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Association between meeting the 24-hour movement guidelines and cardiometabolic syndrome in Korean adults

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Twenty-four-hour movement guidelines are reported to correlate with a reduction in the risk of metabolic disease in all age groups. We explored the association between meeting 24-h Movement Guidelines and cardiometabolic syndrome in the general adult population using data from the Korea National Health and Nutrition Examination Survey (KNHANES). This population-based cross-sectional study used data from the KNHANES 2014–2017 and included 2151 adults. Physical activity and sedentary behavior were measured using a three-axis accelerometer. Sleep time was measured using a self-reported questionnaire. Compared with adherence to none of the three guidelines, the odds ratio (OR) for meeting two of the three guidelines were 0.66 (95% confidence interval 0.45–0.98), whereas the OR for meeting all three guidelines was 0.24 (95% CI 0.10–0.59). In the analysis of specific combinations, the group that met the physical activity and sleep time guidelines had a significantly lower risk of cardiometabolic syndrome (OR 0.45, 95% CI 0.21–0.90). Consequently, we suggest that adherence to two or more physical activity guidelines may reduce the risk of cardiometabolic syndrome in Korean adults. Furthermore, meeting all three guidelines is more closely associated with cardiometabolic health owing to their synergistic effects.

Keywords 24-H movement guidelines, Cardiometabolic syndrome, Physical activity, Sedentary behavior, Sleep time

Abbreviations

24HMG	24-H movement guideline
CMS	Cardiometabolic syndrome
CVD	Cardiovascular disease
HbA1c	Hemoglobin A1c
HDL-C	High-density lipoprotein cholesterol
KNHANES	Korea National Health and Nutrition Examination Survey
MET	Metabolic equivalents
MPA	Moderate PA
MVPA	Moderate-to-vigorous-intensity PA
PA	Physical activity
SB	Sedentary behavior
ST	Sleep time
VPA	Vigorous PA
WC	Waist circumference

Cardiometabolic syndrome (CMS) comprises a cluster of metabolic risk factors, including hypertension, hyperglycemia, hyperlipidemia, and abdominal obesity[1]. It is known as one of the major risk factors that increase the risk of cardiovascular diseases (CVDs), such as coronary heart disease, myocardial infarction, and stroke[2,3]. In South Korea, CVD-related deaths are continually increasing, with a mortality rate of 63.0 per 100,000 people,

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representing a 44.8% increase in 2021 compared with 2009[4]. Therefore, research on the prevention of CMS is important for reducing the prevalence of CVD and its mortality.

From a movement perspective, a 24-h period is distributed among physical activities (PAs) of various intensities (light, moderate, and vigorous), sedentary behaviors (SBs), and sleep time (ST)[5]. These movement behaviors have an interdependent relationship, meaning that allocating more time to one specific action reduces the time required to perform other actions[6]. Therefore, it is essential to consider the integrated aspects of PA, SB, and ST to effectively prevent CVD[7]. For example, even at high levels of moderate-to-vigorous-intensity PA (MVPA), excessive SB during the rest of the day doubles the risk of mortality from CVD[8]. Furthermore, inadequate sleep is associated with mortality and an increased risk of stroke, even if individuals engage in 1200 metabolic equivalents(MET)-min/week of PA[9]. Thus, to effectively prevent and reduce the prevalence of CVD, it is important to comprehensively consider adequate PA, limited SB, and sufficient ST[6,10].

To promote optimal health across all age groups, the Canadian Society for Exercise Physiology published the world's first 24-h Movement Guidelines (24HMGs) for proper PA, SB, and ST[11] Previous studies have reported that adhering to the 24HMGs is associated with reduced risks of mental health, obesity, and cardiometabolic disease compared with adherence to each guideline separately[12–14]. In a study of adults across eight Latin American countries, those who adhered to just one 24HMG had a 15% lower risk of obesity; those who adhered to all three guidelines had a 31% lower risk of obesity[15]. Additionally, Chilean adults who adhered to only one 24HMG exhibited a higher risk of elevated triglycerides, hypertension, type 2 diabetes, metabolic syndrome, and CVD than those who adhered to all three guidelines[5].

Self-reported questionnaire methods are commonly used in large-scale studies to assess movement behavior; however, they can lead to recall bias or overestimation because participants rely on their own memory[16]. Therefore, it is necessary to use objective methods—such as accelerometers—to assess movement behaviors. However, few studies have used accelerometers to measure movement behavior. Furthermore, to the best of our knowledge, no studies have investigated the association between 24HMGs and CMS among Korean adults. Thus, this study aimed to examine the association between meeting the 24HMGs and CMS in the general Korean population using the Korean National Health and Nutrition Examination Survey (KNHANES).

