Scandinavian Journal of Medicine & Science in Sports

WILEY

ORIGINAL ARTICLE OPEN ACCESS

Associations of 24-h Movement Behaviors With Incidence of Cardiovascular Risk Factors: The Finnish Retirement and Aging Study

Kristin Suorsa[1,2] | Tuija Leskinen[1,2] | Jesse Pasanen[1,2] | Jaana Pentti[1,2,3] | Jussi Vahtera[1,2] | Sari Stenholm[1,2,4]

[1]Department of Public Health, University of Turku and Turku University Hospital, Turku, Finland | [2]Centre for Population Health Research, University of Turku and Turku University Hospital Turku, Turku, Finland | [3]Clinicum, Faculty of Medicine, University of Helsinki, Helsinki, Finland | [4]Research Services, Turku University Hospital and University of Turku, Turku, Finland

Correspondence: Kristin Suorsa (kristin.suorsa@utu.fi)

Received: 27 August 2024 | **Revised:** 20 December 2024 | **Accepted:** 8 February 2025

Funding: This study was supported by funding granted by the Research Council Finland (286294, 319246, 294154, 332030 to S.S.), Finnish Ministry of Education and Culture (to S.S.), Juho Vainio Foundation (to S.S. & K.S.), the State Research Funding (Turku University Hospital) (to S.S.), and Finnish Foundation for Cardiovascular Research (to S.S.). These funding bodies did not have a role in study design, collection, analysis, interpretation of data, writing the report, or the decision to submit the report for publication.

Keywords: 24-h time use | compositional data analysis | diabetes | dyslipidemia | hypertension | obesity

ABSTRACT

Low physical activity, high sedentary time (SED), and inadequate sleep increase cardiovascular disease risk, but the codependency between these 24-h movement behaviors has often been neglected. This study examined associations between 24-h movement behaviors and incidence of cardiovascular risk factors. The study included 866 adults (mean age 62.4 years, SD 1.1) from the Finnish Retirement and Aging study who participated in wrist-accelerometry measurements between 2014 and 2018. Incident register-based cardiovascular risk factors including hypertension, dyslipidemia, type 2 diabetes, and questionnaire-based obesity were followed up over on average 3-year follow-up. Compositional Cox regression models were adjusted for age, sex, occupation, smoking, and heavy alcohol consumption. We recorded 84 (17%) new cases of hypertension, 66 (9%) dyslipidemia, 28 (3%) type 2 diabetes, 43 (6%) obesity, and 94 (26%) any of these cardiovascular risk factors. Compared to mean composition (7.8 h sleep, 11.0 h SED, 4.2 h light physical activity [LPA], 60 min moderate-to-vigorous physical activity [MVPA]), having 10 min more MVPA at the cost of other behaviors was associated with 5%–7% risk reduction in hypertension, 10%–13% in obesity, and 6%–7% in any cardiovascular risk factor. Among the least active (sleep 7.9 h, SED 12.1 h, LPA 3.6 h, MVPA 24 min), the risk reductions were nearly twofold. In conclusion, when accounting the interdependence of movement behaviors, MVPA associated with highest risk reduction in hypertension and obesity, especially among the least active participants. This suggests that even a small increase in daily MVPA could help prevent development of cardiovascular risk factors.

1 | Introduction

Cardiovascular diseases (CVDs) are a leading cause of death worldwide [1]. One of the key modifiable health behaviors to reduce the risk of CVD is physical activity [2, 3]. A meta-analysis based on self-reported physical activity measures suggests that increasing the level of moderate-to-vigorous physical activity (MVPA) from inactive to the recommended 150 min/week lowers the risk of incident CVD by 17% to 25% among adults [2].

Physical activity reduces the risk of CVD by affecting cardiovascular risk factors; it reduces the risk of incident hypertension and type 2 diabetes in a dose–response manner [4, 5] and has a favorable effect on body weight and composition [6]. In addition to physical activity, also other movement behaviors accumulated within a 24-h day, that is sleep and sedentary time (SED), have been associated with cardiovascular risk factors. For example, higher SED links with higher incidence of type 2 diabetes [7]. However, detrimental health associations of SED may attenuate markedly with higher levels of MVPA [8]. In addition, replacing sedentary behavior with physical activity, even light physical activity (LPA), has been reported to reduce postprandial glucose and insulin based on experimental evidence [9] and to associate with a lower incidence of type 2 diabetes [10–12]. Short sleep duration (either < 6 h or < 7 h) has been found to associate with higher incidence of hypertension [13], type 2 diabetes [14], and obesity [15], and some studies suggest similar associations for long sleep (either > 8 h or > 9 h) [13, 14]. Collectively, these findings suggest that all movement behaviors accumulated during the 24-h day should be considered when examining cardiovascular health risk.

Given that increasing one behavior, for instance physical activity, inevitably leads to a compensatory effect of decreasing at least one of the remaining behaviors [16, 17], there has been a shift from examining movement behaviors in isolation from each other to a 24-h time-use perspective [17]. Consequently, an increasing number of studies have applied statistical methods to account for this codependency. The most common method has been compositional data analysis (CoDA) that treats movement behaviors as relative and codependent in nature [16, 17]. Large CoDA-based studies harmonizing device-based data on 24-h movement behaviors across several countries have reported that replacing other 24-h movement behaviors with MVPA is associated with more favorable levels of various cardiovascular indicators, that is, BMI, waist circumference, total:HDL cholesterol ratio, triglycerides, glycated hemoglobin (HbA1c), systolic and diastolic blood pressure, and HDL cholesterol [18, 19]. CoDA-based studies have also found that increase in MVPA in relation to the remaining behaviors (either all or only wake-time behaviors) associates with lower incidence of CVD [20–22], but knowledge of how 24-h movement behaviors are associated with the incidence of cardiovascular risk factors is scarce. Previous CoDA-based studies are limited to self-reported measures of 24-h movement behaviors [23, 24] and cross-sectional studies on cardiovascular indicators, (prevalent) dyslipidemia, obesity, and cardiovascular risk score [18, 19, 25–27], which increases the possibility of reverse causation affecting the earlier findings.

To address these gaps in previous literature, we applied CoDA to examine associations between 24-h movement behaviors and incidence of cardiovascular risk factors among late middle-aged adults with varying activity levels at a mean of 3-year follow-up.

2 | Methods

2.1 | Study Population

This study is based on the Finnish Retirement and Aging (FIREA) study, which is an ongoing longitudinal cohort study of older adults in Finland established in 2013 [28]. The eligible population for the FIREA study cohort included all public sector employees whose individual retirement date was between 2014 and 2019 and who were working in 2012 in one of the 27 municipalities in Southwest Finland or in the nine selected cities or five hospital districts around Finland. Information on individual retirement dates was obtained from Keva Public Sector Pensions, the pension insurance institute for the public sector in Finland. The FIREA study cohort members were first contacted 18 months prior to their estimated retirement date by sending them a questionnaire inquiring, for example, about work factors, health behaviors, and health and functioning. Thereafter, the FIREA cohort members were followed up with annual questionnaires. The FIREA study is conducted in line with the Declaration of Helsinki and has been approved by the Ethics Committee of Hospital District of Southwest Finland. The participants provided a written informed consent before participation.

