OPEN

Cross-Sectional Associations of Sedentary Behavior and Sitting with Serum Lipid Biomarkers in Midlife

PETRA TJURIN[1,2], MAISA NIEMELÄ[1,3], MAARIT KANGAS[4], LAURA NAUHA[1], HENRI VÄHÄ-YPYÄ[5], HARRI SIEVÄNEN[5], RAIJA KORPELAINEN[3,6,7], VAHID FARRAHI[1], and TIMO JÄMSÄ[1,3,8]

[1]Research Unit of Medical Imaging, Physics and Technology (MIPT), University of Oulu, Oulu, FINLAND; [2]Department of Medical Rehabilitation, Oulu University Hospital, Oulu, FINLAND; [3]Medical Research Center, University of Oulu and Oulu University Hospital, Oulu, FINLAND; [4]Northern Finland Birth Cohort Center, University of Oulu, Oulu, FINLAND; [5]UKK Institute for Health Promotion Research, Tampere, FINLAND; [6]Department of Sports and Exercise Medicine, Oulu Deaconess Institute, Oulu, FINLAND; [7]Center for Life Course Health Research, University of Oulu, Oulu, FINLAND; and [8]Department of Diagnostic Radiology, Oulu University Hospital, Oulu, FINLAND

ABSTRACT

TJURIN, P., M. NIEMELÄ, M. KANGAS, L. NAUHA, H. VÄHÄ-YPYÄ, H. SIEVÄNEN, R. KORPELAINEN, V. FARRAHI, and T. JÄMSÄ. Cross-Sectional Associations of Sedentary Behavior and Sitting with Serum Lipid Biomarkers in Midlife. *Med. Sci. Sports Exerc.*, Vol. 54, No. 8, pp. 1261–1270, 2022. **Introduction:** Physical inactivity, excessive total time spent in sedentary behavior (SB) and prolonged sedentary bouts have been proposed to be risk factors for chronic disease morbidity and mortality worldwide. However, which patterns and postures of SB have the most negative impacts on health outcomes is still unclear. This population-based study aimed to investigate the independent associations of the patterns of accelerometer-based overall SB and sitting with serum lipid biomarkers at different moderate- to vigorous-intensity physical activity (MVPA) levels. **Methods:** Physical activity and SB were measured in a birth cohort sample ($N = 3272$) at 46 yr using a triaxial hip-worn accelerometer in free-living conditions for 14 d. Raw acceleration data were classified into SB and PA using a machine learning–based model, and the bouts of overall SB and sitting were identified from the classified data. The participants also answered health-related questionnaires and participated in clinical examinations. Associations of overall SB (lying and sitting) and sitting patterns with serum lipid biomarkers were investigated using linear regression. **Results:** The overall SB patterns were more consistently associated with serum lipid biomarkers than the sitting patterns after adjustments. Among the participants with the least and the most MVPA, high total time spent in SB and SB bouts of 15–29.99 and ≥30 min were associated with impaired lipid metabolism. Among those with moderate amount of MVPA, higher time spent in SB and SB bouts of 15–29.99 min was unfavorably associated with serum lipid biomarkers. **Conclusions:** The associations between SB patterns and serum lipid biomarkers were dependent on MVPA level, which should be considered when planning evidence-based interventions to decrease SB in midlife. **Key Words:** PHYSICAL ACTIVITY, SEDENTARY PATTERNS, CARDIOMETABOLIC HEALTH MARKERS, DYSLIPIDEMIAS, ACCELEROMETER

Physical inactivity has been shown to increase the risk of many chronic diseases, such as type 2 diabetes, cardiovascular diseases (CVD), and certain cancers (1). The guidelines on physical activity (PA) for health have been well described and recommend that adults 18–64 yr old do at least 150 to 300 min of moderate-intensity aerobic PA (MPA), at least 75 to 150 min of vigorous-intensity aerobic PA (VPA), or an equivalent combination of moderate- and vigorous-intensity aerobic PA (MVPA) throughout the week (2). The recommendations for sedentary behavior (SB, defined as any waking time spent in a sitting, reclining, or lying posture with an energy consumption ≤1.5 METs) only recommend that adults sit less throughout the day (2), but the detailed recommendations for SB are still missing.

Research concerning SB has rapidly grown over the past decade, and SB has been stated to be among the leading lifestyle risk factors for CVD and all-cause mortality worldwide

Address for Correspondence: Petra Tjurin, M.Sc., Research Unit of Medical Imaging, Physics and Technology, P.O. Box 5000, 90014 University of Oulu, Oulu, Finland; E-mail: petra.tjurin@oulu.fi.
Submitted for publication May 2021.
Accepted for publication March 2022.
Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.acsm-msse.org).

0195-9131/22/5408-1261/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®
Copyright © 2022 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the American College of Sports Medicine. This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial-No Derivatives License 4.0 (CCBY-NC-ND), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.
DOI: 10.1249/MSS.0000000000002916

(3). Based on recent literature, lower volumes of MVPA and higher volumes of SB are associated with the increased risk of CVD (4–8). Traditionally, SB has been thought to be an independent risk factor, but recent findings show that the health risks related to excessive SB are dependent on MVPA levels (9). However, the consensus about the harmful amount of daily SB is still missing, and several thresholds for the maximum daily amount of SB have been suggested (10). In addition, prolonged bouts of SB have also been adversely associated with health outcomes (11–13), but more evidence is needed on the relationship between SB bouts and cardiometabolic health at different MVPA levels (9).

The PA and the SB guidelines so far have mostly been based on self-reported amounts of total participation in MVPA and sitting per day or week. Various studies have shown that self-reported PA and SB induce bigger measurement error and recall bias than accelerometer-measured PA and SB (14–16). Accelerometers have also enabled researchers to measure PA and SB patterns in a free-living environment (9).

The traditional signal-processing methods are based on specific thresholds for different activities, and the use of raw acceleration data has been suggested (17). The thigh has been thought to be the most accurate attachment site for the accelerometer to measure SB. However, novel signal-processing techniques—e.g., angle for posture estimation, machine learning (ML)—have offered promising results when the accelerometer is attached to the hip (18–21). In particular, associations between SB patterns and cardiometabolic health have been suggested to be reliably studied regardless of whether the accelerometer is attached to the hip or the thigh (22).

The aim of this population-based study was to investigate the independent associations of the patterns of accelerometer-measured free-living SB and sitting with serum lipid biomarkers in middle-age Finnish adults at different MVPA levels. We hypothesized that these associations vary according to the MVPA level and that more time spent in SB and prolonged SB bouts is associated with impaired lipid metabolism, especially in the least physically active adults.

MATERIALS AND METHODS

Study population. All pregnant women whose expected dates of delivery were in the year 1966 and who were living in the two northernmost provinces in Finland were invited to participate in the Northern Finland Birth Cohort 1966 study (NFBC1966). From those women, 12,058 live birth children were included in the NFBC1966 study population, comprising 96% of all births in the region in 1966. Since birth, information about these individuals' health conditions, socioeconomic backgrounds, workload, and lifestyles has been recorded regularly through questionnaires, health care records, and clinical examinations (23).

In the years 2012–2014, when the subjects were approximately 46 yr old, the most recent follow-up data were collected from 10,321 participants who provided written informed consent to take part in the 46-yr follow-up study. The 46-yr data collection included questionnaires, clinical examinations, and measurements of PA and SB with a hip-worn triaxial accelerometer. The 46-yr follow-up study was approved by the Ethical Committee of the Northern Ostrobothnia Hospital District in Oulu, Finland (94/2011), and was performed in accordance with the Declaration of Helsinki. Personal identity information was encrypted and replaced with identification codes.