Methods

Study participants

The KNHANES is a series of cross-sectional surveys of nationally representative samples from a civilian, noninstitutionalized population conducted to assess the health and nutritional status of the Korean population[17]. Accelerometer-based measurements of PA and SB were conducted in the KNHANES 2014–2017 for adults aged 19–64 years between 2014 and 2016, and for those aged ≥ 65 years in 2017[18]. For this study, we included 2817 adults aged ≥ 20 years who agreed to participate in the accelerometer measurements. We excluded 547 participants who did not wear an accelerometer for ≥ 10 h a day for ≥ 4 days[19], seven participants with missing anthropometric data, and 70 participants with missing blood sample data. Additionally, 31 participants with a fasting time of < 8 h, and 11 participants with missing demographic and lifestyle data were excluded. Finally, 2,151 participants were included in this study (Fig. 1). The KNHANES was approved by the Institutional Review Board (IRB) of the Korea Disease Control and Prevention Agency, and all participants provided written informed consent. This study was conducted after receiving approval from the IRB of the Korea Maritime & Ocean University (KMOU IRB: 1040371-202303BR-01-02).

Assessment of PA, SB, and ST

PA and SB were measured using a triaxial accelerometer (ActiGraph, Pensacola, FL, USA). The accelerometer was worn on either the left or right side of the waist at the level of the navel for seven continuous days from the day of obtaining consent. The accelerometer data was recorded from midnight, following its distribution. The participants were instructed to wear the accelerometer immediately after waking up until just before going to bed, except when swimming and showering.

The accelerometer count value was calculated using the recorded raw accelerometer data, and the electrical signals were summarized into 1-min epochs. The nonwear time was defined as a continuous zero count lasting at least 1 min. The wear time was then calculated by subtracting the nonwear time throughout the day, but only if the nonwear time lasted for > 60 consecutive minutes[20]. For an accurate assessment of daily PA, we extracted and utilized data that satisfied the criteria of ≥ 4 days for ≥ 10 h a day for the analysis[19].

To classify the PA and SB time, we calculated and summed the duration of the acceleration count value according to the activity intensity criterion using METs. SB was defined as a threshold of < 100 counts/min, and light PA (LPA) intensity was defined as a threshold of < 760 counts/min. Lifestyle activity was defined using a threshold of < 2020 counts/min, and moderate PA (MPA) intensity was defined using a threshold of ≥ 2020 counts/min. Last, vigorous PA (VPA) intensity was defined using a threshold of ≥ 5999 counts/min[20,21].

Self-reported questionnaires were used to investigate the average sleep duration per day on both weekdays and weekends. According to the questionnaire responses, average sleep duration was calculated using the following formula: (average daily ST on weekdays × 5 + average daily ST on weekends × 2)/7[22].

24-Hour movement guidelines

Meeting the aerobic PA guideline was defined when the MPA was ≥ 150 min/week, the VPA was ≥ 75 min/week, or the combined MVPA was ≥ 150 min/week. Meeting the muscle-strengthening guideline was defined as performing muscle-strengthening activities (push-ups, and sit-ups) for ≥ 2 days/week within the prior week as assessed by the questionnaire. Participants were categorized as meeting the PA guidelines if they met both the aerobic and muscle-strengthening activity criteria[11]. Meeting the SB guideline was defined as ≤ 8 h/day of SB.