For the current study, the study population was drawn from the FIREA activity and clinical substudies. Detailed description of the formation of the FIREA study cohort and its substudies have been published elsewhere [28]. Shortly, the eligible study population for the FIREA activity substudy included those Finnish-speaking FIREA cohort members who completed the first questionnaire while they were still working and whose estimated statutory retirement date was between 2016 and 2019 ($n = 2663$). These participants were contacted by mail to invite them to take part in the activity substudy, and of them, 908 (34% of the eligible) agreed and returned the written informed consent. Similarly, the eligible study population for the FIREA clinical substudy included those Finnish-speaking FIREA cohort members who completed the first questionnaire while they were still working, whose estimated retirement date was between 2017 and 2019 and who lived in Southwest Finland ($n = 773$). Of them, 290 (38% of the eligible) agreed to participate and returned the written informed consent.

In the present study, we included only those participants who allowed linkage to the national health registry, provided sufficient amount of accelerometer data (at least four valid measurement days, one valid workday, and one valid day off to represent a typical week), had information from all covariates, and did not have prevalent cardiovascular risk factors at the time of the accelerometer measurement. The formation of the analytical samples for different study outcomes is illustrated in Figure 1. This sample was followed up for register-based cardiovascular risk factors (hypertension, dyslipidemia, and type 2 diabetes) and questionnaire-based obesity from the day of the accelerometer measurement (measurements conducted between 2014 and 2018) until December 31, 2019. Register and cohort data were linked by the use of personal identification codes that for confidentiality purposes were then recoded into research identification codes to be used in the analyses.

2.2 | Assessment of 24-h Movement Behaviors

Triaxial ActiGraph wActiSleep-BT and wGT3X-BT accelerometers (ActiGraph, Pensacola, Florida, USA) were used to estimate the 24-h movement behaviors, that is, sleep, SED, LPA, and MVPA. Accelerometers were initialized to record at 80 Hz sampling frequency and mailed to the participants. Participants

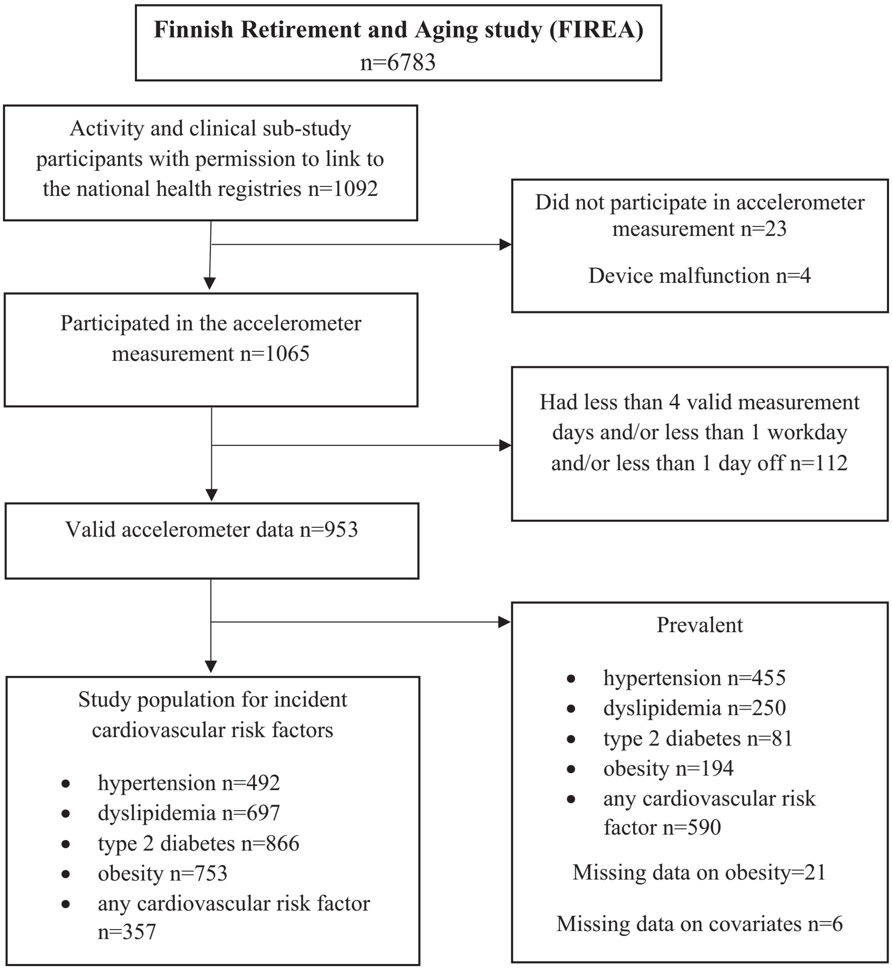

FIGURE 1 | Flow chart for the selection of the study populations for all outcomes.

were asked to wear the device on their nondominant wrist for seven consecutive days and nights at all times, including water-based activities. Participants were also provided a participant log, where they were asked to record the date, waking time, bedtime, and working times on each measurement day. Data from the accelerometers were downloaded in the ActiLife software, version 6.13 (ActiGraph, Pensacola, Florida, USA). The accelerometer data collection was conducted between September 2014 and May 2018 during all four seasons (26% spring, 16% summer, 27% autumn, and 32% winter).

The accelerometer data were processed using previously reported methods [29]. Shortly, the R-package GGIR version 1.7-1 [30] was used to estimate 24-h movement behaviors, after detecting and excluding nonwear time. Sleep time was detected based on the combination of the daily logs and algorithm of the GGIR package, so that sleep was defined as periods of time within the bedtime and waking times reported in the daily logs during which there was no change larger than 5° in the arm angle over at least 5 min. Wake time SED, LPA, and MVPA were defined using the threshold values of < 30 mg, at least 30 mg but less than 100.6 mg, and ≥ 100.6 mg, respectively [29].

The measurement day was determined from each measurement day's bedtime to the next measurement day's bedtime. The analyses were restricted to valid measurement days with at least 10 h of waking wear time. No specific restrictions were made regarding night duration. The average duration of each valid measurement day (from bedtime to bedtime) was 23.6 h (range 18.3–28.8, interquartile range [IQR] 23.4–23.9). Weekly compositional means of time spent in each behavior were calculated and scaled to be proportional to 24-h day.

2.3 | Assessment of Cardiovascular Risk Factors

For the cardiovascular risk factors examined as outcomes, data on hypertension, dyslipidemia, and type 2 diabetes were obtained from the national health registers. To identify cases of hypertension, dyslipidemia, and type 2 diabetes, we used prescription data on purchases of antihypertensive medication, lipid-lowering medication (statins), and antidiabetic medication (data available from 1994 to 2019), respectively, as described previously [31, 32]. Those participants who had become eligible for special reimbursement for antihypertensive or type 2 diabetes treatment (data available from 1980 to 2019), or who had purchased antihypertensive, lipid-lowering, or type 2 diabetes medication for the first time after the accelerometer measurement, were considered as incident cases of hypertension, dyslipidemia, or type 2 diabetes [31, 32]. Participants with corresponding purchases before the accelerometer measurement were considered as prevalent cases and excluded from the study.