Questionnaires. The participants filled postal questionnaires about their health conditions, socioeconomic backgrounds, lifestyles, and work. Their educational levels, employment, marital status, and prevalence of diagnosed diseases and medication were also inquired. Information about smoking habits was collected with multiple questions, and smoking status was dichotomized (nonsmoker or former smoker and current smoker). Drinking habits were estimated using beverage-specific questions on the usual frequencies of consumption and amounts of beer, wine, and spirits per drinking occasion, and the average volume of ethanol consumed per day was calculated. The threshold values for heavy users of alcohol were set at $\geq 40\ g \cdot d^{-1}$ for men and $\geq 20\ g \cdot d^{-1}$ for women based on the recommendations of the Finnish Current Care Guidelines.

The ability to walk was determined using a question about mobility from the 15D instrument (24). The participants were asked to read all five alternative responses and to select only one alternative that best described their present health status. The alternative responses were "I am able to walk normally (without difficulties) indoors, outdoors, and on the stairs," "I am able to walk without difficulty indoors, but outdoors and/or on the stairs, I have slight difficulties," "I am able to walk without help indoors (with or without an appliance) but outdoors and/or on the stairs only with considerable difficulty or with help from others," "I am able to walk indoors only with help from others," and "I am completely bedridden and unable to move about."

Clinical examinations. An invitation to a clinical examination was sent to all participants with known addresses, of which 5861 attended. The clinical examination was conducted by a trained study nurse. The participants' height, weight, and waist circumference were measured. Body mass index was calculated using the measured height and weight data ($kg \cdot m^{-2}$). The cutoff values of waist circumference for abdominal obesity were set at >102 cm for men and >88 cm for women, indicating a substantially increased risk for developing cardiometabolic diseases (25).

Venous blood samples were taken after overnight fasting (12 h) and abstaining from smoking and drinking coffee on the clinical examination day. Triglycerides, total cholesterol, high-density lipoprotein (HDL) cholesterol, and low-density lipoprotein (LDL) cholesterol were analyzed from the fasting serum samples using a previous method (26). Because the ratios of total/HDL cholesterol and LDL/HDL cholesterol have been proposed to be stronger predictors for CVD risk than the isolated lipid biomarkers, these ratios were calculated (27,28).

Measurement of PA and SB. The participants who attended the clinical examinations were invited to participate in PA measurements and wear a triaxial accelerometer (Hookie AM20; Traxmeet Ltd., Espoo, Finland) for 14 consecutive days during all waking hours except during water-related activities.

The accelerometer was attached with an elastic belt to the right posterior side of the hip and served as a data logger without providing feedback to the participants. Raw acceleration signals were collected at a sampling frequency of 100 Hz.

Signal analysis was conducted from the raw accelerations using a previous signal-processing method (29). In brief, the wear time signal was formed by removing nonwear periods, defined as at least 30 min of consecutive zero values in all three axes. Five different activity categories (lying, sitting, light-intensity physical activity [LPA], MPA, and VPA) were recognized from the steady-state wear time acceleration signals using a supervised ML model (21). The model was trained and validated using a data set of 22 adults participating in nine semisupervised activities ranging in intensity from SB to VPA, as described elsewhere (21). These activities also included a dynamic standing activity (i.e., poster viewing) that contained self-selected amount of standing still and standing with slight movement, which were all classified as LPA (30). The ML model analyzed the data in 5-s epochs using the bagged trees classifier and, in total, 20 features (mean, minimum, maximum, zero crossing rate, and mean amplitude deviation [31], extracted in all three axes and the acceleration sum vector). The ML model exhibited excellent total accuracy (96.5%) as well as sensitivity and specificity in recognizing lying and sitting among working-age adults (21).

The maximum daily wear time was limited to 20 h, and the exceeding wear time was removed from the lying time. Lying and sitting bouts were recognized from the classified data, and they were combined to form SB bouts. An SB bout was defined as a minimum of 30 s of continuous lying or sitting, and a break in SB was defined as a PA bout with a minimum of 30 s between successive SB bouts. In addition, sitting bouts were analyzed separately and defined as a minimum of 30 s of continuous sitting (29). Daily sedentary pattern variables were observed from the extracted overall SB and sitting bouts separately, and the observed variables were total time per day ($\text{min}\cdot\text{d}^{-1}$) and time spent in bouts of 15–29.99 and ≥30 min ($\text{min}\cdot\text{d}^{-1}$). The abovementioned variables were selected because they were considered to describe sedentary bout length distribution more clearly than some composite measures of SB, such as fragmentation index (32). In addition, the total time per day ($\text{min}\cdot\text{d}^{-1}$) spent in LPA, MPA, and VPA was observed from the classified PA data, and MPA and VPA were summed up to form MVPA. The participants with four or more days of at least 600 $\text{min}\cdot\text{d}^{-1}$ of valid accelerometer data were included in the analyses.

Statistical methods. Statistical analyses were performed using IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY). Participants providing valid data from questionnaires, clinical examinations, and accelerometer measurements as well as reporting normal walking ability were included in the statistical analyses. The descriptive characteristics of the participants are presented in counts and proportions for categorical variables, means, and SD for normally distributed continuous variables or medians and 25th and 75th percentiles for skewed continuous variables. To consider the possible interaction between SB and MVPA (33), the participants were grouped into three groups according to their measured MVPA level: low activity (total MVPA time <150 $\text{min}\cdot\text{wk}^{-1}$ and total VPA time <75 $\text{min}\cdot\text{wk}^{-1}$), moderate activity (total MVPA time = 150–300 $\text{min}\cdot\text{wk}^{-1}$ and total VPA time <150 $\text{min}\cdot\text{wk}^{-1}$ or total MVPA time <300 $\text{min}\cdot\text{wk}^{-1}$ and total VPA time = 75–150 $\text{min}\cdot\text{wk}^{-1}$), and high activity (total MVPA time >300 $\text{min}\cdot\text{wk}^{-1}$ or total VPA time >150 $\text{min}\cdot\text{wk}^{-1}$). The abovementioned groups were formed based on the guidelines on PA (2). Univariate associations between continuous variables and MVPA groups were analyzed using ANOVA with Tukey's *post hoc* test for normally distributed data or the Kruskal–Wallis test with the Mann–Whitney *U*-test pairwise comparison for skewed data. The chi-square (χ^2) test and the *Z*-test with Bonferroni correction for *post hoc* were used for analyzing differences between categorical variables and MVPA groups.

All serum lipid biomarkers and PA and SB variables were natural log transformed before regression analyses to obtain normal distribution. Multivariable linear regression analyses were performed for the whole study population and in each MVPA group separately. Before the linear regression analyses, regression analyses including an interaction term for SB variables and MVPA groups (low, moderate, and high) were performed to ascertain the possibility of interaction between SB variables and MVPA groups. The significance of interactions between SB variables and MVPA groups could indicate that the associations of SB with serum lipid biomarkers differ significantly between the MVPA groups.

Multivariable associations were conducted using the enter method in linear regression analysis between SB and sitting variables and serum lipid biomarkers. The analyzed SB and sitting variables were total SB time ($\text{min}\cdot\text{d}^{-1}$), times spent in 15–29.99 min and ≥30 min SB bouts ($\text{min}\cdot\text{d}^{-1}$), total sitting time ($\text{min}\cdot\text{d}^{-1}$), and time spent in 15–29.99 min sitting bouts ($\text{min}\cdot\text{d}^{-1}$). The linear regression analyses were conducted using five models that included one of the SB or sitting variables. The confounding variables in the linear regression models were sex, abdominal obesity (men >102 cm, women >88 cm), smoking status (nonsmoker/current smoker), heavy alcohol consumption (men ≥40 $\text{g}\cdot\text{d}^{-1}$, women ≥20 $\text{g}\cdot\text{d}^{-1}$), diagnosis or medication for diabetes or CVD (coronary artery disease, heart failure, myocardial infarction, stroke), accelerometer wear time ($\text{min}\cdot\text{d}^{-1}$), MVPA ($\text{min}\cdot\text{d}^{-1}$), education (no professional education, vocational/college level education, university/polytechnic degree), marital status (married/cohabiting, divorced/widowed, unmarried), and employment status (employed/unemployed/studying/other). SB and sitting variables, MVPA, and covariates had linear relationship with serum lipid biomarkers and had no significant multicollinearity (variance inflation factor <5), autocorrelation (Durbin–Watson statistics $1.5 < d < 2.5$), or heteroscedasticity based on the variance and distribution of residuals. MVPA time and time spent in different lengths of SB and sitting bouts had several zero values, which were eliminated before natural log transformation by adding a constant value of 1.