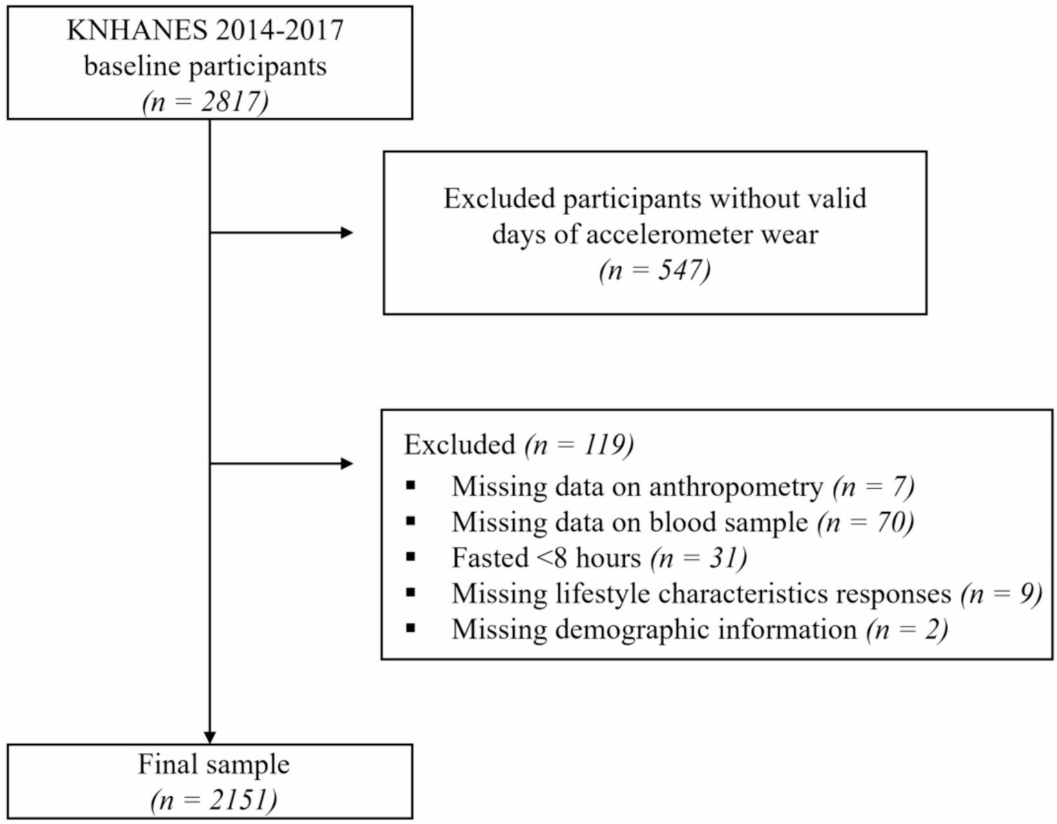

Fig. 1. Flow of study participants.

Meeting the sleep guidelines was defined as follows: an average of 7–9 h per night for adults aged 18–64 years, and an average of 7–8 h per night for adults aged ≥ 65 years[11].

Cardiometabolic risk factors

Cardiometabolic risk factors included waist circumference (WC), systolic blood pressure, diastolic blood pressure, hemoglobin A1c (HbA1c), fasting glucose, total cholesterol, and low high-density lipoprotein cholesterol (HDL-C). We determined each adverse cardiometabolic risk factor based on criteria from previous studies conducted in Korean adults[23,24].

WC (cm) was measured barefoot at the midpoint between the bottom of the last rib and the upper iliac crest in a standing position. Abdominal obesity was defined as a WC > 90 cm in males and > 80 cm in females[25].

Blood pressure was measured using a Littmann Cardiology III stethoscope (3 M, Saint Paul, MN, USA) and Baum Baumanometer (W.A. Baum, Copiague, NY, USA) with the participant in the seated position after ≥ 5 min of rest. Hypertension was defined as a systolic blood pressure ≥ 130 mmHg or diastolic blood pressure ≥ 85 mmHg (using the average value of three blood pressure measurements), and/or the use of medication for the treatment of hypertension.

Blood samples were obtained from all participants following more than 8 h of overnight fasting. A high glycosylated hemoglobin level was defined as an HbA1c level ≥ 6.5%. High fasting glucose was defined as a fasting glucose level ≥ 100 mg/dL or/and taking medication for the treatment of high fasting glucose. High total cholesterol was defined as ≥ 190 mg/dL, while low HDL-C levels were defined as < 40 mg/dL in males and < 50 mg/dL in females. Based on the cardiometabolic risk factor assessment, we calculated the total number of risk factors (ranging from 0 to 6), which included abdominal obesity, high blood pressure, high HbA1c, high fasting glucose, high total cholesterol, and low HDL-C. Finally, individuals with three or more risk factors were diagnosed with CMS[24].

Covariates

Considering the potential confounding effects related to the risk of CMS, the following covariates were used: age, sex, educational level, smoking status, alcohol consumption, household income, marital status, energy intake, and accelerometer wear duration. Education levels were categorized into below high school, high school, and college/university or higher. Smoking status was classified into never smoked, former smoker, or current smoker. Alcohol consumption was classified into never, ≤ 1 time/week, 2–3 times/week, and ≥ 4 times/week. Household income was divided into four categories according to quartiles. Marital status was classified into two categories, namely, married and others (never married, divorced, or bereaved).

