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Independent and joint effects of self-reported physical activity and sedentary behaviors on mortality in community-dwelling older persons: a prospective cohort study

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Abstract

Background This study aims to assess the joint and independent effects of self-reported physical activity and sedentary behavior on mortality in older persons.

Methods A prospective community-based cohort study was conducted to examine physical activity (PA) level and sitting time (ST) in relation to mortality among 1,786 older persons aged 65 years and above. PA was assessed by a checklist of 26 self-reported items about PA and hours per week, and the metabolic equivalent hours/week was derived, and ST was measured by a self-reported item asking the average number of hours spent sitting per day. The participants were divided into four combination groups of PA and ST based on WHO guideline and values found in literature: high PA/short ST group, high PA/long ST group, low PA/long ST group, and low PA/short ST group. Data on death ascertainment were obtained through linkage with the national death datasets and expanded cardiovascular disease (CVD) included cardiovascular disease, diabetes, and chronic kidney disease.

Results After follow-up for a median 11.1 years, 599 mortality cases were recorded, giving a crude all-cause mortality of 32.5/1,000 person-years, CVD mortality of 8.6/1,000 person-years, expanded CVD mortality of 11.9/1,000 person-years, and nonexpanded CVD mortality of 20.8/1,000 person-years. For all-cause, and expanded CVD, the hazards ratios (HRs) for the low PA/long ST group remained significant compared with that for the high PA/short ST group after all covariates were considered [HRs for all-cause mortality: 1.4 [95% confidence interval (CI) 1.1, 1.8]; and expanded CVD mortality: 1.7 (95% CI 1.1, 2.4).

Conclusions The independent effect of PA and the joint effects of PA and ST are associated with all-cause and expanded CVD death risks. Expanded CVD mortality may be minimized by engaging in PA and reducing sedentary behaviors.

Keywords Physical activity, Sitting time, Cardiovascular disease, Mortality

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Background

Many countries worldwide face rapidly growing medical care expenditures due to the increasing number of older persons who are at risk of chronic diseases [1]. The health benefits of regular physical activity include reducing the incidence of chronic diseases, improving body composition, maintaining a good basal metabolic rate, and increasing the function of the immune system [2]. Regular physical activity can reduce aging-related functional degeneration [3] and is the most efficient and safe method for older persons to maintain their life functions and a healthy physical and psychological condition [4].

Promoting regular physical activity has been a major health promotion intervention worldwide. Many organizations have proposed guidelines for regular physical activity [5, 6]. However, the effects of physical activity are not fully understood, especially in older persons. Moderate activity was found to be associated with decreased mortality risk [7–9]. On the contrary, a reverse relationship was observed with vigorous physical activity [10, 11]. The World Health Organization (WHO) released recommendations for sedentary behavior and suggested that older adults should limit the amount of time spent being sedentary. However, the independent and joint effects of physical activity and sedentary behaviors are poorly explored, especially in older persons.

Literature search on the effect of physical activity intensity on mortality revealed that many studies explored the independent associations of physical activity-related variables or sedentary behavior with mortality [12–15]. These prior reports included a study exploring the relationship of muscle density and area with mortality in middle-aged or older adults during a 10-year follow-up [13], a study assessing the effects of the changes in physical activity levels on mortality for older persons [15], a study evaluating the effect of following physical activity guidelines such as doing 30 min of moderate-intensity physical activity a day or more than three times a week of high-intensity physical activity on mortality in older adults aged 50 years and over [14], and a study investigating the patterns of sedentary behaviors in relation to mortality in middle-aged or older adults [12]. However, these works rarely investigated the combined effects of the physical activity habits and sedentary behavior on mortality risk for older persons. In addition, when cardiovascular disease (CVD) mortality was considered, the competing risks of other causes of death were not taken into account. Thus, the current study aimed to evaluate the combined effects of physical activity and sedentary behavior on all-cause mortality, CVD mortality, and expanded and non-expanded CVD mortality in older persons residing in community with and without using the competing risk approach.

Methods

Study design and subjects

This study used the data of older persons aged 65 years and older from three community-based prospective follow-up studies, namely, Taichung Community Health Study (TCHS), TCHS for the elders (TCHS-E), and TCHS for family cohort (TCHS-FC). The inclusion and exclusion criteria are presented in Supplementary Fig. 1. Baseline data were obtained from the first data collection of these studies (2004 for TCHS, 2009 for TCHS-E, and 2010 for TCHS-FC), and the endpoint was specified on December 31, 2016. The TCHS population were residents aged ≥ 40 years in Taichung City, Taiwan as of 2004 [16]. Through a two-stage probability sampling approach, 4,280 residents were selected and 2,359 eligible persons participated in 2004. TCHS-E recruited 3,997 residents aged ≥ 65 years who lived in districts around China Medical University Hospital, Taichung City in 2009. Only 1,347 out of the 2,750 eligible residents participated [17]. TCHS-FC comprised 1,933 participants aged 12–91 years recruited from the blood relatives (parents, children, or siblings) of 494 families of the participants in TCHS and TCHS-E in 2010. After the duplicated subjects were excluded, 4,883 participants were selected. Finally, 1,786 older persons were included in the present study. This study was approved by the Human Research Committee of China Medical University Hospital, Taiwan (CMUH108-REC1-058). All experiments were performed in accordance with the relevant guidelines and regulations. Written informed consent was obtained from each participant.

Death ascertainment

Data on death ascertainment were obtained through linkage with the national death datasets of Taiwan Ministry of Health and Welfare between October 1, 2004 and December 31, 2020 by matching the data of the identification number and date of birth. Causes of death were coded using the International Classification of Diseases 10th revision (ICD-10) and 9th revision (ICD-9). Expanded CVD included cardiovascular disease (ICD-10: codes I00–I99 and ICD-9: codes 390–459), diabetes (ICD-10: codes E10–E14 and ICD-9: code 250), and chronic kidney disease (ICD-10: codes N00–N07, N17–N19, and N25–N27 and ICD-9: codes 580–589).

