Muscle Strengthening, Aerobic Exercise, and Obesity: A Pooled Analysis of 1.7 Million US Adults

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Objective: Both aerobic physical activity and muscle-strengthening exercise are recommended for obesity prevention. However, at the population level, the independent and/or combined associations of these physical activity modalities with obesity are unknown. The aim of this study was to examine the associations between aerobic physical activity and muscle-strengthening exercise with obesity among a representative sample of adults.

Methods: Data were pooled from four US public health surveillance surveys from 2011 to 2017. Cross-sectional associations between adherence to the aerobic physical activity (≥150 min/wk) and muscle-strengthening exercise (≥2 times/wk) guidelines with different classes of BMI-defined obesity were examined using Poisson regression. Prevalence ratios are reported as both unadjusted and adjusted for sociodemographic and lifestyle characteristics.

Results: Data were available for 1,677,108 adults (≥18 years old). Compared with meeting neither guideline (reference category), meeting both guidelines was associated with the lowest adjusted prevalence ratios (APRs) for the following: Class I obesity and above (BMI ≥ 30.0 kg/m^2), APR = 0.54 (95% CI: 0.53-0.54); Class II obesity and above (BMI ≥ 35.0 kg/m^2), APR = 0.32 (95% CI: 0.31-0.33); and Class III obesity and above (BMI ≥ 40.0 kg/m^2), APR = 0.21 (95% CI: 0.20-0.21).

Conclusions: Among nearly 1.7 million US adults, meeting both aerobic and muscle-strengthening exercise guidelines was associated with a lower obesity prevalence, and associations were more pronounced for higher obesity classes.

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Study Importance

What is already known?

- Physical activity is a key modifiable lifestyle behavior for obesity prevention, with most evidence on physical activity for a healthy weight based on studies of aerobic physical activity (walking, cycling, running).
- Emerging evidence suggests that muscle-strengthening exercise may be independently associated with the prevention of weight gain.
- However, at the population level, the independent and/or combined associations between aerobic and muscle-strengthening exercise and obesity are unknown.

What does this study add?

- Compared with other physical activity categories, meeting both aerobic and muscle-strengthening exercise guidelines was associated with the lowest prevalence of obesity.
- The strength of association between physical activity categories and obesity increased with increasing levels of obesity severity.
- Large-scale physical activity interventions that support the uptake/adherence of combined aerobic and muscle-strengthening exercise may be beneficial in reducing or preventing the severity of obesity.

Introduction

Obesity is a medical condition that occurs when individuals carry excess weight or body fat that may negatively affect their health. Having obesity increases the risk of hypertension, coronary heart disease, cerebrovascular disease, type 2 diabetes, depression, osteoarthritis, and breast and colon cancer (1), which are among the leading global causes of adult morbidity and mortality (2,3). Obesity is a particular public health issue in middle- to high-income countries (4). In the United States, for example, it was estimated that approximately 40% of adults (≥18 years) had obesity in 2016, costing the economy nearly $150 billion per year in medical costs (5). Given the high prevalence, significant economic burden, and detrimental health consequences of obesity, preventing this condition is a key global and US public health challenge (1,6,7).

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Physical activity is a key modifiable lifestyle behavior for obesity prevention (1,6,8). The evidence on physical activity for a healthy weight is largely based on studies of aerobic moderate to vigorous physical activity (MVPA; walking, cycling, or running) alone (1,6,8). Emerging epidemiological evidence has suggested that muscle-strengthening exercise (MSE; weight/resistance training) may be independently associated with the prevention of weight gain (9). However, despite the 2010 World Health Organization's Global Recommendations on Physical Activity for Health recommending both MVPA (≥150 min/wk) and MSE (≥2 times/wk) for overall health and well-being (including maintenance of a healthy weight) (10), large-scale population-level studies rarely assess both physical activity modes (11,12). Consequently, the independent and/or combined associations of MVPA and MSE with obesity at the population level are largely unknown.

The aim of this paper was to examine the cross-sectional associations between different combinations of adherence to the MVPA/MSE guidelines and obesity in a pooled population sample of 1.7 million adults.