Statistical analysis

All analyses were performed using SPSS Statistics software (version 22.0; IBM, Armonk, NY, USA); statistical significance was defined as $p < 0.05$.

We used a complex sample design analysis module, and sampling weights were generated for participants to accurately reflect the South Korean population by accounting for the complex survey design, non-response rates, and post-stratification. These weighting factors were calculated using the converse of selection probabilities and the converse of response rates were adapted by adjusting these to be age- and sex-specific for Korean populations (post-stratification)[17].

The study participants' characteristics—including demographics and proportions of cardiometabolic risk factors—were presented as frequencies and weighted percentages (%), and a Rao–Scott chi-squared test was conducted to analyze the statistical significance according to the number of times the guidelines were met. Continuous variables were analyzed using t-tests, and the characteristics of the participants were reported as weighted means and standard errors.

To examine the association between CMS and meeting the 24HMGs, complex sample logistic regression was performed after adjusting for covariates including age, sex, educational level, smoking status, alcohol consumption, household income, marital status, energy intake, and accelerometer wear time. In the general combination of 24HMGs, participants were categorized by the number of guidelines met (0–3) as follows: all three, two of three, one of three, and none (reference). For specific combinations of 24HMGs, participants were categorized by various combinations of adherence to the guidelines for PA, SB, and ST, as follows: all three; PA and SB; PA and ST; SB and ST; only PA; only SB; only ST; and none (reference). For each model, the odds ratio (OR) and 95% confidence interval (CI) were estimated to assess the association between CMS and meeting the 24HMGs.

Additionally, a sensitivity analysis was conducted using models stratified by sex (male or female) and age group (< 60 years or ≥ 60 years) to examine sex and age-related differences in these associations.

Results

Table 1 shows the overall characteristics of the participants based on the 24HMGs. The mean age of the 2,151 participants in the study was 49.9 ± 0.8 years. The mean body mass index of the participants was 23.7 ± 0.1 kg/m^2, and there was no significant difference between the groups ($p < 0.643$). Among the cardiometabolic risk factors, the prevalence of abdominal obesity and low HDL-C was significantly higher in females (all $p < 0.001$), whereas the prevalence of hypertension and high fasting glucose was higher in males ($p < 0.001$ and $p = 0.001$, respectively; Supplementary Table S1). The proportions of CMS according to the number of participants who met none, one, two, and three of the 24HMGs were 41.7%, 36.1%, 32.6%, and 11.7%, respectively (p for trend < 0.001, Table 1).

Table 2 shows the mean level of PA, SB, and ST, as well as the proportion of participants meeting 24HMGs measured using accelerometers and questionnaires. The mean weekly durations of MVPA were 279.8 ± 11.4 min/week for males and 195.1 ± 8.1 min/week for females, with males demonstrating significantly higher activity ($p < 0.001$). The average daily SB and ST were 7.8 ± 0.1 h/day, and 7.1 ± 0.1 h/day, respectively; there was no significant difference between sexes.

Table 3 shows the proportion of participants who met the 24HMGs according to general and specific combinations. In the general combination category, participants adhering to one of the three guidelines accounted for the highest proportion at 44.5%, whereas those meeting all three guidelines accounted for the smallest proportion at 3.5%. In the specific combination category, compared with other groups, those involving PA accounted for a relatively lower proportion. For example, whereas 4.1% met only the PA guidelines, among those adhering to two guidelines, 3.6% met both the PA and SB, and 4.4% met both the PA and ST.

Table 4 shows the relationship between meeting a general combination of 24HMGs and CMS. Compared with participants with adherence to none of the three guidelines (reference), there was no statistically significant association regarding the risk of CMS when meeting one of the three guidelines (OR 0.79, 95% CI 0.56–1.12). Those meeting two of the three guidelines had a lower OR (0.66, 95% CI 0.45–0.98) for CMS, while the lowest OR (0.24; 95% CI 0.10–0.59) for CMS was observed in participants with all three guidelines compared with the reference group. Moreover, when we conducted a sensitivity analysis using models stratified by sex, a significantly lower OR was observed in males with guidelines meeting all three.

