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Objectively measured sedentary behavior and moderate-to-vigorous physical activity on the health-related quality of life in US adults: The National Health and Nutrition Examination Survey 2003–2006

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Abstract

Background Health-related quality of life (HRQOL) represents an individual's perception of physical, mental, and social well-being and is a strong predictor of health status. Few studies have examined associations of sedentary behavior (SB) and moderate-to-vigorous physical activity (MVPA) with HRQOL in the general population.

Purpose This study aimed to determine combined associations of objectively measured SB and MVPA on the risk of poor HRQOL in the general US population, after controlling for potential confounding factors.

Methods We analyzed data from 5359 adults from the National Health and Nutrition Examination Survey 2003–2006. HRQOL was measured using a HRQOL-4 consisting of four questions focused on the self-perception of general health, physical health, mental health, and activity limitation. We dichotomized each HRQOL-4 component as good versus poor and defined poor overall HRQOL when participants had any poor HRQOL components. SB and MVPA were measured using an accelerometer. Survey logistic models were examined to estimate the odds ratio (OR) and 95% confidence interval (CI) for poor HRQOL by SB and MVPA as tertiles.

Results When examined as a combination of SB and MVPA, a substantial decrease in the risk of poor overall HRQOL was found in individuals with low SB/high MVPA [OR 0.69 (95% CI 0.51–0.94) and moderate SB/high MVPA (OR 0.56 (95% CI 0.40–0.78)], but no significant decrease was found in individuals with high SB/high MVPA (vs. high SB/low MVPA).

Conclusion Our findings suggest that both increasing MVPA and reducing time spent in SB may be useful strategies to improve HRQOL.

Keywords Sedentary behavior · Physical activity · Health-related quality of life · NHANES

Abbreviations

BMI	Body mass index
CDC	Centers for Disease Control and Prevention
CI	Confidence interval
HRQOL	Health-related quality of life
MEC	Mobile examination center
METs	Metabolic equivalents
MVPA	Moderate-to-vigorous physical activity
NCHS	National Center for Health Statistics
NHANES	National Health and Nutrition Examination Survey
OR	Odds ratio
SB	Sedentary behavior

Introduction

Health-related quality of life (HRQOL) encompasses a holistic examination of well-being in which health is considered to be "a state of complete physical, mental, and social well-being, and not merely the absence of disease or

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infirmity" [1, 2]. HRQOL is considered the individual's perception of comprehensive general health status including physical, mental, and social function [2]. Over the last decades, it has been seen that levels of HRQOL deteriorate in an aging population [3]. For planning strategies in public health interventions to improve healthy life expectancy, therefore, it is important to understand the risk factors associated with poor HRQOL. Indeed, self-perceived health status made evident in HRQOL proved to be a more powerful predictor of hospitalization and mortality than other objective measures of health [4, 5]. Recent public health policies in the USA have emphasized measures of HRQOL to supplement traditional measures of morbidity and mortality in order to define national health standards [2, 6]. Furthermore, promoting healthy development and healthy behaviors to improve quality of life across all life states is one of the overarching goals of Healthy People 2020 [6].

There is growing evidence that sedentary behavior (SB: any waking activity in a sitting or reclining posture) [7] in combination with lack of moderate-to-vigorous physical activity (MVPA) may have a harmful effect on various health outcomes including obesity, metabolic syndrome, diabetes, cardiovascular disease, and mortality [8–10]. Because individuals who spend more time in SB tend to devote less time to MVPA, it may be important to deal not only with the single effect of either SB or MVPA but also with the balance of SB and MVPA. Those few studies that have examined both SB and MVPA associated with HRQOL have used measures based on self-reported SB (i.e., time spent in SB or watching TV) and MVPA (i.e., time spent in MVPA), and they have produced inconsistent results [11, 12].

We therefore investigated associations of objectively measured SB and MVPA (using accelerometer records) with the risk of poor HRQOL, using the Centers for Disease Control and Prevention (CDC) HRQOL-4 (general, physical, mental health, and activity limitation) after controlling for important confounding factors in a well-defined general adult population of the National Health and Nutrition Examination Survey (NHANES) 2003–2006. We also investigated combined effects of SB and MVPA in order to evaluate whether prolonged time spent in SB weakens the protective effect of MVPA on poor HRQOL.

Methods

Study participants

The NHANES is an ongoing series of cross-sectional surveys, conducted by the National Center for Health Statistics (NCHS), designed to obtain representative data on the nutrition and health status of the civilian non-institutionalized US population. Data were collected through an initial extensive household interview with a subsequent physical examination and medical history interviews at a mobile examination center (MEC) [13].

For the present study, we used data on adults (aged 20 years or older) from NHANES 2003–2004 and 2005–2006 cycles, in which physical activity was objectively measured using an accelerometer ($n = 8056$). Between 2003 and 2006, monitoring of physical activity was conducted for all available participants aged 6 years or older during the seven consecutive days after a household interview. We excluded 1964 participants (24.4%) who had an invalid record in the accelerometer examination as described below [14, 15]. We additionally excluded subjects who had missing data on HRQOL ($n = 370$), health conditions such as diabetes, heart disease, stroke, cancer, asthma, or osteoporosis/arthritis ($n = 66$), and other covariates ($n = 297$). Therefore, data from 5359 participants were available for data analyses (Fig. 1). The NHANES study was approved by the Institutional Review Board of the NCHS, and all participants provided written informed consent.