Measurements

Variables were grouped into anthropometric measures, sociodemographic and lifestyle factors, medical history, and biomarkers. Anthropometric measures included weight, height, and hip and waist circumferences measured during physical check-up. Weight and height were measured with an auto-anthropometer (super-view, HW-666). Waist circumference measurement was taken

in the middle between the superior iliac spine and the margin of the rib, and hip circumference measurement was taken at the maximum point of the buttock point around the pelvis when older persons were in standing position. Blood pressure (systolic and diastolic blood pressure) was recorded by an electronic device (COLIN, VP-1000, Japan).

Data on sociodemographic factors such as gender, baseline age, marital status, and educational attainment were obtained from structured questionnaires facilitated by trained interviewers. Marital status included married, single, divorced, widowed, and separated. Education attainment included post-baccalaureate, junior college, high school, junior high school, and below elementary school. Lifestyle behaviors included level of leisure-time physical activity, sedentary behavior (hours spent sitting), smoking habits, and alcohol consumption determined via structured questionnaires administered by interviewers. Regular physical activity was defined as those who had physical activity at least 3 sessions for 30 min per week by the combination of a single item asking the study subjects whether they had physical activity at least 30 min of exercise per week for at least 6 months and frequency, and time spent in each physical activity. Level of leisure-time physical activity was one of the key independent variables and was determined by 26 items of various kinds of physical activities a person might be involved in, such as dancing, ball games, martial arts, aerobic sports, and others, in addition to the average hours spent on each physical activity and frequency of physical activity per week a person devoted to in the past year. A metabolic equivalent of task (MET) was assigned to each activity, and a person's average MET hours per week (MET hours/week) was derived from the product of the following three terms: MET of an activity, average hours spent on each activity (h) every week a person engages in this activity. Then all activities of MET hours were summed up. The MET value for each activity was listed in the Supplementary Table 1. Leisure-time activity MET hours per week were then categorized into three groups according to WHO guidelines. According to WHO guidelines, older adults should engage in at least 150–300 min of moderate-intensity aerobic activity per week, or at least 75–150 min of vigorous-intensity aerobic activity per week [5]. This equates to approximately 450-1,800 MET minutes (or 7.5–30 MET hours) per week. Individuals were classified as inactive if they had 7.5 MET hours or fewer per week, as active if they had between 7.5 and 30 MET hours per week, and as highly active if they exceeded 30 MET hours per week.

An item in the self-reported questionnaire asked the average number of hours spent sitting per day which was a common measure for non-occupational sedentary behavior of adults [18], and this variable was categorized into 4 sitting time groups according the cutoff points used in Ekelund et al. (2016) [19], which were 4 h, 6 h, and 8 h. Participants were divided into four groups according to their leisure-time activity and sitting hours: active or highly active with short sitting hours (<6 h/day), active or highly active with long sitting hours (≥6 h/day), inactive with long sitting hours (≥6 h/day), and inactive with short sitting hours (<6 h/day). Smoking status and alcohol drinking status were grouped into three classes: present, ever, and never. Information on medical history was obtained from a checklist of items, including hypertension, cerebrovascular disease, heart disease, diabetes, hyperlipidemia, cancer, and gout.

Blood samples were drawn from the anterior elbow vein with minimal trauma in the morning after at least 8 h of fasting and sent for analysis within 4 h of collection. Biochemical markers serum glutamic-pyruvic transaminase (SGPT), serum glutamic-oxalocetic transaminase (SGOT), hemoglobin, creatinine, fasting plasma glucose (FPG), blood urea nitrogen (BUN), uric acid, total cholesterol, urine albumin, HDL-C, TG, and LDL-C were analyzed using a biochemical autoanalyzer (Beckman Coulter Synchron System, Lx-20, Fullerton, CA, USA). Urinary creatinine (Jaffe's kinetic method) and albumin (colorimetyl bromcresol purple) were measured from morning urine samples using an autoanalyzer as an indicator of the albumin excretion rate. The precision measurement of interassay coefficients of variations for creatinine and albumin concentrations was <3.0%. Brachial-ankle pulse wave velocity (baPWV), indicator of arterial stiffness, and ankle-brachial index (ABI), and indicator of atherosclerosis were measured. baPWV and ABI values were determined by using pressure cuffs wrapped around the ankle and brachium and measured using an automatic volume-plethysmographic device PWV/ABI (PWV/ABI; Colin Co., Ltd., Komaki, Japan) [20]. Their values were determined from the maximum of the right and left values for baPWV or ABI. A low ABI indicates the high severity of peripheral artery disease, and a high baPWV indicates the high severity of arterial stiffness.

Statistical analysis

Simple descriptive analyses such as mean, standard deviation, frequency, and proportion were applied to analyze data whenever appropriate. Differences among combined leisure-time physical activity and sitting time groups were assessed by analysis of variance for continuous variables and Chi-square or Fisher's exact test for categorical variables. Kaplan–Meier approach was used to estimate cumulative mortality. Traditional Cox proportional hazards models on CVD or expanded CVD mortality were fitted. Hazard ratios (HRs) and 95% confidence intervals (CI) were estimated and adjusted for multiple variables.

