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Is meeting 24-hour movement guidelines associated with a lower risk of frailty among adults?

Yuhang Liu[1] , Siyao Gao[2]* , Zhigang Dou[3], Zhen Chen[2] and Jialing Tang[2]

Abstract

Background The relationship between 24-hour (24-h) movement guidelines and frailty remains unclear. We aimed to investigate the associations between meeting 24-h movement guidelines and frailty and to conduct secondary analyses by age, gender, and ethnicity.

Methods In this study, we extracted data from the National Health and Nutrition Examination Survey (2007–2018) database. A total of 5,726 participants (50.25 ± 0.31 years) were included in this analysis, representing 38,240,356 noninstitutionalized U.S. individuals. Three 24-h movement behaviors, namely, physical activity, sedentary behavior (SB), and sleep, were self-reported using the standardized questionnaires. The 49-item frailty index was used to measure frailty. Multivariable logistic regression models and trend tests were used to examine the associations between meeting 24-h movement guidelines and frailty. Sensitivity analyses were also conducted to ensure the robustness of our results.

Results The total age-adjusted prevalence of frailty was 30.5%. In the fully adjusted model, compared with not meeting any of the 24-h movement guidelines, the adjusted odds ratios (AORs) of frailty were 0.786 (95% CI: 0.545, 1.133), 1.161 (95% CI: 0.787, 1.711), and 0.915 (95% CI: 0.616, 1.358) for participants meeting only moderate to vigorous physical activity (MVPA), only SB, and only sleep guidelines, respectively, but no statistically significant differences were observed (all P values > 0.05). Participants who met the SB + sleep guidelines (AOR = 0.613, 95% CI: 0.423, 0.887), MVPA + sleep guidelines (AOR = 0.389, 95% CI: 0.255, 0.593), and MVPA + SB guidelines (AOR = 0.555, 95% CI: 0.383, 0.806) presented a significantly lower risk of frailty by 39%, 61%, and 45%, respectively. Meeting all 3 guidelines (AOR = 0.377, 95% CI: 0.264, 0.539) and meeting 2 guidelines (AOR = 0.527, 95% CI: 0.377, 0.736) were associated with a lower risk of frailty (P value < 0.001), showing a linear trend (P for trend < 0.001). The strength of these associations varied somewhat by age, gender, and ethnicity.

Conclusions Significant associations between the 24-h movement guidelines and frailty were observed among U.S. adults. Future studies are warranted to examine the causality and trajectory of these associations.

Keywords 24-hour movement guidelines, Frailty, Age disparities, Gender disparities, Racial disparities, Adults, NHANES

*Correspondence:
Siyao Gao
gaosiyao@csu.edu.cn
[1]School of Physical Education and Sports, Central China Normal University, Wuhan 430079, P. R. China
[2]Department of Physical Education, Central South University, Changsha 410083, P. R. China
[3]Henan Experimental High School, Zhengzhou 450002, P. R. China

Background

There is no doubt that frailty is one of the most serious public health issues [1]. Frailty is characterized by the accumulation of health defects stemming from the impairment of health caused by physical, physiological, and psychological factors [2, 3]. This condition is closely associated with adverse outcomes, including mortality, disability, hospitalization, cognitive decline, and lower quality of life [4]. Individuals with frailty are more likely to present with multimorbidity (≥ 2 diseases) [5], imposing a heavy burden on society and the health care system [6]. Frailty affects millions of older adults globally, and the impact of frailty is expected to continue to increase as the population ages [4].

The severity of frailty is dynamic, and it could be improved through the implementation of nutritional supplementation and physical exercise programs [7]. Therefore, identifying modifiable risk factors is crucial to guide public health and prevent frailty. The associations between several modifiable risk factors related to lifestyle, such as physical activity (PA), sedentary behavior (SB), sleep, diet pattern, and frailty, have been well documented [8–11]. For example, Pond and colleagues reported that each minute of PA was associated with better frailty status in individuals with diabetes mellitus (DM) and highlighted the importance of replacing SB time with PA to improve frailty status [9]. Song et al. reported a strong negative association between more sedentary time and incident physical frailty [10]. Nakakubo et al. reported that sleeping 6 h or less, or 9 h or more, was associated with a greater likelihood of becoming frail [11]. However, most previous studies have focused on the separate effects of one movement behavior on frailty. From a holistic perspective, the joint effects of typical 24-hour (24-h) movement behaviors (PA, SB, and sleep) were comparatively ignored [12]. Recently, a growing body of evidence has supported the combined effects of these movement behaviors on health outcomes [13, 14]. Moreover, based on time-use epidemiology and empirical findings [15], in October 2020, the Canadian 24-hour (24-h) movement guidelines for adults aged 18–64 years were released [16]. The guidelines recommend that adults aged 18–64 years should engage in a minimum of 150 min of moderate to vigorous physical activity (MVPA) per week, limit SB time to no more than 8 h daily, and ensure 7–9 h of high-quality sleep per night. Importantly, the guidelines highlight the importance of movement behaviors throughout the whole day (24-hour period) for health outcomes because engagement in one behavior inevitably impacts the allocation of time to the other two behaviors [16, 17].

The launch of the 24-h movement guidelines has inspired relevant research interest. Recent studies have reported that adhering to the 24-h movement guidelines positively influences several health outcomes among children, adolescents, and adults. For example, an investigation from Canada revealed that, compared with adults who met 2 or fewer recommendations, those who met al.l 3 guidelines had better body mass index (BMI), waist circumference, aerobic fitness, and cardiometabolic values [18]. Another systematic review indicated that meeting 24-h movement guidelines was significantly associated with skeletal health, health-related quality of life, and psychosocial health [12, 19]. However, to the best of our knowledge, the relationship between 24-h movement guidelines and frailty among adults has not been examined.

Considering the evidence on the links between meeting 24-h movement guidelines and health indicators, the 24-h movement guidelines, as a comprehensive and modifiable strategy, may have great potential in preventing and relieving frailty. Information on how 24-h movement behaviors are potentially associated with frailty could be used to inform multicomponent interventions. In addition, previous research has reported differences in the prevalence of frailty and adherence to 24-h movement guidelines by age, gender, and ethnicity [4, 20]. Therefore, based on the National Health and Nutritional Examination Survey (NHANES), we aimed to investigate the associations of meeting 24-h movement guidelines with frailty in U.S. adults and to conduct secondary analyses by age, gender, and ethnicity.

Methods

This cross-sectional study was conducted and reported following the criteria outlined in the Strengthening the Reporting of Observational Studies in Epidemiology statement [21].

Study design and participants

The NHANES, a continuous nationwide survey initiated in 1999, is conducted biennially by the National Center for Health Statistics (NCHS) and the Centers for Disease Control and Prevention to investigate health-related behaviors, socioeconomic and nutritional status, and the physical examination results of the general public. The NHANES researchers employed a complex, stratified, multistage sampling design to secure a nationally representative sample of noninstitutionalized U.S. civilians. The NCHS Ethics Review Board approved all NHANES protocols, and all study participants provided written informed consent. The detailed description and datasets of the NHANES can be found at http://www.cdc.gov/nchs/nhanes/about_nhanes.htm. As NHANES data are free for public use and available online, consent from a medical ethics committee is not required [22].