Accelerometer measures of SB and MVPA

SB and MVPA for each participant were objectively measured using a uniaxial accelerometer (ActiGraph, LLC, Fort Walton Beach, FL, USA). Participants were instructed to wear an accelerometer in an elastic waist belt on the right hip for seven consecutive days during all waking hours (from the time they woke up in the morning until they went to bed at night, except during water-based activities). All acceleration data were recorded as the sum of counts within 1-min epochs. At least 1 min of continuous zero count was defined as non-wear time, and wear time was calculated by subtracting non-wear time (only if non-wear time was continued over 60 consecutive minutes) [14, 16]. A record was considered invalid if it lacked at least 10-h wear time per day for 4 days [15, 17].

We calculated the time spent in SB and MVPA as the mean value per valid day computed from accelerometer records [18]. SB was defined using a threshold of <100 counts/min, and MVPA was defined using a threshold of ≥ 2020 counts/min [16, 17]. Details of the procedure used in this study have been described in the NHANES physical activity monitor protocol [18].

HRQOL

HRQOL was measured using a HRQOL-4 suggested by the CDC. The CDC HRQOL-4 measures consist of four questions focused on the self-perception of general health, physical health, mental health, and limitations on activity [19]. Participants were asked to rate their general health by

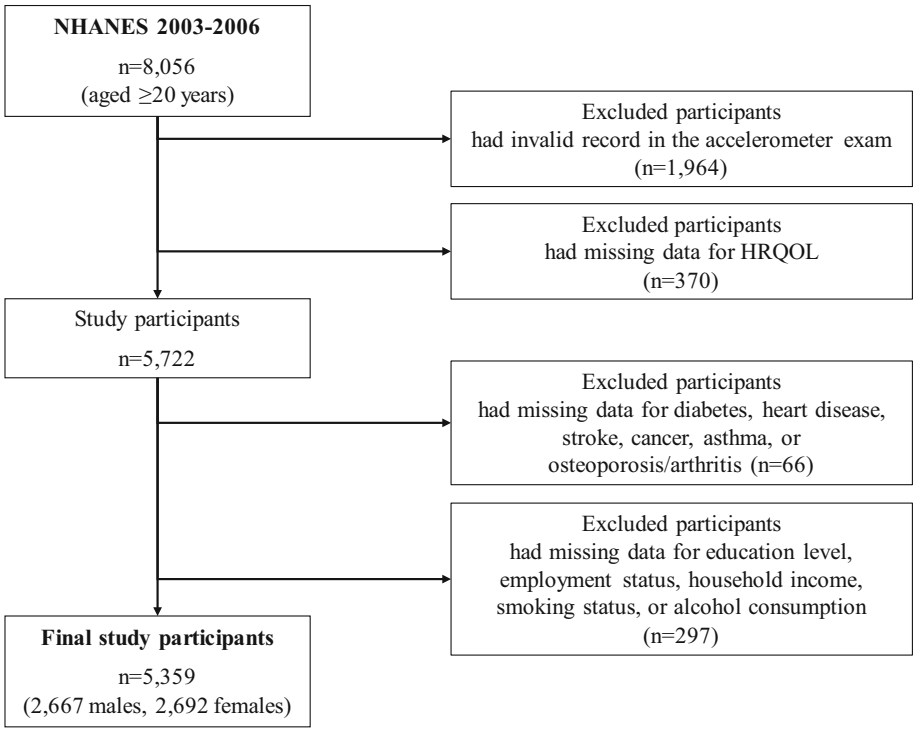

Fig. 1 Flow of study participants

the question "Would you say that in general your health is excellent, very good, good, fair, or poor?". Physical health, mental health, and activity limitation were reported as the number of days by the questionnaires "Now thinking about your physical health, which includes physical illness and injury, for how many days during the past 30 days was your physical health not good?", "Now thinking about your mental health, which includes stress, depression, and problems with emotions, for how many days during the past 30 days was your mental health not good?", and "During the past 30 days, for about how many days did poor physical or mental health keep you from doing your usual activities, such as self-care, work, or recreation?", respectively.

We dichotomized each HRQOL-4 component variables as good versus (vs.) poor: general health into good (good, very good, or excellent health) vs. poor (poor or fair) [20], physical and mental health into good (<14 days/month) vs. poor (≥14 days/month), and activity limitation into good (<14 days/month) vs. poor (≥14 days/month) [20]. In addition, we created an overall HRQOL variable indicating overall health status of general health, physical health, mental health, and activity limitation. The number of "poor" values from four HRQOL-4 components was summed, and we dichotomized the overall HRQOL variable into good (none) vs. poor (one or more).