The first multivariate model was adjusted for age and gender; the second one was additionally adjusted for waist, body mass index (kg/m^2), tobacco use, and alcohol drinking; and the third one was additionally adjusted for hypertension, heart disease, diabetes, stroke, hyperlipidemia, and cancer. Multivariate Cox models with restricted cubic spline plots were used to assess the dose–response or nonlinear relationship of physical activity level and sitting time to mortality. In order to rule out the possibility of reverse causality, we performed an additional analysis by excluding older persons with survival time less than one year, i.e., older persons expiring within one year of follow-up. Analyses were performed with SAS version 9.4 (SAS, Cary, NC). Two-tailed *P* values were calculated, and significance level was specified at 0.05.

Results

The average age of the 1,786 participants was 73.8 years old, and men accounted for 53.3%. The prevalence of smoking, alcohol drinking, and regular physical activity was 23.9%, 20.6%, and 73.9%, respectively. The distribution of physical activity levels was that 30.91% of individuals were inactive, 44.29% were active, and 24.8% were highly active while the distribution of sitting time was that less than 4 h (19.65%), 4 to 5.9 h (26.43%), 6 to 8 h (29.96%), and more than 8 h (23.96%). Among older persons, 608 (34.1%) were classified as high physical activity/short sitting time, 625 (35.0%) as high physical activity/long sitting time, 338 (18.9%) as low physical activity/long sitting time, and 214 (12.0%) as low physical activity/short sitting time.

Table 1 provides the descriptive analysis of the basic demographics factors, lifestyle behaviors, comorbidities, and medications of the groups in this study. Significant differences in baseline age, gender, waist, regular physical activity status, physical activity level, sedentary time, prevalence of smoking, alcohol consumption, diabetes, stroke, hyperlipidemia, peripheral arterial occlusive disease (PAOD), and all-cause mortality were found among the four groups. The older persons in the low physical activity/long sitting time group was more likely to be older, smokers, nonalcohol drinkers, and have higher prevalence of diabetes, stroke, and PAOD and all-cause mortality compared with those in the high physical activity/low sitting time group.

After follow-up for a median 11.1 years, 599 mortality cases were recorded, giving a crude all-cause mortality of 32.5/1,000 person-years, CVD mortality of 8.5/1,000 person-years, expanded CVD mortality of 11.9/1,000 person-years, and nonexpanded CVD mortality of 20.8/1,000 person-years. Kaplan–Meier cumulative incidences for all-cause, CVD, expanded CVD, and nonexpanded CVD mortality of the combined physical activity and sitting time groups are shown in Fig. 1. Significant differences were observed for all-cause, CVD, expanded CVD, and non-expanded CVD mortality ($p<0.001$, $p=0.002$, $p<0.001$, and $p=0.009$, respectively). Older persons in the inactive /long sitting time group and inactive /short sitting time group were associated with the highest risk of all-cause, CVD, expanded CVD, and non-expanded CVD mortality compared with those in the active or highly active/short sitting time group. Restricted multivariable cubic spline plots for metabolic equivalent of task (hour/week) and sedentary time are shown in Fig. 2.

Table 2 shows the HRs for all-cause, CVD, expanded CVD, and non-expanded CVD mortality in subjects grouped by physical activity according to WHO guideline. Relative to that in inactive group, the age-gender adjusted HRs of all-cause mortality in active or highly active groups were 0.7 (95% CI 0.6, 0.8) and 0.6 (0.5, 0.8), respectively. After further considering lifestyle behaviors, the effects of active or highly active groups were slightly attenuated but still significant [0.7 (0.6, 0.9) and 0.7 (0.5, 0.8), respectively]. After further considering comorbidities, the effects of active or highly active groups remained the same and still significant [0.7 (0.6, 0.9) and 0.7 (0.5, 0.9), respectively]. For expanded CVD mortality, the HRs for the active or highly active group remained significant after all covariates were considered [expanded CVD mortality: 0.6 (0.4, 0.9)]. For non-expanded CVD mortality, the HRs for the active or highly active groups persisted as significant following adjustment for all covariates [0.7 (0.6, 0.9) for both groups].

Table 3 shows the HRs for all-cause, CVD, expanded CVD, and non-expanded CVD mortality in subjects grouped by sitting time. Relative to that in group of sitting time<4 h/day, the age-gender adjusted HRs of expanded CVD mortality in group of sitting time>8 h/day were 1.6 (1.0, 2.4) ($p<0.05$). After further considering lifestyle behaviors, the effects of sitting time<4 h/day were slightly attenuated but still significant [1.5 (1.0, 2.3)]. After further considering comorbidities, the effects of sitting time<4 h/day. Became non-significant. For the other outcomes, no significant associations were found.

Individuals who were inactive with long sitting time exhibited significantly elevated HRs for both all-cause, CVD, expanded CVD, and non-expanded CVD mortality compared to those who were active or highly active with short sitting time (Table 4). After adjusting for lifestyle behaviors and comorbidities (as shown in Model 3), low physical activity/long sitting time group demonstrated a significant HR of 1.4 (95% CI: 1.1, 1.8) for all-cause mortality and 1.7 (95% CI: 1.1, 2.4) for expanded CVD mortality. The results of comparing high physical activity and long sitting time with the other groups are presented in the Supplementary Table 2.

