Joint Associations of Aerobic-Based Physical Activity and Muscle-Strengthening Activities on Metabolic Syndrome

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Abstract

OBJECTIVES: The study aims to examine whether meeting the combined guidelines of accelerometer-assessed moderate to vigorous physical activity (MVPA) and self-reported muscle-strengthening activity (MSA) simultaneously are associated with reduced odds of metabolic syndrome (MetS) than meeting neither or one of the guidelines among the Koreans.

METHODS: This cross-sectional analysis included 1,355 participants from the Korea National Health and Nutrition Examination Survey (2014-2015). Logistic regression was used to analyze the associations across groups of MVPA-MSA guideline adherence (meet neither [reference]; MVPA only; MSA only; meet both MVPS-MSA) with MetS components (e.g., abdominal obesity, hypertriglyceridemia, low high-density lipoprotein cholesterol (HDL-C), hypertension, and hyperglycemia). The odds ratios (OR) were adjusted for covariates (e.g., sex, age, body mass index [BMI], and accelerometer wearing time).

RESULTS: MSA only significantly reduced the OR for abdominal obesity (OR 0.34; 95% confidence interval [CI] 0.13–0.91). When meeting both MVPA-MSA, the OR of having hypertriglyceridemia (OR 0.59; 95% CI 0.39–0.88) and low HDL-C (OR 0.46; 95% CI 0.31–0.68) reduced. Compared to meeting neither, MVPA only (OR 0.63; 95% CI 0.44–0.89) and both MVPA-MSA (OR 0.46; 95% CI 0.28–0.76) significantly reduced the OR for MetS.

CONCLUSIONS: Combined MVPA-MSA was most beneficially associated with MetS prevalence compared to MVPA only and MSA only. Considering that more than 85% of

Korean adults do not meet both MVPA-MSA guidelines, public health actions to promote adherence should be supported.

KEY WORDS: Physical activity, Muscle-strengthening activity, Metabolic syndrome, Combined physical activity, Epidemiology

INTRODUCTION

Metabolic syndrome (MetS) is a collection of risk factors generally associated with cardiovascular disease and type-2 diabetes mellitus, which includes high blood pressure (BP), high cholesterol, elevated abdominal adiposity, and abnormal fasting plasma glucose [1, 2]. Increased MetS risk factors are closely associated with mortality [3] and morbidity [4], as well as complications such as stroke, myocardial infarction, and angina [5]. The worldwide prevalence of MetS is estimated to be 20%–25% among adults [6, 7]. Similarly, the prevalence of MetS in Korea has steadily increased from 22.6% in 2013 to 30.4% in 2018 [8], and the high prevalence of MetS is considered a significant public health concern.

The association between physical activity (PA) and metabolic health-related outcomes has been studied extensively [9-11]. For the prevention and treatment of MetS, the World Health Organization (WHO) recommends that adults should participate in aerobic moderate-to-vigorous physical activity (MVPA) and follow the muscle-strengthening activity (MSA) guidelines (MVPA $\geq$ 150 min/week and MSA $\geq$ 2 sessions/week) [12]. Given that these guidelines distinguish between the two types of activities (aerobic MVPA versus MSA), it may help in unique adaptations to particular physiological systems that improve the risk associated with a variety of MetS-related components. Despite the benefits of various PA reported on MetS, the epidemiological studies mostly discussed the benefits of MVPA [13, 14]. Over the last decade, emerging evidence on clinical exercise suggests that MSA can independently ameliorate or prevent MetS-related risk factors [15, 16].

Although there are global recommendations on both types of activities (MVPA and MSA) and benefits of each type, there is a paucity of studies examining the association between combined MVPA-MSA and MetS [4]. Some studies indicated that meeting concurrent MVPA-MSA guidelines had the strongest association with MetS prevalence, as compared to meeting the individual guidelines for MVPA and MSA alone or meeting neither of them [17].

