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ORIGINAL RESEARCH

Conjoint Associations of Adherence to Physical Activity and Dietary Guidelines With Cardiometabolic Health: The Framingham Heart Study

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BACKGROUND: The conjoint associations of adherence to the recent physical activity and dietary guidelines with the metabolic syndrome (MetS) are incompletely understood.

METHODS AND RESULTS: We evaluated 2379 FHS (Framingham Heart Study) Third Generation participants (mean age, 47 years; 54.4% women) attending examination cycle 2. We examined the cross-sectional relations of adherence to the 2018 Physical Activity Guidelines for Americans (binary; moderate-to-vigorous physical activity ≥150 versus <150 min/wk) and 2015 Dietary Guidelines for Americans (binary; 2015 Dietary Guidelines for Americans Adherence Index ≥median versus <median [score, 62.1/100]) with prevalence of the MetS using generalized linear models. We also related adherence to guidelines with the incidence of MetS prospectively, using Cox proportional hazards regression with discrete time intervals. Adherence rates to the 2018 Physical Activity Guidelines for Americans (odds ratio [OR], 0.49; 95% CI, 0.40–0.60) and 2015 Dietary Guidelines for Americans (OR, 0.67; 95% CI, 0.51–0.90) were individually associated with lower odds of prevalent MetS, whereas conjoint adherence to both guidelines was associated with the lowest odds of MetS (OR, 0.35; 95% CI, 0.26–0.47) compared with the referent group (nonadherence to both guidelines). Adherence rates to the 2018 Physical Activity Guidelines for Americans (hazard ratio [HR], 0.66; 95% CI, 0.50–0.88) and 2015 Dietary Guidelines for Americans (HR, 0.68; 95% CI, 0.51–0.90) were associated with lower risk of MetS, prospectively. In addition, we observed a 52% lower risk of MetS in individuals who adhered to both guidelines compared with the referent group.

CONCLUSIONS: Maintaining both regular physical activity and a healthy diet in midlife may be required for optimal cardiometabolic health in later life.

Key Words: cardiometabolic health ■ diet quality ■ guidelines ■ physical activity

The metabolic syndrome (MetS) is the clustering of key cardiometabolic risk factors, such as abdominal obesity, insulin resistance, hyperglycemia, dyslipidemia, and high blood pressure.[1] The presence of MetS is a major risk factor for type 2 diabetes mellitus and cardiovascular disease (CVD).[2,3] However, evidence indicates that healthy lifestyle behaviors are associated with favorable cardiometabolic health.[4] In addition, favorable cardiometabolic health in middle adulthood has been associated with lower disease burden later in life.[5] Thus, adherence to healthy lifestyle modifications in middle adulthood is a feasible approach to improve cardiometabolic health later in life.

The 2018 Physical Activity Guidelines for Americans (PAG) recommend that adults (aged ≥18 years) achieve a minimum of 150 minutes of moderate-to-vigorous physical activity (MVPA) per week to lower the burden of chronic disease.[6] Likewise, the 2015 Dietary Guidelines

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CLINICAL PERSPECTIVE

What Is New?

- Conjoint adherence to the 2018 Physical Activity Guidelines for Americans and 2015 Dietary Guidelines for Americans in midlife has a synergistic effect on cardiometabolic health in later life.

What Are the Clinical Implications?

- Findings from the present investigation highlight the importance of maintaining regular physical activity schedule and following a healthy diet in midlife to lower the risk of developing cardiometabolic disease in later life.

Nonstandard Abbreviations and Acronyms

DGA	Dietary Guidelines for Americans
DGAI	Dietary Guidelines for Americans Adherence Index
FFQ	food frequency questionnaire
FHS	Framingham Heart Study
MetS	metabolic syndrome
MVPA	moderate-to-vigorous physical activity
PA	physical activity
PAG	Physical Activity Guidelines for Americans

for Americans (DGA) suggest adhering to a high-quality healthy dietary pattern for the prevention of chronic disease.[7] Prior studies have reported that time spent in objectively assessed MVPA[8,9] and adherence to DGA,[10,11] quantified by the 2005 DGA Adherence Index (DGAI), are individually associated with lower odds of MetS in middle-aged adults. The independent associations of physical activity (PA) and diet quality with cardiometabolic health are likely attributable to shared biological and behavioral mechanisms. However, it is unclear whether adherence to both recent PAG and DGA (as opposed to one or the other) in midlife confers the most favorable cardiometabolic health later in life.

We hypothesized that adherence to both the 2018 PAG and the 2015 DGA will be associated with lower odds of prevalent MetS cross-sectionally, and with a lower risk of developing MetS prospectively.

METHODS

Study Design and Sample

The data that support the findings of this study are available from the corresponding author on reasonable request.

We evaluated participants from the FHS (Framingham Heart Study) Third Generation cohort who attended the second examination cycle (2008–2011). The study design and methods of this FHS cohort have been described elsewhere.[12] For the current investigation, we examined 2 analytical samples: of the 3411 participants who attended the second examination cycle, 1032 were excluded for the following reasons: refusal to wear an accelerometer or invalid PA data (n=866), unavailable dietary data (n=150), unavailable data on components of MetS (n=13), and missing covariates (n=3), resulting in a sample size of 2379 (sample 1); this sample was used to evaluate the cross-sectional associations of adherence to the 2018 PAG (MVPA ≥150 versus <150 min/wk) and adherence to the 2015 DGA (DGAI-2015 ≥median [score, 62.1/100] versus DGAI-2015 <median) with presence of MetS cross-sectionally. Next, we excluded 817 participants from sample 1 because they had prevalent MetS at baseline (n=496) or did not have available data on components of MetS at follow-up (third examination cycle [2016–2019; n=321]), resulting in a sample size of 1562 (sample 2), which was used for evaluating the longitudinal associations of adherence to the 2018 PAG and 2015 DGA (DGAI-2015 ≥median [score, 63.0/100] versus DGAI-2015 <median) with the incidence of MetS. The study was approved by the Boston University Medical Center institutional review board, and all participants provided written informed consent.

Objective Assessment of PA

At the second examination cycle, participants were asked to wear an omnidirectional accelerometer (Actical model No. 198-0200-00; Philips Respironics) on the hip for 8 days, 24 hours per day (except when bathing or involved in water activity). This accelerometer records signals within 0.5 to 3 Hz and accelerations/decelerations within 0.05 to 2 g. Recorded signals were grouped into "counts" during 30-second intervals and stored on the device. Data were analyzed using customized software (Kinesoft, version 3.3.63; Saskatchewan, Canada) and a predefined protocol for quality control. Measures from the first day of wear were excluded from the analysis. Accelerometer data were considered valid if the device was worn for ≥10 hours per day for at least 4 of 7 days. Nonwear time was defined as 60 consecutive minutes of zero counts, allowing for 2-minute interruption periods. Nonwear bouts were removed during data processing. Each minute of wear time was classified using previously established cut points.[13–15] For the current investigation, MVPA was defined as ≥743 counts per 30-second epoch. We defined adherence to the 2018 PAG as MVPA ≥150 min/wk in accordance with the 2018 PAG Advisory Committee Scientific Report.[6] For participants with <7 days, but ≥4 days, of valid wear time, we averaged the measured time spent in MVPA over the valid days and extrapolated it to estimate MVPA over 7 days.