Methods

Sample

We pooled data from the 2011, 2013, 2015, and 2017 US Behavioral Risk Factor Surveillance System (BRFSS) surveys (13). Initiated in 1984, the BRFSS collects state-specific data on health risk behaviors that are relevant to public health among US adults. Each BRFSS survey was approved by the National Center for Health Statistics Research Ethics Review Board (13). Detailed descriptions of the background and methodology utilized in the BRFSS are available elsewhere (13). The median response rate was 49.7%, 45.9%, 47.2%, and 45.9%, for the 2011, 2013, 2015, and 2017 BRFSS surveys, respectively (13).

Across all BRFSS used in the present study (2011-2017), the same survey instrument and methodology was used to assess self-reported physical activity, self-reported height and weight, and sociodemographic (e.g., education, income) and lifestyle variables (e.g., smoking, self-rated health, fruit/vegetable intake) (13). Initially, data were collected from 1,889,712 respondents. For the present analysis, participants were excluded if data were missing for physical activity (n = 212,604; 11.3% of the total sample). As with our previous studies (14,15), to enhance generalizability, we did not utilize any other exclusion or inclusion criteria.

Physical activity assessments

MVPA was assessed using previously validated questionnaires (16). The items described below have acceptable test-retest reliability (Cohen's k = 0.67-0.84) and concurrent validity (Cohen's k = 0.17-0.22) (using accelerometry as the standard) (17).

When introducing the physical activity survey items, interviewers initially provided the following statement to respondents: "The next few questions are about exercise, recreation, or physical activities other than your regular job duties." Respondents were then asked "During the past month, other than your regular job, did you participate in any physical activities or exercises such as running, calisthenics, golf, gardening, or walking for exercise?" If they answered yes, they were then asked the following questions: "What type of physical activity or exercise did you spend the most time doing during the past month?", "How many times per week or per month did you take part in this activity during the past month?", and "When you took part in this activity, for how many minutes or hours did you usually keep at it?" Physical activity duration was reported in hours and minutes. If applicable, respondents were then asked the same set of questions as above with regard to a second activity.

Physical activities were coded as "aerobic" or "non-aerobic" using a list of 56 activities (17). Examples of aerobic activities included walking, jogging, tennis, and soccer, while non-aerobic activities included gardening, painting/papering, bowling, and golf (17). To count toward meeting the MVPA guideline, an activity had to be "aerobic." As per protocol (17), moderate-intensity activity and vigorous-intensity activity were defined as aerobic physical activity, and classification was based on estimated metabolic expenditure (MET) (18). Moderate-intensity activities were defined as aerobic physical activity of ≥3.0 MET and less than the respondent's vigorous-intensity cut-point (17). To be categorized as vigorous, an activity must be aerobic, with an allocated MET value that is at least 60% of an individual's maximal cardiorespiratory capacity, based on sex and age (17).

MSE was assessed by asking "During the past month, how many times per week or per month did you do physical activities or exercises to strengthen your muscles? Do not count aerobic activities like walking, running, or bicycling. Count activities using your own body weight like yoga, sit-ups or push-ups and those using weight machines, free weights, or elastic bands." This item has acceptable test-retest reliability (Cohen's k = 0.85-0.92) (17) and convergent validity (against metabolic syndrome) (19).

Physical activity categories

Based on meeting or not meeting the global physical activity guidelines (10), four mutually exclusive categories were created: (i) "Meet neither" (MVPA = 0-149 min/wk and MSE < 2 sessions/wk), (ii) "MSE only" (MSE ≥ 2 sessions/wk and MVPA = 0-149 min/wk), (iii) "MVPA only" (MVPA ≥ 150 min/wk and MSE < 2 sessions/wk), or (iv) "Meet both" (MVPA ≥ 150 min/wk and MSE ≥ 2 sessions/wk).

Because the guidelines for physical activity for weight loss and prevention of weight gain recommend higher MVPA doses than those within the global physical activity guidelines (i.e., ≥300 MVPA min/wk vs. 150 MVPA min/wk) (20,21), we further assessed dose-dependent relationships between MVPA/MSE guidelines and obesity. In this dose-dependent analysis, we created further categories based on meeting or not meeting double the global physical activity guidelines (MVPA ≥ 300 min/wk and MSE ≥ 4 sessions/wk).