Incident obesity was defined as body mass index (BMI) ≥ 30 kg/m^2 based on self-reported body weight and height collected in annual postal-delivered questionnaires [33]. Participants with obesity at the baseline questionnaire preceding the accelerometer measurement were considered as prevalent cases and excluded from the study.

Any incident cardiovascular risk factor was defined as at least one of the cardiovascular risk factors examined (hypertension, dyslipidemia, type 2 diabetes, or obesity), and all prevalent cases of hypertension, dyslipidemia, type 2 diabetes, and obesity were excluded for analyses of any incident cardiovascular risk factor.

2.4 | Assessment of Participant Characteristics

Gender, date of birth, and occupational title were obtained from the Keva Public Sector Pensions register. Participants were divided into two groups according to their occupational titles of the last known occupation preceding retirement by using the International Standard Classification of Occupations (ISCO): manual workers (for instance, practical nurses, cooks, cleaners, maintenance workers; ISCO classes 5–9) and nonmanual workers (for instance, teachers, physicians, registered nurses, technicians; ISCO classes 1–4).

Other participant characteristics were obtained from the baseline questionnaire. Marital status was categorized as single or married/cohabiting. Self-reported leisure time physical activity was assessed with a question on average weekly duration and intensity of leisure and commuting physical activity during the past year, and metabolic equivalent (MET) hours per week were calculated. Behavioral cardiovascular risks, including heavy alcohol consumption and current smoking, were defined based on the questionnaire responses. Heavy alcohol consumption was indicated by self-reported average consumption of more than 288 g/week of pure alcohol for men and 192 g/week for women [34]. Self-reported smoking status was dichotomized into current smoker and current nonsmoker. Self-reported health was assessed with a 5-point scale (1 = *good*, ..., 5 = *poor*) and was then categorized as *good/rather good* (1–2) and *average/poor* (3–5) health.

2.5 | Statistical Analyses

Descriptive information on participant characteristics is presented using means and standard deviations for continuous variables and frequencies and percentages for categorical variables. To examine the selection to the current study, the participant characteristics were compared between the current study population providing valid accelerometer data ($n = 953$) and those FIREA study participants who responded only to the survey ($n = 3291$) using chi-squared test for categorical variables and ANOVA for continuous variables.

The 24-h movement behavior data were treated as compositional data, normalized to 24 h per day. The statistical analyses were conducted using the R software (version 4.3.1, R Foundation for Statistical Computing, Vienna, Austria) using "compositions," "robCompositions," and "survival" packages and the SAS software (v.9.4 SAS Institute, Cary, NC, USA). The dataset included four zero values for weekly mean of MVPA. Given that zeros cannot be included in CoDA, these values were imputed close to 1 min using the R package robCompositions. An isometric logratio (ilr) transformation was used to map the compositional data into real-valued coordinates, which reduces the dimensionality of the data and allows standard statistical methods to be used [17]. We used *pivot coordinates*, the specific type of *ilr* coordinates, that are a set of *ilrs* where the first coordinate enables one part of the composition (for instance sleep) to be considered relative to the remaining parts of the composition (i.e., SED, LPA, and MVPA), resulting in four sets of pivot coordinates [16, 18]. The description of the formation of the ilr coordinates is presented in Table S1.

To examine the association of 24-h movement behavior composition with incidence of cardiovascular risk factors, Cox proportional hazards models for each movement behavior were used to estimate hazard ratios (HRs) and 95% confidence intervals (CIs) per one unit increase in *ilr* coordinates. In each model, three *ilr* coordinates were entered as separate variables along with covariates. Model 1 was adjusted for sex and age, while Model 2 was additionally adjusted for occupation and risky health behaviors (smoking or heavy alcohol consumption).

To illustrate how the risk of any incident cardiovascular risk factors varied between different 24-h movement behavior compositions, the previously described Cox Regression Model 2 (adjusted for sex, age, occupation, and risky health behaviors) was used to estimate HRs for simulated 24-h movement behavior compositions ranging within the values observed in the study sample. The mean 24-h movement behavior composition among the large study sample providing valid accelerometer data ($n = 953$) was used as the reference. The mean 24-h movement behavior composition included 7.8 h sleep, 11.0 h SED, 4.2 h LPA, and 60 min MVPA. The resulting compositions were visualized as heat map ternary plots.

To further aid the interpretation of the findings, the compositional isotemporal substitution model [35] was used to estimate the effect of theoretical reallocations between 24-h movement behaviors on the risk of incident individual and any cardiovascular risk factors. Again, the mean 24-h movement behavior composition (sleep 7.8 h, SED 11.0 h, LPA 4.2 h, and MVPA 60 min) was used as the reference and HR and 95% CI was predicted based on the Cox Regression Model 2. The size of the reallocations was set to range in 10-min increments from 10 min to 60 min, except for reallocations from MVPA to other movement behaviors, where the maximum reallocation amount was set to be below the mean MVPA level (60 min) to avoid reducing MVPA to zero. Additionally, to examine how the theoretical effects depend on the baseline level of MVPA, the mean 24-h movement behavior composition of the lowest tertile of MVPA (sleep 7.9 h, SED 12.1 h, LPA 3.6 h, and MVPA 24 min) was used as a reference and HRs and 95% CIs were predicted for this group as well.

Finally, as a sensitivity analysis, to account for potential reverse causation, Cox proportional hazard models were repeated after excluding cases occurring during the first year of the follow-up ($n = 9$–34). Moreover, given that the association between sleep and cardiovascular risk factors may be U-shaped [13, 14], we tested the interaction between the first ilr coordinate (e.g., one behavior in relation to the remaining behaviors) and three-level indicator of the sleep level. Sleep was categorized to (1) "short sleep," that is, < 7 h of sleep per night; (2) "sufficient sleep," that is, between 7 and 9 h of sleep per night; and (3) "long sleep," that is, more than 9 h of sleep per night based on the latest recommendations on healthy sleep range [36]. Interactions were significant for incident hypertension and any of the cardiovascular risk factors examined; thus, we conducted sensitivity analyses by excluding short and long sleepers. To account for the possible effect of total accelerometer wear time per measurement day (from bedtime to bedtime) on the results, we also conducted a sensitivity analysis taking into the mean total accelerometer wear time per measurement day in the age- and sex-adjusted models.

3 | Results

Baseline characteristics of the study populations are presented in Table 1. A majority of the participants were women (84%–87%) and nonmanual workers (67%–69%). Less than one-tenth had risky health behaviors (heavy alcohol consumption and/or smoking). During the follow-up, 84 (17%) cases of new-onset hypertension, 66 (9%) dyslipidemia, 28 (3%) type 2 diabetes, and 43 (6%) obesity were recorded. Among the risk-factor free participants ($n = 355$), 94 (26%) incident cases of any of these cardiovascular risk factors were recorded. The follow-up times for each outcome varied slightly and are shown in Table 1. The current study population was slightly younger, leaner, included more nonmanual workers, and reported more physical activity, less risky health behaviors, and better health compared with the FIREA survey-only study population (Table S2).