Dietary Assessment

Dietary intake was measured using data from the Harvard semiquantitative food frequency questionnaire (FFQ) administered at the second examination cycle. The Harvard FFQ measures the typical frequency and consumption of 150 food items over the past year.[16] The validity of the Harvard FFQ was previously assessed using 7-day dietary records.[16,17] We only used FFQs that were considered valid (<13 blank items and estimated daily caloric intake ≥600 kcal/d and <4000/4200 kcal/d for women/men).[18]

2015 DGA Adherence Index

The DGAI-2015 is designed to measure adherence to the 2015 DGA.[7] Details of the DGAI-2015 have previously been described.[19] The DGAI is composed of 2 subscores: food intake and healthy choice. The food intake subscore measures intake of 14 food groups (fruit; dark green vegetables; orange and red vegetables; starchy vegetables; other vegetables; grains; dairy; meat, proteins, and eggs; seafood; nuts, seeds, and soy; legumes; empty calories, variety in protein choices; and variety of fruits and vegetables). The healthy choice subscore measures adherence to 10 consumption recommendations for intake levels of food groups and nutrients (amounts of total fat, saturated fat, trans fat, sodium, fiber, alcohol; percentage of protein that is lean, dairy that is low fat, grains that are whole grain, and fruits that are whole fruits). Adherence to dietary recommendations for each subscore component is scored as a proportion on a continuous scale of 0 to 1 (food intake maximum=14, and healthy choice maximum=10). The final DGAI-2015 score consists of summed component scores that are standardized to a range of 0–100; $\left(\frac{\text{total food in take score} + \text{total healthy choice score}}{24}\right) \times 100$=final DGAI-2015 score. The maximum DGAI-2015 score is 100, with a higher score indicating higher diet quality. For the present investigation, we dichotomized DGAI-2015 based on the median and used both binary (DGAI-2015 ≥median versus DGAI-2015 <median) and the continuous DGAI-2015 variable (ranging from 0–100).

Metabolic Syndrome

Participants who met at least 3 of the following criteria were considered as having the MetS, according to the American Heart Association/National Heart, Lung, and Blood Institute guidelines[4]: (1) waist circumference ≥40/35 inches (men/women); (2) systolic/diastolic blood pressure ≥130/85 mm Hg or use of antihypertensive medication; (3) fasting glucose ≥100 mg/dL or use of antidiabetic medication; (4) serum triglycerides ≥150 mg/dL or use of lipid-lowering medication; and (5) high-density lipoprotein cholesterol ≤40/50 mg/dL (men/women).

Covariates

All covariates were collected from routine medical history, physical examination, and laboratory assessment at the second examination cycle. In the current investigation, we included the following covariates: age, sex, accelerometer wear time, number of cigarettes smoked per day, total daily calorie intake, and the prevalence of CVD. Accelerometer wear time was determined by subtracting the nonwear time from a 24-hour period. Total daily calorie intake was derived from the aforementioned 150-item FFQ. Prior history of CVD, including fatal or nonfatal myocardial infarction, unstable angina (the prolonged ischemic episode with documented reversible ST-segment changes), peripheral vascular disease (intermittent claudication), cerebrovascular disease (ischemic or hemorrhagic stroke or transient ischemic attack), or heart failure, was collected by medical history questionnaire, physical examination, and hospitalization records. All events were adjudicated by a panel of FHS physicians based on previously reported criteria.[20]

Statistical Analysis

Age- and sex-adjusted linear regression models were used to evaluate the association between adherence to the 2018 PAG (MVPA ≥150 min/wk or MVPA <150 min/wk, independent variable) and the continuous DGAI-2015 (dependent variable). Participants were cross-classified by using the binary DGAI-2015 ≥median versus DGAI-2015 <median and MVPA ≥150 min/wk versus MVPA <150 min/wk variables. We used multivariable-adjusted generalized linear models (SAS PROC GENMOD) to evaluate the individual associations of adherence to the 2018 PAG and 2015 DGA (independent variables, separate model for each) with the prevalence of MetS (dependent variable), accounting for familial relatedness. We aimed to examine the longitudinal associations of adherence to the 2018 PAG and 2015 DGA with the incident MetS. We modeled MVPA as a binary variable (MVPA ≥150 min/wk versus MVPA <150 min/wk [referent]) and as a continuous variable. Adherence to the 2015 DGA was also modeled as a binary variable (DGAI-2015 ≥median versus DGAI-2015 <median [referent]), and a continuous variable. We used Cox proportional hazards regression models with discrete time intervals to evaluate the individual associations of adherence to the 2018 PAG and 2015 DGA (independent variables, separate model for each) with risk of MetS, adjusting for the same covariates at

baseline. We confirmed the proportional hazards assumption by including an interaction term between log-time and each exposure variable (MVPA or DGAI-2015) in the Cox regression models.

We also tested a significant multiplicative interaction between MVPA and DGAI-2015 on the association of each with the risk of MetS (both cross-sectionally and longitudinally) by incorporating cross-product terms in the multivariable-adjusted models. In addition, we created 4 cross-classification groups using adherence to 2018 PAG and 2015 DGA (independent variable, MVPA ≥150 versus <150 min/wk [2 groups] × DGAI-2015 ≥median versus DGAI-2015 <median [2 groups]) to evaluate the cross-sectional and longitudinal associations of conjoint adherence to the 2018 PAG and the 2015 DGA with odds and risk of developing MetS. Participants who did not meet the 2018 PAG (<150 min/wk of MVPA) and had poor adherence to the 2015 DGA (DGAI-2015 <median) were classified as the referent group. All models were adjusted for age, sex, accelerometer wear time, number of cigarettes smoked per day, total daily caloric intake, and prevalence of CVD. As a sensitivity analysis, we categorized DGAI-2015 into 3 groups based on tertile and examined the association of 2015 DGA (tertile of DGAI-2015) with odds and incidence of MetS to evaluate dose-response relation in which participants who met the 2018 PAG (MVPA ≥150 min/wk) had progressively lower odds or risk of MetS with increasing adherence to the 2015 DGA.

A 2-sided value of P<0.05 was considered statistically significant for all models, whereas the value of P<0.10 was used to determine statistically significant multiplicative interaction. All analyses were performed using SAS software version 9.4 (SAS Institute Inc, Cary, NC).

RESULTS

Participant Characteristics

The baseline characteristics by sex are presented in Table 1. The average time spent in MVPA was 27.4±20.7 min/d, and 52.7% of participants met the criteria of the 2018 PAG (MVPA ≥150 min/wk). The average+SD scores of the DGAI-2015 were 61.1±11.2 (52.1±7.9 [DGAI-2015 <median, poor adherence] and 70.0±5.3 [DGAI-2015 ≥median, higher adherence]). Only 28% of participants were characterized as both meeting the 2018 PAG and having higher adherence to the 2015 DGA. However, 47% of participants either met the 2018 PAG (MVPA ≥150 min/wk) or had higher adherence to the 2015 DGA. The characteristics of participants excluded from the analysis are presented in Table S1. Adherence to the 2018 PAG was associated with higher adherence to the 2015 DGA (DGAI-2015 ≥median; odds ratio [OR], 0.61; 95% CI, 0.51–0.72; P<0.001). For the cross-sectional analysis, 66% of participants provided 7 days of valid accelerometry data (23% [6 days of valid accelerometry data], 8% [5 days of valid accelerometry data], and 3% [4 days of valid accelerometry data]). Similarly, 66%, 22%, 8%, and 2% of participants provided 7, 6, 5, and 4 days of valid accelerometry data, respectively, at baseline for the longitudinal analysis.