Covariates

Age, sex, race/ethnicity, smoking status, alcohol consumption, education, household income, living status, employment status, body mass index (BMI), and chronic diseases were considered as potential confounding factors according to literature review and biological consideration. Race/ethnicity was classified as non-Hispanic white, non-Hispanic black, Mexican–American, and other race. Smoking status was classified as never, former, or current smoker, and alcohol consumption was categorized as never, ≤once, 2–3, or ≥4 times/week. Education was classified as less than high school, high school, or more than high school. Household income was calculated by dividing family income by a poverty income ratio (PIR) threshold that was specific to family size and categorized as <1 (below poverty line), 1–<3, or ≥3. Living status was defined as living alone or living with others. Employment status was classified as employed, unemployed, retired, or student/homemaker. BMI was calculated as body weight divided by height squared (kg/m^2). The number of chronic diseases was computed based on self-reports of diagnoses history of diabetes, heart disease, stroke, cancer, asthma, and osteoporosis/arthritis and then classified as none, one, two, and three or more diseases.

Statistical analysis

All statistical analyses were performed using SAS survey procedures (ver. 9.4, SAS Institute, Cary, NC) to account for the complex survey design of stratified, random, and cluster sampling. We computed 4-year sample weights based on recommended methods from NCHS and adjusted for oversampling, post-stratification, and non-response of

ethnic minorities, elderly persons, and low-income persons [13].

Survey logistic regression was used to estimate the odds ratio (OR) and 95% confidence interval (CI) for poor HRQOL by SB and MVPA as tertiles: SB [<438, 438–535, or ≥536 min/day (reference)] and MVPA (<51 (reference), 51–165, or ≥165 min/week). We modeled MVPA as a categorical variable of tertile, because about one-third of participants had 0 or less than 10 min/day MVPA and upper one-third exceeded current guidelines (150 min/week MVPA) recommended by WHO [21]. *P* value for linear trend was computed by fitting the tertile as an ordinal categorical variable coded using integer values (0–2). We developed sequential models to assess the influence of potential confounding factors in the associations of SB and MVPA with HRQOL: Model A was unadjusted model. Model B was adjusted for demographic factors (sex, age, and race/ethnicity) and accelerometer wear time. Model C was additionally adjusted for behavioral factors (smoking status and alcohol consumption). Model D was additionally adjusted for socioeconomic status (education level, household income, living status, and employment). Finally, Model E was additionally adjusted for medical conditions (obesity and number of chronic diseases). We developed single-factor models in order to investigate individual effects of SB (apart from MVPA) and MVPA (apart from SB), as well as multifactor models in which MVPA models were further adjusted for SB and SB models were further adjusted for MVPA. In addition, we evaluated the combined association of SB and MVPA on poor overall HRQOL and its components. We created a categorical variable using a combination of SB tertile by MVPA tertile (reference: low MVPA/high SB). Fully adjusted survey logistic models were used to examine the effect of the created variable on the risk of poor HRQOL. Because a previous study has reported a sex and age difference in terms of HRQOL [3], we conducted sensitivity analyses to examine the combined effects of SB and MVPA after stratifying by sex and age.

Results

A total of 5359 adults [mean age: 51.3 (standard error: 0.2)] had available data for the analysis. Table 1 shows the participant characteristics. Overall, 48.9% were males, 75.3% were non-Hispanic white, and 44.6% had a history of at least one chronic disease. In HRQOL components, 1108 participants (14.9%) had poor general health, 579 participants (9.5%) had poor physical health, 495 participants (9.4%) had poor mental health, and 224 participants

Table 1 Participant characteristics

	N	Weighted%
Total	5359	100.0
Age groups		
20–39 years	1650	32.9
40–59 years	1700	42.3
60–79 years	1608	21.2
≥80 years	401	3.6
Sex		
Males	2667	48.9
Females	2692	51.1
Race/ethnicity		
Non-Hispanic white	2919	75.3
Non-Hispanic black	1003	9.4
Mexican–American	1102	7.5
Other race	335	7.9
Education		
<High school	1376	15.0
High school diploma	1291	25.3
>High school	2692	59.7
Employment		
Employed	3156	69.3
Unemployed	582	9.1
Retired	1240	15.9
Student/homemaker	381	5.7
Household income		
PIR <1	777	9.0
PIR 1 to <3	2253	36.0
PIR ≥3	2329	55.0
Living alone		
No	4543	86.0
Yes	816	14.0
Smoking status		
Never	2785	51.7
Former	1545	27.4
Current	1029	21.0
Alcohol consumption		
Never	2321	37.0
≤Once a week	1998	40.3
2–3 times/week	648	14.4
≥4 times/week	392	8.3
Obese		
No (BMI <30 kg/m^2)	3581	67.7
Yes (BMI ≥30 kg/m^2)	1778	32.3
Chronic condition (no. of diseases)		
0	2781	55.4
1	1556	28.6
2	704	11.1
≥3	318	4.9

Table 1 continued

	N	Weighted%
General health		
Good (good, very good, or excellent health)	4251	85.1
Poor (poor or fair)	1108	14.9
Physical health (unhealthy days)		
Good (<14 days/month)	4780	90.5
Poor (≥14 days/month)	579	9.5
Mental health (unhealthy days)		
Good (<14 days/month)	4864	90.6
Poor (≥14 days/month)	495	9.4
Activity limitation (days)		
Good (<14 days/month)	5135	96.1
Poor (≥14 days/month)	224	3.9
Overall HRQOL (no. of poor HRQOL components)		
Good (none)	3931	74.9
Poor (one or more)	1628	25.1

Values are weighted% for sampling strategy

PIR poverty income ratio, *BMI* body mass index, *HRQOL* health-related quality of life

(3.9%) had activity limitation. For overall HRQOL, 1628 participants (25.1%) had poor overall HRQOL (one or more poor HRQOL components).