Among U.S. adults with hypertension (n=155,791), high cholesterol (n=141,173), and diabetes (n=50,027), the lowest prevalence ratios (PRs) were seen in those who met combined MVPA-MSA, followed by MSA only, MVPA only, and met neither of the two guidelines (reference group) [18]. Despite the finding that meeting both MVPA-MSA recommendations has the most positive effect on MetS-related risk factors, most studies have been conducted mainly on Caucasians [4]. Therefore, whether these beneficial results can be generalized globally remains unclear. Given the possibility that associations between cardiometabolic risk factors may be dissimilar among ethnicities [19, 20], it is necessary to examine these associations in other ethnic groups, such as Asians. Moreover, although accelerometer-assessed MVPA objectively reported a stronger association with the MetS prevalence than self-reported MVPA [11, 21, 22], no study has confirmed the association between MetS and meeting both MVPA guidelines, which is measured by accelerometer and self-reported MSA recommendations simultaneously in Koreans.

Therefore, this study aimed to investigate whether meeting the combined guidelines of accelerometer-assessed MVPA and self-reported MSA simultaneously are associated with reduced odds of MetS than meeting neither or one of the guidelines among Koreans.

MATERIALS AND METHODS

Participants

The data for the study were collected from the 2014-2015 Korea National Health and Nutrition Examination Survey (KNHANES), a nationally representative cross-sectional survey of samples from Korea that was conducted by the Korea Centers for Disease Control and Prevention (KCDC). The KNHANES is designed to collect the health and nutritional status information and to monitor trends of health risk factors and the prevalence of major chronic diseases in Korea.

Among the 2014-2015 KNHANES participants, adults who agreed to wear an accelerometer were selected for this analysis (n=1,827). The following participants were excluded from the analysis: those with loss of accelerometer (n=7), missing or error in accelerometer data (n=47), accelerometer error (n=3), insufficient wearing time of accelerometer (n=342), and insufficient data on MetS-related risk factors and the MSA questionnaire (n=73). Finally, a total of 1,355 participants were eligible for this study (Fig 1).

Accelerometer-assessed physical activity

The accelerometer used in the KNHANES was wGT3X+ (ActiGraph, Florida, USA). The reading on the accelerometer was noted every day for a week from midnight on the day after the examination, and instructed to be worn at all possible times, except during water-based activities, such as swimming, bathing, and sleeping [23]. To ensure the assessment of daily PA patterns, individuals wore the accelerometer for at least 10 hours per day for a minimum of 4 days, and they were included in the analysis regardless of weekdays or weekends [24]. To distinguish the accelerometer non-wearing time, a minimum period of 60 consecutive minutes of zero activity count was defined, with an allowance of 1–2 minutes of activity counts between 0 and 100 [25]. MVPA was defined as >2020 activity counts per minute [25]. According to the PA guidelines for Americans, meeting PA guidelines was defined as

accelerometer-determined MVPA of 600 metabolic equivalent of task (MET)-min/week or more, and every minute of MVPA was used [12].

Self-reported muscle-strengthening activities

The KNHANES, based on the Global Physical Activity Questionnaire (GPAQ), which is a self-reported questionnaire to survey PA along with the number of days of MSA, was investigated. The question on MSA in the questionnaire was as follows: ‘In the past week, on how many days did you do push-ups, sit-ups, pull-ups, dumbbells or barbells training designed to strengthen your muscles?’ The responses can range from “not at all” to “more than 5 days” with a weekly frequency. According to the PA guidelines for Americans, meeting the MSA guidelines was defined as individuals participating for more than 2 days a week [12].