Table 1. Sample Characteristics

Characteristics	Men (n=1086)	Women (n=1293)
Age, y	47±8	47±9
Body mass index, kg/m^2	28.9±4.7	26.8±6.0
Waist circumference, in	40.2±4.8	36.1±5.9
SBP, mm Hg	121±13	113±14
DBP, mm Hg	78±8	72±9
Antihypertensive medication, n (%)	222 (20.5)	173 (13.4)
Hypertension, n (%)	303 (28.0)	222 (17.2)
Fasting blood glucose, mg/dL	100.3±19.7	92.4±13.7
Diabetes mellitus, n (%)	63 (5.8)	43 (3.3)
Total cholesterol, mg/dL	187±35	187±35
Triglycerides, mg/dL	129±83	95±59
HDL-C, mg/dL	51±14	67±18
LDL-C, mg/dL	110±30	101±30
Lipid-lowering medication, n (%)	247 (22.7)	130 (10.1)
Smoking, n (%)	99 (9.1)	102 (7.9)
Total caloric intake, kcal/d	2106±660	1913±594
DGAI-2015 (0–100)	58.0±10.7	65.3±9.7
Accelerometer wear time, min/d	934.0±102.7	911.8±88.4
Sedentary time, min/d	657.8±70.1	668.9±67.1
Light-intensity PA, min/d	129.7±49.6	123.2±42.2
MVPA, min/d	29.9±21.5	25.3±19.9
Total PA, min/d	159.6±59.9	148.5±51.0
MVPA ≥150 min/wk, n (%)	641 (59.0)	613 (47.4)
MetS, n (%)	361 (33.2)	223 (17.3)

Values are mean±SD unless otherwise indicated. Hypertension was defined by SBP/DBP ≥140/90 mm Hg or the use of antihypertensive medications. Diabetes mellitus was defined as a fasting blood glucose ≥126 mg/dL or use of insulin or oral hypoglycemic agents. DBP indicates diastolic blood pressure; DGAI, Dietary Guidelines for Americans Adherence Index; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; MetS, metabolic syndrome; MVPA, moderate-to-vigorous PA; PA, physical activity; and SBP, systolic blood pressure.

Cross-Sectional Associations of Adherence to the 2018 PAG and 2015 DGA With the Prevalence of MetS

The individual and conjoint cross-sectional associations of adherence to the 2018 PAG and 2015 DGA with the prevalence of MetS are shown in Table 2 and the Figure, respectively. The prevalence of MetS was 24.6% (n=584/2379). After adjusting for covariates,

Table 2. Cross-Sectional Associations of Adherence to the 2018 PAG and 2015 DGA With the Presence of MetS

2018 PAG Adherence	No. With MetS/Total No.	OR	95% CI	*P* Value
MVPA <150 min/wk	358/1125	Referent		
MVPA ≥150 min/wk	226/1254	0.49	0.40–0.60	<0.001*
MVPA (per 10-min increment)	584/2379	0.82	0.76–0.88	<0.001*
2015 DGA adherence				
DGAI-2015 <median	342/1186	Referent	…	
DGAI-2015 ≥median	242/1193	0.67	0.54–0.83	<0.001*
DGAI-2015 (per 10-point increment)	584/2379	0.81	0.74–0.89	<0.001*
Conjoint association				
MVPA <150 min/wk and DGAI-2015 <median	210/600	Referent		
MVPA ≥150 min/wk and DGAI-2015 <median	132/586	0.57	0.43–0.75	<0.001*
MVPA <150 min/wk and DGAI-2015 ≥median	148/525	0.80	0.60–1.06	0.12
MVPA ≥150 min/wk and DGAI-2015 ≥median	94/668	0.35	0.26–0.47	<0.001*

Models adjusted for age, sex, accelerometer wear time, number of cigarettes smoked per day, total calorie intake per day, and prevalence of cardiovascular disease at examination 2. Accelerometer wear time was excluded in the model evaluating the association between adherence to the 2015 DGA and presence of MetS. Family relatedness was further adjusted as a random variance-covariance factor in the generalized linear models; median DGAI-2015 was 62.1/100. Both physical activity and diet quality were measured at the second examination cycle (2008–2011). DGA indicates Dietary Guidelines for Americans; DGAI, DGA Adherence Index; MetS, metabolic syndrome; MVPA, moderate-to-vigorous physical activity; OR, odds ratio; and PAG, Physical Activity Guidelines for Americans.

**P* values indicate statistical significance.

participants who met the 2018 PAG had lower odds of MetS, compared with those who did not. Likewise, participants with higher adherence to the DGA (DGAI-2015 ≥median) had lower odds of MetS, compared with those with poor adherence (DGAI-2015 <median). Results were similar in analyses examining the MVPA and DGAI-2015 as continuous variables (Table 2). Every 10 minutes per day increase in MVPA or 10-point increase in DGAI-2015 was associated with 18% or 19% lower odds of prevalent MetS, respectively (Table 2).

We observed a significant multiplicative interaction between MVPA and DGAI-2015 on the association of each with odds of MetS ($P_{interaction}$=0.02). In the conjoint analysis, we observed that participants who met the 2018 PAG (MVPA ≥150 min/wk) had lower odds of MetS with higher adherence to the 2015 DGA. Participants who met the 2018 PAG and had higher adherence to the 2015 DGA were less likely to have MetS compared with the referent group (ie, participants who did not meet the 2018 PAG and had poor adherence to the 2015 DGA; Table 2 and the Figure).

Longitudinal Associations of Adherence to the 2018 PAG and 2015 DGA With the Incidence of MetS

In our sample of participants who were free of MetS at baseline (sample 2; n=1562), 287 (18.4%) individuals developed new-onset MetS over an average follow-up of 8 years. After adjusting for covariates, adherence to the 2018 PAG was associated with a lower risk of developing MetS. Similarly, higher adherence to the 2015 DGA (DGAI-2015 ≥median) was associated with a lower risk of MetS compared with those with poor adherence to the 2015 DGA (DGAI-2015 <median). In addition, every 10 minutes per day increase in MVPA and each 10-point increase in DGAI-2015 were associated with 8% and 13% lower risk of developing MetS, respectively (Table 3).

We also observed a significant multiplicative interaction between MVPA and DGAI-2015 on the association of each with the risk of MetS ($P_{interaction}$=0.03). In our longitudinal analysis, participants who met the 2018 PAG and had higher adherence to the 2015 DGA had a lower risk of MetS when compared with the referent group (MVPA <150 min/wk and DGAI-2015 <median; Table 3 and the Figure).