Table 2 shows the frequency of poor HRQOL components by participant characteristics. As shown in the table, the frequencies of poor physical health and activity limitation were significantly different across SB levels and MVPA levels. Additionally, the frequencies of poor general health, poor mental health, and poor overall HRQOL were significantly different across MVPA levels. We determined the variance inflation factors (VIF) for multicollinearity of SB and MVPA using R version 3.1.1, but these were not significant as all VIF values were <10 [22]. The correlation of SB and MVPA was $R = -0.343$ ($P < 0.001$).

Table 3 shows the individual effects of SB and MVPA as tertiles on each of poor HRQOL components, using survey logistic models after adjustment for different covariates. In all models, we observed dose–response relationship of higher MVPA with a reduced risk of poor general health (*P*-trend <0.05 for Model A–E) and poor physical health (*P*-trend <0.05 for Model A–E). In the fully adjusted models, the OR for poor general health was 0.61 (95% CI 0.45–0.82) in high MVPA and 0.74 (95% CI 0.58–0.94) in moderate MVPA compared to those with low MVPA. Moreover, we found a significantly reduced OR for poor physical health (high MVPA: 0.57 (95% CI 0.40–0.81), moderate MVPA: 0.61 (95% CI 0.46–0.80) vs. low MVPA). Significant dose–response relationships of MVPA with a reduced risk of poor mental health were observed when unadjusted (*P*-trend <0.001 for Model A), adjusted for demographic factors and accelerometer wear time (*P*-trend = 0.002 for Model B), and adjusted for health behaviors (*P*-trend = 0.009 for Model C). However, when further adjusted for socioeconomic status, those associations disappeared (*P*-trend = 0.170 for Model D). Significant dose–response relationships of MVPA with a reduced activity limitation were observed in Model A, B, C, and D (*P*-trend <0.05 for Model A–D), but its significance disappeared in models that were further adjusted for obesity and chronic diseases (Model E, fully adjusted model). The OR for poor activity limitation was 0.67 (95% CI 0.39–1.15) in high MVPA and 0.50 (95% CI 0.32–0.80) in moderate MVPA in the fully adjusted model.

We also found a significant dose–response relationship of lower SB with the reduced risk of activity limitation in all models (*P*-trend <0.05 for Model A–E). In the fully adjusted model, individuals with low SB showed a significantly reduced OR for activity limitation [low SB: 0.48 (95% CI 0.27–0.87), moderate SB: 0.65 (95% CI 0.43–0.98) vs. high SB]. A lower SB was significantly associated with a decreased risk of poor general health in Model D and was marginally associated in the fully adjusted model (*P*-trend = 0.088). In addition, the significantly reduced OR for poor physical health was observed in moderate SB [0.80 (95% CI 0.63–0.99)], but not low SB (Model E). SB was not associated with poor mental health. All models in Table 3 were multifactor models in which SB models were adjusted for MVPA and MVPA models were adjusted for SB. We also examined single-factor models that were not adjusted for SB or MVPA and observed similar but more significant results (Table A1 in online appendices).

Figure 2 shows the results from overall HRQOL. We examined individual effects of SB (Fig. 2a) and MVPA (Fig. 2b) and examined their combined effect (Fig. 2c). When SB and MVPA were individually examined, we observed that an increased MVPA was significantly associated with a reduced risk of poor overall HRQOL (Fig. 2b, *P*-trend = 0.012) but did not observe that SB is individually associated with overall HRQOL (Fig. 2a). In a combination of SB and MVPA, compared to the high SB/low MVPA (i.e., a risky group), there was a substantial decrease in the risk of poor overall HRQOL in individuals with both moderate SB/MVPA [OR 0.67 (95% CI 0.49–0.91)], low SB/moderate MVPA [OR: 0.60 (95% CI 0.43–0.83)], moderate SB/high MVPA [OR 0.56 (95% CI 0.40–0.78)], and low SB/high MVPA [OR: 0.69 (95% CI 0.51–0.94)] but no significant decrease in the risk of poor overall HRQOL in individuals with high SB/moderate-to-high MVPA (Fig. 2c). Figure 3 shows a combined effect of SB and MVPA on each poor HRQOL component. Results