Metabolic syndrome

The presence of MetS was determined according to the criteria established by the National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III) [26]. However, waist circumference was determined according to the Asian standard criteria [27]. Participants meeting three or more of the following five criteria were classified as having MetS: (1) waist circumference ≥ 90 cm in men and ≥ 85 cm in women; (2) serum triglyceride level of ≥ 150 mg/dL; (3) high-density lipoprotein cholesterol (HDL-C) level < 40 mg/dL in men and < 50 mg/dL in women; (4) fasting glucose level ≥ 100 mg/dL; (5) systolic BP ≥ 130 mmHg and/or diastolic BP ≥ 85 mmHg. Medication users of dyslipidemia, diabetes, and hypertension were excluded from the study.

Covariates

In the present study, sex, age, family income, education, alcohol consumption, smoking, body mass index (BMI), and accelerometer wearing time were selected as covariates [28-30]. Age was used as a continuous variable and BMI was classified into 3 groups (underweight <18.5 kg/m²; normal 18.5 kg/m²– 24.9 kg/m²; and obese ≥ 25 kg/m²) according to the Asian-Pacific recommendations). Family income was divided into quartiles. Educational level was divided into elementary school degree or less, middle school degree or less, high school degree or less, and college or higher. Alcohol consumption was classified into three categories based on respondents' reported alcohol consumption: a person who never drinks, a person who consumed one drink or less per month in the past 1 year, and a person who consumed one drink or more in the past 1 year. Smoking was divided into past smoking, non-smoking, and current smoking.

Statistical analysis

Baseline characteristics and adherence rate of PA guidelines according to MetS are presented as mean (standard error) for continuous variables and as count and percentage for categorical variables. A chi-square frequency test was used to assess the adherence rate of the PA guidelines concerning MetS. Odds ratios (OR) and 95% confidence intervals (CIs) were obtained using logistic regression to analyze the associations between meeting only MVPA guidelines, meeting only MSA guidelines, or meeting both MVPA and MSA guidelines with MetS. Accelerometer raw data processing was performed using the SAS ver. 9.4 (SAS Institute, Cary, NC, USA), and STATA (SE) 12.0 (Stata Corp., College Station, TX) was used for statistical analysis. The statistical significance level was established as p-value of <0.05 .

Ethics statement

This study protocol was approved by the Institutional Review Board of Seoul National University (IRB no. E2011/001-011). Informed consent was obtained from each participant during the survey.

149 RESULTS

150 The baseline characteristics of the participants are presented in Table 1. The average age of
 151 1,355 adults was 44.7 years, and 63.6% were females. Among the participants, 64.3% had
 152 normal BMI, 31.5% were obese, and 4.1% were underweight. In PA categories, 37.6% of the
 153 participants did not meet combined or isolated MVPA and MSA guidelines, 41.5% met only
 154 MVPA guidelines, 6.0% met only MSA guidelines, and 14.7% met both guidelines.
 155 Additionally, in terms of MetS components, 21.1% had abdominal obesity, 30.1% had
 156 hypertriglyceridemia, 36.7% had low HDL-C, 27.9% had hypertension, and 27.3% had
 157 hyperglycemia.

158 The adherence rate of PA guidelines according to MetS are described in Table 2. The
 159 proportion of people who did not meet neither PA guidelines was higher in the group with
 160 MetS compared to the group without MetS (41.6% vs 36.4%). On the other hand, the
 161 proportion of people meeting both PA guidelines was lower in the group with MetS compared
 162 to the group without MetS (11.7% vs 15.6%). MSA only (with MetS 6.1%; without MetS 6.0%)
 163 and MVPA only (with MetS 40.3%; without MetS 41.8%) showed similar proportions
 164 according to MetS. There was no statistical differences in the adherence rate of PA guidelines
 165 concerning MetS.

166 The associations of PA categories (reference group = met neither guideline) with MetS
 167 components (abdominal obesity, hypertriglyceridemia, low HDL-C, hypertension, and
 168 hyperglycemia) are described in Table 3. Meeting MSA only significantly reduced the odds
 169 ratios (OR) of having abdominal obesity (OR 0.34, 95% CI 0.13–0.91). In contrast, MVPA did
 170 not show any statistically significant association. Nevertheless, when meeting combined
 171 MVPA-MSA, the ORs of having hypertriglyceridemia and low HDL-C were reduced (OR 0.59,
 172 95% CI: 0.39–0.88; OR 0.46, 95% CI 0.31–0.68).