Obesity classification

BMI was calculated from self-reported height (meters) and weight (kilograms) using the formula: BMI = kg/m^2. A strong correlation (r = 0.95) has been shown between self-reported height/weight-calculated BMI and objectively measured height/weight-calculated BMI (22). Because the health risks of obesity increase with the severity of obesity, with the highest morbidity observed among those

TABLE 1 Weighted[a] sample characteristics, physical activity levels[b], and BMI[c] classifications among 2011, 2013, 2015, and 2017 Behavioral Risk Factor Surveillance System respondents

	N[d]	Weighted % (95% CI)
Total	1,677,108	–
Sex		
Female	980,521	51.6 (51.3-51.6)
Male	696,527	48.6 (48.4-48.7)
Age (y)		
18-24	87,561	7.6 (7.5-7.7)
25-34	166,830	11.8 (11.7-11.9)
35-44	203,473	14.1 (13.9-14.2)
45-54	284,211	19.0 (18.8-19.1)
55-64	375,035	20.7 (20.6-20.9)
≥ 65		26.8 (26.7-27.0)
Race/ethnicity		
White, non-Hispanic	1,294,693	65.4 (65.2-65.6)
Black, non-Hispanic	126,901	11.1 (11.0-11.2)
Other race, Non-Hispanic	62,608	4.9 (4.9-5.0)
Multiracial, Non-Hispanic	55,189	5.1 (5.0-5.2)
Hispanic	115,661	13.5 (13.4-13.7)
Employment status		
Student	42,618	5.9 (5.8-6.0)
Employed	832,693	56.3 (56.2-56.5)
Unemployed	83,935	6.9 (6.8-7.0)
Homemaker	104,987	6.8 (6.7-6.8)
Retired	484,324	17.4 (17.3-17.5)
Unable to work	121,315	6.7 (6.6-6.8)
Education level		
Did not graduate high school	131,638	14.0 (13.9-14.2)
Graduated high school	468,083	27.9 (27.8-28.1)
Attended college/technical	461,397	31.1 (31.0-31.3)
Graduated college	612,491	26.9 (26.8-27.0)
Income categories		
Less than $15,000	161,227	12.0 (11.9-12.2)
$15,000-$24,999	245,989	17.3 (17.1-17.4)
$25,000-$34,999	70,429	5.1 (5.0-5.2)
$35,000-$49,999	302,769	19.3 (19.2-19.5)
$50,000 or more	665,551	46.3 (46.1-46.4)
Self-rated health		
Excellent	288,989	18.6 (18.5-18.7)
Very good	549,605	32.2 (32.0-32.3)
Good	515,176	31.2 (31.1-31.4)
Fair	226,534	13.3 (13.2-13.4)
Poor	91,900	4.7 (4.7-4.8)
Smoking status		
Current	258,340	18.6 (18.5-18.7)
Former smoker	484,933	24.7 (24.5-24.8)
Never smoked	925,820	57.8 (57.6-57.9)
Fruit and vegetable servings per day, mean (95% CI)	1,655,117	3.15 (3.14-3.16)
Number of chronic conditions, mean (95% CI)[e]	1,672,281	1.55 (1.55-1.56)
Physical activity guideline adherence		
Meet neither	673,117	40.1 (39.9-40.2)
MSE only	133,805	9.5 (9.4-9.6)
MVPA only	551,240	30.2 (30.0-30.3)
Meet both	318,946	20.2 (20.1-20.4)
BMI, kg/m		
< 18.5 (underweight)	26,458	1.8 (1.8-1.9)
18.5-24.9 (healthy weight)	518,958	33.7 (33.5-38.8)
25.0-29.9 (overweight)	575,587	35.6 (35.4-35.8)
30.0-34.9 (Class I obesity)	288,673	17.6 (17.5-17.7)
35.0-39.9 (Class II obesity)	110,877	6.9 (6.8-6.9)
≥ 40.0 (Class III obesity)	71,647	4.4 (4.4-4.5)

