

Original article

# Associations between walking parameters and subsequent sleep difficulty in older adults: A 2-year follow-up study

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## Abstract

**Purpose:** This 2-year follow-up study aimed to examine the associations between total volume, frequency, duration, and speed of walking with subsequent sleep difficulty in older adults.

**Methods:** A total of 800 older adults aged 65 years and over participated in the first survey in 2012 and 511 of them were followed 2 years later. The 5-item Athens Insomnia Scale (AIS-5) was used to measure sleep difficulty. Frequency, duration, and speed of outdoor walking were self-reported. Walking speed was assigned a metabolic equivalent value (MET) from 2.5 to 4.5. Total walking volume in MET-h/week was calculated as frequency  $\times$  duration  $\times$  speed. Negative binomial regressions were performed to examine the associations between volume and components of walking with subsequent sleep difficulty with covariates of age, sex, education, marital status, living arrangement, smoking, alcohol consumption, mental health, Charlson Index, exercise (excluding walking), and sleep difficulty at baseline.

**Results:** Participants with low walking volume had a higher level of sleep difficulty 2 years later compared with those with high walking volume (incident rate ratios = 1.61,  $p = 0.004$ ). When speed, frequency, and duration of walking were simultaneously entered into 1 model, only walking speed was significantly associated with subsequent sleep difficulty (after the model was adjusted for covariates and baseline sleep difficulty). Sensitivity analyses showed that walking duration emerged as a significant predictor among 3 walking parameters, with 2-year changes of sleep scores as dependent variable.

**Conclusion:** Total amount of walking (especially faster walking and lasting for more than 20 min) is associated with less subsequent sleep difficulty after 2 years among older adults.

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**Keywords:** Disturbed sleep; Exercise; Insomnia; Physical activity; Prospective study; Sleep disorder

## 1. Introduction

Poor sleep quality is associated with increased risks of several medical conditions including inflammatory diseases, cardiovascular disease, diabetes, obesity, depression, and also

mortality.<sup>1–5</sup> Older people are especially susceptible to sleep-related problems. With increasing age, sleep quantity and quality may change considerably with more sleep fragmentation, earlier awakening, and reduced slow-wave sleep.<sup>6–8</sup> The increased prevalence of chronic conditions in later life may contribute to sleep difficulty for older adults.<sup>6</sup>

Physical activity (PA) has increasingly been recognized for its beneficial effects on sleep quality and reduced risk of insomnia in older adults.<sup>9–13</sup> Walking is the most common PA among older adults across different countries.<sup>14,15</sup> It does not require special

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skills and equipment; it is an accessible and inexpensive form of PA that carries minimal adverse effects;<sup>16–18</sup> and it can be incorporated into everyday life. Therefore, for older adults, walking provides an ideal way to increase their PA levels.<sup>18</sup> Hence, it has been featured prominently in national guidelines for health, especially for those who are initially inactive or frail.<sup>19</sup>

Several causal pathways between exercise or PA and sleep have been proposed.<sup>20,21</sup> The thermogenic hypothesis suggests that exercise or PA raises body temperature, and as a result, body heating acclimation helps to promote sleep.<sup>22</sup> Also, exercise and PA both deplete energy stores, which increases the need for sleep due to energy conservation or body restoration.<sup>20</sup>

Walking can be quantified through the assessment of overall volume, which is usually expressed in terms of 3 parameters: frequency, duration, and intensity.<sup>18</sup> Volume as an overall estimate can indicate the degree to which walking is associated with sleep. However, each of the underlying parameters may expose different mechanisms underpinning walking–sleep relationships. For example, higher speeds or intensities of walking may stimulate greater metabolic adaptation whereas frequency will reflect regularity of exposure, which might be critical to sustained sleep benefits. Thus, it may be beneficial to examine the independent effects of the 3 parameters in addition to volume of walking. Previous research has examined the relationships of these parameters of PA with depressive symptoms<sup>23</sup> and activities of daily living.<sup>24</sup> The results showed that while controlling for the other parameters of PA, only intensity was an independent predictor of depressive symptoms and only duration was associated with activities of daily living. However, no study, either cross-sectional or longitudinal in design, has been identified that has investigated the independent associations between walking parameters and sleep among older adults. This prospective cohort study was therefore designed to explore, in addition to total volume of walking, the independent relationships between frequency, duration, and intensity of walking with self-reported sleep difficulty in older adults 2 years later.