Table 1 Comparison of the basic demographics factors, lifestyle behaviors, comorbidities and medication according to combined groups of physical activity and sitting time

Variables	*n* (%) or mean (SD)				
	≥7.5 MET-h per week (active or highly active) and < 6 h/day of sitting time	≥7.5 MET-h per week (active or highly active) but ≥6 h/day of sitting time	< 7.5 MET-h per week (inactive) and ≥6 h/day of sitting time	< 7.5 MET-h per week (inactive) and < 6 h/day of sitting time	*p*-values
Total	609 (34.1)	625 (35.0)	338 (18.9)	214 (12.0)	
Age (year)	73.1 ± 5.6	74.1 ± 6.3	74.8 ± 7.1*	73.5 ± 6.7	< 0.001
Gender					0.003
Men	343 (56.3)	350 (56.0)	162 (47.9)*&	96 (44.9)*&	
Women	266 (43.7)	275 (44.0)	176 (52.1)	118 (55.1)	
BMI (kg/m2)	24.2 ± 3.3	24.4 ± 3.3	24.5 ± 4.0	24.4 ± 3.6	0.59
Waist (cm)	83.8 ± 9.2	85.2 ± 9.6	86.0 ± 10.2*	83.7 ± 9.7	0.002
Regular physical activity#					< 0.001
No	0 (0.0)	0 (0.0)	288 (85.2)*&	176 (82.2)*&	
Yes	609 (100.0)	625 (100.0)	50 (14.8)	38 (17.8)	
Physical activity (MET-hours/week)	34.2 ± 27.5	29.3 ± 23	0.7 ± 1.8*&	0.9 ± 2.0*&	< 0.001
Sedentary time (hours/day)	3.7 ± 1.3	8.7 ± 2.7	9.5 ± 2.9*&	3.7 ± 1.3*&	< 0.001
Smoking					0.008
No	485 (79.6)	466 (74.6)	241 (71.3)*&	165 (77.1)	
Yes	48 (7.9)	49 (7.8)	44 (13.0)	23 (10.8)	
Ever	76 (12.5)	110 (17.6)	53 (15.7)	26 (12.2)	
Alcohol consumption					0.006
No	474 (77.8)	487 (77.9)	283 (83.7)*&	176 (82.2)	
Yes	100 (16.4)	96 (15.4)	26 (7.7)	26 (12.2)	
Ever	35 (5.8)	42 (6.7)	29 (8.6)	12 (5.6)	
Heart disease	153 (25.1)	158 (25.3)	104 (30.8)	52 (24.3)	0.20
Hypertension	305 (50.1)	319 (51.0)	192 (56.8)	103 (48.1)	0.15
Diabetes	100 (16.4)	124 (19.8)	81 (24.0)*	23 (10.8)*&	< 0.001
Stroke	28 (4.6)	44 (7.0)	36 (10.7)*	20 (9.4)*	0.003
Hyperlipidemia	137 (22.5)	172 (27.5)	91 (26.9)	44 (20.6)	0.07
Cancer	38 (6.2)	37 (5.9)	19 (5.6)	12 (5.6)	0.98
Arterial stiffness	584 (95.9)	590 (94.4)	321 (95)	197 (92.1)	0.18
PAOD	6 (1.0)	13 (2.1)	19 (5.6)*&	7 (3.3)*	< 0.001
Biomarker					
SBP (mmHg)	141.4 ± 18.3	139.8 ± 19.7	143.6 ± 20.8&	141.9 ± 21.3	0.04
DBP (mmHg)	79.5 ± 10.7	78.1 ± 11	79.8 ± 12	79.5 ± 12	0.07
FPG (mg/dL)	108.2 ± 26.8	110.9 ± 28.5	112.6 ± 34.8	104.7 ± 21&	0.005
HDL (mg/dL)	46.4 ± 14.3	45.8 ± 13.3	45.6 ± 13.4	49.1 ± 14.5&	0.02
LDL (mg/dL)	116.3 ± 29.6	118.8 ± 30.8	118.5 ± 33	120.9 ± 33.2	0.26
TC (mg/dL)	192.5 ± 34	194.6 ± 36	195.1 ± 38.3	200.5 ± 38.2*	0.05
TG (mg/dL)	111.5 ± 64.5	119.7 ± 67.4	130.8 ± 97.4*	115 ± 64.1	0.001
Creatinine (mg/dL)	1.0 ± 0.5	1.0 ± 0.4	1.1 ± 0.9*&	0.9 ± 0.3	< 0.001
eGFR (ml/min/1.73m^2)	74.4 ± 18.7	74.2 ± 19.9	67.7 ± 22.8*&	76.8 ± 21	< 0.001
Microalbumin (mg/g cr)	48.6 ± 243.4	62.9 ± 328.5	123.5 ± 413.3*&	39.6 ± 87.5	< 0.001
Right ABI	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1*&	1.1 ± 0.1	< 0.001
Left ABI	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1*&	1.1 ± 0.1	< 0.001
Right baPWV (cm/s)	2045.5 ± 482.8	2018.4 ± 478.3	2153.4 ± 593.4*&	2001.7 ± 506.9	< 0.001
Left baPWV (cm/s)	2045.0 ± 476.1	2025.2 ± 469.4	2162.2 ± 587.2*&	2007.7 ± 555.2	< 0.001
Death					< 0.001

Table 1 (continued)

Variables	*n* (%) or mean (SD)				
	≥7.5 MET-h per week (active or highly active) and < 6 h/day of sitting time	≥7.5 MET-h per week (active or highly active) but ≥6 h/day of sitting time	< 7.5 MET-h per week (inactive) and ≥6 h/day of sitting time	< 7.5 MET-h per week (inactive) and < 6 h/day of sitting time	*p*-values
No	431 (70.8)	426 (68.2)	188 (55.6)*&	142 (66.4)	
Yes	178 (29.2)	199 (31.8)	150 (44.4)	72 (33.6)	

Differences in continue variables were tested using the analysis of variance in mean ± standard deviation. Differences in categorical variables were tested using the chi-square test in number (%)

SD: standard deviation; BMI: body mass index; MET: metabolic equivalent of task; PAOD: peripheral arterial occlusive disease; SBP: systolic blood pressure; DBP: diastolic blood pressure; FPG: fasting plasma glucose; HDL: high-density lipoprotein; LDL: low-density lipoprotein; TC: Total cholesterol; TG: triglyceride; eGFR: estimated glomerular filtration rate; ABI: ankle-brachial index; baPWV: brachial-ankle pulse wave velocity