In the present study, we extracted data from six survey cycles of the NHANES (2007–2008, 2009–2010,

2011–2012, 2013–2014, 2015–2016, and 2017–2018). Initially, 59,389 participants were enrolled in this study. Following the Canadian 24-Hour Movement Guidelines for Adults aged 18–64 years, individuals younger than 18 years or older than 64 years were excluded ($n = 31,322$). Participants without complete information on 24-h movement guidelines ($n = 110$), who had poor frailty index (FI) assessments ($n = 20,564$), or who lacked the necessary covariate information ($n = 1,667$) were also excluded from this analysis. The selection process for participants is shown in Fig. 1.

Measurement of meeting 24-h movement guidelines

The Canadian 24-hour movement guidelines for adults aged 18–64 years included MVPA, SB time, and sleep duration. Data on self-reported moderate to vigorous physical activity (MVPA) and sedentary behavior (SB) in the NHANES were obtained from the Global Physical Activity Questionnaire [23], which has been widely utilized globally, and its validity and reliability have been demonstrated across various populations [24]. The participants were asked how many days of MVPA (e.g., moderate working activities, recreational activities) they typically engaged in a week, and further asked the amount of time they spent performing MVPA (vigorous-intensity work activities, recreational activities) each day [25]. Individuals who accumulated ≥ 150 min/week of MVPA (1 min of vigorous PA equating to 2 min of moderate PA) were considered to meet the PA guidelines. SB is defined as activities that do not increase energy expenditure beyond rest (< 1.5 MET), such as watching television, working on a computer, lying and sitting during waking hours, and engaging in other forms of screen-based entertainment [26]. The SB time was calculated through self-reported data on the PAD 680: question "How much time do you usually spend sitting on a typical day?" (https://wwwn.cdc.gov/Nchs/Nhanes/2017-2018/P_PAQ.htm#PAD680). Sleep duration was self-reported by participants. The sleep duration data were derived from the SLD010H question: "How much sleep do you get (hours)?" (https://wwwn.cdc.gov/Nchs/Nhanes/2013-2014/SLQ_H.htm#SLD010H) from 2007 to 2014, and the
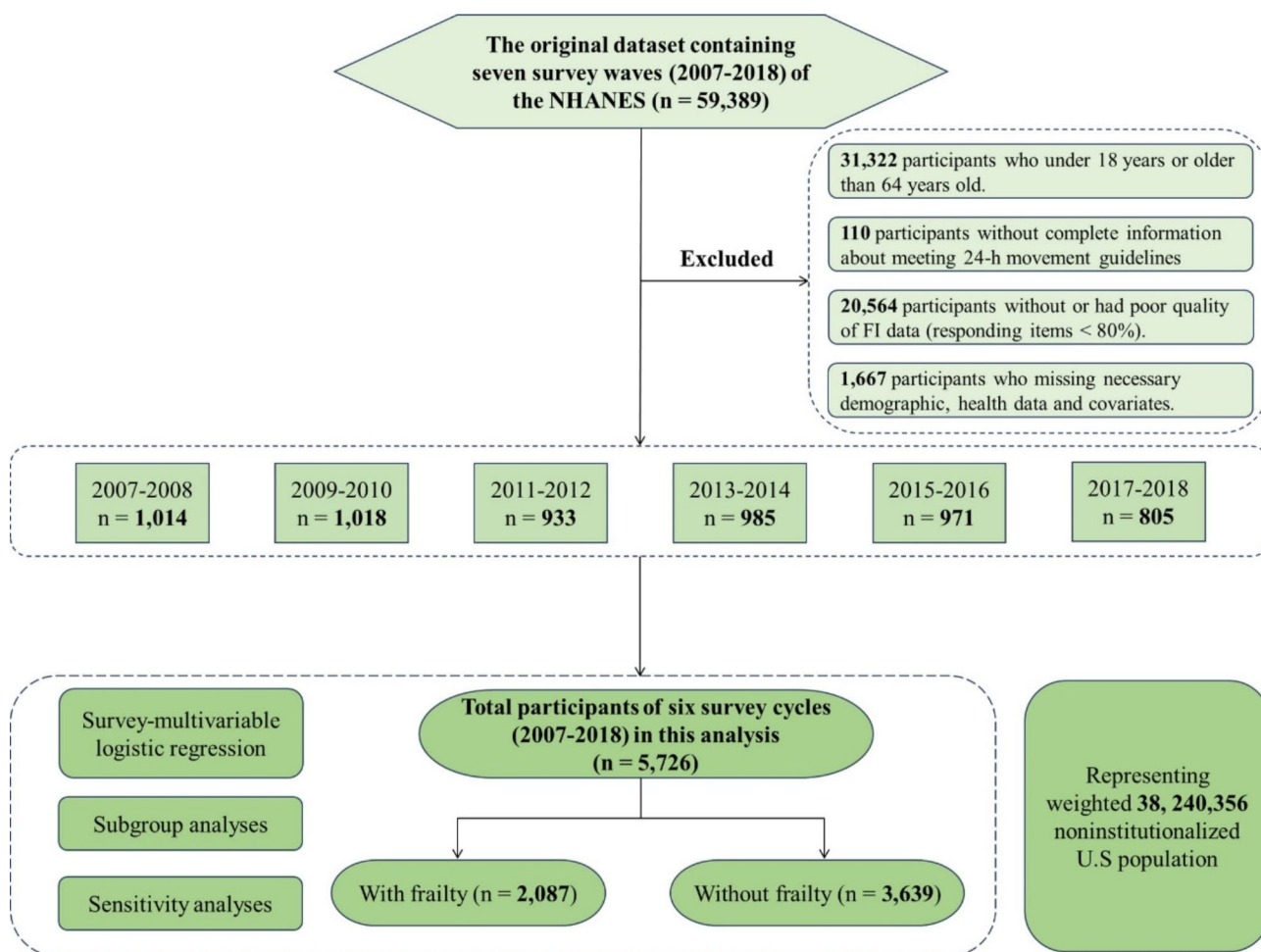

Fig. 1 Flowchart of selection of participants. Abbreviations: NHANES = national health and nutrition examination survey; FI = frailty index

SLD012 question: "How much sleep do you usually get at night on weekdays or workdays?" (https://wwwn.cdc.gov/Nchs/Nhanes/2017-2018/SLQ_J.htm#SLD012) from 2015 to 2018.

Ascertainment of frailty

Frailty was assessed using the FI developed by Hakeem et al., on the basis of the standard procedure introduced by Searle and colleagues [27, 28]. The FI includes 49 diagnostic items that cover cognition (1 item), dependence (15 items), depressive symptoms (7 items), comorbidities (13 items), hospital utilization and access to care (5 items), physical performance and anthropometry (2 items), and laboratory values (6 items). Each entry is evaluated according to adjudication criteria, which allot a score within a range of 0 (no defect present) to 1 (most severe defect). The FI is subsequently derived by dividing the cumulative score by the total number of items responded to. To ensure the quality of frailty diagnoses, individuals who responded to at least 80% of 49 items (approximately 40) were included in this analysis. It has been reported that if a sufficient number of items are responded to, they could be randomly selected and still yield similar results for the risk of poor outcomes [29]. The cut-off point of the FI was 0.21 [30], and participants with an FI greater than or equal to 0.21 were considered frail. The detailed scoring criteria are presented in Supplementary Table 1.