Table 5 shows the relationship between meeting the 24HMGs according to specific combinations and CMSs. Compared with the reference group (none of the three guidelines), no significant associations were observed in the groups following only one of the PA, SB, or ST guidelines. Conversely, the group that met both PA and ST guidelines demonstrated a significantly lower OR (0.45; 95% CI 0.21–0.90) for CMS. The group that met all three guidelines demonstrated the lowest OR (0.26; 95% CI 0.11–0.62) for CMS.

Discussion

This is the first study to describe the associations between meeting the 24HMGs and CMS in Korean adults using objectively measured PA data from the KNHANES. We found that adhering to two or more movement guidelines, including PA guidelines, significantly reduced the risk of CMS compared with adherence to fewer guidelines. Specifically, the lowest risk of CMS was observed when individuals adhered to all three 24HMGs. These findings suggest that engaging in regular PA, limiting SB, and obtaining adequate sleep may help improve cardiometabolic health in Korean adults.

A recent systematic review reported that meeting all guidelines related to PA, SB, and ST was significantly associated with cardiometabolic risk factors[26]. Another cross-sectional study reported that the composition of movement behaviors within a 24-h period may have important implications for cardiometabolic health[5]. In this study, we found that the group that met both guidelines had an approximately 34% lower risk of CMS.

Variables	None (n = 409)		One (n = 983)		Two (n = 685)		Three (n = 74)		Overall (n = 2,151)		*p*-value
Age [years][a]	53.8	± 1.2	50.8	± 0.8	50.7	± 0.9	44.1	± 2.2	49.9	± 0.8	0.002
BMI [kg/m^2]	23.9	± 0.2	23.7	± 0.1	23.8	± 0.1	23.4	± 0.3	23.7	± 0.1	0.643
Accelerometer wear time [hour]	15.1	± 0.1	13.2	± 0.1	11.9	± 0.1	13.1	± 0.3	13.3	± 0.1	< 0.001
Energy intake [kcal]	1906.8	± 54.4	2000.9	± 37.1	2178.2	± 47.6	2514.2	± 152.5	2150.1	± 44.7	< 0.001
Sex [n (%)][b]											0.001
Male	148	(40.3)	336	(42.7)	283	(49.5)	46	(66.2)	813	(45.2)	
Female	261	(59.7)	647	(57.3)	402	(50.5)	28	(33.8)	1338	(54.8)	
Age group [n (%)]											0.018
< 60 years	290	(56.7)	739	(65.4)	498	(63.9)	57	(76.6)	1584	(63.5)	
≥ 60 years	119	(43.3)	244	(34.6)	187	(36.1)	17	(23.4)	567	(36.5)	
Education level [n (%)]											0.705
< High school	102	(30.5)	242	(27.8)	176	(28.4)	14	(18.6)	534	(28.2)	
High school	146	(32.8)	368	(36.5)	250	(35.9)	29	(41.1)	793	(35.7)	
> High school	161	(36.6)	373	(35.7)	259	(35.7)	31	(40.4)	824	(36.1)	
Alcohol consumption [n (%)]											0.093
Never	113	(29.6)	268	(28.7)	170	(23.9)	9	(13.9)	560	(26.8)	
Once a week	231	(53.4)	551	(53.7)	353	(51.8)	50	(66.2)	1185	(53.5)	
2–3 days/week	48	(11.5)	122	(13.1)	115	(17.2)	11	(14.1)	296	(14.1)	
≥ 4 days/week	17	(5.4)	42	(4.7)	47	(7.1)	4	(5.8)	110	(5.6)	
Smoking status [n (%)]											0.079
Never	296	(69.1)	716	(69.2)	455	(62.1)	45	(64.5)	1512	(66.7)	
Former	65	(19.9)	150	(17.9)	149	(25.8)	21	(24.1)	385	(21.1)	
Current	48	(11.1)	117	(12.9)	81	(12.3)	8	(11.5)	254	(12.3)	
Household income [n (%)]											0.005
Q1	59	(22.6)	133	(19.1)	67	(12.5)	4	(7.7)	263	(17.3)	
Q2	103	(26.3)	260	(25.8)	212	(32.5)	17	(22.1)	592	(27.9)	
Q3	115	(24.5)	301	(27.8)	221	(29.1)	30	(41.1)	667	(28.1)	
Q4	132	(26.6)	289	(27.4)	185	(25.9)	23	(29.2)	629	(26.8)	
Marital status											0.433
Married	293	68.0	715	68.2	535	72.7	56	70.6	1599	69.7	
Others	116	32.0	268	31.8	150	27.3	18	29.4	552	30.3	
Individual cardiometabolic biomarker											*p* for trend
Abdominal obesity [n (%)]	148	(40.6)	362	(35.1)	245	(36.9)	16	(23.2)	771	(36.3)	0.109
High blood pressure [n (%)]	151	(44.5)	335	(38.3)	239	(37.4)	19	(24.7)	744	(38.8)	0.014
High glycosylated hemoglobin [n (%)]	29	(9.5)	88	(10.9)	58	(8.2)	0	(0.0)	175	(9.4)	0.098
High fasting glucose [n (%)]	143	(39.6)	310	(34.4)	219	(33.1)	20	(25.4)	692	(34.7)	0.040
High total cholesterol [n (%)]	205	(49.6)	467	(46.3)	355	(49.9)	27	(37.3)	1054	(47.8)	0.664
Low HDL cholesterol [n (%)]	151	(37.2)	361	(35.8)	208	(28.1)	10	(14.2)	730	(32.8)	< 0.001
Cardiometabolic syndrome [n (%)]	144	(41.7)	336	(36.1)	221	(32.6)	9	(11.7)	710	(35.2)	< 0.001