SB variables that were significantly and consistently associated with serum lipid and lipoprotein levels were entered into receiver operating characteristic (ROC) analyses to determine the threshold values of the SB variables. Before ROC analyses, the serum lipid and lipoprotein variables were dichotomized according to the recommendations of the Finnish Current Care Guidelines: triglycerides <1.7 mmol·L^{-1}, total cholesterol <5.0 mmol·L^{-1}, LDL cholesterol <3.0 mmol·L^{-1}, HDL cholesterol for men >1.0 mmol·L^{-1} and for women >1.2 mmol·L^{-1}, total/HDL cholesterol ratio <4, and LDL/HDL cholesterol ratio <3. The statistical significance was set to $P < 0.05$.

RESULTS

A total of 5861 NFBC1966 cohort members (56.8% of living NFBC1966 cohort members in Finland in the years 2012–2014) participated in clinical examinations and agreed to wear the accelerometer after filling the questionnaires. From those attending the clinical examinations, 3272 (55.8% of all the 46-yr follow-up study participants) provided data from questionnaires, clinical examinations, and accelerometer measurement and reported that they could walk normally without difficulties indoors, outdoors, and on the stairs (Fig. 1). Those who did not agree to participate in the clinical examinations and wear accelerometer were more often men (53% vs 44%, $P < 0.001$), heavy users of alcohol (10% vs 8%, $P < 0.001$), and smokers (29% vs 19%, $P < 0.001$) and had more often abdominal obesity (76% vs 37%, $P < 0.001$) and diagnosis or medication to CVD or diabetes (22% vs 19%, $P < 0.001$) compared with participants who agreed to participate. Those who did not provide enough valid accelerometer data were more often smokers (22% vs 17%, $P < 0.001$) and had more often abdominal obesity (45% vs 32%, $P < 0.001$) and diagnosis or medication to CVD or diabetes (22% vs 18%, $P < 0.001$) compared with participants who were included in the statistical analyses.

The characteristics of the study participants by MVPA groups are presented in Table 1. The participants were, on average, 46.1 ± 0.6 yr old, and 1395 (42.6%) were men. The low activity group included 1341 (41.0%) participants, the moderate activity group 1238 (37.8%) participants, and the high activity group 693 (21.2%) participants. The percentages of men (about 40%) and women (about 60%) were the same in all activity groups.

The mean accelerometer-measured PA, SB, and sitting variables and serum lipid biomarkers by MVPA groups are presented in Table 2. The average measurement period was 14 d, and the median wear time was 903.4 min·d^{-1} (25th–75th percentiles 859.3–945.5 min·d^{-1}). The participants' weekly mean MVPA time was 175 min, and they spent most (64.7%, 584.9 min·d^{-1}) of their wear time sedentary, of which 360.2 min·d^{-1} (61.6%) were performed in a sitting posture. The participants in the low activity group had more total sedentary time, and they accumulated their sedentary time more often in longer bouts (≥30 min) than the participants in the moderate or high activity groups ($P < 0.001$). However, the total time spent sitting and the time spent in ≥30-min sitting bouts were greater among the high activity group compared with the low and moderate activity groups ($P < 0.001$). There were not statistically significant differences in LPA between the activity groups.

The associations of total sedentary time with LDL cholesterol, total/HDL cholesterol ratio, and LDL/HDL cholesterol ratio differed significantly between MVPA groups ($P = 0.006$–0.029). In addition, the associations of time spent in SB bouts of ≥30 min with triglycerides, LDL/HDL cholesterol ratio, total/HDL cholesterol ratio, LDL cholesterol, and HDL cholesterol differed significantly between MVPA groups ($P = 0.001$–

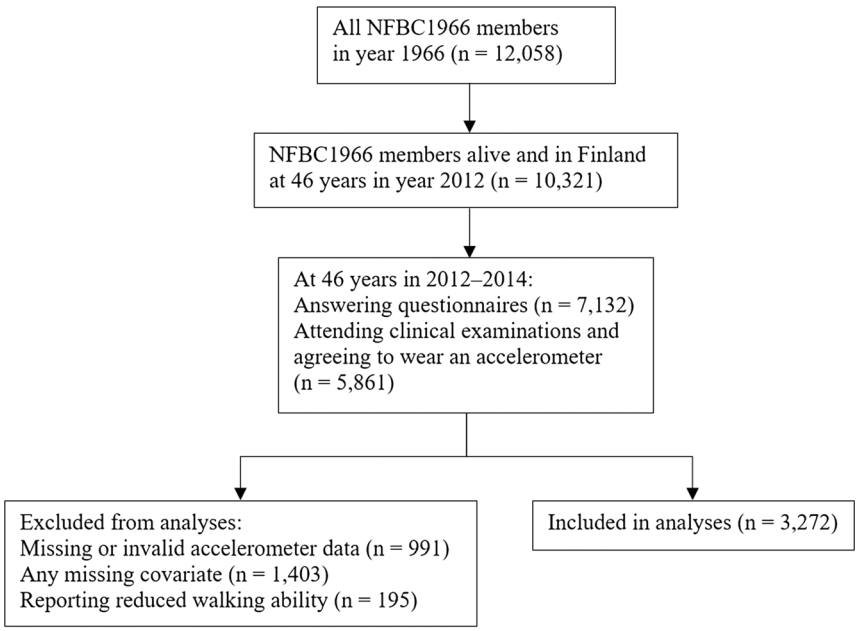

FIGURE 1—The selection of study participants from the Northern Finland Birth Cohort 1966 (NFBC1966).

TABLE 1. Characteristics of study participants by physical activity group.