Sensitivity Analysis

In cross-sectional analysis, participants with either second or third tertile of DGAI-2015 had lower odds of MetS, after adjusting for covariates (Table S2). In addition, among participants who met the 2018 PAG (MVPA ≥150 min/wk), we observed a dose-response relation, with progressively lower odds of MetS as adherence to the 2015 DGA increased

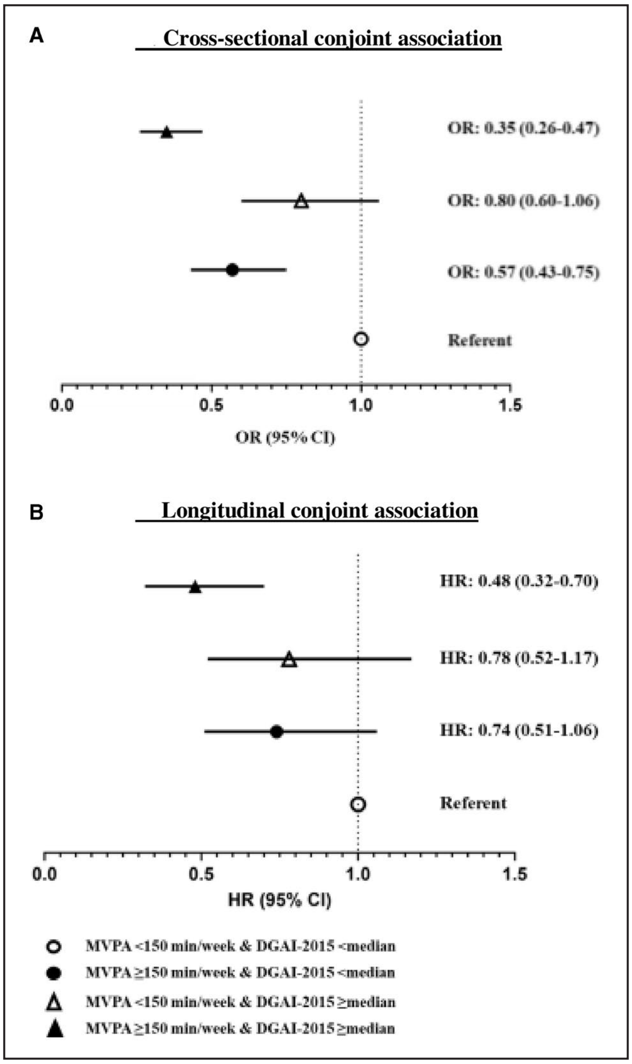

Figure. Conjoint cross-sectional (A) and longitudinal (B) associations of adherence to the 2018 Physical Activity Guidelines for Americans and 2015 Dietary Guidelines for Americans (DGA) with the prevalence (A) and incidence (B) of metabolic syndrome.
DGAI indicates DGA Adherence Index; HR, hazard ratio; MVPA, moderate-to-vigorous physical activity; and OR, odds ratio.

(across tertiles of the DGAI-2015). Participants who met the 2018 PAG and had optimal adherence to the 2015 DGA (third tertile of DGAI-2015) were 68% less likely to have MetS compared with participants who did not meet the 2018 PAG and had poor adherence to the 2015 DGA (first tertile of DGAI-2015; Table S3 and Figure S1). However, we did not observe an association between either second or third tertile of DGAI-2015 and risk of MetS compared with the first tertile of the DGAI-2015 prospectively (Table S4). Only participants who met the 2018 PAG and had optimal adherence to the 2015 DGA (third tertile of DGAI-2015) had lower risk of MetS when compared with the referent group (MVPA <150 min/wk and first tertile of DGAI-2015; Table S5 and Figure S2).

DISCUSSION

Principal Findings

The primary finding of our investigation is that adherence to both PA and dietary guidelines in middle adulthood is inversely associated with odds of MetS cross-sectionally, and with a lower risk of developing MetS later in life prospectively. Particularly, we observed a dose-response association, in which there were lower odds or risk of MetS for those who met both the 2018 PAG and demonstrated higher (≥median) or optimal (≥third tertile) adherence to the 2015 DGA, which is suggestive of a potential synergistic effect of PA and diet on cardiometabolic health. Overall, our findings underscore the importance of maintaining both a regular PA schedule and following a healthy diet in middle adulthood to lower risk of developing cardiometabolic disease in later life.

Comparison With the Literature

Consistent with the current investigation, numerous cross-sectional studies have reported an inverse association between objectively assessed MVPA and odds of MetS.[8,9,21,22] In addition, several longitudinal studies have observed an inverse association between adherence to the 2008 PAG, using self-reported MVPA, and incident MetS across different demographic groups, showing ≈20% to 60% lower risk of MetS.[23–25] Furthermore, several studies have reported inverse associations between healthy dietary patterns and MetS. This includes studies evaluating both cross-sectional and longitudinal relations of dietary patterns, such as the 2005 DGAI,[10,11] Dietary Approaches to Stop Hypertension score,[26] Mediterranean Diet Score,[27,28] and the Alternative Healthy Eating Index,[29] with MetS. In particular, adherence to the 2005 DGA was associated with a lower odds of MetS in the Framingham Offspring Cohort, in which an interaction in the relation of the 2005 DGAI with MetS by age was observed, with larger effect sizes reported in adults aged <55 years.[10] The effect size they observed in adults aged <55 years is consistent with ours (OR, 0.57; 95% CI, 0.36–0.92 [highest 2005 DGAI quintile versus lowest DGAI quintile] in the previous report versus OR, 0.67; 95% CI, 0.54–0.83 [DGAI-2015 ≥median versus DGAI-2015 <median] or OR, 0.58; 95% CI, 0.45–0.75 [highest DGAI-2015 tertile versus lowest DGAI-2015 tertile] in the current investigation). The present investigation adds to the existing literature by using objectively measured MVPA and the most recent guidelines for both PA and diet. These data strengthen current

Table 3. Longitudinal Associations of Adherence to the 2018 PAG and 2015 DGA With the Incidence of MetS

2018 PAG Adherence	No. of Events/No. at Risk	HR	95% CI	*P* Value
MVPA <150 min/wk	141/648	Referent		
MVPA ≥150 min/wk	146/914	0.66	0.50–0.88	0.004*
MVPA (per 10-min increment/d)	287/1562	0.92	0.86–0.99	0.03*
2015 DGA adherence				
DGAI-2015 <median	174/781	Referent		
DGAI-2015 ≥median	113/781	0.68	0.51–0.90	0.008*
DGAI-2015 (per 10-point increment)	287/1562	0.87	0.76–0.99	0.03*
Conjoint association				
MVPA <150 min/wk and DGAI-2015 <median	86/339	Referent		
MVPA ≥150 min/wk and DGAI-2015 <median	88/442	0.74	0.51–1.06	0.10
MVPA <150 min/wk and DGAI-2015 ≥median	55/309	0.78	0.52–1.17	0.22
MVPA ≥150 min/wk and DGAI-2015 ≥median	58/472	0.48	0.32–0.70	<0.001*

Models adjusted for age, sex, accelerometer wear time, number of cigarettes smoked per day, total calorie intake per day, and prevalence of cardiovascular disease at baseline. Accelerometer wear time was excluded in the model evaluating the association between adherence to the 2015 DGA and incidence of MetS; median DGAI-2015 was 63.0/100. Both physical activity and diet quality were measured at the second examination cycle (2008–2011). DGA indicates Dietary Guidelines for Americans; DGAI, DGA Adherence Index; HR, hazard ratio; MetS, metabolic syndrome; MVPA, moderate-to-vigorous physical activity; and PAG, Physical Activity Guidelines for Americans.

**P* values indicate statistical significance.

evidence that adherence to both guidelines in middle adulthood may confer the lowest risk of MetS, which often precedes overt CVD.