173 The associations of PA categories (reference = meet neither guideline) with MetS are shown

in Figure 2. Compared to meeting neither guideline, meeting MVPA and both guidelines significantly reduced the OR of having MetS, respectively (OR 0.63, 95% CI 0.44–0.89; OR 0.46, 95% CI 0.28–0.76). On the other hand, MSA did not show significant association (OR 0.81, 95% CI 0.40–1.62).

Discussion

We investigated for the first time the associations between different combinations of accelerometer-measured MVPA and self-reported MSA guideline compliance with detrimental MetS in a large sample of Asian adults. The main finding was that achieving the combined MVPA-MSA guidelines was associated with independently more beneficial MetS-related outcomes than meeting neither, MVPA or MSA alone. Our key findings show that meeting both MVPA-MSA guidelines is independently associated with optimal MetS prevalence ratio in Korean adults.

Currently, the epidemiological evidence on the association between PA and metabolic health is based on aerobic MVPA guidelines. Both self-reported MVPA and objectively measured MVPA have reported many positive effects on MetS-related outcomes [31-34]. However, some studies have reported significant low-to-moderate correlations between objectively measured MVPA and self-reported MVPA [35, 36]. In particular, objectively measured MVPA using an accelerometer showed much stronger associations with MetS-related components than self-reported MVPA, even after adjusting for several potential confounders [11, 22]. Our results also showed that meeting the MVPA only significantly reduced the prevalence of MetS (OR 0.63, 95% CI 0.44–0.89). This is similar to the results of previous studies on populations in Western countries (OR 0.39, 95% CI 0.31–0.48) [17]. However, the relationship between MVPA only and MetS-related components was not statistically significant. These results may be affected by whether the physical activity was measured objectively or subjectively,

statistical techniques, and the differences in study participants (e.g., medical history of participants and ethnicity). On the other hand, compared with studies on the epidemiology of aerobic MVPA for decades, studies on MSA are scarce. Studies on clinical exercise show that MSA is associated with metabolic health indicators (e.g., glucose/lipid metabolism, obesity, and BP) [37, 38], skeletal muscle (e.g., bone density and hypertrophy) [39, 40], and functional capacity (e.g., balance and performance) [41, 42]. However, we showed that meeting the MSA recommendation alone (≥ 2 days/week) was not associated with MetS-related components other than waist circumference, which supports the findings of another study involving Korean adults [4]. These findings might be explained by the optimal dose, intensity, and frequency of MSA on metabolic health, which remain unclear, and bias due to subjective reporting (e.g., error in recall and overestimation of exercise) that cannot be excluded. In addition, since MSA requires relatively more exercise equipment (dumbbell and exercise machine), exercise skill proficiency (e.g., to perform squats, push-ups, and deadlift), and understanding of terminology and principles related to resistance exercises (e.g., set, repeated maximum, progression, and overload), it is judged that it will be more difficult to achieve the recommendations for MSA as compared to aerobic MVPA.

Our results provide early insights into the potentially beneficial role of MVPA, MSA, and combined MVPA-MSA on detrimental MetS-related components in a large population-based sample. Our key findings support the extensive literature on the benefits of achieving both aerobic and resistance PA recommendations for metabolic health. In particular, although there was no decrease in the abdominal obesity, this reduction in MetS prevalence appears to have been achieved through the improvement of dyslipidemia. Furthermore, compared with previous studies in other countries, which predominantly included Caucasians as participants, we identified comparable beneficial MetS-related components for meeting combined MVPA-MSA recommendations [17]. Our findings support the findings of Bennie et al. [4], who

measured MVPA subjectively in Korean adults, and a longitudinal study showed that achieving both MVPA-MSA recommendations is associated with lower metabolic-related prevalence and components compared with achieving one recommendation [43]. These positive physiological effects may be explained by the fact that the combined effects of both MVPA and MSA can be greater than their individual effects [44].