Variable	All (n = 3272)	Low Activity (n = 1341)	Moderate Activity (n = 1238)	High Activity (n = 693)	P Value
Sex					0.070[a]
Men, n (%)	1395 (42.6)	589 (43.9)	537 (43.4)	269 (38.8)	
Women, n (%)	1877 (57.4)	752 (56.1)	701 (56.6)	424 (61.2)	
Height, cm	170.3 (163.9–177.7)	170.4 (164.0–178.0)**	170.5 (164.4–177.7)***	169.5 (162.9–176.5)	0.003[b]
Weight, kg	75.6 (65.4–86.6)	78.6 (67.0–89.8)*,**	75.8 (65.5–85.8)***	71.0 (63.0–81.2)	<0.001[b]
BMI, kg·m^{-2}					<0.001[a]
<18.5, n (%)	20 (0.6)	8 (0.6)	7 (0.6)	7 (0.7)	
18.5–24.99, n (%)	1372 (41.9)	473 (35.2)*,**	526 (42.5)***	373 (53.8)	
25–29.99, n (%)	1319 (40.3)	560 (41.8)**	517 (41.7)***	242 (34.9)	
≥30, n (%)	561 (17.2)	300 (22.4)*,**	188 (15.2)***	73 (10.6)	
Waist circumference, cm	89.5 (80.5–98.0)	92.0 (82.5–101.0)*,**	89.0 (81.0–97.5)***	85.0 (78.0–93.5)	<0.001[b]
Abdominal obesity (men >102 cm, women >88 cm), n (%)	1047 (32.0)	525 (39.1)*,**	372 (30.0)***	150 (21.6)	<0.001[a]
Marital status					0.020[a]
Married/cohabiting, n (%)	2631 (80.4)	1104 (82.3)**	1000 (80.8)***	527 (76.0)	
Divorced/widowed, n (%)	628 (19.2)	232 (17.3)**	233 (18.8)***	163 (23.5)	
Unmarried, n (%)	13 (0.4)	5 (0.4)	5 (0.4)	3 (0.5)	
Education					<0.001[a]
No professional education, n (%)	171 (5.2)	95 (7.1)*,**	54 (4.4)	21 (3.0)	
Vocational/college level education, n (%)	2062 (63.0)	907 (67.6)*,**	769 (62.1)***	386 (55.7)	
Polytechnic/university degree, n (%)	1039 (31.8)	339 (25.3)*,**	414 (33.4)***	286 (41.3)	
Employment status					0.211[a]
Employed, n (%)	3182 (97.2)	1298 (96.8)	1207 (97.5)	677 (97.7)	
Unemployed, n (%)	28 (0.9)	15 (1.1)	12 (1.0)	1 (0.1)	
Studying, n (%)	16 (0.5)	6 (0.5)	7 (0.5)	3 (0.5)	
Other, n (%)	46 (1.4)	22 (1.6)	12 (1.0)	12 (1.7)	
Smoking					<0.001[a]
Nonsmoker, n (%)	2708 (82.8)	1063 (79.3)*,**	1043 (84.2)	602 (86.9)	
Current smoker, n (%)	564 (17.2)	278 (20.7)*,**	195 (15.8)	91 (13.1)	
Alcohol consumption, g·d^{-1}	4.6 (1.2–13.1)	4.3 (1.0–13.0)	4.9 (1.4–13.2)	4.3 (1.1–13.2)	0.181[b]
Heavy user (men ≥40 g·d^{-1}, women ≥20 g·d^{-1}), n (%)	241 (7.4)	101 (7.5)	88 (7.1)	52 (7.5)	0.908[a]
CVD or diabetes diagnosis or medication, n (%)	573 (17.5)	261 (19.5)**	218 (17.6)	94 (13.6)	0.004[a]

Values are presented as median (25th–75th percentiles) if not otherwise stated.
[a]Chi-square test, *post hoc*: Z-test with Bonferroni correction.
[b]Kruskal–Wallis, *post hoc*: Mann–Whitney U-test with Bonferroni correction. Only significant ($P < 0.05$) pairwise comparison P values are reported: * low activity vs moderate activity, ** low activity vs high activity, *** moderate activity vs high activity.
BMI, body mass index; CVD, cardiovascular disease (coronary artery disease, heart failure, myocardial infarction, stroke).

0.032). SB and sitting variables having statistically significant linear associations with serum lipid and lipoprotein levels are summarized in Table 3. The models used in the linear regression analyses are presented in Table 4 and Supplementary File 1 (see Appendix, Supplemental Digital Content 1, Associations of Sedentary Behavior and Sitting Variables with Serum Lipids and Lipoproteins in the Low, Moderate, and High Activity Groups, http://links.lww.com/MSS/C549). The linear regression models predicting the total/HDL cholesterol ratio had the greatest coefficients of determination, explaining on average 34.5% ($P < 0.001$) of the variance among the whole study sample (Table 3). Sedentary time and time spent in SB

TABLE 2. Accelerometer-measured physical activity, SB and sitting, and serum lipid biomarkers by physical activity group.

Variable	All (N = 3272)	Low Activity (n = 1341)	Moderate Activity (n = 1238)	High Activity (n = 693)	P Value
Accelerometer-measured PA					
Wear time, min·d^{-1}	903.4 (859.3–945.5)	895.4 (848.3–940.5)*,**	904.7 (860.6–945.9)***	916.2 (879.2–953.5)	<0.001[a]
MVPA time, min·d^{-1}	25.0 (14.2–38.7)	12.3 (7.4–16.7)*,**	29.5 (25.2–34.8)***	55.3 (47.8–66.3)	<0.001[a]
LPA time, min·d^{-1}	266.8 (207.9–337.1)	266.1 (198.8–340.0)	270.8 (216.5–338.6)	262.0 (209.1–329.3)	0.084[a]
Accelerometer-measured overall SB (lying and sitting)					
Sedentary time, min·d^{-1}	584.9 (514.9–655.2)	592.8 (520.9–672.1)*,**	581.8 (513.0–646.2)	577.6 (507.4–637.0)	<0.001[a]
Time spent in <15 min SB bouts, min·d^{-1}	194.6 (165.1–225.2)	190.1 (159.6–223.6)*,**	197.0 (171.1–225.5)	195.5 (166.5–227.7)	0.001[a]
Time spent in 15–29.99 min SB bouts, min·d^{-1}	120.5 (100.3–141.8)	116.1 (95.9–137.8)*,**	123.2 (102.5–143.3)	125.1 (105.8–144.5)	<0.001[a]
Time spent in ≥30 min SB bouts, min·d^{-1}	194.8 (128.2–265.7)	206.1 (137.8–293.8)*,**	189.5 (120.6–255.5)	184.8 (126.3–249.4)	<0.001[a]
Accelerometer-measured sitting					
Sitting time, min·d^{-1}	360.2 (288.1–437.8)	345.0 (275.2–422.8)*,**	368.3 (295.4–439.7)***	378.3 (303.2–453.8)	<0.001[a]
Time spent in <15 min sitting bouts, min·d^{-1}	149.9 (116.8–180.0)	145.1 (111.8–175.7)*,**	153.4 (121.9–182.4)	152.4 (118.6–183.5)	<0.001[a]
Time spent in 15–29.99 min sitting bouts, min·d^{-1}	76.3 (57.9–97.0)	71.3 (52.6–91.8)*,**	78.0 (60.7–99.3)	81.0 (62.1–102.6)	<0.001[a]
Time spent in ≥30 min sitting bouts, min·d^{-1}	69.3 (38.7–128.9)	61.6 (36.5–128.1)*,**	70.3 (39.9–125.7)	74.5 (40.1–134.3)	0.001[a]
Serum lipid biomarkers					
Triglycerides, mmol·L^{-1}	1.0 (0.8–1.5)	1.1 (0.8–1.6)*,**	1.0 (0.8–1.4)***	0.9 (0.7–1.3)	<0.001[a]
Total cholesterol, mmol·L^{-1}	5.2 (4.7–5.9)	5.3 (4.7–5.9)**	5.3 (4.7–5.9)***	5.1 (4.6–5.7)	0.008[a]
LDL cholesterol, mmol·L^{-1}	3.3 (2.8–4.0)	3.4 (2.8–4.1)**	3.4 (2.8–4.0)***	3.1 (2.6–3.8)	<0.001[a]
HDL cholesterol, mmol·L^{-1}	1.5 (1.3–1.8)	1.5 (1.2–1.7)**	1.5 (1.3–1.8)***	1.6 (1.4–1.9)	<0.001[a]
Total/HDL cholesterol ratio	3.4 (2.8–4.2)	3.6 (3.0–4.4)*,**	3.4 (2.8–4.2)***	3.1 (2.6–3.9)	<0.001[a]
LDL/HDL cholesterol ratio	2.2 (1.7–2.9)	2.4 (1.8–3.1)*,**	2.2 (1.7–2.9)***	2.0 (1.5–2.7)	<0.001[a]

Values are presented as median (25th–75th percentiles) if not otherwise stated.
[a]Kruskal–Wallis, *post hoc*: Mann–Whitney U-test with Bonferroni correction. Only significant ($P < 0.05$) pairwise comparison P values are reported: *low activity vs moderate activity, **low activity vs high activity, ***moderate activity vs high activity.
PA, physical activity; MVPA, moderate-to-vigorous physical activity; LPA, light physical activity; SB, sedentary behavior; LDL, low-density lipoprotein; HDL, high-density lipoprotein.