Assessment of covariates

The covariates included sociodemographic variables [(age, gender, ethnicity, education level, marital status, and the poverty income ratio (PIR)], lifestyle variables [(BMI, smoking status, alcohol consumption, Healthy Eating Index-2015 (HEI-2015), and total energy intake)], and health-related variables: hypertension, cardiovascular diseases (CVDs), and DM.

Age was divided into 3 groups: 18–39 years, 40–59 years, and 60–64 years. Ethnicity was classified into 4 categories: non-Hispanic White, non-Hispanic Black, Mexican American, and other races. Education levels were classified into 3 categories: less than high school, high school, and more than high school. The participants were classified according to their marital status, as widowed/divorced/separated, never married, or married/living with their partner. The PIR was categorized as < 1.3, 1.3–3.5, or > 3.5. BMI was categorized into 4 groups: underweight (< 18.5 kg/m^2), normal (18.5–25 kg/m^2), overweight (25–30 kg/m^2), and obese (≥ 30 kg/m^2). Both smoking and alcohol consumption status were categorized into 3 groups: never, former, and current. Total energy intake and HEI-2015 scores were obtained through 24-hour dietary interviews. The HEI-2015 is a comprehensive indicator for evaluating dietary quality,

with scores ranging from 0 to 100, with higher scores reflecting better diet quality. The diagnosis of hypertension was established based on the average of 3 consecutive tests, with a systolic pressure ≥ 140 mmHg and a diastolic pressure ≥ 90 mmHg. The presence of CVDs (coronary heart disease, myocardial infarction, stroke, or angina) was determined by participants receiving these diagnoses from a health professional before the survey. DM was defined as fasting plasma glucose ≥ 126 mg/dL, 2-h plasma glucose ≥ 200 mg/dL, hemoglobin A1c $\geq 6.5\%$, or self-reported diabetes diagnosed by a professional doctor.

Statistical analysis

We followed the analytical guidelines and survey weights recommended by the NHANES in this analysis [31]. To compare the characteristics between the frail and non-frail populations, we employed t-tests to compare continuous variables [presented as weighted mean ± standard error (SE)] and chi-squared tests for categorical variables (reported as counts and weighted percentages). Multivariable weighted logistic regression models were used to evaluate the adjusted odds ratios (AOR) and 95% confidence intervals (CI) for the associations of meeting 24-h movement guidelines (none, MVPA, SB, sleep, MVPA + SB, MVPA + sleep, and SB + sleep), the number of guidelines met (none, 1, 2, and 3) with frailty status ("yes" or "no"). We presented the results of these associations in the same table and conducted multivariable weighted logistic regressions separately for each association. The reference group for all comparisons is set as participants who did not adhere to any of the 24-h movement guidelines. A total of three models were constructed. The crude model was unadjusted. Model 1 was adjusted for age, gender, and ethnicity. Based on Model 1, we further adjusted for more demographic, lifestyle, and health-related variables (education level, marital status, the PIR, BMI, smoking status, alcohol consumption status, and total energy intake) into Model 2 to increase the accuracy of our results. Trend tests were performed to investigate the linear trends between the number of guidelines met and frailty. We also conducted analyses stratified by gender, age, and ethnicity, and the results are presented separately for each group. To ensure the robustness of our results, we conducted two sensitivity analyses: (1) additional adjustments accounting for the survey cycle, HEI-2015, CVDs, hypertension, and DM in Model 2, respectively; and (2) modification of the frailty diagnostic criteria to the threshold of 0.25 [32]. In addition, we investigated the associations of FI (continuous variable) with 24-h movement guidelines. All the statistical analyses were performed using R language (X64 Version 4.3.1, R Foundation for Statistical Computing).

A two-tailed *P*-value of < 0.05 was considered to indicate statistical significance across all analyses.

Results

Characteristics of the study participants

A total of 5,726 participants were included in this analysis from six survey waves ranging from 2007 to 2018, representing 38,240,356 noninstitutionalized U.S. individuals. The characteristics of the participants stratified by frailty status are summarized in Table 1. The weighted mean age of the sample was 50.25 ± 0.31 (mean $\pm$ SE) years, with 52.4% ($n = 2,956$) being females. The majority of participants were non-Hispanic White (71.4%, $n = 2,435$), followed by non-Hispanic Black (11.3%, $n = 1,382$), other races (11.3%, $n = 1,131$), and Mexican American (5.9%, $n = 252$). More than half of the participants (57.1%, $n = 2,785$) had more than a high school education, and approximately two-thirds of the participants were overweight (29.5%, $n = 1,701$) or obese (46.5%, $n = 2,719$). Approximately 60% of the sample ($n = 3,231$) were married or living with parents, whereas 45.8% ($n = 2,570$) and 73.5% ($n = 3,876$) of the respondents were never smokers and now drinking alcohol, respectively. The participants without frailty were likely to be male, non-Hispanic white, married/living with parents, have a higher education level, have a higher PIR, be nonsmokers, and have no chronic diseases (all *P* values < 0.05). The characteristics of the participants stratified by meeting the 24-h movement guidelines and the number of guidelines met are displayed in Supplementary Tables 2 and 3, and the characteristics of the participants stratified by age, sex, and ethnicity are presented in Supplementary Tables 4–6.

Prevalence of adherence to the 24-h movement guidelines

Overall, 386 (7.0%), 718 (9.2%), and 534 (10.2%) participants met only the MVPA guidelines, only the SB guidelines, and only the sleep guidelines, respectively. Approximately one-tenth of the participants (8.5%, $n = 524$) met none of the 3 movement guidelines, whereas a quarter of the participants (23.8%, $n = 1,272$) followed all 3 movement guidelines. Approximately 40% of the participants met 2 of the 3 guidelines ($n = 2,292$), whereas approximately one-fifth (17.3%, $n = 1,035$) met the MVPA + SB guidelines. The total age-adjusted prevalence of frailty was 30.5%. The participants who met 0, 1, 2, and all 3 of the 24-h movement guidelines, with the age-adjusted prevalence of frailty, were 47.9%, 41.0%, 26.5%, and 20.5%, respectively (Table 1).

Association of meeting individual guidelines with frailty

As shown in Fig. 2, compared with participants who did not meet any of the 3 guidelines, those who adhered to either the MVPA [crude model: (crude odds ratios) COR = 0.524, 95% CI: 0.368, 0.744; Model 1: AOR = 0.546, 95% CI: 0.382, 0.779] or sleep (crude model: COR = 0.683, 95% CI: 0.481, 0.970; Model 1: AOR = 0.673, 95% CI: 0.475, 0.953) guidelines presented a lower likelihood of frailty. In the fully adjusted model (Model 2), the AOR of frailty was 0.786 (95% CI: 0.545, 1.133), 1.161 (95% CI: 0.787, 1.711), and 0.915 (95% CI: 0.616, 1.358) for participants who met only MVPA, only SB, or only sleep guidelines, respectively (All *P* values > 0.05). Furthermore, the associations between meeting individual guidelines and frailty stratified by age, gender, and ethnicity were similar, and not found to be statistically significant after adjusting for relative covariates (Tables 2, 3 and 4).