Table 1. Participants characteristics. [a]Weighted mean ± standard error from survey means. [b]Weighted percentages from survey frequency (all such values). *p* Values were calculated using *t*-test for continuous variables and Rao–Scott chi-square test for categorical variables.

Furthermore, compared with the reference group, the group meeting all three guidelines showed the greatest reduction (approximately 76%) in the risk of CMS. Consequently, simultaneously following as many of the three movement guidelines as possible is necessary for ensuring cardiometabolic health.

As none of the 24-h movement behaviors were independent of each other, it is inappropriate to examine their associations with health in isolation. According to research regarding the impact of PA on sleep, engaging in regular PA is associated with improved sleep quality and adequate sleep duration[27]. Additionally, an excessively sedentary lifestyle increases the risk of sleep disorders or insomnia[28]. In our study, the group that met all three guidelines had the highest average MVPA level (470.9 min/week) compared with other groups. Their SB was the shortest at 6.2 h/day, and their ST was sufficient at 7.5 h/day. Therefore, considering all three movement behaviors is essential as the proportion of each movement behavior can influence the behavior of the others.

Furthermore, we analyzed the prevalence risk of CMS in the seven groups based on specific combinations that meet the 24HMGs. The group that met only one guideline (PA, SB, or ST) did not show a significant reduction in the prevalence of CMS. However, the group that met both PA and ST guidelines demonstrated a significant reduction in the risk of CMS. The fundamental mechanism underlying cardiometabolic diseases is insulin

Meeting guidelines	Overall (n = 2151)		Male (n = 813)		Female (n = 1338)		*p*-value
Physical activity parameters[a]							
Moderate activity [min/week]	229.4	± 6.7	268.4	± 10.9	190.4	± 8.1	< 0.001
Vigorous activity [min/week]	4.1	± 0.6	5.7	± 1.1	2.2	± 0.4	0.009
Sedentary behavior [hour/day]	7.8	± 0.1	7.8	± 0.1	7.8	± 0.1	0.606
Sleep time [hour/day]	7.1	± 0.1	7.1	± 0.1	7.1	± 0.1	0.924
Meeting 24-h guidelines[b]							
Guidelines met PA [n (%)]	302	(15.5)	172	(22.4)	130	(9.8)	< 0.001
Guidelines met SB [n (%)]	1072	(48.5)	413	(49.6)	659	(47.6)	0.464
Guidelines met ST [n (%)]	1201	(54.6)	455	(55.1)	746	(54.1)	0.705

Table 2. Physical activity parameters and proportion (%) of meeting guidelines. [a]Continues variables were presented as weighted mean ± standard error. [b]Categorical variables were presented as frequency (weighted %). PA, physical activity; SB, sedentary behavior; ST, sleep time.