TABLE 3. SB and sitting variables significantly associated with serum lipids and lipoproteins by physical activity group according to linear regression analyses.

	All (N = 3272)		Low Activity (n = 1341)		Moderate Activity (n = 1238)		High Activity (n = 693)	
Serum Lipids and Lipoproteins SB or Sitting Variables	**Model R^2**	**β (95% CI)**	**Model R^2**	**β (95% CI)**	**Model R^2**	**β (95% CI)**	**Model R^2**	**β (95% CI)**
Total cholesterol								
Sedentary time, min·d^{-1}	0.060**	0.036 (0.000 to 0.072)*	0.070**	0.050 (–0.006 to 0.106)	0.071**	0.018 (–0.042 to 0.077)	0.067**	0.030 (–0.044 to 0.104)
HDL cholesterol								
Sedentary time, min·d^{-1}	0.266**	–0.116 (–0.160 to –0.071)**	0.282**	–0.127 (–0.193 to –0.060)**	0.226**	–0.079 (–0.154 to –0.004)*	0.257**	–0.160 (–0.259 to –0.061)*
Time spent in 15–29.99 min SB bouts, min·d^{-1}	0.264**	–0.053 (–0.079 to –0.027)**	0.275**	–0.028 (–0.067 to 0.010)	0.229**	–0.069 (–0.114 to –0.023)*	0.253**	–0.080 (–0.140 to –0.019)*
Time spent in ≥30 min SB bouts, min·d^{-1}	0.263**	–0.018 (–0.030 to –0.007)*	0.278**	–0.025 (–0.042 to –0.007)*	0.224**	–0.007 (–0.026 to 0.011)	0.250**	–0.029 (–0.057 to –0.001)*
Sitting time, min·d^{-1}	0.262**	–0.032 (–0.056 to –0.009)*	0.275**	–0.027 (–0.062 to 0.007)	0.226**	–0.041 (–0.083 to 0.001)	0.248**	–0.036 (–0.089 to 0.017)
Time spent in 15–29.99 min sitting bouts, min·d^{-1}	0.262**	–0.018 (–0.034 to –0.003)*	0.275**	–0.015 (–0.036 to 0.005)	0.225**	–0.024 (–0.055 to 0.007)	0.247**	–0.022 (–0.060 to 0.016)
LDL cholesterol								
Sedentary time, min·d^{-1}	0.133**	0.109 (0.055 to 0.164)**	0.131**	0.159 (0.075 to 0.243)**	0.125**	0.036 (–0.055 to 0.128)	0.149**	0.131 (0.014 to 0.249)*
Time spent in 15–29.99 min SB bouts, min·d^{-1}	0.132**	0.057 (0.025 to 0.090)*	0.124**	0.043 (–0.006 to 0.092)	0.126**	0.050 (–0.006 to 0.105)	0.153**	0.101 (0.029 to 0.173)*
Time spent in ≥30 min SB bouts, min·d^{-1}	0.131**	0.021 (0.007 to 0.035)*	0.129**	0.037 (0.014 to 0.059)*	0.124**	0.001 (–0.022 to 0.024)	0.147**	0.031 (–0.002 to 0.064)
Sitting time, min·d^{-1}	0.129**	0.012 (–0.018 to 0.041)	0.122**	–0.010 (–0.054 to 0.033)	0.124**	0.007 (–0.045 to 0.058)	0.148**	0.066 (0.003 to 0.129)*
Total/HDL cholesterol ratio								
Sedentary time, min·d^{-1}	0.349**	0.151 (0.104 to 0.199)**	0.362**	0.176 (0.104 to 0.248)**	0.316**	0.097 (0.017 to 0.176)*	0.324**	0.190 (0.084 to 0.296)
Time spent in 15–29.99 min SB bouts, min·d^{-1}	0.346**	0.073 (0.045 to 0.102)**	0.353**	0.046 (0.004 to 0.088)*	0.319**	0.082 (0.033 to 0.130)*	0.325**	0.121 (0.056 to 0.185)**
Time spent in ≥30 min SB bouts, min·d^{-1}	0.344**	0.025 (0.013 to 0.038)**	0.358**	0.037 (0.017 to 0.056)**	0.313**	0.007 (–0.013 to 0.027)	0.318**	0.038 (0.008 to 0.068)*
Sitting time, min·d^{-1}	0.342**	0.027 (0.001 to 0.052)*	0.351**	0.004 (–0.033 to 0.042)	0.315**	0.039 (–0.006 to 0.083)	0.317**	0.062 (0.005 to 0.119)*
Time spent in 15–29.99 min sitting bouts, min·d^{-1}	0.342**	0.021 (0.005 to 0.038)*	0.352**	0.010 (–0.012 to 0.032)	0.315**	0.032 (–0.001 to 0.065)	0.315**	0.038 (–0.003 to 0.078)
LDL/HDL cholesterol ratio								
Sedentary time, min·d^{-1}	0.302**	0.225 (0.153 to 0.297)**	0.311**	0.286 (0.177 to 0.394)**	0.268**	0.115 (–0.005 to 0.236)	0.288**	0.291 (0.001 to 0.457)*
Time spent in 15–29.99 min SB bouts, min·d^{-1}	0.299**	0.110 (0.067 to 0.153)**	0.300**	0.072 (0.008 to 0.135)*	0.272**	0.118 (0.045 to 0.191)*	0.289**	0.181 (0.080 to 0.282)**
Time spent in ≥30 min SB bouts, min·d^{-1}	0.297**	0.040 (0.021 to 0.058)**	0.307**	0.061 (0.032 to 0.090)**	0.266**	0.008 (–0.022 to 0.038)	0.282**	0.060 (0.013 to 0.106)*
Sitting time, min·d^{-1}	0.267**	0.044 (0.026 to 0.083)*	0.298**	0.017 (–0.039 to 0.073)	0.267**	0.048 (–0.020 to 0.116)	0.281**	0.102 (0.013 to 0.191)
Time spent in 15–29.99 min sitting bouts, min·d^{-1}	0.295**	0.031 (0.006 to 0.056)*	0.298**	0.018 (–0.015 to 0.051)	0.267**	0.038 (–0.012 to 0.088)	0.279**	0.054 (–0.009 to 0.117)
Triglycerides								
Sedentary time, min·d^{-1}	0.293**	0.280 (0.195 to 0.366)**	0.322**	0.185 (0.055 to 0.315)*	0.267**	0.311 (0.164 to 0.458)	0.251**	0.401 (0.213 to 0.588)*
Time spent in 15–29.99 min SB bouts, min·d^{-1}	0.286**	0.081 (0.030 to 0.133)*	0.319**	0.060 (–0.015 to 0.135)	0.260**	0.109 (0.019 to 0.199)*	0.233**	0.068 (–0.047 to 0.184)
Time spent in ≥30 min SB bouts, min·d^{-1}	0.290**	0.058 (0.035 to 0.080)**	0.324**	0.060 (0.026 to 0.095)*	0.259**	0.036 (–0.001 to 0.073)	0.245**	0.092 (0.039 to 0.144)**

Adjusted for sex, employment status, marital status, smoking, alcohol consumption (heavy user), waist circumference (abdominal obesity), diagnosis or medication for CVD (coronary artery disease, heart failure, myocardial infarction, stroke) or diabetes, physical strenuousness of work, accelerometer wear time, and MVPA.

*Significant association at level $P < 0.05$.

**Significant association at level $P < 0.001$.

SB, sedentary behavior; LDL, low-density lipoprotein; HDL, high-density lipoprotein.