Association of meeting specific guideline combinations with frailty

Compared with participants who met none of the guidelines, those who adhered to SB + sleep guidelines (Model 2: AOR = 0.613, 95% CI: 0.423, 0.887), MVPA + sleep guidelines (Model 2: AOR = 0.389, 95% CI: 0.255, 0.593), and MVPA + SB guidelines (Model 2: AOR = 0.555, 95% CI: 0.383, 0.806) had a significantly decreased risk of frailty (Fig. 2). The associations of meeting specific guideline combinations with frailty, stratified by age, gender, and ethnicity, and not adhering to any 24-h movement guidelines was set as the reference, are presented in Tables 2, 3 and 4. First, regarding age group differences, no significant associations were observed between adherence to MVPA + sleep (18–39 years), SB + sleep (18–39 years), MVPA + SB guidelines (40–64 years), and frailty (all *P*-value > 0.05). Second, in males, meeting the SB + sleep guidelines (Model 2: AOR = 0.803, 95% CI: 0.469, 1.374) was not significantly associated with frailty after controlling for the covariates. Finally, the associations between meeting specific guideline combinations and frailty were stronger among the non-Hispanic White population compared to non-Hispanic black, Mexican American, and other races.

Association of the number of guidelines met with frailty

When comparing frailty status between groups with different counts of 24-h movement guidelines met, participants who met all 3 guidelines (Model 2: AOR = 0.377, 95% CI: 0.264, 0.539; *P* value < 0.001) and those who met 2 guidelines (Model 2: AOR = 0.527, 95% CI: 0.377, 0.736; *P* value < 0.001) had a significantly lower likelihood of frailty (Fig. 2). The relationship between meeting only 1 guideline and a reduced risk of frailty was not statistically significant (Model 2: AOR = 1.076, 95% CI: 0.816, 1.407; *P* value > 0.05). The trend test revealed significant results in all age groups (Table 2; all *P* values for trend < 0.001), and this effect was more pronounced in individuals aged 18–39 years than in those in the other two age groups. As shown in Table 3, the number of guidelines met was significantly associated with a lower risk of frailty in

Table 1 Survey-weighted baseline characteristics of study participants stratified by frailty

	Prevalence of age-adjusted frailty [(weighted, % (SE)]	Estimate U.S population (n)	Total participants	Frailty		P-value[a]
				Yes	No	
Overall	30.5 (1.04)	38,240,356	5,726 (100%)	2,087 (31.4)	3,639 (68.6)	-
Age	-	-	50.25 ± 0.31	50.81 ± 0.31	49.99 ± 0.42	0.12
18–39	-	8,363,840	1,090 (21.9)	295 (16.0)	795 (24.6)	**< 0.001**
40–59	-	15,909,506	2,170 (41.6)	1,146 (60.7)	1,024 (32.9)	
60–64	-	13,967,010	2,466 (36.5)	646 (23.3)	1,820 (42.6)	
Gender						
Female	36.7 (1.37)	20,029,120	2,956 (52.4)	1,245 (62.0)	1,711 (48.0)	**< 0.001**
Male	24.0 (1.24)	18,211,236	2,770 (47.6)	842 (38.0)	1,928 (52.0)	
Race/ethnicity						
Non-Hispanic White	28.3 (1.42)	27,320,808	2,435 (71.4)	875 (65.1)	1,560 (74.4)	**< 0.001**
Non-Hispanic Black	42.7 (1.98)	43,26,130	1,382 (11.3)	585 (16.2)	797 (9.1)	
Mexican American	26.9 (2.02)	2,254,032	778 (5.9)	252 (5.7)	526 (6.0)	
Other Races	34.4 (2.08)	4,339,386	1,131 (11.3)	375 (13.0)	756 (10.6)	
Education level						
Less than high school	47.3 (4.30)	1,837,285	569 (4.8)	249 (7.4)	320 (3.6)	**< 0.001**
High school	36.0 (1.51)	14,577,396	2,372 (38.1)	990 (46.2)	1,382 (34.4)	
More than high school	25.4 (1.18)	21,825,675	2,785 (57.1)	848 (46.3)	1,937 (62.0)	
PIR	-	-	2.75 ± 0.05	1.99 ± 0.06	3.09 ± 0.06	**< 0.001**
<1.3	45.7 (1.37)	11,359,008	2,394 (29.7)	1,194 (46.6)	1,200 (22.0)	**< 0.001**
1.3–3.5	29.6 (1.42)	12,306,713	1,871 (32.2)	634 (33.0)	1,237 (31.8)	
>3.5	17.1 (1.78)	14,574,635	1,461 (38.1)	259 (20.4)	1,202 (46.2)	
BMI (kg/m²)	-	-	30.60 ± 0.16	33.13 ± 0.27	29.44 ± 0.17	**< 0.001**
Underweight (< 18.5)	26.6 (4.19)	720,798	99 (1.9)	39 (1.8)	60 (1.9)	**< 0.001**
Normal (18.5–25)	23.1 (1.68)	8,404,260	1,207 (22.0)	316 (15.4)	891 (25.0)	
Overweight (25–30)	26.8 (1.83)	11,281,329	1,701 (29.5)	509 (24.2)	1,192 (31.9)	
Obese (≥ 30)	37.1 (1.42)	17,833,970	2,719 (46.6)	1,223 (58.6)	1,496 (41.1)	
Marital status						
Married/Living with Partner	28.4 (1.44)	23,289,542	3,231 (60.9)	1,035 (54.4)	2,196 (63.9)	**< 0.001**
Never married	29.0 (2.04)	6,444,753	969 (16.9)	330 (14.7)	639 (17.9)	
Widowed/Divorced/Separated	45.3 (2.80)	8,506,060	1,526 (22.2)	722 (30.9)	804 (18.3)	
Smoking status						
Never	22.3 (1.04)	17,514,971	2,570 (45.8)	750 (33.3)	1,820 (51.5)	**< 0.001**
Former	31.3 (2.14)	10,122,100	1,464 (26.5)	533 (26.4)	931 (26.5)	
Current	41.8 (1.74)	10,603,285	1,692 (27.7)	804 (40.3)	888 (22.0)	
Alcohol consumption						
Never	27.5 (2.88)	3,910,625	746 (10.2)	237 (8.7)	509 (10.9)	**< 0.001**
Former	44.5 (2.62)	6,224,614	1,104 (16.3)	558 (25.1)	546 (12.3)	
Current	28.1 (1.08)	28,105,118	3,876 (73.5)	1,292 (66.3)	2,584 (76.8)	
Hypertension						
No	20.1 (1.05)	19,136,353	2,612 (50.0)	644 (32.4)	1,968 (58.1)	**< 0.001**
Yes	45.8 (1.76)	19,104,003	3,114 (50.0)	1,443 (67.6)	1,671 (41.9)	
DM						
No	24.7 (1.04)	27,392,181	3,780 (71.6)	1,098 (56.4)	2,682 (78.6)	**< 0.001**
Yes	50.4 (2.06)	10,848,175	1,946 (28.4)	957 (21.4)	989 (43.6)	
CVDs						
No	26.4 (0.99)	33,531,879	4,894 (87.7)	1,487 (73.9)	3,407 (94.0)	**< 0.001**
Yes	64.3 (2.97)	4,708,477	832 (12.3)	600 (26.1)	232 (6.0)	
SB time (Minutes/per day)	-	-	381.59 ± 4.11	394.56 ± 6.78	375.64 ± 4.88	**< 0.05**
Sleep time	-	-	7.06 ± 0.03	6.84 ± 0.06	7.17 ± 0.04	**< 0.001**
Total MVPA (Minutes/per week)	-	-	1,175.71 ± 41.54	1,036.45 ± 79.21	1,224.42 ± 47.40	**< 0.05**
Total energy intake (kcal)	-	-	2,147.56 ± 16.93	2,009.50 ± 26.90	2,210.82 ± 21.36	**< 0.001**