Meeting guidelines	Overall (n = 2,151)		Male (n = 813)		Female (n = 1,338)		*p*-value
General combination [n (%)]							
Guidelines met none	409	(20.2)	148	(18.1)	261	(22.1)	0.001
Guidelines met one of three	983	(44.5)	336	(42.1)	647	(46.6)	
Guidelines met two of three	685	(31.7)	283	(34.7)	402	(29.2)	
Guidelines met all three	74	(3.5)	46	(5.2)	28	(2.2)	
Specific combination [n (%)]							
Guidelines met none	409	(20.2)	148	(18.1)	261	(22.1)	< 0.001
Guidelines met only PA	76	(4.1)	41	(5.6)	35	(2.6)	
Guidelines met only SB	397	(17.7)	135	(16.8)	262	(18.3)	
Guidelines met only ST	510	(22.9)	160	(19.6)	350	(25.6)	
Guidelines met PA and SB	68	(3.6)	34	(4.5)	34	(2.9)	
Guidelines met PA and ST	84	(4.4)	51	(7.2)	33	(2.1)	
Guidelines met SB and ST	533	(23.7)	198	(23.1)	335	(24.2)	
Guidelines met all three	74	(3.5)	46	(5.2)	28	(2.2)	

Table 3. Proportion (%) of meeting 24-hour movement guidelines. All variables were presented as frequency (weighted %). PA, physical activity; SB, sedentary behavior; ST, sleep time.

General combination of meeting guidelines	Overall Adjusted OR (95% CI)	Male Adjusted OR (95% CI)	Female Adjusted OR (95% CI)
Guidelines met none	1.00 (reference)	1.00 (reference)	1.00 (reference)
Guidelines met one of three	0.79 (0.56–1.12)	0.86 (0.49–1.51)	0.86 (0.54–1.37)
Guidelines met two of three	0.66 (0.45–0.98)*	0.64 (0.36–1.12)	0.71 (0.43–1.20)
Guidelines met all three	0.24 (0.10–0.59)*	0.29 (0.11–0.79)*	0.23 (0.41–1.31)
p for trend	0.002	0.014	0.086

Table 4. Odds ratio (95% CI) for cardiometabolic syndrome according to general combination of meeting 24-hour movement guidelines. Odds ratio adjusted for age, education level, smoking status, alcohol consumption, household income, marital status, energy intake, and accelerometer wear time (The overall model was additionally adjusted for sex). **p*-value < 0.05 versus reference group. OR, odds ratio; CI, confidence interval.

resistance[29], which leads to the compensatory hypersecretion of insulin, thereby resulting in the development of cardiometabolic risk factors such as abdominal obesity, diabetes, and hypertension[30]. Regular PA has been shown increase insulin sensitivity and has a positive impact on cardiometabolic health[31,32]. Moreover, adequate sleep significantly contributes to maintaining the body's energy balance, as it directly influences metabolic and hormonal processes. According to previous research investigating hormonal changes with sleep, average leptin

Specific combination of meeting guidelines	Overall		Male		Female	
	Adjusted OR (95% CI)		Adjusted OR (95% CI)		Adjusted OR (95% CI)	
Guidelines met none	1.00	(reference)	1.00	(reference)	1.00	(reference)
Guidelines met only PA	0.47	(0.19–1.13)	0.53	(0.19–1.50)	0.64	(0.19–2.20)
Guidelines met only SB	1.14	(0.75–1.73)	1.22	(0.60–2.47)	1.14	(0.66–1.96)
Guidelines met only ST	0.72	(0.50–1.04)	0.78	(0.42–1.45)	0.78	(0.47–1.30)
Guidelines met PA and SB	0.41	(0.15–1.12)	0.90	(0.31–2.63)	0.15	(0.03–0.64)*
Guidelines met PA and ST	0.45	(0.21–0.90)*	0.47	(0.21–1.09)	0.52	(0.17–1.62)
Guidelines met SB and ST	0.89	(0.59–1.33)	0.75	(0.39–1.43)	1.03	(0.61–1.75)
Guidelines met all three	0.26	(0.11–0.62)*	0.31	(0.12–0.84) *	0.25	(0.05–1.40)

Table 5. Odds ratio (95% CI) for cardiometabolic syndrome according to specific combination of meeting 24-hour movement guidelines. Odds ratio adjusted for age, education level, smoking status, alcohol consumption, household income, marital status, energy intake, and accelerometer wear time (The overall model was additionally adjusted for sex). **p*-value < 0.05 versus reference group. PA, physical activity; SB, sedentary behavior; ST, sleep time; OR, odds ratio; CI, confidence interval.

levels were reported to increase by approximately 22%, while ghrelin levels decreased by around 30% during periods of insufficient sleep (≤ 5 h). Conversely, ghrelin levels decreased by approximately 21% during periods of excessive sleep (≥ 9 h)[33]. These findings suggest that inadequate sleep disrupts the body's energy balance and acts as an independent risk factor for weight gain and obesity by regulating appetite hormones[33]. Adherence to sleep guidelines may have a beneficial effect on the regulation of hormonal processes and maintenance of the body's energy balance. This may be associated with a reduction in the prevalence of CMS.