TABLE 4. Associations of SB and sitting variables with serum lipids and lipoproteins according to linear regression analyses ($N = 3272$).

SB or Sitting Models	Total Cholesterol		HDL Cholesterol		LDL Cholesterol		Total/HDL Cholesterol Ratio		LDL/HDL Cholesterol Ratio		Triglycerides	
	R^2	β (95% CI)	R^2	β (95% CI)	R^2	β (95% CI)	R^2	β (95% CI)	R^2	β (95% CI)	R^2	β (95% CI)
Model 1	0.060**		0.266**		0.133**		0.349**		0.302**		0.293**	
MVPA, min·d^{-1}		−0.005 (−0.013 to 0.003)		0.019 (0.010 to 0.029)**		−0.018 (−0.030 to −0.006)*		−0.025 (−0.035 to −0.014)**		−0.037 (−0.053 to −0.021)**		−0.040 (−0.059 to −0.021)**
Sedentary time, min·d^{-1}		0.036 (0.000 to 0.072)*		−0.116 (−0.160 to −0.071)**		0.109 (0.055 to 0.164)**		0.151 (0.104 to 0.199)**		0.225 (0.153 to 0.297)**		0.280 (0.195 to 0.366)**
Model 2	0.060**		0.264**		0.132**		0.346**		0.299**		0.286**	
MVPA, min·d^{-1}		−0.007 (−0.015 to 0.000)		0.026 (0.016 to 0.035)**		−0.024 (−0.035 to −0.012)**		−0.033 (−0.043 to −0.022)**		−0.049 (−0.065 to −0.033)**		−0.054 (−0.072 to −0.035)**
Time spent in 15–29.99 min SB bouts, min·d^{-1}		0.020 (−0.001 to 0.042)		−0.053 (−0.079 to −0.027)**		0.057 (0.025 to 0.090)*		0.073 (0.045 to 0.102)**		0.110 (0.067 to 0.153)**		0.081 (0.030 to 0.133)*
Model 3	0.060**		0.263**		0.131**		0.344**		0.297**		0.290**	
MVPA, min·d^{-1}		−0.006 (−0.014 to 0.002)		0.022 (0.012 to 0.032)**		−0.020 (−0.032 to −0.008)*		−0.028 (−0.038 to −0.017)**		−0.042 (−0.057 to −0.026)**		−0.045 (−0.064 to −0.026)**
Time spent in ≥30 min SB bouts, min·d^{-1}		0.007 (−0.002 to 0.016)		−0.018 (−0.030 to −0.007)*		0.021 (0.007 to 0.035)*		0.025 (0.013 to 0.038)**		0.040 (0.021 to 0.058)**		0.058 (0.035 to 0.080)**
Model 4	0.062**		0.262**		0.129**		0.342**		0.267**		0.284**	
MVPA, min·d^{-1}		−0.007 (−0.014 to 0.001)		0.025 (0.015 to 0.034)**		−0.022 (−0.034 to −0.010)**		−0.031 (−0.041 to −0.021)**		−0.047 (−0.062 to −0.031)**		−0.051 (−0.070 to −0.032)**
Sitting time, min·d^{-1}		−0.005 (−0.024 to 0.014)		−0.032 (−0.056 to −0.009)*		0.012 (−0.018 to 0.041)		0.027 (0.001 to 0.052)*		0.044 (0.026 to 0.083)*		−0.002 (−0.048 to 0.044)
Model 5	0.062**		0.262**		0.129**		0.342**		0.295**		0.285**	
MVPA, min·d^{-1}		−0.007 (−0.015 to 0.001)		0.025 (0.015 to 0.035)**		−0.023 (−0.035 to −0.011)**		−0.032 (−0.042 to −0.022)**		−0.048 (−0.064 to −0.032)**		−0.052 (−0.071 to −0.033)**
Time spent in 15–29.99 min sitting bouts, min·d^{-1}		0.003 (−0.009 to 0.016)		−0.018 (−0.034 to −0.003)*		0.013 (−0.006 to 0.032)		0.021 (0.005 to 0.038)*		0.031 (0.006 to 0.056)*		0.011 (−0.019 to 0.041)

Adjusted for sex, employment status, marital status, educational level, smoking, alcohol consumption (heavy user), waist circumference (abdominal obesity), diagnosis or medication for CVD (coronary artery disease, heart failure, myocardial infarction, stroke) or diabetes, accelerometer wear time, and MVPA.

*Significant association at level $P < 0.05$.

**Significant association at level $P < 0.001$.

MVPA, moderate-to-vigorous physical activity; SB, sedentary behavior; LDL, low-density lipoprotein; HDL, high-density lipoprotein.

bouts of 15–29.99 and ≥30 min were inversely associated with total/HDL and LDL/HDL cholesterol ratios, HDL and LDL cholesterols, and triglycerides. Sitting time and time spent in sitting bouts of 15–29.99 min were inversely associated with HDL cholesterol related biomarkers. MVPA time was consistently associated with all serum lipid and lipoprotein levels besides total cholesterol among the whole study sample (Table 4).

Total sedentary time and time spent in SB bouts of ≥30 min were inversely associated with HDL and LDL cholesterol, total/HDL and LDL/HDL cholesterol ratios, and triglycerides in the low activity group (Table 3). In addition, time spent in SB bouts of 15–29.99 min was inversely associated with total/HDL and LDL/HDL cholesterol ratios in the low activity group. Total sedentary time was inversely associated with HDL cholesterol and total/HDL cholesterol ratio, and time spent 15–29.99 min SB bouts was inversely associated with HDL cholesterol, total/HDL ratio LDL/HDL cholesterol ratios, and triglycerides in the moderate activity group. Sedentary time and time spent in SB bouts of 15–29.99 and ≥30 min were inversely associated with HDL cholesterol and LDL/HDL cholesterol ratio in the high activity group. MVPA time was most consistently associated with total/HDL and LDL/HDL cholesterol ratios and triglycerides in the low activity group (Supplementary File 1, Supplemental Digital Content 1, Associations of Sedentary Behavior and Sitting Variables with Serum Lipids and Lipoproteins in the Low, Moderate, and High Activity Groups, http://links.lww.com/MSS/C549). However, MVPA time was not associated with any serum lipid and lipoprotein biomarkers in the moderate and low activity groups.

According to the linear regression analyses, the SB variables significantly associated with serum lipid biomarkers were most often the total SB time (min·d^{-1}) and the time spent in SB bouts of 15–29.99 min (min·d^{-1}) and ≥30 min (min·d^{-1}). These SB variables were entered into ROC analyses to investigate the threshold values for the harmful amount of SB. The results of ROC analyses are presented in Supplementary File 2 (see Appendix, Supplemental Digital Content 2, ROC Curves and Thresholds of Total Sedentary Time and Time Spent in SB Bouts, http://links.lww.com/MSS/C550). Among the total study population, the total SB time and the time spent in SB bouts of ≥30 min had higher AUC values for total/HDL cholesterol ratio, LDL/HDL cholesterol ratio, and triglycerides (AUC = 0.59–0.60) than the time spent in SB bouts of 15–29.99 min (AUC = 0.52–0.54).

DISCUSSION

The results of this population-based study showed that the accumulation patterns of overall SB and sitting and their associations with serum lipid biomarkers varied among MVPA groups. The patterns of overall SB were more consistently associated with serum lipid biomarkers than those of sitting. Total sedentary time and time spent in SB bouts of ≥30 min were most consistently associated with impaired lipid metabolism among the adults who did not meet the recommended minimum amount (150–300 min·wk^{-1}) of MVPA. More total sedentary time and time spent in SB bouts of 15–29.99 min were detrimentally associated with serum lipid biomarkers in middle-age adults meeting the lower recommended limit (150–300 min·wk^{-1}) of MVPA. In addition, total sedentary time and time spent in SB bouts of 15–29.99 and ≥30 min were inversely associated with serum lipid biomarkers among the middle-age adults meeting the higher limit (>300 min·wk^{-1}) of MVPA.