Table 1 (continued)

	Prevalence of age-adjusted frailty [(weighted, % (SE)]	Estimate U.S population (*n*)	Total participants	Frailty		P-value[a]
				Yes	**No**	
Meeting 24-h movement guidelines						
None	47.9 (3.46)	3,267,676	524 (8.5)	295 (13.4)	229 (6.3)	**< 0.001**
Meeting individual guidelines						
MVPA	33.2 (3.10)	2,690,772	386 (7.0)	150 (7.6)	236 (6.8)	
SB	50.8 (3.43)	3,509,966	718 (9.2)	398 (15.4)	320 (6.3)	
Sleep	37.2 (3.21)	3,912,983	534 (10.2)	234 (13.0)	300 (8.9)	
Meeting specific guideline combinations						
SB + Sleep	32.9 (2.55)	4,619,359	762 (12.1)	269 (12.8)	493 (11.7)	
MVPA + Sleep	28.5 (1.97)	6,606,322	495 (11.8)	99 (6.2)	396 (14.4)	
MVPA + SB	17.7 (2.10)	4,513,279	1,035 (17.3)	354 (16.5)	681 (17.6)	
Number of guidelines met						
0	47.9 (3.46)	3,267,676	524 (8.5)	295 (13.4)	229 (6.3)	**< 0.001**
1	41.0 (1.98)	10,113,722	1,638 (26.4)	782 (36.0)	856 (22.1)	
2	26.5 (1.31)	15,738,960	2,292 (41.2)	722 (35.5)	1,570 (43.8)	
3	20.5 (1.39)	9,119,998	1,272 (23.8)	288 (15.0)	984 (27.9)	
Year cycle						
2007–2008	31.9 (2.98)	5,737,947	1,014 (15.0)	375 (15.3)	639 (14.9)	0.5
2009–2010	30.0 (2.10)	5,626,439	1,018 (14.7)	377 (14.5)	641 (14.8)	
2011–2012	28.8 (2.93)	6,751,423	933 (17.7)	331 (15.9)	602 (18.5)	
2013–2014	33.3 (2.06)	6,907,893	985 (18.1)	380 (20.0)	605 (17.2)	
2015–2016	29.7 (2.26)	7,072,092	971 (18.5)	359 (19.1)	612 (18.2)	
2017–2018	29.4 (2.06)	6,144,562	805 (16.1)	265 (15.3)	540 (16.4)	

Continuous variables are presented as weighted mean ± SE, and categorical variables are presented as n (weighted %)

[a]*P*-values were assessed by T-test (continuous variables) or by Chi-square test (categorical variables). *P*-values shown in bold were statistically significant.

Abbreviations: BMI = body mass index; CVDs = cardiovascular diseases; DM = diabetes mellitus; MVPA = moderate-to-vigorous physical activity; PIR = poverty income ratio; SB = sedentary behavior; SE = standard error
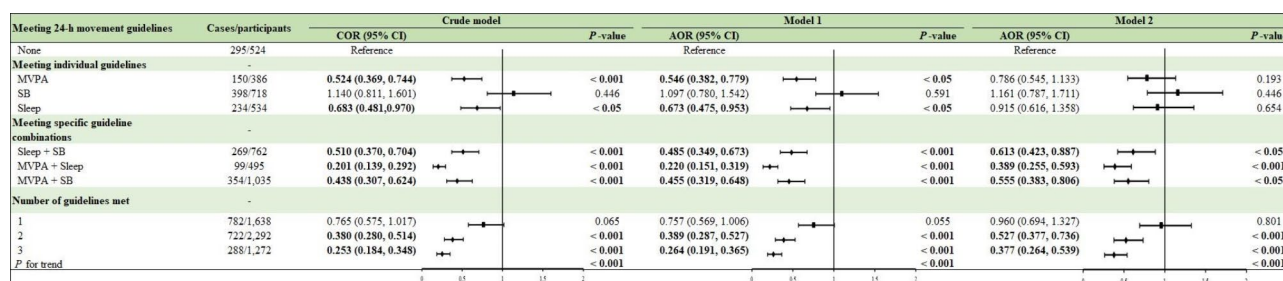
Meeting 24-h movement guidelines	Cases/participants	Crude model		Model 1		Model 2	
		COR (95% CI)	P-value	AOR (95% CI)	P-value	AOR (95% CI)	P-value
None	295/524	Reference		Reference		Reference	
Meeting individual guidelines	-						
MVPA	150/386	**0.524 (0.369, 0.744)**	**< 0.001**	**0.546 (0.382, 0.779)**	**< 0.05**	0.786 (0.545, 1.133)	0.193
SB	398/718	1.140 (0.811, 1.601)	0.446	1.097 (0.780, 1.542)	0.591	1.161 (0.787, 1.711)	0.446
Sleep	234/534	**0.683 (0.481,0.970)**	**< 0.05**	**0.673 (0.475, 0.953)**	**< 0.05**	0.915 (0.616, 1.358)	0.654
Meeting specific guideline combinations	-						
Sleep + SB	269/762	**0.510 (0.370, 0.704)**	**< 0.001**	**0.485 (0.349, 0.673)**	**< 0.001**	**0.613 (0.423, 0.887)**	**< 0.05**
MVPA + Sleep	99/495	**0.201 (0.139, 0.292)**	**< 0.001**	**0.220 (0.151, 0.319)**	**< 0.001**	**0.389 (0.255, 0.593)**	**< 0.001**
MVPA + SB	354/1,035	**0.438 (0.307, 0.624)**	**< 0.001**	**0.455 (0.319, 0.648)**	**< 0.001**	**0.555 (0.383, 0.806)**	**< 0.05**
Number of guidelines met	-						
1	782/1,638	0.765 (0.575, 1.017)	0.065	0.757 (0.569, 1.006)	0.055	0.960 (0.694, 1.327)	0.801
2	722/2,292	**0.380 (0.280, 0.514)**	**< 0.001**	**0.389 (0.287, 0.527)**	**< 0.001**	**0.527 (0.377, 0.736)**	**< 0.001**
3	288/1,272	**0.253 (0.184, 0.348)**	**< 0.001**	**0.264 (0.191, 0.365)**	**< 0.001**	**0.377 (0.264, 0.539)**	**< 0.001**
P for trend			**< 0.001**		**< 0.001**		**< 0.001**

Fig. 2 Associations of meeting 24-h movement guidelines with frailty. The results of COR (95% CI), AOR (95% CI), and *P*-value shown in bold were statistically significant. Model 1 was adjusted for age, gender, race/ethnicity. Model 2 was additionally adjusted for education level, marital status, PIR, BMI, smoking, alcohol consumption and total energy intake. AOR = adjusted odds ratio; BMI = body mass index; CI = confidence interval; COR = crude odds ratio; MVPA = moderate-to-vigorous physical activity; PIR = poverty income ratio; SB = sedentary behavior

both men and women. In addition, when this association was stratified by ethnicity, a significant inverse relationship between the number of guidelines met and the risk of frailty was also observed, except for in Mexican Americans (Model 2: AOR = 0.421, 95% CI: 0.175, 1.013) (Table 4).