The association between the combination of two movement behaviors and a reduction in the prevalence of CMS requires interpretation from a continuous behavioral perspective. According to a systematic review of PA and sleep, regular PA increases sleep efficacy, improves sleep onset latency, and enhances the overall quality of sleep[27]. Simultaneously adhering to both guidelines may provide greater benefits, such as a reduced risk of all-cause mortality, CVD, coronary artery disease, and some types of cancer[9], as it combines the advantages of regular PA for preventing risk factors, such as insulin resistance and elevated blood pressure[31], along with the positive interaction of hormone regulation achieved via sufficient sleep[34].

In the sensitivity analysis stratified by sex using a general combination of adherence to the 24HMGs, significant results were only observed in males. This variation in findings may be attributed to differences in PA levels between males and females. Indeed, the average MVPA level was higher in males (279.8 min/week vs. 194.8 min/week), and according to KNHANES data, the rate of adherence to muscle-strengthening activity was also higher among males (31.9% vs. 16.2%)[35]. In addition to aerobic PA, resistance exercise has been reported to be effective in improving cardiometabolic health (including blood glucose control) through increased insulin sensitivity and improvement of hypertension[36–38]. Higher levels of aerobic PA and compliance with muscle-strengthening activity among males may have a positive impact on their cardiometabolic health. Our study also demonstrated a significant correlation between meeting both PA and SB guidelines and a decreased risk of CMS through sensitivity analyses. When both PA and SB guidelines were met, the model stratified by sex showed a significant reduction of approximately 85%; in the model stratified by age group, adults aged ≥ 60 years exhibited a significant reduction of approximately 81% in the risk of CMS. According to most previous studies, replacing SB with either VPA or LPA and increasing PA was reported to reduce the risk of CVD[6,10]. Our findings therefore suggest that meeting PA, SB, and ST guidelines may lead to greater benefits for cardiometabolic health than following a single guideline in isolation.

The major strength of this study was that PA and SB were measured using triaxial accelerometers, thereby minimizing measurement errors. Additionally, we used a nationwide sample from the KNHANES that represents Korean adults; therefore, the results of this study facilitate comparisons between domestic and overseas studies. Finally, we conducted an analysis by adjusting for various demographic and lifestyle variables, considering the potential impact of confounding variables. However, this study had a cross-sectional design, which limited the causal inference between meeting the 24HMGs and cardiometabolic risk factors. Therefore, intervention and longitudinal studies with long-term follow-up are required to establish a causal relationship between the 24HMGs and cardiometabolic risk factors.

Using a self-reported questionnaire to assess ST may introduce errors as it relies on participants' subjective recall, and the precise ST may not be accurately captured. Moreover, the questionnaire may not have adequately reflected the quality of sleep experienced by the participants. Additionally, muscle-strengthening activity was only evaluated based on the number of times per week using the questionnaire; therefore, the precise volume of the muscle-strengthening activity was not considered.

Previous studies have reported an association between LPA occurring in daily life and metabolic diseases. However, to focus on evaluating whether the PA guidelines were met in this study, only MVPA (which combines MPA and VPA) was analyzed. Therefore, the potential effect of LPA on CMS was not considered in this study.

Conclusion
Adherence to two or more guidelines from the 24HMGs, including the PA guideline, may contribute to reducing the risk of CMS in Korean adults. Furthermore, simultaneously considering all three movement behaviors of the 24HMGs may have the most positive impact on cardiometabolic health owing to their potential joint effects. Our results provide evidence that the 24HMGs may support optimal cardiometabolic health among Korean adults.

Data availability
The datasets generated and/or analyzed during the current study are publicly available at https://knhanes.kdca.go.kr/knhanes/eng/index.do.

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Author contributions
J. Kim designed the study; Y. Choi participated in the literature search and analysis; Y. Choi and J. Kim contributed to the interpretation of data and wrote the manuscript; S.J. Kang and J. Kim also contributed to the critical revision of the manuscript for important intellectual content; All authors have read and approved the final version of the manuscript and agree with the order of authorship as presented.

Declarations

Competing interests
The authors declare no competing interests.

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