Table 2 Frequency of poor HRQOL by participant characteristics

	N	General health[a] (poor, %)	Physical health[b] (poor, %)	Mental health[b] (poor, %)	Activity limitation[b] (poor, %)	Overall HRQOL[c] (poor, %)
Age groups						
20–39 years	1650	9.3	5.6	8.3	2.1	19.3
40–59 years	1700	16.5	10.5	10.9	4.6	26.3
60–79 years	1608	19.6	12.7	9.0	5.1	30.2
≥80 years	401	20.6	15.4	4.8	4.8	33.4
P value		<0.001	<0.001	0.019	<0.001	<0.001
Sex						
Males	2667	13.9	8.2	6.6	4.2	21.8
Females	2692	15.9	10.8	12.1	3.6	28.2
P value		0.073	0.016	<0.001	0.424	<0.001
Chronic condition (no. of diseases)						
0	2781	9.4	5.1	6.5	2.0	17.1
1	1556	15.7	11.9	11.3	4.3	28.7
2	704	28.9	18.3	15.0	8.3	42.7
≥3	318	41.2	25.7	19.4	13.4	53.8
P value		<0.001	<0.001	<0.001	<0.001	<0.001
MVPA						
Low (<51 min/week)	1780	26.1	17.7	12.8	8.3	38.6
Moderate (51–165 min/week)	1789	13.5	7.8	9.6	2.6	22.9
High (≥165 min/week)	1790	8.8	5.6	7.1	2.3	18.2
P value		<0.001	<0.001	<0.001	<0.001	<0.001
SB						
Low (<438 min/day)	1786	14.5	8.3	9.2	2.5	24.6
Moderate (438–535 min/day)	1785	14.4	9.1	10.2	3.8	24.8
High (≥536 min/day)	1788	16.0	11.1	8.9	5.5	25.9
P value		0.386	0.046	0.505	<0.001	0.742

Values are weighted% for sampling strategy

P values were calculated using Rao–Scott Chi-square tests according to survey procedures

HRQOL health-related quality of life, *MVPA* moderate-to-vigorous physical activity, *SB* sedentary behavior

[a] Poor general health defined as reported poor or fair health

[b] Poor physical, mental health, and activity limitation were defined as unhealthy days ≥14 days/month

[c] Poor overall HRQOL was defined as individuals having any poor HRQOL components

from general health, physical activity, and activity limitation were similar to the results from overall HRQOL, while mental health did not show any significant effect of SB and MVPA.

Additionally, we examined combined models stratified by sex and age, but observed no statistically significant difference by sex or age strata (*P*-interaction = 0.470 for sex and 0.246 for age, data not shown).

Discussion

In a representative sample of US adults who participated in NHANES 2003–2006, we observed that low SB and high MVPA were associated with the decreased risk of poor HRQOL and its components, particularly general health, physical health, and activity limitation. When we examined a combination of SB and MVPA, we observed a substantial decrease in the risk of poor overall HRQOL in individuals with low-to-moderate SB combined with moderate-to-high MVPA, but no significant decrease was observed in individuals with high SB combined with moderate and high MVPA when compared to those with high SB combined with low MVPA. Therefore, our findings suggest that prolonged SB may weaken any protective effect of MVPA on the risk of poor HRQOL.

Associations between prolonged SB and PA on the HRQOL have been relatively unknown. Although previous studies have reported an association of PA and SB on the HRQOL using self-reported measures (i.e., watching TV

Table 3 OR for poor HRQOL by sedentary behavior and moderate-to-vigorous physical activity

Variables	No. of poor HRQOL/ participants	Model A OR (95% CI)	Model B OR (95% CI)	Model C OR (95% CI)	Model D OR (95% CI)	Model E OR (95% CI)
General health						
SB						
High (≥536 min/day)	383/1788	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Moderate (438–535 min/day)	347/1785	0.88 (0.73–1.07)	0.79 (0.66–0.95)	0.79 (0.65–0.96)	0.75 (0.59–0.94)	0.78 (0.63–1.00)
Low (<438 min/day)	378/1786	0.89 (0.73–1.09)	0.86 (0.68–1.08)	0.83 (0.65–1.05)	0.70 (0.53–0.92)	0.77 (0.58–1.03)
P for trend		0.263	0.178	0.121	0.015	0.088
MVPA						
Low (<51 min/week)	540/1780	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Moderate (51–165 min/week)	320/1789	0.44 (0.35–0.56)	0.47 (0.38–0.57)	0.51 (0.42–0.63)	0.63 (0.51–0.79)	0.74 (0.58–0.94)
High (≥165 min/week)	248/1790	0.27 (0.21–0.35)	0.31 (0.23–0.43)	0.37 (0.27–0.51)	0.48 (0.35–0.66)	0.61 (0.45–0.82)
P for trend		<0.001	<0.001	<0.001	<0.001	0.002
Physical health						
SB						
High (≥536 min/day)	222/1788	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Moderate (438–535 min/day)	186/1785	0.80 (0.64–1.01)	0.75 (0.60–0.94)	0.74 (0.60–0.92)	0.76 (0.60–0.96)	0.80 (0.63–0.99)
Low (<438 min/day)	171/1786	0.73 (0.55–0.95)	0.78 (0.54–1.12)	0.75 (0.52–1.09)	0.77 (0.51–1.15)	0.84 (0.55–1.29)
P for trend		0.017	0.145	0.102	0.161	0.363
MVPA						
Low (<51 min/week)	296/1780	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Moderate (51–165 min/week)	163/1789	0.39 (0.31–0.50)	0.45 (0.35–0.58)	0.47 (0.37–0.61)	0.55 (0.42–0.72)	0.61 (0.46–0.80)
High (≥165 min/week)	120/1790	0.28 (0.22–0.37)	0.37 (0.27–0.52)	0.40 (0.29–0.57)	0.51 (0.35–0.74)	0.57 (0.40–0.81)
P for trend		<0.001	<0.001	<0.001	<0.001	0.003
Mental health						
SB						
High (≥536 min/day)	158/1788	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Moderate (438–535 min/day)	169/1785	1.16 (0.84–1.60)	1.02 (0.74–1.41)	1.01 (0.73–1.39)	1.03 (0.74–1.45)	1.07 (0.76–1.51)
Low (<438 min/day)	168/1786	1.03 (0.80–1.33)	0.95 (0.71–1.29)	0.91 (0.67–1.23)	0.92 (0.65–1.29)	0.99 (0.71–1.40)
P for trend		0.832	0.708	0.482	0.577	0.933
MVPA						
Low (<51 min/week)	186/1780	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Moderate (51–165 min/week)	170/1789	0.73 (0.56–0.94)	0.67 (0.49–0.91)	0.69 (0.50–0.96)	0.82 (0.56–1.18)	0.90 (0.61–1.32)
High (≥165 min/week)	139/1790	0.53 (0.38–0.72)	0.56 (0.39–0.80)	0.59 (0.40–0.87)	0.74 (0.47–1.14)	0.82 (0.52–1.31)
P for trend		<0.001	0.002	0.009	0.170	0.398
Activity limitation						
SB						
High (≥536 min/day)	102/1788	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Moderate (438–535 min/day)	72/1785	0.67 (0.46–0.98)	0.62 (0.43–0.90)	0.61 (0.42–0.89)	0.63 (0.41–0.95)	0.65 (0.43–0.98)
Low (<438 min/day)	50/1786	0.44 (0.30–0.66)	0.45 (0.28–0.75)	0.43 (0.25–0.72)	0.45 (0.26–0.78)	0.48 (0.27–0.87)
P for trend		<0.001	<0.001	<0.001	0.002	0.007
MVPA						
Low (<51 min/week)	119/1780	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Moderate (51–165 min/week)	60/1789	0.29 (0.20–0.44)	0.31 (0.20–0.48)	0.34 (0.22–0.53)	0.45 (0.29–0.70)	0.50 (0.32–0.80)