Figure 2 illustrates the risk of any incident cardiovascular risk factor across different 24-h movement behavior compositions, using the mean 24-h movement behavior composition as a reference (marked in the figure as black triangle). Different combinations of 24-h movement behaviors seemed to produce similar risk reductions (Figure 2A–D, green areas). However, the proportion of MVPA in relation to the remaining behaviors appeared to be the dominant behavior in reducing risk. Lower MVPA in relation to the remaining behaviors resulted in higher risk, whereas lower risks were observed with higher MVPA (Figure 2A–C).

Higher MVPA in relation to the remaining behaviors was associated with a lower risk of incident hypertension, obesity, and any cardiovascular risk factor, whereas no associations were observed for incident dyslipidemia or type 2 diabetes (Table S3). Figure 3 illustrates the theoretical effects of reallocating time between MVPA and the remaining behaviors, using the mean 24-h movement behavior composition as a reference (sleep 7.8 h, SED 11.0 h, LPA 4.2 h, and MVPA 60 min). The estimates and their CIs are given in Table S4. Compared to the mean 24-h movement behavior composition, having 10 min less MVPA and 10 min more sleep, SED, or LPA was associated with 7%–9% higher risk of incident hypertension, 13%–17% higher risk of incident obesity, and 7%–9% higher risk of any incident cardiovascular risk factor. In contrast, having 10 min more MVPA

TABLE 1 | Baseline characteristics of the participants included in different cardiovascular risk factor outcome analyses.

	Hypertension $n = 492$	Dyslipidemia $n = 697$	Type 2 diabetes $n = 866$	Obesity $n = 749$	Any cardiovascular risk factor $n = 355$
Follow-up time (years), mean (SD)	3.0 (1.2)	3.3 (1.0)	3.3 (1.0)	3.3 (0.7)	2.8 (1.2)
Age (years), mean (SD)	62.4 (1.1)	62.4 (1.1)	62.4 (1.1)	62.4 (1.1)	62.4 (1.0)
Women, *n* (%)	411 (84)	604 (87)	736 (85)	634 (85)	306 (86)
Occupation, *n* (%)					
Nonmanual	330 (67)	479 (69)	591 (68)	517 (69)	240 (68)
Manual	162 (33)	218 (31)	275 (32)	232 (31)	115 (32)
Risky health behavior[a], *n* (%)	37 (8)	49 (7)	66 (8)	56 (7)	26 (7)
Incident cases, *n* (%)	84 (17)	66 (9)	28 (3)	43 (6)	94 (26)
Number of valid accelerometer measurement days, mean (IQR)	7.5 (7–8)	7.5 (7–8)	7.5 (7–7)	7.5 (7–7)	7.6 (7–8)
Compositional mean, sleep (h), SED (h), LPA (h), and MVPA (min)	7.8, 10.8, 4.3, 64	7.8, 11.0, 4.2, 60	7.8, 11.0, 4.2, 60	7.8, 10.9, 4.3, 63	7.8, 10.7, 4.4, 66

[a]Including current smoking or heavy alcohol consumption.

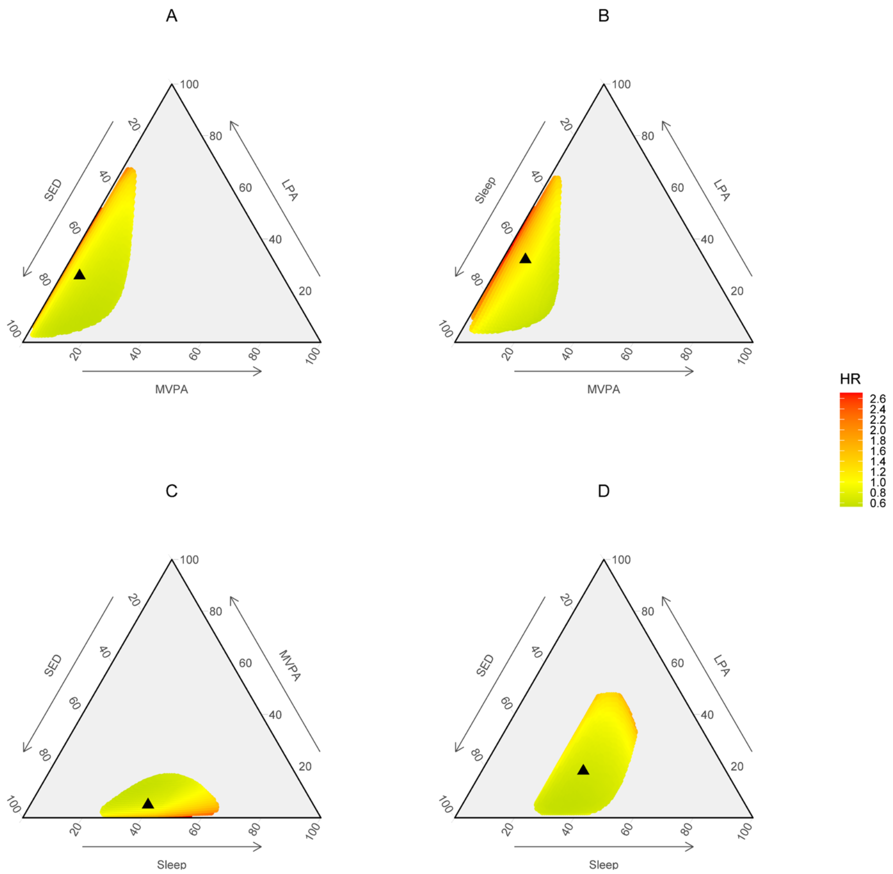

FIGURE 2 | Heat map ternary plots (A-D) illustrating the association of 24-h movement behaviors with the incidence of any cardiovascular risk factor (hypertension, dyslipidemia, type 2 diabetes, or obesity) compared to the mean 24-h movement behavior composition used as the reference composition (sleep 7.8 h, SED 11.0 h, LPA 4.2 h, and MVPA 60 min), indicated as black triangle. Range of proportions of 24-h movement behaviors reflects observed data in the study sample and color scale hazard ratios (HRs).

and 10 min less sleep, SED, or LPA was associated with 5%–7% reduction in the risk of incident hypertension, 10%–13% risk reduction in incident obesity, and 6%–7% risk reduction in any incident cardiovascular risk factor.

Regarding other 24-h movement behaviors, longer sleep time in relation to the remaining behaviors was associated with a lower incidence of type 2 diabetes, whereas higher SED and LPA were associated with higher incidence (Table S3). The theoretical effects of reallocating time between sleep, SED and LPA, and the remaining behaviors are illustrated in Figures S1–S3. Both replacing SED or LPA with sleep, and replacing SED with MVPA were associated with a lower risk (Figures S1–S3). Reallocations between sleep and MVPA were not associated with significant changes in the risk (Table S4). For instance, replacing 10 min of SED or LPA with sleep was associated with 10% lower risk and replacing SED with MVPA with 8% lower risk of incident type 2 diabetes. However, these results should be interpreted with caution due to small event rate for type 2 diabetes.