#: Regular physical activity was defined the study subjects whether they had physical activity at least 30 min per day and 2 or more days per week for at least 6 months

*: $p < 0.05$ compared to ≥7.5 MET-h per week and < 6 h/day of sitting time; &: $p < 0.05$ compared to ≥7.5 MET-h per week but ≥6 h/day of sitting time

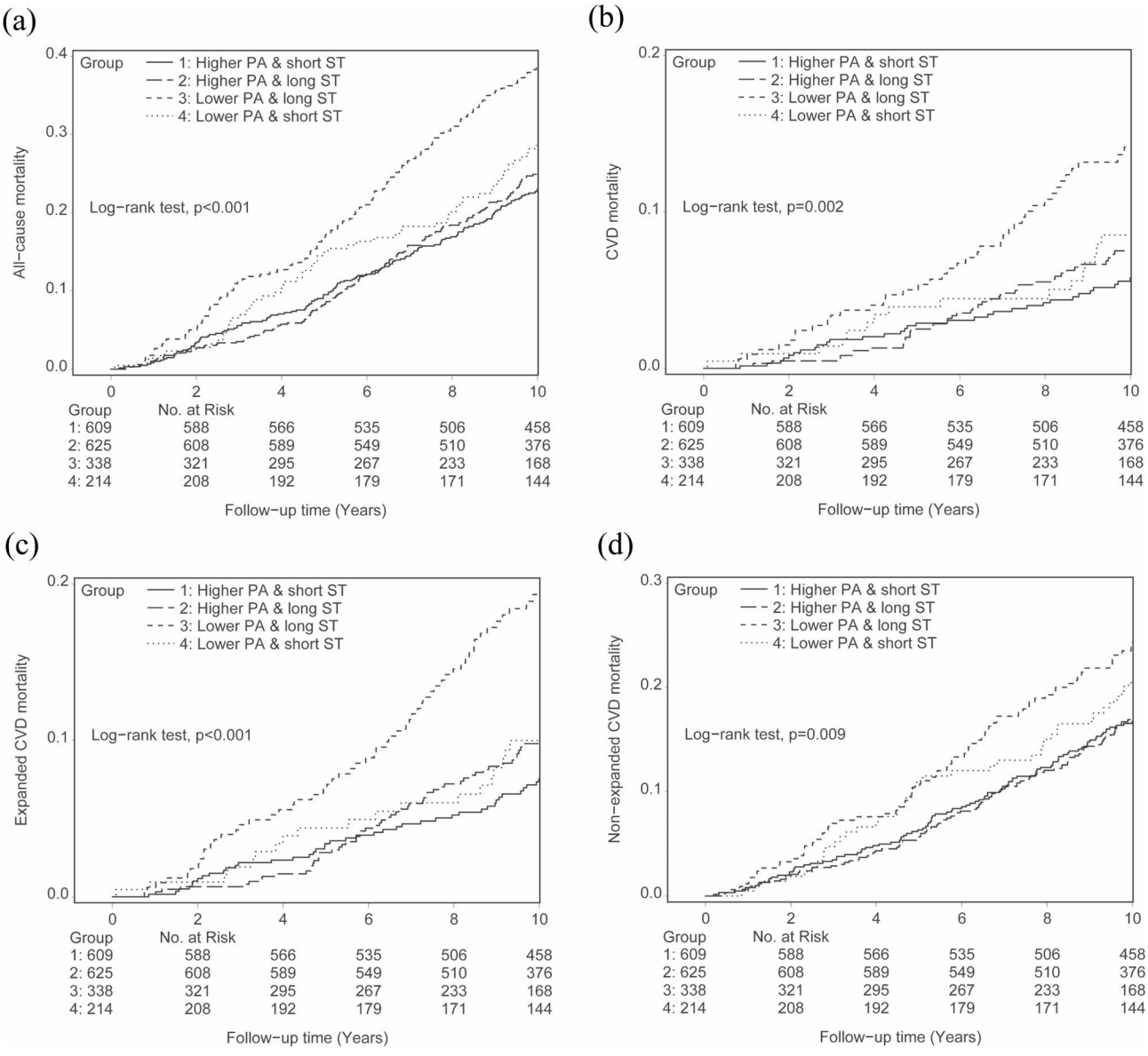

Fig. 1 Kaplan-Meier cumulative incidences (**a**) all-cause, (**b**) CVD mortality, (**c**) expanded CVD mortality, and (**d**) non-expanded CVD mortality by combined physical activity and sitting time