Table 3 continued

Variables	No. of poor HRQOL/ participants	Model A OR (95% CI)	Model B OR (95% CI)	Model C OR (95% CI)	Model D OR (95% CI)	Model E OR (95% CI)
High (≥165 min/week)	45/1790	0.26 (0.17–0.39)	0.30 (0.17–0.50)	0.34 (0.20–0.60)	0.59 (0.35–1.00)	0.67 (0.39–1.15)
P for trend		<0.001	<0.001	<0.001	0.041	0.134

Values are odds ratio (95% CI)

Model A: unadjusted model

Model B: adjusted for age, sex, race/ethnicity, and accelerometer wear time

Model C: additionally adjusted for smoking status and alcohol consumption

Model D: additionally adjusted for education level, household income, living status, and employment

Model E: additionally adjusted for obesity and number of chronic diseases

SB models were further adjusted for MVPA, and MVPA models were further adjusted for SB

HRQOL health-related quality of life, *SB* sedentary behavior, *MVPA* moderate-to-vigorous physical activity

and using a computer) [12, 23, 24], few studies have been able to measure SB and MVPA objectively in the general population. Several small studies of cancer survivors (sample size between 54 and 710) examined associations of objectively measured SB and PA using an accelerometer on the HRQOL [25, 26] but did not have consistent associations, due possibly to small sample size and health behaviors specific to cancer survivors. Our findings have confirmed previous studies' observations indicating the protective effects of decreased SB and increased MVPA on poor HRQOL and have extended the limited evidence from self-reporting studies using a small sample into an objectively measured study using a large sample.

To our knowledge, only one brief report has demonstrated the association of objectively measured SB and MVPA with HRQOL in the US general population (although it observed no significant effects of SB independent of MVPA) [27]. That report modeled overall HRQOL as a continuous variable, without defining or describing its components. The current study deals with specific components of HRQOL as well as the effect of associations of SB and MVPA on the risk of poor HRQOL. Further, we measured "poor" HRQOL as defined by each threshold, which may have implications for public health policy.

The current study suggests a combined effect of SB and MVPA on poor HRQOL, in particular a potentiating interaction effect: High MVPA may have a favorable protective effect on the risk of poor HRQOL, while prolonged SB may play a role in weakening the protective effect of high MVPA on the risk of poor HRQOL. Yet, low SB had no protective effect on the HRQOL in the absence of sufficient MVPA. Many studies have examined a combined effect of SB and MVPA, in other health outcomes [8, 28, 29]. A follow-up study of African-American women reported that prolonged television watching plays a role in reducing the effect of PA on type 2 diabetes, consistent with the combined effect in our observations [30]. In addition, a study of US adults using NIH-AARP Diet and Health Study suggested that even high levels of MVPA do not fully mitigate the risk of all-cause mortality when there are greater hours of television viewing [28]. One study in England examined combined effects of SB and MVPA using objectively measured data and suggested that high MVPA had a more desirable health profile and that low SB in the absence of MVPA is associated with the risk in cardiometabolic health [29]. Therefore, our current findings and those of previous studies support the importance of higher MVPA as well as a combination of higher MVPA with lower SB to improve public health.