Finally, to examine the benefit of increasing physical activity among the least active participants in the current study population, theoretical effects of time reallocations using the mean 24-h movement behavior composition among the lowest MVPA tertile as a reference were calculated (Figure S4). Compared to the mean 24-h movement behavior composition (sleep 7.9 h, SED 12.1 h, LPA 3.6 h, and MVPA 24 min), having 10 min more MVPA and 10 min less sleep, SED, or LPA was associated with 12%–14% reduction in the risk of incident hypertension, 22%–24% of incident obesity, and 13%–14% of any incident cardiovascular risk factor.

A sensitivity analysis excluding incident cases occurring during the first year of the follow-up did not alter interpretation of the main results (Table S5). After excluding short sleepers, longer sleep relative to the remaining behaviors was associated with a higher incidence of hypertension, whereas higher SED was associated with a lower incidence of hypertension (Table S6). In contrast, excluding long sleepers did not change interpretation of the findings (Table S7). Additional adjustment for the total accelerometer wear time per measurement day did not change interpretation of the results (Table S8).

4 | Discussion

This study among 60-year-old adults demonstrated that higher amount of MVPA in relation to the remaining behaviors was associated with a lower incidence of hypertension and obesity at a mean of 3-year follow-up. Lower incidence of any cardiovascular risk factor (hypertension, dyslipidemia, type 2 diabetes, or obesity) was also observed among risk-factor free individuals.

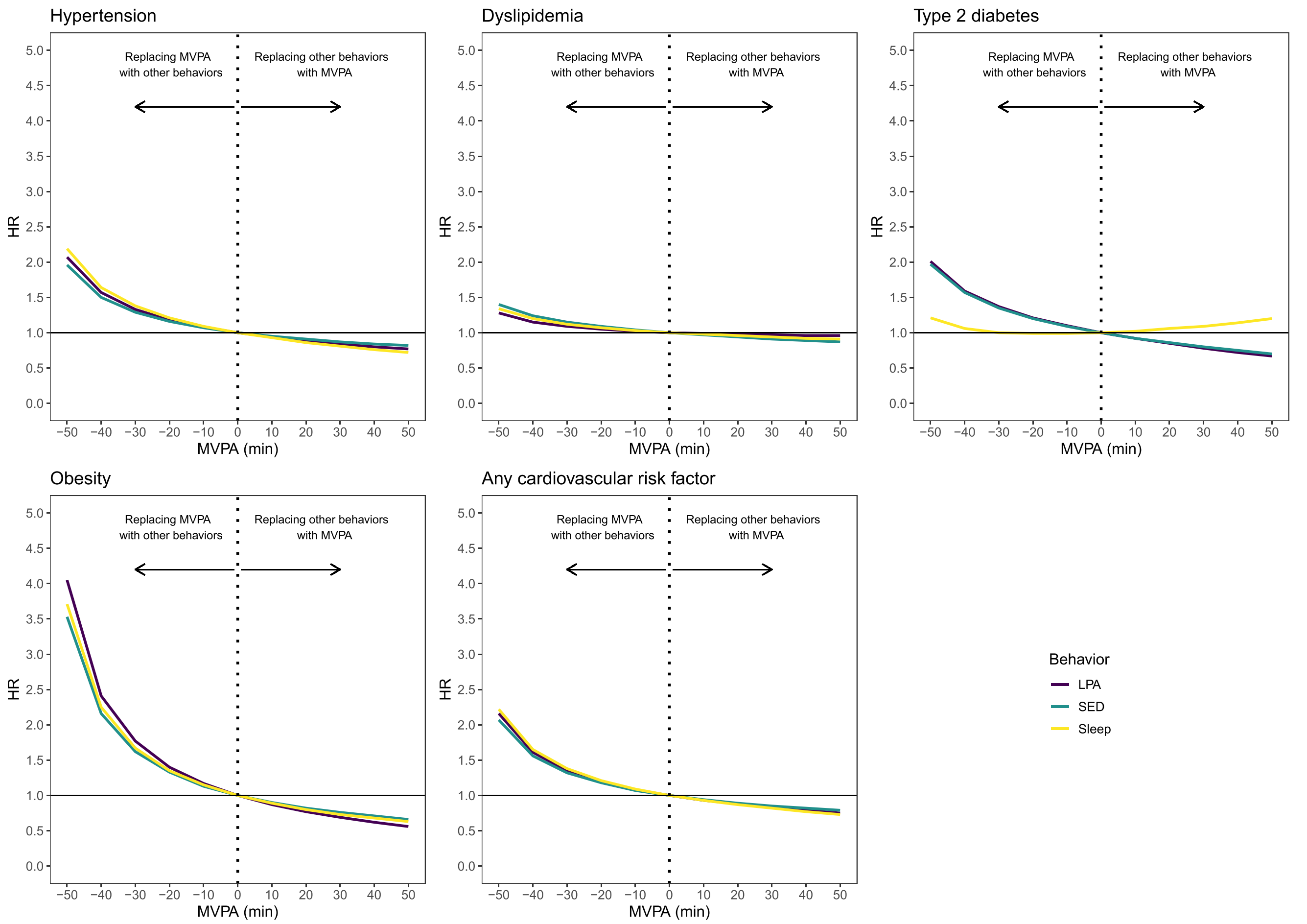

FIGURE 3 | Hazard ratios (HRs) of incident individual and any cardiovascular risk factor for theoretical time reallocations between MVPA and sleep, SED, and LPA. Dashed line represents the mean 24-h movement behavior composition used as the reference composition (sleep 7.8 h, SED 11.0 h, LPA 4.2 h, and MVPA 60 min).

No significant associations were found for dyslipidemia. There was some indication that more sleep and less SED and LPA may be associated with a lower risk of incident type 2 diabetes.

Our findings broaden previous knowledge from the CoDA-based cross-sectional studies on the association between device-measured 24-h movement behaviors, cardiovascular indicators [18, 19], and prevalent cardiovascular risk factors [25–27] as well as prospective studies that have used self-reports to estimate 24-h movement behaviors [23, 24]. Our findings are in line with large cross-sectional harmonization studies showing that reallocating time from other movement behaviors to MVPA is associated with lower BMI [18] and systolic and diastolic blood pressure [19]. Our study also aligns with a previous prospective device-based study among middle-aged adults from the United States, suggesting that reallocating time from SED or LPA to MVPA was associated with lower odds of cardiovascular risk and/or functional burden (defined as ≥ 2 risk factors including hypertension, hypercholesterolemia, type 2 diabetes, reduced kidney function, and/or reduced physical functioning and depressive symptoms) 10 years later [37]. However, unlike in the current study, the study of Full et al. [37] did not consider sleep, and they did not use compositional isotemporal substitution analysis, accounting for the codependency between movement behaviors [35].