Evidence is limited with regard to the conjoint association of adherence to both the PAG and DGA with MetS. Prior clinical intervention studies have highlighted the adoption of both a physically active lifestyle and well-balanced diet to improve cardiometabolic health.[30] In particular, a 1-year intervention study among men with MetS demonstrated a strong reduction in the prevalence of MetS in the combined intervention group (67.4%) compared with a single PA (23.5%) or dietary intervention (35.3%).[31]

In accordance with the present investigation, prior cross-sectional studies in Asian populations have reported that the combination of a sedentary lifestyle with poor diet quality is associated with higher odds of MetS.[32,33] Differences between our investigation and these previous reports may be because of the use of self-reported PA data, which could lead to overestimation of PA. Similar to the present investigation, other investigators have reported that nonadherence to the 2008 PAG (MVPA <150 min/wk) and an unhealthy diet (Healthy Eating Index-2005 <60th percentile) were associated with a more than doubling of the odds of MetS compared with adherence to the 2008 PAG (MVPA ≥150 min/wk) and a healthy diet (Healthy Eating Index-2005 ≥60th percentile).[34] However, a direct comparison between this study and ours is challenging because of differences in dietary assessment methods (24-hour recall versus 150-item FFQ) and the type of accelerometer (uniaxial versus omnidirectional).

There is a lack of evidence on the conjoint association of PA and diet quality with the *incidence* of MetS in a large prospective cohort study. Our results indicate that adherence to both PA and dietary guidelines in middle adulthood may have synergistic effects on lowering the risk of cardiometabolic disease later in life. Furthermore, we observed that 28% of participants adhered to both the 2018 PAG (MVPA ≥150 min/wk) and 2015 DGA (DGAI-2015 ≥median), and 47% adhered to one of the respective guidelines. Only 19% of participants adhere to both guidelines, and 67% adhered to one of the respective guidelines when 2015 DGA was categorized into 3 groups based on the tertile of DGAI-2015. These data suggest that adherence to both 2018 PAG and 2015 DGA may be a good approach to improve cardiometabolic health for most middle-aged adults.

Previous studies have suggested improved endothelial function, insulin resistance, inflammatory profile, and adiposity measures as plausible underlying biological mechanisms mediating associations of PA and diet quality with MetS.[35,36] However, mechanistic links on the conjoint effects of PA and diet quality on MetS are not fully understood. Several intervention studies have demonstrated improved lipid profiles and glycemic control with reductions in blood pressure, body weight, fat mass, visceral fat, and midthigh muscle fat content in participants undergoing combined healthy diet and PA interventions compared with a single PA or dietary intervention.[37,38] Moreover, from a behavioral perspective, a meta-analysis conducted by Colcombe and Kramer reported that higher PA is associated with improved cognitive function, which leads to better self-regulatory skills and robust goal-oriented behavior.[39] Thus, higher PA may indirectly promote healthier eating habits. Indeed, adherence to the 2018 PAG was associated with higher odds of adherence to the 2015 DGA (DGAI-2015 ≥median) in our investigation. Further studies are warranted to explore the underlying biological or behavioral mechanisms that may explain the conjoint associations of PA and diet quality with occurrence of the MetS.

There are several strengths of our investigation. The FHS Third Generation cohort is a deeply phenotyped, large community-based sample of middle-aged adults, which may reduce selection bias with respect to comorbidities. Furthermore, the comprehensive and detailed assessment of CVD risk factors minimizes residual confounding. We measured PA objectively using an accelerometer to reduce measurement bias. The use of the latest dietary guidelines adherence index (DGAI-2015) as a more comprehensive measure of dietary quality is another strength of our investigation. The DGAI provides a more comprehensive measure of dietary quality and adherence to the DGA than other scores (eg, the Healthy Eating Index).[40] Furthermore, the DGAI penalized excessive consumption of energy-dense foods, limiting the possibility that their overconsumption could lead to higher scoring.[41] Last, we used a cross-sectional and prospective cohort study design, rendering our findings more robust. However, there are limitations that should be recognized. The DGAI-2015 was derived using data from the Harvard semiquantitative 150-item FFQ, which is a self-administered questionnaire. Therefore, nondifferential misclassification may affect our results. In addition, in the present investigation, we observed significant multiplicative interactions only when MVPA and DGAI-2015 were modeled as continuous variables. However, given that the purpose of the present investigation is to examine the conjoint associations of adherence to the 2018 PAG and the 2015 DGA with MetS and to provide more specific behavioral goals, we evaluated the conjoint associations using categorical variables. Although we adjusted for established cardiometabolic risk factors, potential confounding effects may still exist because of unmeasured risk factors (ie, serum uric acid). All participants in the current investigation were White individuals of European ancestry, limiting the generalizability of our findings to other racial groups. Further studies with a multiethnic sample are needed to assess for effect modification by race/ethnicity.

CONCLUSIONS

In the present investigation, conjoint adherence to the 2018 PAG and 2015 DGA was associated with the lowest odds of prevalent MetS and lowest risk of developing MetS later in life. These findings emphasize the importance of maintaining adequate PA and consuming a healthy diet in midlife on cardiometabolic health later in life.

ARTICLE INFORMATION

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Disclosures

None.

Supplementary Material

Tables S1–S5
Figures S1–S2

REFERENCES

1. Zimmet PZ, Magliano DJ, Herman WH, Shaw JE. Diabetes: a 21st century challenge. *Lancet Diabetes Endocrinol*. 2014;2:56–64. DOI: 10.1016/S2213-8587(13)70112-8.
2. Ford ES, Mokdad AH, Giles WH, Brown DW. The metabolic syndrome and antioxidant concentrations: findings from the Third National Health and Nutrition Examination Survey. *Diabetes*. 2003;52:2346–2352. DOI: 10.2337/diabetes.52.9.2346.
3. Alberti K, Eckel RH, Grundy SM, Zimmet PZ, Cleeman JI, Donato KA, Fruchart JC, James WP, Loria CM, Smith SC Jr. Harmonizing the metabolic syndrome: a joint interim statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. *Circulation*. 2009;120:1640–1645. DOI: 10.1161/CIRCULATIONAHA.109.192644.