It is biologically plausible that lower SB and higher MVPA may affect poor HRQOL. In general, increased time spent in SB brings about a reduction in light-intensity non-excise activity, which is associated with a substantial decrease of energy expenditure [31] and a disruption of metabolic activities that result in deterioration in physical health and well-being [32]. We did not include light-intensity activity in the models so as to avoid over-adjustment because of the high correlation with SB ($R = -0.445$, $P < 0.001$). Thus, we tried to model light-intensity activity instead of SB and evaluated its effects with MVPA on the poor overall HRQOL and its components, which was similar in pattern to a combination of SB and MVPA (Table A2 and Figure A1–2 in online appendices). Therefore, our observation could be explained as a combined effect of higher light-intensity PA (i.e., lower SB) and higher MVPA on poor HRQOL.

Moreover, metabolic diseases and frailty may, in part, be potential causal intermediates. Prolonged SB and insufficient MVPA are associated with declined physical function, frailty, and various metabolic diseases such as cardiovascular disease, overweight, and diabetes [9, 33],

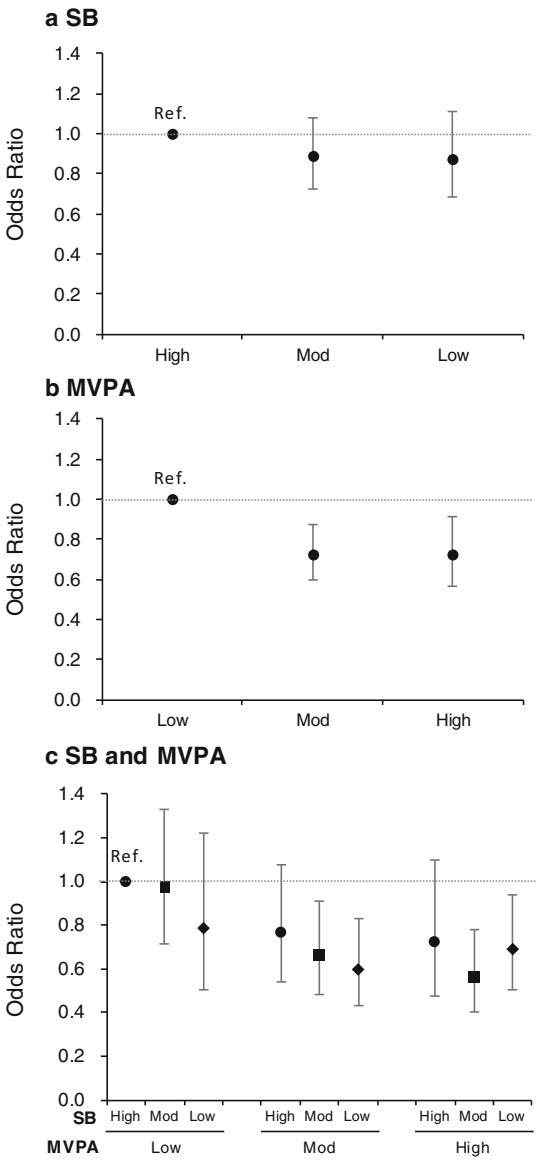

Fig. 2 Odds ratio (95% CI) for poor overall HRQOL according to individuals and combination of SB and MVPA. Values were odds ratio (95% CI). Adjusted for sex, age, race/ethnicity, accelerometer wear time, education level, household income, living status, employment, obesity, and number of chronic diseases. *SB* sedentary behavior, *MVPA* moderate-to-vigorous physical activity. Measure of trend: SB (**a**), *P*-trend = 0.240; MVPA (**b**), *P*-trend = 0.012. Measure of interaction: *P*-interaction = 0.298

and these health conditions are linked to poor HRQOL [34]. Therefore, we compared estimates from models that included all covariates except BMI and historical existence of chronic diseases, finding that the associations were similar but slightly stronger when BMI and existence of chronic diseases were excluded (data not shown). In this context, we evaluated combined effects of SB and MVPA on the risk of poor HRQOL after excluding participants with any chronic disease ($n = 2781$): A statistical significance was not observed (data not shown). Chronic diseases predict a decreased HRQOL [34], and prolonged SB and insufficient MVPA are known to be linked to higher risk of chronic diseases [8, 9]. These findings suggest that chronic disease may act as one potential pathway in the association of SB and MVPA with poor HRQOL.

We found no association of SB and MVPA with mental health. Because the present study estimated SB as overall time spent, we may not explain different domains of SB such as leisure time, occupational, and transported-related SB. Previous studies have reported that the risk of poor mental health may differ depending on the domain of SB: Screen-based SB (i.e., TV viewing and computer use) and non-occupational SB were found to be adversely associated with mental health, an association not found with social and transport-related SB [12]. Thus, more evidence is needed to determine associations between domain-specific SB and mental health problems in the general population.