We observed that the risk of incident hypertension and obesity associated with decreasing MVPA was substantially larger in absolute terms compared to the risk reduction associated with increasing MVPA. This commonly reported asymmetry was particularly pronounced in the case of obesity. This is consistent with the exercise physiology principles implicating that deconditioning begins rapidly when physical activity levels drop, but it takes much more time to improve health/fitness by exercise overload [16, 38].

An important observation was that among the least active adults, the benefits of increasing MVPA are larger than in the general population. Our findings suggest that the risk reduction in hypertension, obesity, and any of these cardiovascular risk factors associated with having 10 min more MVPA was nearly twofold, when MVPA was increased from the lowest level observed in the current study population (24 min/day) in comparison to the mean level (60 min per day). These findings are consistent with a previously observed curvilinear association between device-measured MVPA and incident CVD [20, 39]. For instance, in the device-based study by Yerramalla et al. [20] involving 70-year-olds adults from the Whitehall II study (from the UK), theoretical risk reductions in incident CVD associated with a 10-min increase in MVPA were 13% among those with 10 min of MVPA compared to 6% among those with 30 min of MVPA.

Recent findings related to all-cause mortality [40] suggest that different combinations of 24-h movement behaviors associate with similar reductions in health risks (for instance, similar risk reduction could be achieved by replacing small amounts of SED with MVPA without changing LPA or high amounts of SED with LPA without changing MVPA). Some implications toward this were also seen in our heat map ternary plots. However, our study and the study of Yerramalla et al. [20] underline that MVPA seems to be the dominant behavior associated with incidence of cardiovascular risk factors and CVD, while varying proportions of sleep, SED, and LPA did not seem to associate with notable changes in the risks.

The role of 24-h movement behaviors in preventing incidence of type 2 diabetes seems to be more complex. Theoretically, replacing SED with MVPA was associated with a lower incidence of type 2 diabetes, but similar associations were also observed for replacing SED or LPA with sleep. However, these findings should be interpreted with caution due to low incidence of type 2 diabetes in our study sample (3%). Therefore, further studies with more cases of new-onset type 2 diabetes are needed to elaborate the association of 24-h movement behaviors with incidence of type 2 diabetes.

We also observed that baseline sleep level affected the associations between 24-h movement behaviors and incidence of hypertension. After exclusion of short sleepers, longer sleep appeared to associate with higher incidence of hypertension. This might be related to the previous experimental evidence that sleep extension from insufficient level improves cardiovascular health [41], whereas long sleep has been associated with higher incidence of hypertension [13], also known as U-shaped association between sleep duration and cardiovascular health [13, 14].

Our study suggests that daily MVPA may be important in preventing incident hypertension and obesity, especially among the least active 60-year-old adults. Increasing MVPA may be optimally pursued by minimizing the time spent sedentary, as sufficient sleep [13–15] and LPA [9, 42] have been shown to prevent cardiovascular risks. Our findings also highlight that even maintaining current MVPA levels may prevent the relatively high estimated increase in cardiovascular risks that is observed when MVPA decreases. Possible ways to preserve or increase MVPA among late middle-aged adults is to engage in active commuting, which has been observed to be an important source of daily MVPA in this age group [43]. Other strategies to increase MVPA could include supervised exercise programs and self-guided exercises. Additionally, many household chores and gardening may fulfill the energy expenditure requirements of MVPA among adults aged 60 years or older.

The major strengths of this study are a prospective study design, device-based measurement of all 24-h movement behaviors, and register-based follow-up for hypertension, dyslipidemia, and type 2 diabetes [31, 32]. Moreover, we used state-of-art statistical methods to account for the codependency between the 24-h movement behaviors.

Our study naturally has some limitations. Obesity was defined using self-reported height and weight, which may have led to an underestimation of its prevalence and incidence. However, the hazard curves of new-onset diabetes of participants with obesity defined from hospital discharge registers do not differ from hazard curves in participants with obesity defined from self-reports [44]. Thus, obesity based on self-reports is unlikely a source of a major bias in our study. The follow-up time was relatively short (mean of 3 years, up to 6 years), and the incidence of cardiovascular risk factors, especially type 2 diabetes and obesity, was low, limiting the robustness and generalizability of the findings. Therefore, further studies are needed to examine associations between 24-h movement behaviors and incident cardiovascular risk factors in the long term. The possibility of reverse causation cannot be fully eliminated, but excluding cases occurring during the first year of the follow-up did not alter interpretation of the results. Our study was observational and utilized data on 24-h movement behaviors from one time point; thus, we were unable to examine how actual changes in 24-h movement behavior and long-term engagement in movement behaviors affect cardiovascular risks. In addition, with threshold-based data processing methods for wrist-worn accelerometers, it is not possible to differentiate standing from sitting positions; thus, there might be some misclassification between SED and LPA. Our accelerometer-based sleep estimates reflected time in bed rather than biological sleep, and we were not able to consider sleep quality. In our study population, the mean physical activity levels estimated by a wrist-worn accelerometer were relatively high (50–60 min of MVPA per day). However, similar levels have been reported in another wrist-accelerometer–based study among older adults applying similar data processing methods [45]. Finally, there is also a possibility that unmeasured confounding factors, for example, diet, affected our findings.

Regarding generalizability of the findings, our study population consisted of individuals who were in the working life after age of 60 years and were thus healthier and better functioning than general population of the same age. When compared to the FIREA survey-only study population, the current study population with valid accelerometer data was healthier and more physically active. Thus, possible selection to the current study likely weakened the observed associations. However, as we found associations between 24-h movement behaviors and incident cardiovascular risk factors even in this relatively healthy study population, the observed associations can be expected to be stronger in a more representative study population. These issues should be taken into account when interpreting the generalizability of the findings.

5 | Perspective

In recent years, there has been a growing interest in examining sleep, sedentary behavior, and physical activity, that is, 24-h movement behaviors, as constraints of a 24-h day. Previous knowledge on the associations between these behaviors and cardiovascular risk factors has mainly been based on cross-sectional studies and self-reported data on movement behaviors. Therefore, we carried out device-based 24-h measurements among late middle-aged adults to explore how the composition of these behaviors is associated with the incidence of cardiovascular risk factors over a mean follow-up period of 3 years. Our study revealed that a higher amount of MVPA in relation to the remaining behaviors was associated with a lower incidence of hypertension and obesity, especially among the least active participants. This suggests that daily MVPA may play a crucial role in preventing hypertension and obesity, and even a small increase in daily MVPA could benefit those who are physically less active. Future intervention studies are needed to examine how changes in 24-h movement behaviors can impact the onset of cardiovascular risk factors.

Author Contributions

S.S. and J.V. designed this study and the data collection. K.S. conducted the statistical analyses with the help of J.P. and J.P. K.S. drafted the manuscript. All authors contributed to data interpretation, revised article critically, and approved the final version of manuscript.

Acknowledgments

The authors want to thank the FIREA participants for their willingness to participate in the study and the FIREA study staff members for their contribution in the data collection.