[a]Data weighted using stratum weight provided by Centers for Disease Control and Prevention.
[b]Physical activity levels: Meet neither: MVPA = 0-149 min/wk and MSE < 2 sessions/wk; MSE only: MSE ≥ 2 sessions/wk and MVPA = 0-149 min/wk; MVPA only: MVPA ≥ 150 min/wk and MSE < 2 sessions/wk; and Meet both: MVPA ≥ 150 min/wk and MSE ≥ 2 sessions/wk.
[c]BMI calculated from self-reported height and weight.
[d]Numbers different because of missing responses; missing cases as follows: Age *n* = 177 (0.01%); Race/ethnicity *n* = 21,623 (1.6%); Education level *n* = 4,840 (0.3%); Income categories *n* = 220,768 (15.9%); Self-rated health *n* = 5,127 (0.4%); Smoking status *n* = 36,256 (2.6%); BMI *n* = 84,908 (5.1%).
[e]To be classified as having chronic health condition, respondent had to report having doctor, nurse, or other health professional diagnose each condition. Chronic health conditions assessed were hypertension, high cholesterol, diabetes, myocardial infarction, coronary heart disease, stroke, depressive disorder, chronic obstructive pulmonary disease, asthma, kidney disease, cancer (nonskin), and arthritis.
MVPA, moderate to vigorous physical activity; MSE, muscle-strengthening exercise.

with the most severe obesity (23), we classified increasing levels of obesity by using standardized BMI cut-points: (i) 30.0-34.9 kg/m^2 (Class I), (ii) 35.0-39.9 kg/m^2 (Class II), and (iii) ≥40.0 kg/m^2 (Class III) (5).

Covariates

Sociodemographic (age, sex, income, education, race/ethnicity) and lifestyle (smoking status, self-rated health, fruit/vegetable intake) characteristics were assessed using standardized survey items. All covariates were included in the models as potential confounding factors because of their recognized association with both physical activity (24) and obesity (6). Each subcategory was chosen to be consistent with previous studies from BRFSS (12,14,25). We also made further adjustments for the presence of clinically diagnosed chronic health conditions, including hypertension, high cholesterol, diabetes, myocardial infarction, coronary heart disease, stroke, depressive disorder, chronic obstructive pulmonary disease, asthma, kidney disease, cancer (non-skin) and arthritis.

Statistical analysis

All analyses were conducted with the Complex Samples module of SPSS version 22 (SPSS Inc., an IBM Company, Chicago, Illinois). In the analysis, weighting factors to correct for nonresponse, stratification,

TABLE 2 PRs[a] describing association between PA guideline adherence[b] and meeting double the PA guidelines[c] and class-specific BMI[d]-derived obesity (*n* = 1,677,108)

		Unadjusted PR (95% CI)	Adjusted PR (95% CI)[e]
	PA guideline adherence		
BMI ≥ 30.0, Class I obesity and above[f]	Meet neither (reference)	1	1
	MSE only	0.71 (0.71-0.72)	0.70 (0.69-0.71)
	MVPA only	0.71 (0.70-0.71)	0.72 (0.71-0.72)
	Meet both	0.51 (0.50-0.51)	0.50 (0.50-0.51)
BMI ≥ 35.0, Class II obesity and above[g]	Meet neither (reference)	1	1
	MSE only	0.62 (0.61-0.63)	0.61 (0.61-0.62)
	MVPA only	0.55 (0.55-0.56)	0.55 (0.55-0.56)
	Meet both	0.35 (0.35-0.36)	0.35 (0.35-0.36)
BMI ≥ 40.0, Class III obesity and above[h]	Meet neither (reference)	1	1
	MSE only	0.60 (0.58-0.62)	0.58 (0.56-0.60)
	MVPA only	0.45 (0.44-0.46)	0.45 (0.44-0.46)
	Meet both	0.28 (0.27-0.28)	0.27 (0.27-0.28)
	Double PA guidelines		
BMI ≥ 30.0, Class I obesity and above[f]	Meet neither (reference)	1	1
	MSE only	0.67 (0.66-0.68)	0.67 (0.65-0.68)
	MVPA only	0.69 (0.68-0.70)	0.69 (0.68-0.70)
	Meet both	0.51 (0.50-0.52)	0.51 (0.50-0.52)
BMI ≥ 35.0, Class II obesity and above[g]	Meet neither (reference)	1	1
	MSE only	0.56 (0.55-0.58)	0.56 (0.54-0.58)
	MVPA only	0.53 (0.52-0.54)	0.53 (0.52-0.54)
	Meet both	0.36 (0.35-0.38)	0.36 (0.35-0.38)
BMI ≥ 40.0, Class III obesity and above[h]	Meet neither (reference)	1	1
	MSE only	0.54 (0.51-0.56)	0.52 (0.49-0.55)
	MVPA only	0.43 (0.42-0.44)	0.42 (0.41-0.44)
	Meet both	0.29 (0.27-0.31)	0.29 (0.27-0.31)