In our study, only 14.7% of Korean adults met the combined MVPA-MSA recommendations. This achievement rate was similar to that in Australia (15%) [45], but lower than that in Germany (22.6%) [46] and the USA (20.2%) [47]. Despite the growing number of potential health benefits of combined MVPA-MSA, approximately 80%–85% of currently reported sample populations from multiple countries do not meet the recommended aerobic MVPA and MSA guidelines from a public health perspective. Moreover, as a result of examining the adherence rate of PA guidelines according to the presence or absence of MetS in our study, the MVPA only and MSA only categories showed similar PA achievement rates whether with or without MetS. On the other hand, despite the many benefits of combined MVPA-MSA, people with MetS have a lower achievement rate with combined MVPA-MSA recommendations than those without MetS. Therefore, we need to closely examine the requirements for achieving both MVPA and MSA recommendations and support various strategies to promote adherence to both MVPA-MSA modes.

Our study has certain limitations. First, because the nature of cross-sectional studies makes it difficult to infer causality, the results of this study should be interpreted with caution. Future longitudinal studies that meet both MVPA and MSA guidelines are needed to clarify the associations between achieving both MVPA-MSA recommendations and MetS-related components. Second, our results were derived from subjects who measured PA using an accelerometer, which may have affected the results. For example, those excluded from the analysis for not wearing an accelerometer may be among the most physically inactive

participants, which may have affected the results in less predictable ways. Lastly, MSA was measured using self-reported questionnaires. Although the validity of this questionnaire was proven, it may have been influenced by bias (e.g., over-estimated PA dose and recall bias). In addition, the MSA questionnaire lacks in some amount of information about the frequency, intensity, and time of participation compared to the MVPA questionnaire which may be required for a more detailed analysis.

CONCLUSION

Among a sample of 1,355 Korean adults, combined accelerometer-measured aerobic MVPA and self-reported MSA recommendation adherence was most beneficially associated with MetS compared to meeting the MVPA and MSA recommendations only. Longitudinal studies are needed to confirm the temporal relationship between meeting the MVPA-MSA recommendations and metabolic health. Considering that more than 85% of Korean adults cannot achieve both MVPA-MSA guidelines, public health actions to promote adherence should be supported.

267 **References**

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412 **Figure 1.** Flow diagram of study participant selection.

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415 **Figure 2.** Odds ratios (OR) with 95% confidence intervals (95% CI) for metabolic syndrome
416 among individuals meeting MSA and MVPA, and both guidelines. OR and 95% CI are as
417 follows: MSA only: OR= 0.81 (95% CI 0.40–1.62), MVPA only: OR=0.63 (95% CI 0.46–
418 0.89), Meet both: OR=0.46 (95% CI 0.28–0.76). The values were adjusted for the following
419 covariates: sex, age, family income, education, alcohol consumption, smoking, body mass
420 index (BMI), and accelerometer wearing time.

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Table 1. Characteristics of participants