In line with the existing literature (4,6,13,34,35), we found that the times spent in SB and prolonged sedentary bouts were unfavorably associated with cardiometabolic health. However, these relationships were dependent on the MVPA group. More total MVPA time had a favorable association with lipid metabolism in the low activity group but not among the moderate or high activity groups. However, more time spent in SB and prolonged SB bouts were associated with unfavorable serum lipid and lipoprotein levels in the moderate and high activity groups. Our results support previous studies that have shown that health risks related to high volumes of SB can be attenuated by increasing MVPA or decreasing total SB time or time spent in prolonged SB bouts, especially among the least physically active adults (4,35–37). Recently, reallocating sedentary time to LPA or MVPA was found to be favorably associated with both glucose and lipid metabolism in the same study population as this study (38).

Few previous studies have investigated the associations of sedentary time and prolonged SB bouts with cardiometabolic health at different MVPA levels. The low PA level combined with high sedentary time has been reported to be unfavorably associated with cardiometabolic health (39). On the contrary, the risks of metabolic syndrome and type 2 diabetes have been shown to be greatest in the 40- to 75-yr adults characterized by low cardiorespiratory fitness regardless of MVPA or SB level. However, higher sedentary time was associated with metabolic syndrome and type 2 diabetes even in adults with high cardiorespiratory fitness (40).

In this study, the risk of unfavorable serum lipid and lipoprotein levels was increased by the total sedentary time of approximately 582.5 min·d^{-1} and the time spent in SB bouts of ≥30 min (approximately 190 min·d^{-1}). Although these thresholds provided limited accuracy, they are supporting the results of previous studies proposing several thresholds between 6 and 10 h·d^{-1} for limiting the amount of total sedentary time (10). In the meta-analysis of nine prospective cohort studies, the increased risk of CVD was associated only with very high levels (>10 h·d^{-1}) of SB after adjustment for PA and other CVD risk factors (8). On the contrary, the risk of all-cause and CVD mortality has been reported to increase even with 6–8 h of daily sitting (41).

As far as we know, no previous research has investigated the associations of overall SB and sitting separately with serum lipid biomarkers in a free-living environment over a long measurement period. Our results revealed more consistent associations between the serum lipid biomarkers and the patterns of overall SB than those of sitting. However, some of these different relationships involving overall SB and sitting may be explained by the fact that the total time spent in overall SB was

greater and accumulated in longer bouts than sitting. Nevertheless, several studies have investigated sitting posture in office workplaces, and strong evidence shows that replacing sitting with standing or ambulatory activities is associated with improvements in cardiometabolic health risk biomarkers (42,43).

The strengths of this study were the relatively large population-based study sample, the 2-wk monitoring of PA and SB using accelerometry, and the use of raw accelerometer data and the ML-based signal-processing method. In addition, the patterns of SB and sitting were evaluated separately in different MVPA groups. However, this study had some limitations. Participants providing valid PA data seemed to smoke less, consume less alcohol, and have more preferable body composition and lower rate of CVD or diabetes compared with those not providing valid PA data, which might induce some selection bias. The accelerometer was worn during waking hours. Considering the existing literature suggesting an interconnection between sleep and other daily activities (38), this may be a limitation. The MVPA groups used in this study could contain varying proportions of MPA and VPA, and the role of these two activity intensities in explaining lipid metabolism separately remains unclear. All kinds of standing were classified as LPA, which may be considered as a limitation. In addition, LPA time or the behavioral characteristics (e.g., watching TV, computer work, transportation) of SB were not studied. Given the cross-sectional study design, causal interactions could not be determined. The results of this study cannot be generalized to more diverse populations because the study participants had the same ethnic background and were of the same age. Further studies with more heterogeneous study samples, longitudinal study designs, and different health outcomes are needed to better understand the significance of the patterns of SB with cardiovascular health.

CONCLUSIONS

This population-based study was the first to investigate the associations of the patterns of SB and sitting separately with serum lipid biomarkers at different MVPA groups in free-living conditions using accelerometry. There were more consistent associations between the serum lipid biomarkers and the patterns of SB than those of sitting. More total sedentary time and time spent in SB bouts of 15–29.99 and ≥30 min were associated with impaired lipid metabolism in the low and high MVPA groups. Among the moderate MVPA group, total sedentary time and time spent in SB bouts of 15–29.99 min were unfavorably associated with serum lipid and lipoproteins levels. More total MVPA time was favorable associated with lipid metabolism among those with the least MVPA but not among those meeting the recommended levels of MVPA. Because the associations between SB patterns and lipid metabolism were dependent on MVPA level, this should be considered when planning evidence-based interventions to decrease SB in midlife.

The authors thank all cohort members, researchers, and study nurses who participated in the 46-yr follow-up study. They also acknowledge the work of the NFBC project center. NFBC1966 received financial support from the University of Oulu (grant number 24000692), the Oulu University Hospital (grant number 24301140), and the European Regional Development Fund (ERDF) (grant number 539/2010 A31592). The study was supported by the Ministry of Education and Culture (grant numbers OKM/86/626/2014, OKM/43/626/2015, OKM/17/626/2016, OKM/54/626/2019, OKM/85/626/2019, and OKM/1096/626/2020) and the Northern Ostrobothnia Hospital District. This research is also connected to the DigiHealth-project, a strategic profiling project at the University of Oulu, which is supported by the Academy of Finland (project number 326291) and the University of Oulu. The funders played no role in designing the study, collecting, analyzing, and interpreting the data, or writing the manuscript.

The authors declare no conflicts of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

REFERENCES

1. Guthold R, Stevens GA, Riley LM, Bull FC. Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1.9 million participants. *Lancet Glob Health*. 2018;6(10):e1077–86.
2. WHO guidelines on physical activity and sedentary behaviour. Geneva: World Health Organization; 2020.
3. Lavie CJ, Ozemek C, Carbone S, Katzmarzyk PT, Blair SN. Sedentary behavior, exercise, and cardiovascular health. *Circ Res*. 2019; 124(5):799–815.
4. Stamatakis E, Gale J, Bauman A, Ekelund U, Hamer M, Ding D. Sitting time, physical activity, and risk of mortality in adults. *J Am Coll Cardiol*. 2019;73(16):2062–72.
5. Katzmarzyk PT, Powell KE, Jakicic JM, Troiano RP, Piercy K, Tennant B. Sedentary behavior and health: update from the 2018 Physical Activity Guidelines Advisory Committee. *Med Sci Sports Exerc*. 2019; 51(6):1227–41.
6. Ekelund U, Tarp J, Steene-Johannessen J, et al. Dose–response associations between accelerometry measured physical activity and sedentary time and all-cause mortality: systematic review and harmonised meta-analysis. *BMJ*. 2019;366:l4570.
7. Lear SA, Hu W, Rangarajan S, et al. The effect of physical activity on mortality and cardiovascular disease in 130,000 people from 17 high-income, middle-income, and low-income countries: the PURE study. *Lancet*. 2017;390(10113):2643–54.
8. Pandey A, Salahuddin U, Garg S, et al. Continuous dose–response association between sedentary time and risk for cardiovascular disease: a meta-analysis. *JAMA Cardiol*. 2016;1(5):575–83.
9. Owen N, Healy GN, Dempsey PC, et al. Sedentary behavior and public health: integrating the evidence and identifying potential solutions. *Annu Rev Public Health*. 2020;41:265–87.
10. Stamatakis E, Ekelund U, Ding D, Hamer M, Bauman AE, Lee IM. Is the time right for quantitative public health guidelines on sitting? A narrative review of sedentary behaviour research paradigms and findings. *Br J Sports Med*. 2019;53(6):377–82.
11. Chastin SFM, Egerton T, Leask, Stamatakis E. Meta-analysis of the relationship between breaks in sedentary behavior and cardiometabolic health. *Obesity (Silver Spring).* 2015;23(9):1800–10.
12. Diaz KM, Howard VJ, Hutto B, et al. Patterns of sedentary behavior and mortality in U.S. middle-aged and older adults: a national cohort study. *Ann Intern Med*. 2017;167(7):465–75.
13. Bellettiere J, LaMonte MJ, Evenson KR, et al. Sedentary behavior and cardiovascular disease in older women: the objective physical activity and cardiovascular health (OPACH) study. *Circulation*. 2019; 139(8):1036–46.
14. Barone Gibbs B, Paley JL, Jones MA, Whitaker KM, Connolly CP, Catov JM. Validity of self-reported and objectively measured sedentary behavior in pregnancy. *BMC Pregnancy Childbirth*. 2020; 20(1):99.