[a]PRs calculated using Poisson regression with a robust error variance.
[b]PA levels: Meet neither: MVPA = 0-149 min/wk and MSE < 2 sessions/wk; MSE only: MSE ≥ 2 sessions/wk and MVPA = 0-149 min/wk; MVPA only: MVPA ≥ 150 min/wk and MSE < 2 sessions/wk; and Meet both: MVPA ≥ 150 min/wk and MSE ≥ 2 sessions/wk.
[c]Double the World Health Organization guidelines = Meet neither: MVPA = 0-299 min/wk and MSE < 4 sessions/wk; Meet muscle-strengthening exercise only: MSE ≥ 4 sessions/wk and MVPA = 0-299 min/wk; Meet MVPA only: MVPA ≥ 300 min/wk and MSE < 4 sessions/wk; Meet both: MVPA ≥ 300 min/wk and MSE ≥ 4 sessions/wk.
[d]BMI calculated from self-reported height and weight.
[e]PRs adjusted for sex, age, race/ethnicity, employment status, education, income, smoking, self-rated health, fruit/vegetable intake, and medical professional-diagnosed chronic health conditions (e.g., diabetes, hypertension, arthritis).
[f]Reference: ≤ 29.99 kg/m^2.
[g]Reference: ≤ 34.99 kg/m^2.
[h]Reference: ≤ 39.99 kg/m^2.
PA, physical activity; PR, prevalence ratio; MVPA, moderate to vigorous physical activity; MSE, muscle-strengthening exercise.

and clustering were implemented to enhance population representativeness (26). We assessed the associations between physical activity guidelines adherence (exposure variable; reference = meet neither physical activity guidelines) and each obesity class (dependent variables) using Poisson regression with a robust error variance to calculate prevalence ratios (PR). PRs are reported as both unadjusted and adjusted for all covariates. In cross-sectional epidemiological studies, presenting adjusted prevalence ratios (APR) derived from Poisson regression is considered a more robust statistical approach than the usually used logistic regression (27,28).

To examine sex differences, we conducted a sex-stratified analysis. In addition, to minimize the potential for reverse causation, we conducted two further stratified analyses. First, we compared APRs among those with and without "excellent" self-rated health ("yes", "no"). Second, we compared APRs among those with or without a chronic health condition(s) ("yes," "no") (e.g., hypertension, high cholesterol, diabetes, arthritis).

Results

The sample characteristics are shown in Table 1. Data were available for 1,677,108 adults (≥ 18 years old). In brief, 26.8% were ≥65 years old, 51.6% were female, and most were either white or Hispanic. Over half had never smoked, and 18.6% had "excellent" self-rated health. For physical activity, 40.1% met neither guideline, 9.5% met MSE only, 30.2% met MVPA only, and 20.2% met both guidelines. For BMI, 35.6% had a BMI between 18.5 and 24.9 ("healthy weight"), and 28.9% had a BMI ≥ 30 ("obese").

TABLE 3 PRs[a] describing association between PA guideline adherence[b] and class-specific BMI[c]-derived obesity: stratified by sex, self-rated health, and number of chronic conditions ($n = 1{,}677{,}108$)