Variables	Mean (standard error) or number (%)	95% Confidence interval
Age (years) ¹	44.7 (0.3)	44.1–45.4
Sex (% female)	862 (63.6)	61.0–66.1
Educational level (%)		
< Elementary School	112 (8.2)	6.7–9.7
< Middle School	135 (9.9)	8.3–11.5
< High School	545 (40.2)	37.6–42.8
> Undergraduate	563 (41.5)	38.9–44.1
Family income (%)		
< 25 th	91 (6.7)	5.3–8.0
25–50 th	343 (25.3)	22.9–27.6
50–75 th	457 (33.7)	31.2–36.2
75–100 th	464 (34.2)	31.7–36.7
Smoking ² (%)		
No	1,175 (86.7)	84.9–88.5
Yes	180 (13.2)	11.4–15.0
Alcohol (%) ³		
No	612 (45.1)	42.5–47.8
Yes	743 (54.8)	52.1–57.4
BMI (%)		
Underweight (< 18.5 kg/m ²)	56 (4.1)	3.0–5.1
Normal (18.5 kg/m ² –24.9 kg/m ²)	872 (64.3)	61.8–66.9
Obese (≥ 25 kg/m ²)	427 (31.5)	29.0–33.9
Physical activity guideline adherence (%)		
Meet neither	510 (37.6)	35.0–40.2
MVPA only ⁴	563 (41.5)	38.9–44.1
MSA only ⁵	82 (6.0)	4.7–7.3
Meet both	200 (14.7)	12.8–16.6
Metabolic syndrome (%)	307 (22.6)	20.4–24.8
High waist circumference	287 (21.1)	19.0–23.3
High triglyceride	408 (30.1)	27.6–32.5
Low HDL-cholesterol	498 (36.7)	34.1–39.3
High blood pressure	379 (27.9)	25.5–30.3
High fasting glucose	371 (27.3)	25.0–29.7

Data are presented as mean (standard error)¹ or number (%)

BMI: body mass index, MVPA: moderate-to-vigorous physical activity, MSA: muscle strengthening activity, HDL: high-density lipoprotein

²Smoking: No means that ‘have never smoked cigarette before’ or ‘past smoker,’ Yes means that ‘current smoker.’

³Alcohol: No means that ‘have never consumed alcohol before’ or ‘less than one glass of alcohol was consumed in a month in a recent year,’ Yes means that ‘more than one glass of alcohol was consumed in a month in a recent year.’

⁴MVPA only: A group that meets the MVPA guidelines but not the MSA guidelines

⁵MSA only: A group that meets the MSA guidelines but not the MVPA guidelines

Table 2. Adherence rate of physical activity guidelines according to metabolic syndrome

	People with MetS	People without MetS	Chi-Squared <i>p</i> -value
Meet neither	128 (41.6)	382 (36.4)	0.095
MSA only	19 (6.1)	63 (6.0)	0.909
MVPA only	124 (40.3)	439 (41.8)	0.639
Meet both	36 (11.7)	164 (15.6)	0.088

Data are presented as number (%)

MetS: metabolic syndrome, MSA: muscle-strengthening activity, MVPA: moderate-to-vigorous physical activity

Table 3. Adjusted odds ratios detailing the independent and combined effects of meeting MSA and MVPA guidelines

MetS risk factors	Odds ratio	95% CI	P value
High waist circumference			
Meet neither	reference		
MSA only	0.34	0.13–0.91	0.032
MVPA only	0.92	0.58–1.45	0.724
Meet both	0.87	0.46–1.64	0.673
High triglyceride			
Meet neither	reference		
MSA only	0.86	0.49–1.51	0.613
MVPA only	0.82	0.61–1.09	0.179
Meet both	0.59	0.93–0.88	0.011
Low HDL-cholesterol			
Meet neither	reference		
MSA only	0.90	0.54–1.50	0.691
MVPA only	0.84	0.64–1.09	0.191
Meet both	0.46	0.31–0.68	<0.001
High blood pressure			
Meet neither	reference		
MSA only	1.41	0.79–2.25	0.243
MVPA only	1.27	0.94–1.71	0.117
Meet both	1.03	0.68–1.57	0.859
High fasting glucose			
Meet neither	reference		
MSA only	1.07	0.59–1.93	0.819
MVPA only	1.03	0.76–1.39	0.816
Meet both	0.92	0.61–1.40	0.712

MetS: metabolic syndrome, CI: confidence interval, MSA: muscle-strengthening activity, MVPA: moderate-to-vigorous physical activity, HDL: high-density lipoprotein

Adjusted for the following covariates: sex, age, family income, education, alcohol consumption, smoking, body mass index (BMI), and accelerometer wearing time

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