4. Grundy SM, Cleeman JI, Daniels SR, Donato KA, Eckel RH, Franklin BA, Gordon DJ, Krauss RM, Savage PJ, Smith SC, et al. Diagnosis and management of the metabolic syndrome: an American Heart Association/National Heart, Lung, and Blood Institute scientific statement. *Circulation*. 2005;112:2735–2752. DOI: 10.1161/CIRCULATIONAHA.105.169404.
5. Lloyd-Jones DM, Leip EP, Larson MG, d'Agostino RB, Beiser A, Wilson PW, Wolf PA, Levy D. Prediction of lifetime risk for cardiovascular disease by risk factor burden at 50 years of age. *Circulation*. 2006;113:791–798. DOI: 10.1161/CIRCULATIONAHA.105.548206.
6. 2018 Physical Activity Guidelines Advisory Committee. *2018 Physical Activity Guidelines Advisory Committee Scientific Report*. Washington, DC: US Department of Health and Human Services; 2018.
7. US Department of Agriculture and US Department of Health and Human Services. *Dietary Guidelines for Americans, 2015–2020*. Washington, DC: US Government Printing Office; 2015.
8. Amirfaiz S, Shahril MR. Objectively measured physical activity, sedentary behavior, and metabolic syndrome in adults: systematic review of observational evidence. *Metab Syndr Relat Disord*. 2019;17:1–21. DOI: 10.1089/met.2018.0032.
9. Loprinzi PD, Cardinal BJ. Association between biologic outcomes and objectively measured physical activity accumulated in≥ 10-minute bouts and< 10-minute bouts. *Am J Health Promot*. 2013;27:143–151.
10. Fogli-Cawley JJ, Dwyer JT, Saltzman E, McCullough ML, Troy LM, Meigs JB, Jacques PF. The 2005 dietary guidelines for Americans and risk of the metabolic syndrome. *Am J Clin Nutr*. 2007;86:1193–1201. DOI: 10.1093/ajcn/86.4.1193.
11. Hosseini-Esfahani F, Jessri M, Mirmiran P, Bastan S, Azizi F. Adherence to dietary recommendations and risk of metabolic syndrome: Tehran Lipid and Glucose Study. *Metabolism*. 2010;59:1833–1842. DOI: 10.1016/j.metabol.2010.06.013.
12. Splansky GL, Corey D, Yang Q, Atwood LD, Cupples LA, Benjamin EJ, D'Agostino RB, Fox CS, Larson MG, Murabito JM, et al. The third generation cohort of the National Heart, Lung, and Blood Institute's Framingham Heart Study: design, recruitment, and initial examination. *Am J Epidemiol*. 2007;165:1328–1335. DOI: 10.1093/aje/kwm021.
13. Crouter SE, Bassett DR. A new 2-regression model for the Actical accelerometer. *Br J Sports Med*. 2008;42:217–224. DOI: 10.1136/bjsm.2006.033399.
14. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc*. 2008;40:181–188. DOI: 10.1249/mss.0b013e31815a51b3.
15. Heil DP. Predicting activity energy expenditure using the Actical® activity monitor. *Res Q Exerc Sport*. 2006;77:64–80. DOI: 10.1080/02701367.2006.10599333.
16. Rimm EB, Giovannucci EL, Stampfer MJ, Colditz GA, Litin LB, Willett WC. Reproducibility and validity of an expanded self-administered semiquantitative food frequency questionnaire among male health professionals. *Am J Epidemiol*. 1992;135:1114–1126. DOI: 10.1093/oxfordjournals.aje.a116211.
17. Feskanich D, Rimm EB, Giovannucci EL, Colditz GA, Stampfer MJ, Litin LB, Willett WC. Reproducibility and validity of food intake measurements from a semiquantitative food frequency questionnaire. *J Am Diet Assoc*. 1993;93:790–796. DOI: 10.1016/0002-8223(93)91754-E.
18. Willett W. *Nutritional Epidemiology*. New York City, NY: Oxford University Press; 2012.
19. Lin H, Rogers GT, Lunetta KL, Levy D, Miao X, Troy LM, Jacques PF, Murabito JM. Healthy diet is associated with gene expression in blood: the Framingham Heart Study. *Am J Clin Nutr*. 2019;110:742–749. DOI: 10.1093/ajcn/nqz060.
20. Cupples LA, D'Agostino RB. Section 34: some risk factors related to the annual incidence of cardiovascular disease and death in pooled repeated biennial measurements. In: Kannel WB, Wolf PA, Garrison RJ, eds. *Framingham Heart Study: 30 Year Follow-Up*. Bethesda, MD: US Department of Health and Human Services; 1987:1–22.
21. Clarke J, Janssen I. Sporadic and bouted physical activity and the metabolic syndrome in adults. *Med Sci Sports Exerc*. 2014;46:76–83. DOI: 10.1249/MSS.0b013e31829f83a0.
22. Dankel SJ, Loenneke JP, Loprinzi PD. The individual, joint, and additive interaction associations of aerobic-based physical activity and muscle strengthening activities on metabolic syndrome. *Int J Behav Med*. 2016;23:707–713. DOI: 10.1007/s12529-016-9570-y.
23. Carnethon MR, Loria CM, Hill JO, Sidney S, Savage PJ, Liu K. Risk factors for the metabolic syndrome: the Coronary Artery Risk Development in Young Adults (CARDIA) study, 1985–2001. *Diabetes Care*. 2004;27:2707–2715. DOI: 10.2337/diacare.27.11.2707.
24. Cheriyath P, Duan Y, Qian Z, Nambiar L, Liao D. Obesity, physical activity and the development of metabolic syndrome: the Atherosclerosis Risk in Communities study. *Eur J Cardiovasc Prev Rehabil*. 2010;17:309–313. 10.1097/HJR.0b013e32833189b8
25. He D, Xi B, Xue J, Huai P, Zhang M, Li J. Association between leisure time physical activity and metabolic syndrome: a meta-analysis of prospective cohort studies. *Endocrine*. 2014;46:231–240. DOI: 10.1007/s12020-013-0110-0.
26. Pimenta AM, Toledo E, Rodriguez-Diez MC, Gea A, Lopez-Iracheta R, Shivappa N, Hébert JR, Martinez-Gonzalez MA. Dietary indexes, food patterns and incidence of metabolic syndrome in a Mediterranean cohort: the SUN project. *Clin Nutr*. 2015;34:508–514. DOI: 10.1016/j.clnu.2014.06.002.
27. Kesse-Guyot E, Ahluwalia N, Lassale C, Hercberg S, Fezeu L, Lairon D. Adherence to Mediterranean diet reduces the risk of metabolic syndrome: a 6-year prospective study. *Nutr Metab Cardiovasc Dis*. 2013;23:677–683. DOI: 10.1016/j.numecd.2012.02.005.
28. Rumawas ME, Meigs JB, Dwyer JT, McKeown NM, Jacques PF. Mediterranean-style dietary pattern, reduced risk of metabolic syndrome traits, and incidence in the Framingham Offspring Cohort. *Am J Clin Nutr*. 2009;90:1608–1614. DOI: 10.3945/ajcn.2009.27908.
29. Akbaraly TN, Singh-Manoux A, Tabak AG, Jokela M, Virtanen M, Ferrie JE, Marmot MG, Shipley MJ, Kivimaki M. Overall diet history and reversibility of the metabolic syndrome over 5 years: the Whitehall II prospective cohort study. *Diabetes Care*. 2010;33:2339–2341. DOI: 10.2337/dc09-2200.
30. Magkos F, Yannakoulia M, Chan JL, Mantzoros CS. Management of the metabolic syndrome and type 2 diabetes through lifestyle modification. *Annu Rev Nutr*. 2009;29:223–256. DOI: 10.1146/annurev-nutr-080508-141200.
31. Anderssen S, Carroll S, Urdal P, Holme I. Combined diet and exercise intervention reverses the metabolic syndrome in middle-aged males: results from the Oslo Diet and Exercise Study. *Scand J Med Sci Sports*. 2007;17:687–695. DOI: 10.1111/j.1600-0838.2006.00631.x.
32. Kim YJ, Hwang JY, Kim H, Park S, Kwon O. Diet quality, physical activity, and their association with metabolic syndrome in Korean adults. *Nutrition*. 2019;59:138–144. DOI: 10.1016/j.nut.2018.08.009.
33. He Y, Li Y, Lai J, Wang D, Zhang J, Fu P, Yang X, Qi L. Dietary patterns as compared with physical activity in relation to metabolic syndrome among Chinese adults. *Nutr Metab Cardiovasc Dis*. 2013;23:920–928. DOI: 10.1016/j.numecd.2012.09.001.
34. Loprinzi PD, Smit E, Mahoney S. Physical activity and dietary behavior in US adults and their combined influence on health. *Mayo Clin Proc*. 2014;89:190–198. DOI: 10.1016/j.mayocp.2013.09.018.
35. Esposito K, Marfella R, Ciotola M, Di Palo C, Giugliano F, Giugliano G, D'Armiento M, D'Andrea F, Giugliano D. Effect of a Mediterranean-style diet on endothelial dysfunction and markers of vascular inflammation in the metabolic syndrome: a randomized trial. *JAMA*. 2004;292:1440–1446. DOI: 10.1001/jama.292.12.1440.
36. Dumortier M, Brandou F, Perez-Martin A, Fedou C, Mercier J, Brun J. Low intensity endurance exercise targeted for lipid oxidation improves body composition and insulin sensitivity in patients with the metabolic syndrome. *Diabetes Metab*. 2003;29:509–518. DOI: 10.1016/S1262-3636(07)70065-4.
37. Christ M, Iannello C, Iannello PG, Grimm W. Effects of a weight reduction program with and without aerobic exercise in the metabolic syndrome. *Int J Cardiol*. 2004;97:115–122. DOI: 10.1016/j.ijcard.2004.01.034.
38. Watkins LL, Sherwood A, Feinglos M, Hinderliter A, Babyak M, Gullette E, Waugh R, Blumenthal JA. Effects of exercise and weight loss on cardiac risk factors associated with syndrome X. *Arch Intern Med*. 2003;163:1889–1895. DOI: 10.1001/archinte.163.16.1889.
39. Colcombe S, Kramer AF. Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci*. 2003;14:125–130. DOI: 10.1111/1467-9280.t01-1-01430.
40. Fogli-Cawley JJ, Dwyer JT, Saltzman E, McCullough ML, Troy LM, Jacques PF. The 2005 dietary guidelines for Americans adherence index: development and application. *J Nutr*. 2006;11:2908–2915. DOI: 10.1093/jn/136.11.2908.
41. Jessri M, Lou WY, L'Abbé MR. The 2015 dietary guidelines for Americans is associated with a more nutrient-dense diet and a lower risk of obesity. *Am J Clin Nutr*. 2016;104:1378–1392. DOI: 10.3945/ajcn.116.132647.