Sensitivity analyses

To ensure the robustness of our findings, sensitivity analyses were conducted. First, we additionally adjusted for the survey cycle, the HEI-2015 scores, CVDs, hypertension, and DM in Model 2, respectively (Supplementary Table 7), and further modified the diagnostic criteria of frailty from 0.21 to 0.25 (Fig. 2). The results of these supplementary analyses were generally in line with the primary analysis to support the strength and reliability of

Table 2 Associations of meeting 24-h movement guidelines with frailty stratified by age

Meeting 24-h movement guidelines	Age 18–39 years (n = 1,090)			Age 40–59 years (n = 2,170)			Age 60–64 years (n = 2,466)		
	Cases/participants	AOR (95% CI)	P-value	Cases/participants	AOR (95% CI)	P-value	Cases/participants	AOR (95% CI)	P-value
None	44/88	Reference		150/228	Reference		101/208	Reference	
Meeting individual guidelines									
MVPA	28/94	0.681 (0.290, 1.598)	0.371	84/153	0.836 (0.471,1.483)	0.535	38/139	0.679 (0.334,1.379)	0.279
SB	51/98	1.190 (0.520, 2.721)	0.677	227/319	1.114 (0.660,1.880)	0.681	120/301	1.049 (0.619,1.779)	0.857
Sleep	18/65	0.605 (0.274, 1.334)	0.209	125/217	0.874 (0.503,1.519)	0.629	91/252	1.095 (0.569,2.107)	0.784
Meeting specific guideline combinations									
Sleep + SB	18/87	**0.400 (0.166, 0.965)**	**<0.05**	165/281	0.910 (0.495,1.674)	0.76	86/394	**0.467 (0.257,0.850)**	**<0.05**
MVPA + Sleep	19/116	0.495 (0.201, 1.224)	0.126	53/166	**0.393 (0.219,0.705)**	**<0.05**	27/213	**0.268 (0.123,0.587)**	**<0.05**
MVPA + SB	68/253	**0.398 (0.182, 0.872)**	**<0.05**	186/388	**0.518 (0.305,0.879)**	**<0.05**	100/394	0.808 (0.431,1.513)	0.499
Number of guidelines met									
1	97/257	0.811 (0.407, 1.615)	0.546	463/689	0.945 (0.603,1.481)	0.802	249/692	0.983 (0.582,1.659)	0.948
2	105/456	**0.421 (0.201, 0.879)**	**<0.05**	404/835	**0.573 (0.347,0.947)**	**<0.05**	213/1,001	**0.523 (0.309,0.885)**	**<0.05**
3	49/289	**0.282 (0.140, 0.570)**	**<0.001**	156/418	**0.413 (0.237,0.722)**	**<0.05**	83/565	**0.432 (0.233,0.801)**	**<0.05**
P for trend			**<0.001**			**<0.001**			**<0.001**

The results of AOR (95% CI), and *P*-value shown in bold were statistically significant. The multivariable model was adjusted for gender, race/ethnicity, education level, marital status, PIR, BMI, smoking, alcohol consumption and total energy intake. Abbreviations: AOR = adjusted odds ratio; BMI = body mass index; CI = confidence interval; MVPA = moderate-to-vigorous physical activity; PIR = poverty income ratio; SB = sedentary behavior

the observed associations (Supplementary Fig. 1). Specifically, when the diagnostic threshold value of frailty was 0.25, a statistically significant association was observed between only meeting MVPA guidelines and a lower risk of frailty, and the AOR of frailty was much lower (Model 2: AOR = 0.279, 95%CI: 0.187, 0.416) for participants who met all 3 guidelines than for those who met none of the 3 guidelines. We also examined the associations of the frailty index (continuous variable) with 24-h movement guidelines, which is consistent with our main results. In addition, when the FI was the outcome, significant relationships between only met the MVPA guideline (Model 2: β= -0.031, 95% CI: -0.049, -0.014), only met sleep guideline (Model 2: β= -0.029, 95% CI: -0.045, -0.013), and FI were detected (Supplementary Table 8).

Discussion

Main findings

The main findings of this study can be condensed into the following points: (1) adherence to any of the MVPA, SB, or sleep guidelines alone was not significantly associated with a reduced risk of frailty; (2) meeting 2 guidelines was significantly associated with a lower likelihood of frailty, and there were differences in the associations according to age, gender and ethnicity. Notably, meeting the MVPA and sleep guidelines in combination had the strongest negative association with frailty; and (3) compared with participants who did not meet any guidelines, individuals who met all three 24-h movement guidelines had a significantly lower risk of frailty. Specifically, as the number of 24-h movement guidelines met increased, the risk for frailty decreased. However, among Mexican Americans, there was no statistically significant difference between meeting all 3 guidelines and frailty risk. After sensitivity analyses were performed, our results remained stable. Our study broadens the knowledge regarding the importance of 24-h movement behaviors on frailty among general adults.

Comparison with prior studies

The present study revealed that meeting only one of three guidelines was not significantly associated with a lower AOR of frailty. When the diagnostic threshold value of frailty was adjusted to 0.25, we observed a reduction in frailty risk for individuals who met only the MVPA guidelines, which corroborates the consensus to adhere to the World Health Organization recommendation of 150 min of MVPA per week for the prevention of non-communicable diseases [33]. A systematic review and meta-analysis that included 10 cohort studies showed that a higher level of PA was associated with decreased risks of frailty, and even stratified by PA measurement tools, produced a similar protective effect [34]. However, the relationships of adherence solely to SB guidelines or sleep

guidelines with the risk of frailty were not fully consistent with previous related works. A study using NHANES data revealed that frail individuals were highly sedentary and that SB was associated with frailty in middle-aged to older adults [35]. A Mendelian randomization study demonstrated that SB (especially watching television) inversely affected frailty, suggesting potential biological heterogeneity behind specific sedentary activities [36]. Thus, the different types of sedentary activities may influence this association between SB guidelines and frailty, which might partly result in mixed results. A study from Mexico showed that, over a 4.4-year follow-up period, individuals who slept ≤ 5 h or ≥ 9 h presented a significantly increased risk of frailty [37]. Salinas-Rodríguez et al. reported that individuals with a moderate/poor stable sleep trajectory had greater odds of frailty than those with a very-good increasing trajectory [38]. Therefore, sleep quality may largely contribute to the inconsistent results of the association between only meeting sleep guidelines and frailty. Overall, meeting only one of the 24-h movement guidelines, while ignoring the other two, had limited impacts on frailty.

