-analysis, to the best of our knowledge, synthesizing the relationships between MD adherence and PF components (CRF, MF, and MSF) from cross-sectional, prospective cohort, and RCT studies in the general adult population. Second, we found several research gaps in MD–PF relationships that will play a key role in understanding these relationships through future scientific evidence. In particular, our findings identified a need for more prospective cohort studies (particularly on CRF and MSF outcomes and in young and middle-aged adults) and long-term RCTs to provide consistent conclusions for all PF components. Concerning PF outcomes, more studies analyzing CRF (particularly in older adults) and MF and MSF (particularly in young and middle-aged adults) and considering underanalyzed parameters (e.g., flexibility for MSF) could provide essential information. Moreover, there are still fundamental gaps in the knowledge about the role of specific MD elements, with high MD adherence, on PF status that must be clarified. Last, diet efficacy can be specific to age ranges, health conditions, geographic regions, sex, and PF components. It is desirable to promote high-quality research that, in addition to providing a better understanding of the MD–PF links, provides vital evidence to identify specific nutritional requirements related to MD according to PF outcomes and associated factors (sex, age, health status, and region).

Some limitations of our systematic review and meta-analysis should be acknowledged. First, some pooled estimates were accompanied by moderate to considerable unexplained between-study heterogeneity. The studies were performed in different types of populations (e.g., healthy, with obesity or type 2 diabetes, young, older) and with high variability in confounding factors and measurements of MD, which may have increased heterogeneity and limited the implications of our results. In particular, the high variability in the levels of evidence of validity and reliability of PF tests (88, 89) developed in the studies might lead to some bias. Moreover, we cannot rule out residual confounding due to factors unavailable in most of the studies, such as cooking techniques, eating behavior, genetic variants, or social support. Second, the overall risk of bias for observational studies showed fair quality in most studies, and sensitivity analyses revealed variation in the pooled estimates concerning specific studies. Finally, there was evidence of publication bias per Egger's test for MF in cross-sectional studies. Therefore, our findings should be considered and extrapolated with caution.

In conclusion, pooled analysis of cross-sectional studies showed that high MD adherence was associated with higher levels of CRF, MSF, and overall PF in the entire adult population. Moreover, high (compared with low) MD adherence significantly improved MSF and overall PF levels in the pooled analysis of prospective cohort studies (3- to 12-y follow-up) in which only older adults were included. Promoting optimal adherence to MD during adulthood, which was positively associated with a powerful health indicator such as PF, should be a cornerstone of public health initiatives to prevent different diseases. Future long-term clinical trials and prospective cohort studies are needed to provide evidence on the biological and environmental mechanisms underlying the associations between high MD adherence with specific Mediterranean foods and higher PF levels.

Acknowledgments

The authors' responsibilities were as follows—BB-P, JB-S, VM-V, and AEM: designed and conducted the research, wrote the manuscript, and had primary responsibility for final content; BB-P, IC-R, and AEM: contributed to data analysis; RF-R, JFL-G, VD-G, and IC-R: contributed to data collection and reviewed and edited the manuscript; and all authors: read and approved the final manuscript.

Data Availability

The data used in this review are available from the corresponding author upon reasonable request.

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