Major strengths of this study include objective measures of SB and MVPA; the use of data from a nationally representative sample of the general US population; and the adjustment of robust measures of potential covariates. However, this study has several limitations. First, the cross-sectional design may raise an issue of reverse causal inferences. For example, a prior mental health problem may affect prolonged SB and/or lack of MVPA; a prior physical health problem may also affect a lack of MVPA. Therefore, further research, including longitudinal and/or trial studies, may be needed in order to verify temporal causal relationships in the findings of the current study. Second, the limitation regarding misclassification of standing time as sitting/lying must be considered. We defined SB as a threshold of <100 counts/min measured using accelerometer records, and thus standing time that has benefit for health outcomes compared to prolonged sitting, may be misclassified as SB (i.e., sitting/lying). Finally, 24.4% of participants were excluded from our analysis due to invalid records in accelerometer measures; thus, one might argue that the observed associations could differ from those in people excluded from our analysis. In the present study, participants who were included were more likely to be older than those excluded (data not shown); however, our sensitivity analysis confirmed that the influence of MVPA and SB on the risk of HRQOL does not significantly differ depending on age.

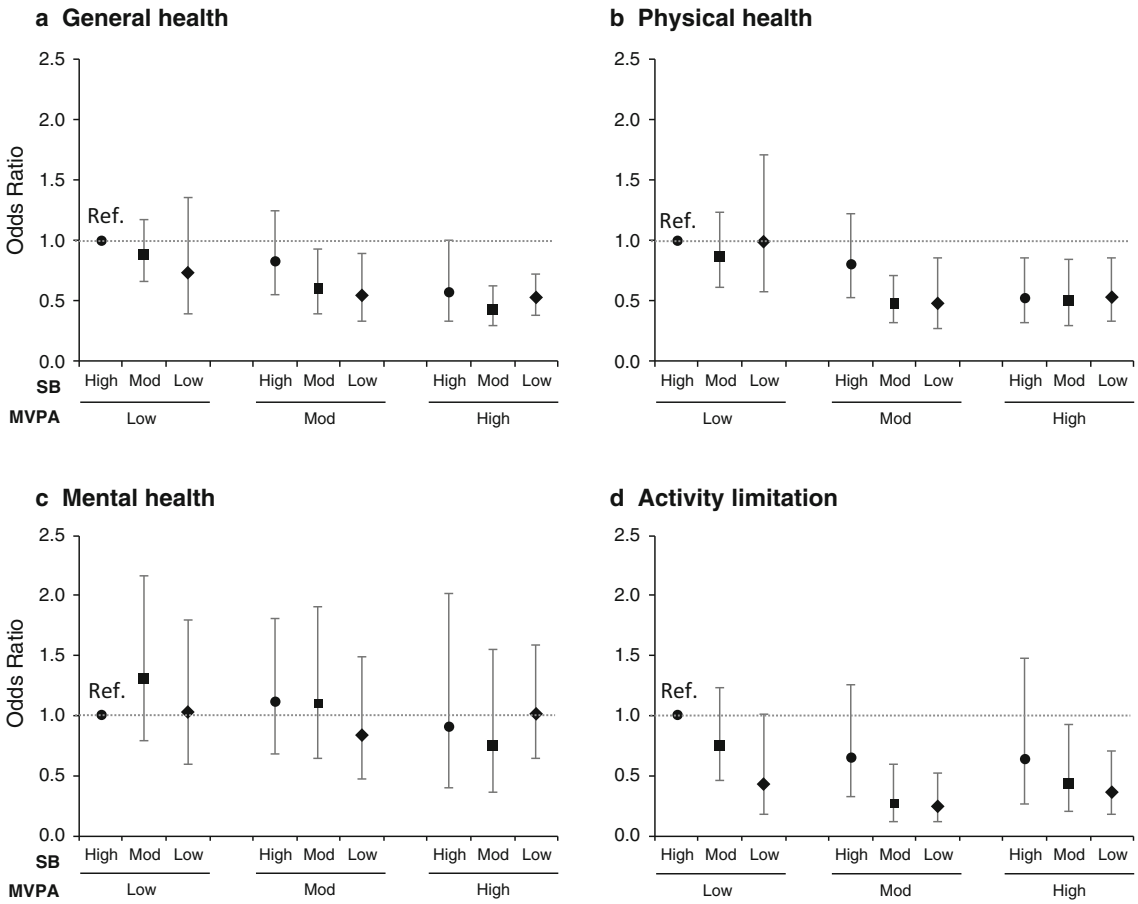

Fig. 3 Odds ratio (95% CI) for poor HRQOL components according to combination of SB and MVPA. Adjusted for sex, age, race/ethnicity, accelerometer wear time, education level, household income, living status, employment, obesity, and number of chronic diseases. *SB* sedentary behavior, *MVPA* moderate-to-vigorous physical activity. Measure of interaction: general health, *P*-interaction = 0.526; physical health, *P*-interaction = 0.618; mental health, *P*-interaction = 0.884; activity limitation, *P*-interaction = 0.471

Conclusions

In conclusion, the present cross-sectional analysis of a well-defined representative sample of US adults suggests that a combination of higher SB and lower MVPA, estimated using objective measures, is associated with poor HRQOL. High MVPA may have a more favorable effect on HRQOL, while prolonged SB may play a role in weakening the protective effect of high MVPA on HRQOL. Our findings suggest that both increasing MVPA and reducing time spent in SB may be useful strategies to improve HRQOL and healthy life expectancy.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Informed consent Informed consent was obtained from all individual participants included in the study.

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