Regarding specific guideline combinations and frailty, our results showed a negative association between meeting any two of three guidelines and frailty. However, the associations varied by age, gender, and ethnicity to some extent. For meeting the MVPA + SB guidelines, we found that adhering to the combined guidelines for MVPA and SB was associated with a reduced risk of frailty, which is generally consistent with the existing evidence [39–41]. However, this significant association was not apparent in individuals aged 60 to 64 years. Research has shown that frailty is an extreme consequence of the normal aging process [4]. Thus, according to the geroscience hypothesis, this difference may be partly explained by the aging process decreasing the thresholds necessary for disease-specific insults to result in overt pathology [42]. For meeting SB + sleep guidelines in combination, our results revealed that adhering to the combined guidelines for SB + sleep was significantly correlated with a lower risk of frailty. A Mendelian randomization study suggested that genetic predispositions towards increased television viewing and diurnal napping were positively correlated with the FI, whereas sleep duration was inversely associated with the FI [43]. Compared with males, females generally have more SB time and experience greater sleeping disturbances [44, 45]. Therefore, the potential benefits of adhering to the combined guidelines for SB + sleep in mitigating frailty may be more sensitive for females [46]. The origin of the sex differences in this association needs to be further investigated in future studies. Notably, we observed the strongest relationship between adhering to the combined guidelines for MVPA + sleep and frailty. Based on the current evidence [47], one possible

Table 3 Associations of meeting 24-h movement guidelines with frailty stratified by gender

Meeting 24-h movement guidelines	Cases/participants	Female (n=2,956)				Cases/participants	Male (n=2,770)			
		Crude model		Adjusted Model			Crude model		Adjusted Model	
		COR (95% CI)	P-value	AOR (95% CI)	P-value		COR (95% CI)	P-value	AOR (95% CI)	P-value
None	169/279	Reference		Reference		126/245	Reference		Reference	
Meeting individual guidelines	-					-				
MVPA	94/181	0.702 (0.418, 1.180)	0.179	0.981 (0.547, 1.758)	0.947	56/205	**0.411 (0.246, 0.687)**	**<0.001**	0.614 (0.358, 1.054)	0.076
SB	251/427	1.037 (0.664, 1.619)	0.871	1.048 (0.629, 1.746)	0.856	147/291	1.246 (0.782, 1.985)	0.351	1.314 (0.781, 2.211)	0.3
Sleep	152/326	0.597 (0.369, 0.968)	0.037	0.877 (0.507, 1.517)	0.635	82/208	0.759 (0.443, 1.301)	0.312	0.948 (0.569, 1.581)	0.837
Meeting specific guideline combinations	-					-				
Sleep+SB	170/459	**0.397 (0.262, 0.602)**	**<0.001**	**0.520 (0.328, 0.823)**	**<0.05**	99/303	0.685 (0.421, 1.114)	0.125	0.803 (0.469, 1.374)	0.418
MVPA+Sleep	55/234	**0.183 (0.107, 0.312)**	**<0.001**	**0.342 (0.198, 0.592)**	**<0.001**	44/261	**0.243 (0.148, 0.398)**	**<0.001**	**0.450 (0.259, 0.781)**	**<0.05**
MVPA+SB	193/459	**0.458 (0.297, 0.706)**	**<0.001**	**0.529 (0.322, 0.867)**	**<0.05**	161/576	**0.448 (0.283, 0.710)**	**<0.001**	**0.581 (0.363, 0.930)**	**<0.05**
Number of guidelines met	-					-				
1	497/934	0.755 (0.510, 1.119)	0.159	0.954 (0.605, 1.506)	0.839	285/704	0.755 (0.507, 1.126)	0.166	0.950 (0.622, 1.452)	0.812
2	418/1,152	**0.355 (0.244, 0.515)**	**<0.001**	**0.477 (0.315, 0.724)**	**<0.001**	304/1,140	**0.421 (0.284, 0.624)**	**<0.001**	**0.594 (0.386, 0.914)**	**<0.05**
3	161/591	**0.224 (0.141, 0.357)**	**<0.001**	**0.345 (0.211, 0.564)**	**<0.001**	127/681	**0.305 (0.196, 0.473)**	**<0.001**	**0.418 (0.245, 0.713)**	**<0.05**
P for trend			**<0.001**		**<0.001**			**<0.001**		**<0.001**

The results of COR (95% CI), AOR (95% CI), and *P*-value shown in bold were statistically significant. Adjusted Model was adjusted for age and race/ethnicity, education level, marital status, PIR, BMI, smoking, alcohol consumption and total energy intake. Abbreviations: AOR=adjusted odds ratio; BMI=body mass index; CI=confidence interval; MVPA=moderate-to-vigorous physical activity; PIR=poverty income ratio; SB=sedentary behavior

explanation for this association is the bidirectional relationship between sleep and PA. A study that examined cross-lagged time series of sleep and PA over 14 days and nights found that better sleep quality can lead to more PA the next day [48], and physical activity is recognized to maintain or improve the function of many physiological systems, including muscle and cardiac function, cognition, endocrine system, and inflammation, thereby improving frailty status [49]. Additionally, the ethnicity disparity in relationships may be partly explained by the imbalance in the number of people included in this study among the various ethnic groups.

Previous studies have demonstrated the close relationship between frailty and chronic diseases, such as CVDs, chronic kidney diseases, and chronic obstructive pulmonary diseases [50–52]. Moreover, the coexistence of frailty and multimorbidity is often observed [53]. The present study suggested that adherence to 24-hour movement guidelines is associated with lower odds of frailty, which is in line with previous related studies. As depicted in the systematic reviews, children who met the 24-h movement guidelines demonstrated better health-related quality, better cognition, and greater aerobic fitness [12]. Kastelic et al. reported that the likelihood of better self-rated health increased with the number of guidelines met among adults [54]. Furthermore, prior research revealed that adherence to all three 24-h movement guidelines was significantly associated with physical (muscle, adiposity), mental (depression, cognitive performance), and metabolic health [55–59], which are closely related to the content of the FI. Therefore, it is not surprising that the number of 24-h movement guidelines met is associated with a lower risk of frailty in adults.

Implications
This study has important implications for public health and practice. First, our findings revealed a significant association between 24-h movement guidelines and frailty. This result highlights the importance of improving adults' daily movement behaviors (MVPA, SB, and sleep) in frailty prevention. Second, secondary analyses suggest that there may be optimal combinations of 24-h movement guidelines for preventing frailty among the different sociodemographic groups. Moreover, adherence to the counts of guidelines was inversely associated with the prevalence of frailty. This means that in cases where the 24-h movement guidelines cannot be fully adhered to, individuals may strategically follow specific combinations of 24-h movement guidelines, thereby gaining relatively substantial health benefits. Third, these findings provide valuable insights for policy-makers in the development of frailty prevention strategies, and health professionals may advise that improving lifestyles may help frailty prevention. Finally, further high-quality studies are needed

to validate the gender, age, and ethnicity differences in the associations of 24-h movement guidelines with frailty, and to identify optimal combinations of these guidelines to efficiently manage frailty risk when people cannot fully adhere to the 24-h movement guidelines in daily lives.