SUPPLEMENTAL MATERIAL

Table S1. Characteristics of participants included and excluded from the analysis.

	Included (n=2,379)	Excluded (n=1,032)
Age (years)	47±9	46±9
Body Mass Index (kg/m^2)	27.8±5.6	28.6±6.5
Waist circumference (inches)	38.0±5.8	38.7±6.6
Total cholesterol (mg/dL)	187±35	187±36
HDL-C (mg/dL)	60±18	59±17
LDL-C (mg/dL)	105±30	104±31
Use of lipid-lowering medications, n (%)	377 (15.9)	161 (15.6)
SBP (mm Hg)	116±14	116±15
DBP (mm Hg)	74±9	74±10
Hypertension, n (%)	525 (22.1)	233 (22.8)
Use of antihypertensive medications, n (%)	395 16.7)	178 (17.4)
Fasting glucose (mg/dL)	96±16	98±20
Diabetes, n (%)	106 (4.5)	60 (5.9)
Diabetes medication, n (%)	72 (3.0)	45 (4.4)
Current Smoking, n (%)	201 (8.5)	150 (14.6)

HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure; DBP, diastolic blood pressure. Values are mean±SD unless otherwise indicated; Hypertension was defined by SBP/DBP ≥ 140/90 mmHg or the use of antihypertensive medications; Diabetes was defined as a fasting blood glucose ≥126 mg/dL or use of insulin or oral hypoglycemic agents.

Table S2. The cross-sectional association of adherence to the 2015 DGA (tertiles of DGAI-2015) with the presence of MetS.

2015 DGA Adherence	#MetS/#total	OR	95% CI	p-value
Poor (1st tertile DGAI-2015)	249/781	Referent		
Moderate (2nd tertile DGAI-2015)	181/805	0.68	0.53-0.87	**.002**
Optimal (3rd tertile DGAI-2015)	154/793	0.58	0.45-0.75	**<.001**
DGAI-2015 (per 10 point increment)	584/2,379	0.81	0.74-0.89	**<.001**

DGA, Dietary Guidelines for Americans; DGAI, dietary guidelines for Americans adherence index; MetS, metabolic syndrome; OR, odds ratio; CI, confidence interval. Models adjusted for age, sex, number of cigarettes smoked per day, total calorie intake per day, and prevalence of CVD at exam 2; Family relatedness was further adjusted as a random variance-covariance factor in the generalized linear models; Bold p-values indicate statistical significance.

Table S3. The cross-sectional association of conjoint adherence to the 2018 PAG and 2015 DGA (tertiles of DGAI-2015) with the presence of MetS.

Joint association	#MetS/#total	OR	95% CI	p-value
MVPA <150 min/week & 1st tertile DGAI-2015	154/413	Referent		
MVPA ≥150 min/week & 1st tertile DGAI-2015	95/368	0.61	0.44-0.85	**.004**
MVPA <150 min/week & 2nd tertile DGAI-2015	111/373	0.78	0.57-1.08	.14
MVPA ≥150 min/week & 2nd tertile DGAI-2015	70/432	0.38	0.27-0.54	**<.001**
MVPA <150 min/week & 3rd tertile DGAI-2015	93/339	0.75	0.53-1.07	.11
MVPA ≥150 min/week & 3rd tertile DGAI-2015	61/454	0.32	0.22-0.45	**<.001**

PAG, physical activity guidelines; DGA, dietary guidelines for Americans; DGAI, dietary guidelines for Americans adherence index; MetS, metabolic syndrome; OR, odds ratio; CI, confidence interval; MVPA, moderate to vigorous physical activity.Models adjusted for age, sex, accelerometer wear time, number of cigarettes smoked per day, total calorie intake per day, and prevalence of CVD at exam 2; Family relatedness was further adjusted as a random variance-covariance factor in the generalized linear model; Both PA and diet quality were measured at the second examination cycle (2008-2011); Bold p-values indicate statistical significance.

Table S4. The longitudinal association of adherence to the 2015 DGA (tertiles of DGAI-2015) with the incidence of MetS.

2015 DGA Adherence	#Events/#At risk	HR	95% CI	p-value
Poor (1st tertile DGAI-2015)	105/452	Referent		
Moderate (2nd tertile DGAI-2015)	99/541	0.85	0.62-1.18	.37
Optimal (3rd tertile DGAI-2015)	83/569	0.70	0.49-1.00	.05
DGAI-2015 (per 10 point increment)	287/1,562	0.87	0.76-0.99	**.03**