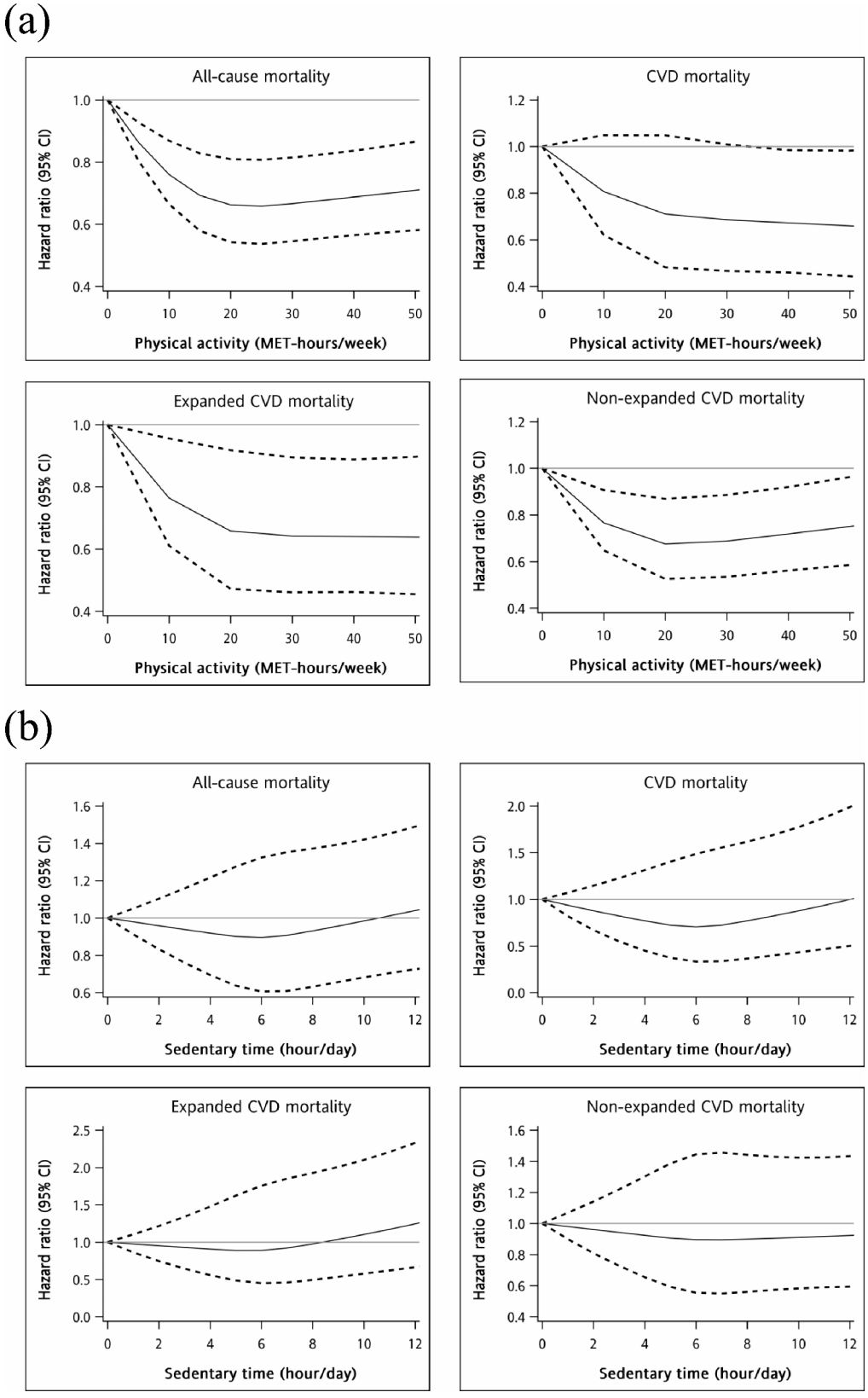

Fig. 2 Restricted multivariable cubic spline plots for (**a**) metabolic equivalent of task (hour/week) and (**b**) sedentary time

Table 2 Adjusted hazard ratios of all-cause, CVD mortality, expanded CVD mortality, and non-expanded CVD mortality according to combined groups of physical activity

Variables	HR (95% CI)		
	< 7.5 MET-h per week (inactive) (*n* = 552)	7.5–30 MET-h per week (active) (*n* = 791)	> 30 MET-h per week (highly active) (*n* = 443)
All-cause mortality			
Model 1	1.0	0.7 (0.6, 0.8)***	0.6 (0.5, 0.8)***
Model 2	1.0	0.7 (0.6, 0.9)***	0.7 (0.5, 0.8)***
Model 3	1.0	0.7 (0.6, 0.9)**	0.7 (0.5, 0.9)**
CVD mortality			
Model 1	1.0	0.7 (0.5, 0.9)*	0.5 (0.3, 0.9)**
Model 2	1.0	0.7 (0.5, 1.0)	0.6 (0.4, 0.9)*
Model 3	1.0	0.8 (0.6, 1.2)	0.6 (0.4, 1.0)
Expanded CVD mortality			
Model 1	1.0	0.6 (0.5, 0.9)**	0.5 (0.3, 0.8)***
Model 2	1.0	0.7 (0.5, 0.9)*	0.5 (0.4, 0.8)**
Model 3	1.0	0.8 (0.6, 1.0)	0.6 (0.4, 0.9)**
Non-expanded CVD mortality			
Model 1	1.0	0.7 (0.5, 0.9)**	0.7 (0.5, 0.9)*
Model 2	1.0	0.7 (0.6, 0.9)*	0.7 (0.6, 0.9)*
Model 3	1.0	0.7 (0.6, 0.9)*	0.7 (0.6, 0.9)*

Model 1 adjusting for age and gender

Model 2 adjusting for body mass index, waist, smoke and alcohol consumption in the first multivariate model

Model 3 adjusting for heart disease, hypertension, diabetes, stroke, hyperlipidemia cancer, arterial stiffness and peripheral arterial occlusive disease in second multivariate model

HR: hazard ratio; CI: confidence interval

*$p<0.05$, **$p<0.01$, ***$p<0.001$

Table 3 Adjusted hazard ratios of all-cause, CVD mortality, expanded CVD mortality, and non-expanded CVD mortality according to combined groups of sitting time