		Sex	
		Males	Females
	PA guideline adherence	Adjusted PR (95% CI)[d]	Adjusted PR (95% CI)[d]
BMI ≥ 30.0, Class I obesity and above[g]	Meet neither (reference)	1	1
	MSE only	0.75 (0.73-0.76)	0.65 (0.63-0.66)
	MVPA only	0.88 (0.87-0.89)	0.71 (0.70-0.72)
	Meet both	0.65 (0.64-0.66)	0.43 (0.43-0.44)
BMI ≥ 35.0, Class II obesity and above[h]	Meet neither (reference)	1	1
	MSE only	0.55 (0.53-0.57)	0.53 (0.51-0.54)
	MVPA only	0.68 (0.67-0.70)	0.52 (0.51-0.63)
	Meet both	0.39 (0.38-0.40)	0.27 (0.26-0.28)
BMI ≥ 40.0, Class III obesity and above[i]	Meet neither (reference)	1	1
	MSE only	0.47 (0.45-0.50)	0.51 (0.49-0.53)
	MVPA only	0.48 (0.46-0.50)	0.38 (0.37-0.39)
	Meet both	0.25 (0.24-0.26)	0.19 (0.18-0.20)
		"Excellent" self-rated health	
		Yes	**No**
		Adjusted PR (95% CI)[e]	**Adjusted PR (95% CI)[e]**
BMI ≥ 30.0, Class I obesity and above[g]	Meet neither (reference)	1	1
	MSE only	0.58 (0.55-0.61)	0.64 (0.64-0.65)
	MVPA only	0.70 (0.68-0.72)	0.84 (0.83-0.84)
	Meet both	0.44 (0.42-0.45)	0.64 (0.64-0.65)
BMI ≥ 35.0, Class II obesity and above[h]	Meet neither (reference)	1	1
	MSE only	0.39 (0.35-0.26)	0.62 (0.60-0.64)
	MVPA only	0.47 (0.44-0.50)	0.64 (0.63-0.65)
	Meet both	0.24 (0.22-0.26)	0.41 (0.41-0.42)
BMI ≥ 40.0, Class III obesity and above[i]	Meet neither (reference)	1	1
	MSE only	0.35 (0.29-0.40)	0.57 (0.55-0.59)
	MVPA only	0.37 (0.33-0.40)	0.46 (0.45-0.47)
	Meet both	0.18 (0.16-0.20)	0.28 (0.27-0.28)
		Number of chronic conditions[j]	
		0	**≥ 1**
		Adjusted PR (95% CI)[f]	**Adjusted PR (95% CI)[f]**
BMI ≥ 30.0, Class I obesity and above[g]	Meet neither (reference)	1	1
	MSE only	0.66 (0.64-0.68)	0.77 (0.76-0.79)
	MVPA only	0.76 (0.75-0.78)	0.81 (0.80-0.81)
	Meet both	0.52 (0.50-0.53)	0.59 (0.58-0.60)
BMI ≥ 35.0, Class II obesity and above[h]	Meet neither (reference)	1	1
	MSE only	0.48 (0.45-0.51)	0.62 (0.60-0.64)
	MVPA only	0.60 (0.58-0.63)	0.60 (0.59-0.61)
	Meet both	0.33 (0.32-0.35)	0.36 (0.35-0.37)

TABLE 3. (continued).

		Number of chronic conditions[j]	
		0	≥1
		Adjusted PR (95% CI)[f]	Adjusted PR (95% CI)[f]
BMI ≥ 40.0, Class III obesity and above[i]	Meet neither (reference)	1	1
	MSE only	0.59 (0.57-0.60)	0.34 (0.31-0.38)
	MVPA only	0.42 (0.41-0.43)	0.51 (0.48-0.54)
	Meet both	0.24 (0.23-0.25)	0.24 (0.22-0.25)

[a]PRs calculated using Poisson regression with obust error variance.
[b]PA levels: Meet neither: MVPA = 0-149 min/wk and MSE < 2 sessions/wk; MSE only: MSE ≥ 2 sessions/wk and MVPA = 0-149 min/wk; MVPA only: MVPA ≥ 150 min/wk and MSE < 2 sessions/wk; and Meet both: MVPA ≥ 150 min/wk and MSE ≥ 2 sessions/wk.
[c]BMI calculated from self-report height and weight.
[d]PRs adjusted for age, race/ethnicity, employment status, education, income, smoking, self-rated health, fruit/vegetable intake, and medical professional-diagnosed chronic health conditions (e.g., diabetes, hypertension, arthritis).
[e]PRs adjusted for sex, age, race/ethnicity, employment status, education, income, smoking, fruit/vegetable intake, and medical professional-diagnosed chronic health conditions (e.g., diabetes, hypertension, arthritis).
[f]PRs adjusted for sex, age, race/ethnicity, employment status, education, income, smoking, self-rated health, and fruit/vegetable intake.
[g]Reference ≤ 29.99 kg/m^2.
[h]Reference ≤ 34.99 kg/m^2.
[i]Reference ≤ 39.99 kg/m^2.
[j]To be classified as having chronic health condition, respondent had to report having doctor, nurse, or other health professional diagnose each condition. Chronic health conditions assessed were hypertension, high cholesterol, diabetes, myocardial infarction, coronary heart disease, stroke, depressive disorder, chronic obstructive pulmonary disease, asthma, kidney disease, cancer (nonskin), and arthritis.
PR, prevalence ratio; MVPA, moderate to vigorous physical activity; MSE, muscle-strengthening exercise; PA, physical activity.