Ethics Statement

The FIREA study is conducted in line with the Declaration of Helsinki and has been approved by the Ethics Committee of Hospital District of Southwest Finland (84/1801/2014).

Consent

The participants provided written informed consent before participation.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Anonymized partial datasets of the FIREA study are available by application with bona fide researchers with an established scientific record and bona fide organizations. In case of data requests, please contact the Principal Investigator Sari Stenholm, sari.stenholm@utu.fi.

References

1. World Health Organisation. World Health Organization (WHO), "Cardiovascular Diseases [Internet]," (2023), https://www.who.int/health-topics/cardiovascular-diseases#tab=tab_1.

2. A. Wahid, N. Manek, M. Nichols, et al., "Quantifying the Association Between Physical Activity and Cardiovascular Disease and Diabetes: A Systematic Review and Meta-Analysis," *Journal of the American Heart Association* 5, no. 9 (2016): e002495.

3. C. W. Tsao, A. W. Aday, Z. I. Almarzooq, et al., "Heart Disease and Stroke Statistics—2023 Update: A Report From the American Heart Association," *Circulation* 147, no. 8 (2023): e93–e621.

4. X. Liu, D. Zhang, Y. Liu, et al., "Dose–Response Association Between Physical Activity and Incident Hypertension: A Systematic Review and Meta-Analysis of Cohort Studies," *Hypertens Dallas Texas 1979* 69, no. 5 (2017): 813–820.

5. D. Aune, T. Norat, M. Leitzmann, S. Tonstad, and L. J. Vatten, "Physical Activity and the Risk of Type 2 Diabetes: A Systematic Review and Dose–Response Meta-Analysis," *European Journal of Epidemiology* 30, no. 7 (2015): 529–542.

6. P. Oja, P. Kelly, E. M. Murtagh, M. H. Murphy, C. Foster, and S. Titze, "Effects of Frequency, Intensity, Duration and Volume of Walking Interventions on CVD Risk Factors: A Systematic Review and Meta-Regression Analysis of Randomised Controlled Trials Among Inactive Healthy Adults," *British Journal of Sports Medicine* 52, no. 12 (2018): 769–775.

7. A. Biswas, P. I. Oh, G. E. Faulkner, et al., "Sedentary Time and Its Association With Risk for Disease Incidence, Mortality, and Hospitalization in Adults: A Systematic Review and Meta-Analysis," *Annals of Internal Medicine* 162, no. 2 (2015): 123–132.

8. E. H. Sagelv, L. A. Hopstock, B. Morseth, et al., "Device-Measured Physical Activity, Sedentary Time, and Risk of All-Cause Mortality: An Individual Participant Data Analysis of Four Prospective Cohort Studies," *British Journal of Sports Medicine* 57, no. 22 (2023): 1457–1463.

9. S. Chastin, M. D. Craemer, K. D. Cocker, et al., "How Does Light-Intensity Physical Activity Associate With Adult Cardiometabolic Health and Mortality? Systematic Review With Meta-Analysis of Experimental and Observational Studies," *British Journal of Sports Medicine* 53, no. 6 (2019): 370–376.

10. M. Llavero-Valero, J. Escalada-San Martín, M. A. Martínez-González, F. J. Basterra-Gortari, A. Gea, and M. Bes-Rastrollo, "Physical Activity Intensity and Type 2 Diabetes: Isotemporal Substitution Models in the "Seguimiento Universidad de Navarra" (SUN) Cohort," *Journal of Clinical Medicine* 10, no. 13 (2021): 2744.

11. Z. Cao, C. Xu, P. Zhang, and Y. Wang, "Associations of Sedentary Time and Physical Activity With Adverse Health Conditions: Outcome-Wide Analyses Using Isotemporal Substitution Model," *EClinicalMedicine* 48 (2022): 101424.

12. M. Aadahl, A. H. Andreasen, C. B. Petersen, N. Gupta, A. Holtermann, and C. J. Lau, "Should Leisure-Time Sedentary Behavior Be Replaced With Sleep or Physical Activity for Prevention of Diabetes?," *Scandinavian Journal of Medicine & Science in Sports* 31, no. 5 (2021): 1105–1114.

13. Y. Wang, H. Mei, Y. R. Jiang, et al., "Relationship Between Duration of Sleep and Hypertension in Adults: A Meta-Analysis," *Journal of Clinical Sleep Medicine* 11, no. 9 (2015): 1047–1056.

14. Z. Shan, H. Ma, M. Xie, et al., "Sleep Duration and Risk of Type 2 Diabetes: A Meta-Analysis of Prospective Studies," *Diabetes Care* 38, no. 3 (2015): 529–537.

15. Y. Wu, L. Zhai, and D. Zhang, "Sleep Duration and Obesity Among Adults: A Meta-Analysis of Prospective Studies," *Sleep Medicine* 15, no. 12 (2014): 1456–1462.

16. S. Chastin, J. P. Albaladejo, M. Dontje, and D. Skelton, "Combined Effects of Time Spent in Physical Activity, Sedentary Behaviors and Sleep on Obesity and Cardio-Metabolic Health Markers: A Novel Compositional Data Analysis Approach," *PLoS One* 10, no. 10 (2015): e0139984.

17. D. Dumuid, Ž. Pedišić, J. Palarea-Albaladejo, J. A. Martín-Fernández, K. Hron, and T. Olds, "Compositional Data Analysis in Time-Use Epidemiology: What, Why, How," *International Journal of Environmental Research and Public Health* 17, no. 7 (2020): 2220.

18. J. M. Blodgett, M. N. Ahmadi, A. J. Atkin, et al., "Device-Measured Physical Activity and Cardiometabolic Health: The Prospective Physical Activity, Sitting, and Sleep (ProPASS) Consortium," *European Heart Journal* 45, no. 6 (2024): 458–471.

19. J. M. Blodgett, M. N. Ahmadi, A. J. Atkin, et al., "Device-Measured 24-Hour Movement Behaviors and Blood Pressure: A 6-Part Compositional Individual Participant Data Analysis in the ProPASS Consortium," *Circulation* 151, no. 2 (2025): 159–170, https://doi.org/10.1161/CIRCULATIONAHA.124.069820.

20. M. S. Yerramalla, D. E. McGregor, V. T. van Hees, et al., "Association of Daily Composition of Physical Activity and Sedentary Behaviour With Incidence of Cardiovascular Disease in Older Adults," *International Journal of Behavioral Nutrition and Physical Activity* 18 (2021): 83.

21. M. Niemelä, A. Kiviniemi, T. M. Ikäheimo, et al., "Compositional Association of 24-h Movement Behavior With Incident Major Adverse

Cardiac Events and All-Cause Mortality," *Scandinavian Journal of Medicine & Science in Sports* 33, no. 5 (2023): 641–650.

22. R. Walmsley, S. Chan, K. Smith-Byrne, et al., "Reallocation of Time Between Device-Measured Movement Behaviours and Risk of Incident Cardiovascular Disease," *British Journal of Sports Medicine* 56, no. 18 (2021): 1008–1017.