Strengths and limitations
To the best of our knowledge, this is the first study to examine the relationship between meeting the 24-h movement guidelines and frailty. We also explored the age, gender, and ethnicity disparities in this relationship. This work addresses the evidence gaps and provides basic lifestyle recommendations for protecting against frailty in adults. Additional strengths include the nationally representative sample, and the adjustment for several potential confounders, such as CVDs, diet quality, hypertension, and DM, which allowed our findings to be generalizable at the population level. However, some limitations should be noted. First, because of the cross-sectional design, we cannot determine the causal relationship between meeting 24-h movement guidelines and a lower risk of frailty. Second, the data of all three 24-h movement behaviors were collected with self-reported items. Although these measures have been well validated in previous investigations, the findings of our study may have been affected by recall errors and social desirability bias. Future studies are warranted to validate these findings using objectively measured data. Third, the sample sizes in the secondary analyses of the associations between meeting 24-h movement guidelines and frailty were relatively small. Further studies are needed to validate the observed associations with larger sample sizes. Finally, despite our best efforts to select potential confounders, our analysis may still be affected by unmeasured or insufficiently measured confounders.

Conclusions
In summary, our study indicated that the number of guidelines met was significantly associated with a lower risk of frailty. Following any combination of two guidelines may have benefits in reducing the risk of frailty. However, there may be differences in this association according to age, gender, and ethnicity. For a single guideline, meeting the MVPA guideline has a stronger positive association with frailty than the other two guidelines. Future research is warranted to examine the causality of these associations, and to employ a longitudinal study design to investigate the trajectories of how meeting the 24-h movement guidelines affects frailty progression.

Table 4 Associations of meeting 24-h movement guidelines with frailty stratified by race

Meeting 24-h movement guidelines	Non-Hispanic White (n=2,435)			Non-Hispanic Black (n=1,382)			Mexican American (n=778)			Other Races (n=1,131)		
	Cases/participants	AOR (95% CI)	P-value	Cases/participants	AOR (95% CI)	P-value	Cases/participants	AOR (95% CI)	P-value	Cases/participants	AOR (95% CI)	P-value
None	145/242	Reference	-	83/149	Reference	-	20/40	Reference	-	47/93	Reference	-
Meeting individual guidelines												
MVPA	62/172	0.773 (0.471, 1.270)	0.305	56/126	0.710 (0.372, 1.355)	0.293	30/Jul	0.483 (0.131, 1.784)	0.265	20/58	1.450 (0.561, 3.752)	0.438
SB	153/242	1.141 (0.627, 2.074)	0.662	109/208	1.161 (0.697, 1.935)	0.559	65/124	1.364 (0.505, 3.680)	0.529	71/144	1.238 (0.642, 2.384)	0.519
Sleep	105/257	0.816 (0.476, 1.397)	0.453	68/131	0.989 (0.566, 1.729)	0.97	26/58	1.066 (0.404, 2.814)	0.894	35/88	1.585 (0.583, 4.312)	0.362
Meeting specific guideline combinations												
Sleep + SB	90/271	**0.567 (0.326, 0.985)**	**<0.05**	74/167	0.704 (0.422, 1.177)	0.177	45/154	0.490 (0.210, 1.145)	0.097	60/170	1.052 (0.501, 2.209)	0.891
MVPA + Sleep	55/281	**0.392 (0.227, 0.676)**	**<0.05**	23/87	**0.442 (0.234, 0.834)**	**<0.05**	May-37	0.470 (0.204, 1.082)	0.074	16/90	0.453 (0.178, 1.151)	0.095
MVPA + SB	140/416	**0.509 (0.297, 0.873)**	**<0.05**	104/282	0.671 (0.413, 1.090)	0.105	40/131	**0.176 (0.045, 0.695)**	**<0.05**	70/206	0.712 (0.353, 1.433)	0.336
Number of guidelines met												
1	325/671	0.895 (0.570, 1.404)	0.624	233/465	0.957 (0.596, 1.535)	0.852	98/212	1.063 (0.433, 2.608)	0.891	126/290	1.379 (0.719, 2.645)	0.328
2	285/968	**0.489 (0.304, 0.787)**	**<0.05**	201/536	**0.639 (0.414, 0.986)**	**<0.05**	90/322	**0.417 (0.191, 0.909)**	**<0.05**	146/466	0.767 (0.406, 1.449)	0.408
3	120/554	**0.404 (0.248, 0.659)**	**<0.001**	68/232	**0.379 (0.220, 0.651)**	**<0.001**	40/204	0.421 (0.175, 1.013)	0.053	56/282	**0.270 (0.130, 0.563)**	**<0.001**
P for trend			**<0.001**			**<0.001**			**<0.001**			**<0.001**

The results of AOR (95% CI), and P-value shown in bold were statistically significant. The multivariable model was adjusted for age, gender, education level, marital status, PIR, BMI, smoking, alcohol consumption and total energy intake. Abbreviations: AOR, Adjusted odds ratio; BMI, Body mass index; CI, Confidence interval; MVPA, Moderate-to-vigorous physical activity; PIR, Poverty income ratio; SB, Sedentary behavior

Abbreviations

AOR	Adjusted odds ratios
BMI	Body mass index
CI	Confidence intervals
CVDs	Cardiovascular diseases
COR	Crude odds ratio
DM	Diabetes mellitus
FI	Frailty index
HEI-2015	Healthy eating index-2015
MVPA	Moderate to vigorous physical activity
NCHS	National Center for Health Statistics
NHANES	National Health and Nutritional Examination Survey
PA	Physical activity
PIR	Poverty income ratio
SB	Sedentary behavior
SE	Standard error
24-h	24-hour

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12966-025-01722-x .

> **Supplementary Material 1**: **Supplementary Fig. 1** Associations of meeting 24-h movement guidelines with frailty (the cut of point = 0.25). **Supplementary Table 1** Variables in the 49-item frailty index and their respective scorings. **Supplementary Table 2** Baseline characteristics of study participants stratified by meeting 24-h movement guidelines. **Supplementary Table 3** Baseline characteristics of study participants stratified by the number of guidelines met. **Supplementary Table 4** Baseline characteristics of study participants stratified by age. **Supplementary Table 5** Baseline characteristics of study participants stratified by gender. **Supplementary Table 6** Baseline characteristics of study participants stratified by race/ethnicity. **Supplementary Table 7** Associations of meeting 24-h movement guidelines with frailty index (continuous variable). **Supplementary Table 8** Further adjustments in sensitivity analyses for associations of meeting 24-h movement guidelines with frailty
>
> **Supplementary Material 2**: STROBE checklist
>
> **Supplementary Material 3**: Graphical abstract

Data availability

The data could be collected from openly available resources at https://www.cdc.gov/nchs/nhanes/index.htm.

Declarations

Ethical approval and consent to participate

The NHANES protocols were approved by the National Center for Health Statistics Ethics Review Board (Protocol# 2005–06, Protocol #2011-17, and Protocol #2018-01) and all participants provided written informed consent.

Consent for publication

Not applicable.

Competing interests

All authors claimed no conflicts of interest.

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