The unadjusted PRs and APRs for obesity by physical activity guideline adherence (reference = "meet neither") are shown in Table 2. Compared with other categories, those meeting both guidelines had the lowest APRs across all classes of obesity (range: 0.27-0.50) (Table 2). The PRs were lowest for all physical activity categories for the Class III obesity outcome. Compared with meeting the current physical activity guidelines, meeting double the guidelines resulted in similar APRs across different physical activity categories and obesity classes (Table 2). All associations remained after adjustment for sociodemographic and/or lifestyle characteristics and chronic health conditions.

The results from the sex-stratified analysis are shown in Table 3. Overall, similar associations between MVPA/MSE guideline adherence and obesity were observed for both sexes, with meeting both guidelines associated with the lowest APRs across all classes of obesity. However, the APRs were lower among females (range: 0.19-0.71) compared with males (range: 0.25-0.88). Table 3 shows that the APRs were lower among those reporting "excellent" self-rated health (range: 0.18-0.70) compared with those not reporting "excellent" self-rated health (range: 0.28-0.84). A similar pattern was observed among those with no chronic conditions (range: 0.24-0.76) compared with those with ≥ 1 chronic condition (range: 0.24-0.81).

Discussion

Among almost 1.7 million US adults, compared with other physical activity guideline adherence categories, meeting both MVPA and MSE guidelines was associated with the lowest prevalence of obesity. Notably, the strength of association between the guideline categories and obesity increased with increasing levels of obesity severity. While prospective studies and controlled designs are needed to better support causal evidence, this study suggests that a combination of MVPA and MSE has the most beneficial associations with overall obesity and obesity severity. The findings presented here suggest that large-scale physical activity interventions that support the uptake/adherence of concurrent MVPA and MSE are likely to be beneficial in the prevention and management of obesity at the population level.

The main findings presented in this study are consistent with a US longitudinal study that assessed MVPA and MSE and their associations with waist circumference change among 10,500 healthy males (9). Using data from the Health Professionals Follow-up Study (1996-2008), results showed that the most favorable associations between relative waist circumference change were observed among men who met the aerobic guideline and engaged in the highest levels of MSE (e.g., > 25 min/d) (9). However, a limitation of that study was the inclusion of males only, as well as a predominately white, well-educated, and high-income sample (9). While recognizing the restrictions of the cross-sectional analysis, our study, which includes a significantly larger and more representative sample, suggests that these findings are likely to be generalizable to women, different races and ethnicities, and those with varying levels of income and education.

To our knowledge, this is the first population-level study examining the associations between MSE, combined MVPA and MSE, and obesity. Current physical activity recommendations for a healthy weight are generally based on engaging in MVPA, and it is recommended that an adult should achieve between 150 and 250 min/wk to prevent weight gain and between 225 and 420 min/wk for weight loss (29). With regard to our dose-dependent analysis, two key findings were observed. First, meeting double the MVPA guideline (300 min/wk) resulted in similar APRs for obesity prevalence compared with those engaging in 150 min/wk. Although the present lack of dose-dependent associations between BMI and MVPA is contradictory to the MVPA recommendations for weight loss and/or prevention of weight gain, it should be noted that these recommendations are based on prospective studies (29). Therefore, our associations of MVPA with BMI from a single time point provide no insight into the temporal associations, and as such, our lack of dose-dependent associations should be interpreted with caution. The second finding was that, compared with MSE and MVPA alone, across all doses of physical activity, meeting both guidelines had the most favorable associations with obesity prevalence. We hope that this finding provides the stimulus for researchers to examine data from prospective cohort studies with representative samples to replicate these preliminary epidemiological observations.