23. A. García-Hermoso, J. F. López-Gil, Y. Ezzatvar, R. Ramírez-Vélez, and M. Izquierdo, "Twenty-Four-Hour Movement Guidelines During Middle Adolescence and Their Association With Glucose Outcomes and Type 2 Diabetes Mellitus in Adulthood," *Journal of Sport and Health Science* 12, no. 2 (2023): 167–174.

24. A. García-Hermoso, Y. Ezzatvar, A. M. Alonso-Martinez, R. Ramírez-Vélez, M. Izquierdo, and J. F. López-Gil, "Twenty-Four-Hour Movement Guidelines During Adolescence and Its Association With Obesity at Adulthood: Results From a Nationally Representative Study," *European Journal of Pediatrics* 182, no. 3 (2023): 1009–1017.

25. X. Na, Y. Chen, X. Ma, et al., "Relations of Lifestyle Behavior Clusters to Dyslipidemia in China: A Compositional Data Analysis," *International Journal of Environmental Research and Public Health* 18, no. 15 (2021): 7763.

26. I. Willems, V. Verbestel, D. Dumuid, et al., "Cross-Sectional Associations Between 24-h Movement Behaviors and Cardiometabolic Health Among Adults With Type 2 Diabetes Mellitus: A Comparison According to Weight Status," *Journal of Science and Medicine in Sport* 27, no. 3 (2024): 179–186.

27. J. Lee, M. E. Walker, K. A. Matthews, L. H. Kuller, N. Ranjit, and K. P. Gabriel, "Associations of Physical Activity and Sleep With Cardiometabolic Risk in Older Women," *Preventive Medical Reports* 18 (2020): 101071.

28. S. Stenholm, K. Suorsa, T. Leskinen, et al., "Finnish Retirement and Aging Study: A Prospective Cohort Study," *BMJ Open* 13, no. 12 (2023): e076976.

29. K. Suorsa, T. Leskinen, J. Pasanen, et al., "Changes in the 24-h Movement Behaviors During the Transition to Retirement: Compositional Data Analysis," *International Journal of Behavioral Nutrition and Physical Activity* 19, no. 1 (2022): 121.

30. J. H. Migueles, A. Rowlands, F. Huber, S. Sabia, and V. van Hees, "GGIR: A Research Community–Driven Open Source R Package for Generating Physical Activity and Sleep Outcomes From Multi-Day Raw Accelerometer Data," *Journal for the Measurement of Physical Behaviour* 2, no. 3 (2019): 188–196.

31. T. Leskinen, S. Stenholm, A. Pulakka, J. Pentti, M. Kivimäki, and J. Vahtera, "Comparison Between Recent and Long-Term Physical Activity Levels as Predictors of Cardiometabolic Risk: A Cohort Study," *BMJ Open* 10, no. 2 (2020): e033797.

32. J. I. Halonen, S. Stenholm, J. Pentti, et al., "Childhood Psychosocial Adversity and Adult Neighborhood Disadvantage as Predictors of Cardiovascular Disease: A Cohort Study," *Circulation* 132, no. 5 (2015): 371–379.

33. S. T. Nyberg, G. D. Batty, J. Pentti, et al., "Obesity and Loss of Disease-Free Years Owing to Major Non-Communicable Diseases: A Multicohort Study," *Lancet Public Health* 3, no. 10 (2018): e490.

34. P. Anderson and J. Colom, *Riskikulutuksen Varhainen Tunnistaminen Ja Mini-Interventio -Hoitosuosituksen Yhteenveto [Alcohol and Primary Health Care: Clinical Guidelines on Identification and Brief Interventions]* (Työterveyslaitos, 2015).

35. D. Dumuid, Z. Pedišić, T. Stanford, et al., "The Compositional Isotemporal Substitution Model: A Method for Estimating Changes in a Health Outcome for Reallocation of Time Between Sleep, Physical Activity and Sedentary Behaviour," *Statistical Methods in Medical Research* 28, no. 3 (2019): 846–857.

36. M. Hirshkowitz, K. Whiton, S. M. Albert, et al., "National Sleep Foundation's Sleep Time Duration Recommendations: Methodology and Results Summary," *Sleep Health* 1, no. 1 (2015): 40–43.

37. K. M. Full, K. M. Whitaker, K. Pettee Gabriel, et al., "Cardiovascular Risk and Functional Burden at Midlife: Prospective Associations of Isotemporal Reallocations of Accelerometer-Measured Physical Activity and Sedentary Time in the CARDIA Study," *Preventive Medicine* 150 (2021): 106626.

38. V. Ávila-Gandía, D. J. Ramos-Campo, E. García-Sánchez, A. J. Luque-Rubia, A. López, and F. J. López-Román, "Training, Detraining and Retraining Effects of Moderate vs. High Intensity Exercise Training Programme on Cardiovascular Risk Factors," *Journal of Hypertension* 41, no. 3 (2023): 411.

39. P. C. Dempsey, T. Strain, K. T. Khaw, N. J. Wareham, S. Brage, and K. Wijndaele, "Prospective Associations of Accelerometer-Measured Physical Activity and Sedentary Time With Incident Cardiovascular Disease, Cancer, and all-Cause Mortality," *Circulation* 141, no. 13 (2020): 1113–1115.

40. S. F. M. Chastin, D. E. McGregor, S. J. H. Biddle, et al., "Striking the Right Balance: Evidence to Inform Combined Physical Activity and Sedentary Behavior Recommendations," *Journal of Physical Activity & Health* 18, no. 6 (2021): 631–637.

41. R. H. P. Henst, P. R. Pienaar, L. C. Roden, and D. E. Rae, "The Effects of Sleep Extension on Cardiometabolic Risk Factors: A Systematic Review," *Journal of Sleep Research* 28, no. 6 (2019): e12865.

42. R. Loh, E. Stamatakis, D. Folkerts, J. Allgrove, and H. Moir, "Effects of Interrupting Prolonged Sitting With Physical Activity Breaks on Blood Glucose, Insulin and Triacylglycerol Measures: A Systematic Review and Meta-Analysis," *Sports Medicine* 50, no. 2 (2020): 295–330.

43. S. Pasanen, J. I. Halonen, A. Pulakka, et al., "Contexts of Sedentary Time and Physical Activity Among Ageing Workers and Recent Retirees: Cross-Sectional GPS and Accelerometer Study," *BMJ Open* 11, no. 5 (2021): e042600.

44. V. Vahtera, J. Pajarinen, M. Kivimäki, et al., "Cohort Study on Incidence of New-Onset Type 2 Diabetes in Patients After Bariatric Surgery and Matched Controls," *British Journal of Surgery* 111, no. 4 (2024): znae105.

45. V. Cabanas-Sánchez, I. Esteban-Cornejo, J. H. Migueles, et al., "Twenty Four-Hour Activity Cycle in Older Adults Using Wrist-Worn Accelerometers: The Seniors-ENRICA-2 Study," *Scandinavian Journal of Medicine & Science in Sports* 30, no. 4 (2020): 700–708.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.