Variables	HR (95% CI)			
	< 4 h/day of sitting time (*n* = 351)	4–5.9 h/day of sitting time (*n* = 472)	6–8 h/day of sitting time (*n* = 535)	> 8 h/day of sitting time (*n* = 428)
All-cause mortality				
Model 1	1.0	1.0 (0.7, 1.2)	1.0 (0.8, 1.2)	1.2 (0.9, 1.5)
Model 2	1.0	1.0 (0.7, 1.2)	0.9 (0.7, 1.2)	1.1 (0.9, 1.4)
Model 3	1.0	0.9 (0.7, 1.2)	0.9 (0.7, 1.2)	1.1 (0.8, 1.4)
CVD mortality				
Model 1	1.0	0.8 (0.5, 1.3)	0.9 (0.5, 1.4)	1.3 (0.8, 2.0)
Model 2	1.0	0.8 (0.5, 1.4)	0.9 (0.6, 1.4)	1.3 (0.8, 2.0)
Model 3	1.0	0.8 (0.5, 1.3)	0.9 (0.5, 1.4)	1.2 (0.7, 1.9)
Expanded CVD mortality				
Model 1	1.0	1.0 (0.6, 1.5)	1.1 (0.7, 1.6)	1.6 (1.0, 2.4)*
Model 2	1.0	1.0 (0.6, 1.5)	1.0 (0.7, 1.6)	1.5 (1.0, 2.3)*
Model 3	1.0	0.9 (0.6, 1.4)	1.0 (0.6, 1.5)	1.3 (0.9, 2.0)
Non-expanded CVD mortality				
Model 1	1.0	1.0 (0.7, 1.3)	0.9 (0.7, 1.3)	1.0 (0.7, 1.3)
Model 2	1.0	1.0 (0.7, 1.3)	0.9 (0.7, 1.2)	0.9 (0.7, 1.3)
Model 3	1.0	1.0 (0.7, 1.3)	0.9 (0.7, 1.3)	0.9 (0.7, 1.3)

Model 1 adjusting for age and gender

Model 2 adjusting for body mass index, waist, smoke and alcohol consumption in the first multivariate model

Model 3 adjusting for heart disease, hypertension, diabetes, stroke, hyperlipidemia cancer, arterial stiffness and peripheral arterial occlusive disease in second multivariate model

HR: hazard ratio; CI: confidence interval

*$p<0.05$, **$p<0.01$, ***$p<0.001$

Discussion

In this study, three cohorts of older persons over 65 years old in Taichung communities were investigated to assess whether physical activity (defined by MET hours per week from a checklist of self-reported items according to WHO guideline for grouping) and a sedentary lifestyle (defined by sitting time of a self-reported item) are associated with all-cause and CVD mortality. Our study findings revealed that physical activity lower than WHO guideline is associated with an increased risks of all-cause mortality and expanded and non-expanded CVD mortality. In addition, lower physical activity combined with long sitting time is associated with an elevated risk of all-cause mortality. These findings indicated an independent effect of low physical activity, as well as the joint effect of low physical activity and long sitting hour. Compared to those who were active or highly active with shorter sitting hours, older adults who were inactive with longer sitting time faced significantly higher risks of all-cause mortality (40%), and expanded CVD mortality (70%).

Our study's findings show that low physical activity was independently associated with an increased risk of expanded CVD mortality in older persons, which was consistent with those reported by prior studies conducted in adults [14, 15, 21–25] or persons with CVD [26] exploring the associations between physical activity and CVD incidence or mortality. Our study also found the joint effect of low physical activity and long sedentary time on expanded CVD mortality. A long-term follow-up study also found that the combined behavior of increasing sedentary time and reducing moderate-intensity physical activity increased the risk of cardiometabolic deterioration in middle-aged and older adults [27]. However, only a limited number of studies explored the combined effects of physical activity and sedentary time on mortality. The present work added to the knowledge in this research area.

Our study's findings on the association between low physical activity and expanded CVD mortality can be explained by a number of biological mechanisms, one example being the age-related adverse changes in plasma lipid. A lower physical activity would suppress the triglyceride uptake from plasma to muscle and further reduce serum HDL concentrations because of the decrease in the skeletal muscle's lipoprotein lipase. Elevated lipoprotein levels have been reported in older adults who live a

Table 4 Adjusted hazard ratios of all-cause, CVD mortality, expanded CVD mortality, and non-expanded CVD mortality according to combined groups of physical activity and sitting time

Variables	HR (95% CI)			
	≥7.5 MET-h per week and <6 h/day of sitting time (*n* = 609)	≥7.5 MET-h per week but ≥6 h/day of sitting time (*n* = 625)	<7.5 MET-h per week and ≥6 h/day of sitting time (*n* = 338)	<7.5 MET-h per week and <6 h/day of sitting time (*n* = 214)
All-cause mortality				
Model 1	1.0	1.0 (0.8, 1.2)	1.6 (1.3, 2.0)***	1.3 (1.0, 1.7)
Model 2	1.0	0.9 (0.8, 1.2)	1.5 (1.2, 1.9)***	1.2 (0.9, 1.6)
Model 3	1.0	1.0 (0.8, 1.2)	1.4 (1.1, 1.8)**	1.3 (0.9, 1.7)
CVD mortality				
Model 1	1.0	1.1 (0.7, 1.6)	1.8 (1.2, 2.9)**	1.4 (0.8, 2.4)
Model 2	1.0	1.1 (0.7, 1.6)	1.7 (1.1, 2.7)*	1.4 (0.8, 2.4)
Model 3	1.0	1.1 (0.7, 1.6)	1.5 (0.9, 2.3)	1.2 (0.7, 2.2)
Expanded CVD mortality				
Model 1	1.0	1.1 (0.8, 1.6)	2.1 (1.4, 3.0)***	1.4 (0.8, 2.2)
Model 2	1.0	1.1 (0.8, 1.6)	1.9 (1.3, 2.8)***	1.3 (0.8, 2.2)
Model 3	1.0	1.1 (0.8, 1.6)	1.7 (1.1, 2.4)*	1.3 (0.8, 2.1)
Non-expanded CVD mortality				
Model 1	1.0	0.9 (0.7, 1.2)	1.4 (1.1, 1.9)*	1.3 (0.9, 1.8)
Model 2	1.0	0.9 (0.7, 1.1)	1.3 (1.0, 1.7)	1.2 (0.9, 1.7)
Model 3	1.0	0.9 (0.7, 1.1)	1.3 (1.0, 1.7)	1.2 (0.9, 1.7)