Although it is beyond the scope of the current study to report on the physiological mechanisms explaining the relationship between combined MVPA and MSE and obesity, it is necessary to briefly discuss some potential pathways. Although it is limited, there is some clinical evidence suggesting that MSE combined with MVPA may increase lean body mass, more than either activity alone (30), thus resulting in an increased metabolic rate and/or total energy expenditure among those who engage in both physical activity modes (30,31). Moreover, clinical exercise studies have identified that, compared with one mode alone, combining MVPA and MSE has unique cardiometabolic health benefits, including more favorable associations with low-density lipoprotein/high-density lipoprotein cholesterol, triglycerides (32), insulin sensitivity (33), and glycosylated hemoglobin (34). We have recently provided epidemiological evidence to support these clinical findings (11). Among a sample of ~10,000 Korean adults, compared with meeting one guideline, combined MVPA/MSE guideline adherence was associated with a more favorable cardiometabolic biomarker profile (11).

A further key finding was that sex differences were observed, with the beneficial associations between MVPA, MSE, and obesity being stronger among women compared with men. This suggests that public health physical activity interventions focusing on women could be the most effective for obesity prevention. The targeting of women in physical activity promotion strategies is further warranted by the fact that descriptive epidemiological research has consistently shown that, compared with men, women have lower prevalence of combined MVPA/MSE guideline adherence (12,15,26,35).

A unique aspect of this study is the description of the associations between mutually exclusive groupings of physical activity guideline adherence with obesity. While previous research on physical activity and obesity has focused largely on aerobic MVPA (6,31), our physical activity classification categories provide insights into the potential associations between different physical activity modes and markers of adiposity. In addition, because MSE is rarely assessed in physical activity epidemiology (36,37), this study provides a unique insight into the health consequences of this often neglected physical-activity-related behavior.

While the cross-sectional analysis limits the ability for causal inferences between combined MVPA and MSE and obesity, our stratified analyses that intended to minimize the risk of reverse causation suggests some potential for a causal association. Compared with “less healthy” population subgroups, such as those without “excellent” self-rated health and the presence of chronic conditions (e.g., diabetes, hypertension), the APRs for obesity across all physical activity categories were consistently lower among the “more healthy” subgroups.

A key limitation of this study is the use of self-reported assessments of physical activity and height and weight. However, probable overreporting of physical activity among some adult populations with obesity (38) as well as underestimation of BMI are likely biasing associations toward the null. As noted, the cross-sectional design is also a key limitation. It is equally plausible that those who have obesity are less likely to participate in physical activity because of their weight. In addition, BMI has limitations for measuring adiposity and is confounded by muscle mass (39). Nevertheless, compared with other obesity assessment methods, including waist circumference and waist-hip ratio, BMI has been shown (at the population level) to be a comparable assessment method as a predictor of morbidity and mortality (39). A further limitation was the crude assessments of diet quality utilized in the current study (e.g., fruit/vegetable intake). It is well established that macronutrient factors, including protein, fat, and carbohydrate content, have a key influence on the risk of obesity (40). Future studies on MVPA, MSE, and obesity should include better assessments of diet quality (e.g., food diaries/diet recall).

A key strength was the use of a large representative sample of US adults. Moreover, the use of previously validated questionnaires and standardized collection/reduction procedures make it possible to compare our findings to similar studies and future BRFSS data. A further strength was the detailed data collection process used in the BRFFS, which allowed for assessment of multiple sociodemographic (income, education, race/ethnicity) and lifestyle-related variables (e.g., smoking, fruit/vegetable consumption, presence of chronic health conditions).

Conclusion

Among nearly 1.7 million adults, combined MVPA and MSE guideline adherence was most beneficially associated with obesity. Assuming that the associations that we observed are causal, our findings suggest that successful public health policies and strategies that support the uptake and adherence of concurrent MVPA and MSE at the population level may assist in reducing the significant public health burden of obesity. Future longitudinal studies are needed to determine the temporal associations between MVPA/MSA guideline adherence and indicators of obesity. **O**

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