15. Nelson MC, Taylor K, Vella CA. Comparison of self-reported and objectively measured sedentary behavior and physical activity in undergraduate students. *Meas Phys Educ Exerc Sci*. 2019;23(3): 237–48.
16. Jefferis BJ, Sartini C, Ash S, Lennon LT, Wannamethee SG, Whincup PH. Validity of questionnaire-based assessment of sedentary behaviour and physical activity in a population-based cohort of older men: comparisons with objectively measured physical activity data. *Int J Behav Nutr Phys Act*. 2016;13:14.
17. Wijndaele K, Westgate K, Stephens SK, et al. Utilization and harmonization of adult accelerometry data: review and expert consensus. *Med Sci Sports Exerc*. 2015;47(10):2129–39.
18. Farrahi V, Niemelä M, Kangas M, Korpelainen R, Jämsä T. Calibration and validation of accelerometer-based activity monitors: a systematic review of machine-learning approaches. *Gait Posture*. 2019;68:285–99.
19. Vähä-Ypyä H, Husu P, Suni J, Vasankari T, Sievänen H. Reliable recognition of lying, sitting, and standing with a hip-worn accelerometer. *Scand J Med Sci Sports*. 2018;28(3):1092–102.
20. Ellis K, Kerr J, Godbole S, Staudenmayer J, Lanckriet G. Hip and wrist accelerometer algorithms for free-living behavior classification. *Med Sci Sports Exerc*. 2016;48(5):933–40.
21. Tjurin P, Niemelä M, Huusko M, Ahola R, Kangas M, Jämsä T. Classification of physical activities and sedentary behavior using raw data of 3D hip acceleration. In: *EMBEC & NBC 2017: Joint Conference of the European Medical and Biological Engineering Conference (EMBEC) and the Nordic-Baltic Conference on Biomedical Engineering and Medical Physics (NBC)* (IFMBE Proceedings, 2018; 65:872–875). Tampere (Finland): Springer; 2018.
22. Edwardson CL, Henson J, Biddle SJH, et al. ActivPAL and ActiGraph assessed sedentary behavior and cardiometabolic health markers. *Med Sci Sports Exerc*. 2020;52(2):391–7.
23. Northern Finland Birth Cohort 1966 Web site [Internet]. University of Oulu. [cited 2021 May 5]. Available from: http://urn.fi/urn:nbn:fi:att:bc1e5408-980e-4a62-b899-43bec3755243
24. Sintonen H. The 15D instrument of health-related quality of life: properties and applications. *Ann Med*. 2001;33(5):328–36.
25. Program National Cholesterol Education. Third report of the National Cholesterol Education Program (NCEP) expert panel on detection, evaluation, and treatment of high blood cholesterol in adults (adult treatment panel III) final report. *Circulation*. 2002;106(25):3143–421.
26. Kiviniemi AM, Perkiömäki N, Auvinen J, et al. Fitness, fatness, physical activity, and autonomic function in midlife. *Med Sci Sports Exerc*. 2017;49(12):2459–68.
27. Prospective Studies Collaboration, Lewington S, Whitlock G, et al. Blood cholesterol and vascular mortality by age, sex, and blood pressure: a meta-analysis of individual data from 61 prospective studies with 55,000 vascular deaths. *Lancet*. 2007;370(9602):1829–39.
28. Millán J, Pintó X, Muñoz A, et al. Lipoprotein ratios: physiological significance and clinical usefulness in cardiovascular prevention. *Vasc Health Risk Manag*. 2009;5:757–65.
29. Tjurin P, Niemelä M, Kangas M, et al. Accelerometry-based characteristics of overall sedentary behavior and sitting in middle-aged adults. *Meas Phys Educ Exerc Sci*. 2019;23(3):249–57.
30. Chong J, Tjurin P, Niemelä M, Jämsä T, Farrahi V. Machine-learning models for activity class prediction: a comparative study of feature selection and classification algorithms. *Gait Posture*. 2021;89:45–53.
31. Vähä-Ypyä H, Vasankari T, Husu P, Suni J, Sievänen H. A universal, accurate intensity-based classification of different physical activities using raw data of accelerometer. *Clin Physiol Funct Imaging*. 2015;35(1):64–70.
32. Boerema ST, van Velsen L, Vollenbroek MM, Hermens HJ. Pattern measures of sedentary behaviour in adults: a literature review. *Digit Health*. 2020;6:2055207620905418.
33. Rosenberger ME, Fulton JE, Buman MP, et al. The 24-hour activity cycle: a new paradigm for physical activity. *Med Sci Sports Exerc* 2019;51(3):454–64.
34. Vasankari V, Husu P, Vähä-Ypyä H, et al. Association of objectively measured sedentary behaviour and physical activity with cardiovascular disease risk. *Eur J Prev Cardiol*. 2017;24(12):1311–8.
35. Mossavar-Rahmani Y, Hua S, Qi Q, et al. Are sedentary behavior and physical activity independently associated with cardiometabolic benefits? The Hispanic community health study/study of Latinos. *BMC Public Health*. 2020;20(1):1400.
36. Matthews CE, Moore SC, Sampson J, et al. Mortality benefits for replacing sitting time with different physical activities. *Med Sci Sports Exerc*. 2015;47(9):1833–40.
37. von Rosen P, Dohrn IM, Hagströmer M. Association between physical activity and all-cause mortality: a 15-year follow-up using a compositional data analysis. *Scand J Med Sci Sports*. 2020;30(1):100–7.
38. Farrahi V, Kangas M, Walmsley R, et al. Compositional associations of sleep and activities within the 24-h cycle with cardiometabolic health markers in adults. *Med Sci Sports Exerc*. 2021;53(2):324–32.
39. Huang BH, Hamer M, Chastin S, Pearson N, Koster A, Stamatakis E. Cross-sectional associations of device-measured sedentary behaviour and physical activity with cardio-metabolic health in the 1970 British cohort study. *Diabet Med*. 2021;38(2):e14392.
40. van der Velde JHPM, Schaper NC, Stehouwer CDA, et al. Which is more important for cardiometabolic health: sedentary time, higher intensity physical activity or cardiorespiratory fitness? *Diabetologia*. 2018;61(12):2561–9.
41. Patterson R, McNamara E, Tainio M, et al. Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. *Eur J Epidemiol*. 2018;33(9):811–29.
42. Winkler EAH, Chastin S, Eakin EG, et al. Cardiometabolic impact of changing sitting, standing, and stepping in the workplace. *Med Sci Sports Exerc*. 2018;50(3):516–24.
43. Graves LEF, Murphy RC, Shepherd SO, Cabot J, Hopkins ND. Evaluation of sit-stand workstations in an office setting: a randomised controlled trial. *BMC Public Health*. 2015;15:1145.