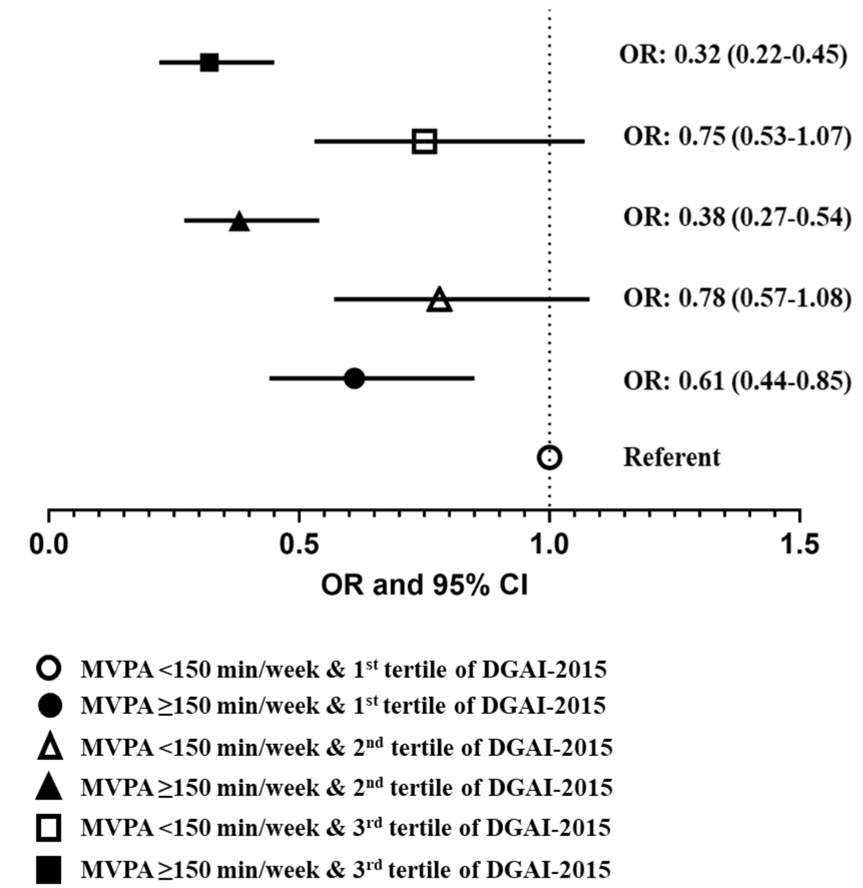
DGA, dietary guidelines for Americans; DGAI, diet guidelines for Americans adherence index; MetS, metabolic syndrome; HR, hazard ratio; CI, confidence interval. Models adjusted for age, sex, number of cigarettes smoked per day, total calorie intake per day, and prevalence of CVD at baseline; Both PA and diet quality were measured at the second examination cycle (2008-2011); Bold p-values indicate statistical significance.

Table S5. The longitudinal association of conjoint adherence to the 2018 PAG and 2015 DGA (tertiles of DGAI-2015) with the incidence of MetS.

Conjoint association	#Events/#At risk	HR	95% CI	p-value
MVPA <150 min/week & 1st tertile DGAI-2015	52/212	Referent		
MVPA ≥150 min/week & 1st tertile DGAI-2015	53/240	0.90	0.57-1.43	.66
MVPA <150 min/week & 2nd tertile DGAI-2015	47/213	1.07	0.67-1.72	.78
MVPA ≥150 min/week & 2nd tertile DGAI-2015	52/328	0.67	0.42-1.05	.08
MVPA <150 min/week & 3rd tertile DGAI-2015	42/223	0.96	0.59-1.58	.88
MVPA ≥150 min/week & 3rd tertile DGAI-2015	41/346	0.53	0.33-0.86	**.009**

PAG, physical activity guidelines; DGA, dietary guidelines for Americans; DGAI, diet guidelines for Americans adherence index; MetS, metabolic syndrome; HR, Hazards ratio; CI confidence interval; MVPA, moderate to vigorous physical activity. Models adjusted for age, sex, accelerometer wear time, number of cigarettes smoked per day, total calorie intake per day, and prevalence of CVD at baseline; Both PA and diet quality were measured at the second examination cycle (2008-2011); Bold p-values indicate statistical significance.

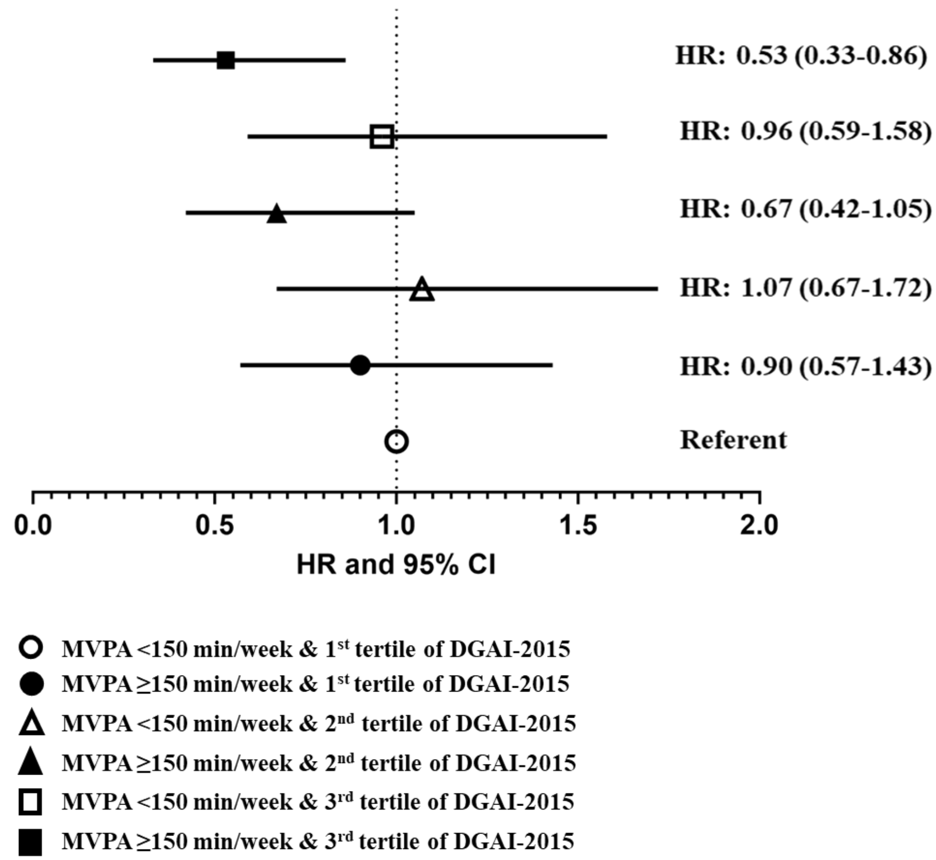
Figure S1. The conjoint cross-sectional association of adherence to the 2018 PAG and 2015 DGA with the presence of MetS.



Abbreviations: PAG, physical activity guidelines; DGA, dietary guidelines for Americans; MetS, metabolic syndrome; OR, odds ratio; CI, confidence interval; MVPA, moderate to vigorous physical activity; DGAI, dietary guidelines for Americans adherence index.

Note: Models adjusted for age, sex, accelerometer wear time, number of cigarettes smoked per day, total calorie intake per day, and prevalence of CVD at exam 2; Family relatedness was further adjusted as a random variance-covariance factor in the generalized linear model; Bold p-values indicate statistical significance

Figure S2. The conjoint longitudinal association of adherence to the 2018 PAG and 2015 DGA with the incidence of MetS.



PAG, physical activity guidelines; DGA, dietary guidelines for Americans; MetS, metabolic syndrome; HR, hazard ratio; CI, confidence interval; MVPA, moderate to vigorous physical activity; DGAI, dietary guidelines for Americans adherence index.

Note: Models adjusted for age, sex, accelerometer wear time, number of cigarettes smoked per day, total calorie intake per day, and prevalence of CVD at baseline; Bold p-values indicate statistical significance.