Model 1 adjusting for age and gender

Model 2 adjusting for body mass index, waist, smoke and alcohol consumption in the first multivariate model

Model 3 adjusting for heart disease, hypertension, diabetes, stroke, hyperlipidemia cancer, arterial stiffness and peripheral arterial occlusive disease in second multivariate model

HR: hazard ratio; CI: confidence interval

*$p<0.05$, **$p<0.01$, ***$p<0.001$

sedentary life [28]. These abnormalities have been identified as major risk factors for CVD. However, a physically active lifestyle enables older adults to maintain good internal body composition, allowing lipids and lipoproteins to remain at normal levels. Regular aerobic exercise affects plasma lipoproteins by increasing the amount of cardioprotective HDL cholesterol and reducing the incidence of CVD [28].

Although this study did not detect the independent effect of long sitting time, the significant joint association of high physical activity and long sitting time was observed. The possible potential mechanisms for the association between a sedentary lifestyle and mortality included metabolic function disorders [29], such as decreased insulin sensitivity resulting in increased total cholesterol and triglycerides and reduced reactive hyperemia in the lower legs because of impaired microvascular function [30].

Only a few studies assessed the impact of sedentary behaviors on mortality [31–33]. Some works used accelerometry to measure physical activity and sedentary behaviors [21–24]; however, they focused on CVD, diabetes, or cancer incidence. A prior research focused on the effect of inactivity or sitting time on mortality among 9,518 community-dwelling white women aged over 65 years. The investigators classified participants into four groups according to the changes in their physical activity levels based on daily walking amount, frequency and duration of leisure activities. These four groups included staying sedentary, becoming sedentary, staying active, and becoming active [31]. After 12.5 years of follow-up, they found that women who increased their physical activity levels between baseline and follow-up had lower all-cause and CVD mortality rates compared with continually sedentary women [31].

The WHO provides guidelines on physical activity and sedentary behavior for older persons [5], suggesting that older adults should engage in 150–300 min of moderate or 75–150 min of vigorous aerobic activity per week, totaling about 450-1,800 MET minutes (7.5–30 MET hours). The cutoff value of MET hours in the present study is based on this guideline. However, the WHO has not released a cutoff for sitting time. The sitting time in this study is 6 h, which is lower than that of a previous study (12.5 h/day) measured using a hip-mounted accelerometer for sedentary time [33].

This study has several strengths, namely, the use of a population-based approach for older persons residing in community, the use of standardized instrument to collect leisure-time physical activity, its prospective cohort design, and the focus on older persons. Our analyses have adjusted for many traditional risk factors for mortality.

Our study has three limitations. First, this study measured physical activity using participants' self-reported data on types and times of physical activity over the past year, without using any type of "activity trackers" or "fitness trackers" such as wrist-type activity meter. Second, this study measured sitting time based on self-reported data, rather than using objective measurement such as wearing a uniaxial accelerometer [34]. A prior study indicates participants often report less sedentary time than what is recorded by the accelerometer, and this discrepancy tend to decrease at higher levels of sedentary time [35]. As a result, this bias could lead to misclassification of some older adults into either short or long sitting groups. The third limitation is that although the analysis methods allow us to assess the independent and joint effects of physical activity and sitting time, this study cannot provide the best cut-off to identify physical activity and sedentary behaviors in older persons. The last limitation is that this study has been conducted in older persons residing in a community of Taiwan and our findings may not be generalizable to all older persons. But it can be applied to older persons with characteristics and physical activity level similar to those enrolled in the present study.

Conclusion

Our study found that the independent effect of physical activity and the joint effect of physical activity and sitting time are associated with expanded CVD death risk. Expanded CVD mortality may be minimized by engaging in physical activity and reducing sedentary behaviors.

Abbreviations

WHO	World Health Organization
CVD	Cardiovascular disease
TCHS	Taichung Community Health Study
TCHS-E	Taichung Community Health Study for Elders
TCHS-FC	Taichung Community Health Study for family cohort
ICD-10-CM	International Classification of Disease, 10th Revision, Clinical Modification
ICD-9-CM	International Classification of Disease, 9th Revision, Clinical Modification
MET	Metabolic equivalent of task
SGPT	Serum glutamic-pyruvic transaminase
SGOT	Serum glutamic-oxalocetic transaminase
FPG	Fasting plasma glucose
BUN	Blood urea nitrogen
baPWV	Brachial-ankle pulse wave velocity
ABI	Ankle-brachial index
HRs	Hazard ratios
CI	Confidence interval
PAOD	Peripheral arterial occlusive disease

Supplementary Information

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Supplementary Material 1

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Not applicable.

Author contributions

CCL and TCL contributed equally to the design of the study and the direction of its implementation, including supervision of the field activities, quality assurance and control. CIL, CSL, CHL and YCL supervised the field activities. TCL and CCL helped conduct the literature review and prepare the Methods and the Discussion sections of the text. CIL, YCL and SYY designed the study's analytic strategy and conducted the data analysis. All authors read and approved the final manuscript.

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Data availability

The datasets generated and/or analyzed during the current study are not publicly available due to the policy declared by National Health Insurance in Taiwan but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This present study was approved by the Ethical Review Board of China Medical University Hospital (CMUH108-REC1-058). Written informed consent was obtained from all the study participants. Informed consent was taken from family members/legal guardians of illiterate participants. All methods were performed in accordance with the relevant guidelines and regulations.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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