## 2. Methods

### 2.1. Participants

A total of 800 older adults who attended the 2012 health examination at Taipei City Hospital were selected and consented to participate in this study. Quota sampling by sex and age group was employed to provide a sample that was similar to the total Taipei older population (aged 65 years and older). Those who were prescribed psychotropic medications (e.g., antipsychotics, antidepressants, anti-anxiety medications, and mood stabilizers) ( $n = 5$ ) were excluded due to the possible influence on their sleep by these medications. Among the selected participants, 511 older adults also completed the health examination and questionnaire surveys at follow-up in 2014 (response rate = 63.9%). The study was approved by the Institutional Review Board of Taipei City Hospital. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional review board, national research committee, or both, and with the 1964 Declaration of Helsinki and its later amend-

ments or comparable ethical standards. The written informed consent was obtained from all individual participants included in the study.

### 2.2. Measures

In both surveys, all participants completed a comprehensive medical examination, which included anthropometric measures, scans, and the collection of blood samples. While attending, they also had face-to-face interviews with doctors of family medicine about health conditions and were asked to complete a questionnaire to assess sleep and PA.

#### 2.2.1. Outcome variable: sleep difficulty

The Athens Insomnia Scale (AIS) was used to measure sleep difficulty at baseline and follow-up. It has an 8-item version (AIS-8) and a brief 5-item version (AIS-5). The Chinese version of AIS-5 was used in this study, which has been shown to be valid and reliable in the Chinese population.<sup>25</sup> The AIS-5 assesses time to sleep induction, number of awakenings during the night, time of the final awakening, sleep duration, and sleep quality during the last month. A higher score indicates greater sleep difficulty.<sup>26</sup> The cut-off point for defining sleep difficulty (insomnia symptoms) for the Chinese version of AIS-5 is suggested to be 5.<sup>25</sup>

#### 2.2.2. Exposure variable: walking

Participants were asked to estimate the frequency and the average daily amount of time they had spent walking outdoors during the past 7 days. They were also asked to indicate their usual outdoor walking speed: easy (<2 mile/h), average (2–2.9 mile/h), brisk (3–3.9 mile/h), or very brisk ( $\geq 4$  mile/h).<sup>27</sup> Walking speed was assigned a metabolic equivalent value (MET): 2.5 METs for easy pace, 3.0 METs for average pace, 3.5 METs for brisk pace, and 4.5 METs for very brisk pace. Self-reported walking speed has been shown to be a good marker of measured walking speed in older adults<sup>28</sup> and has been used in several studies.<sup>27,29,30</sup> The total walking volume in MET-h/week was calculated by multiplying frequency by duration and by walking speed (METs).<sup>29</sup> Each walking parameter was categorized into tertiles: low, moderate, and high.

#### 2.2.3. Covariates

Sex, age, education, marital status, living arrangements, smoking habits, alcohol consumption, metabolic syndrome, mental health, exercise (excluding walking), and sleep difficulty at baseline were used as covariates in the regression analyses. Age (65–74 and 75+) and education (schooling  $\leq 9$  years and  $>9$  years) were both separated into 2 groups. Marital status was grouped into married or cohabitating and others (including never married, divorced, widowed, and separated). Living arrangements were categorized into “living alone” and “living with others”. Smoking and alcohol consumption was categorized as “Yes (current smoker or drinker)” or “No”.

Health conditions among participants (which included heart disease, hypertension, hyperlipidemia, diabetes, stroke, pulmonary disease, physical pains, gout, arthritis, Parkinson’s disease, dementia, liver disease, renal disease, and cancer) were checked from the medical records and diagnosed by medical doctors. As

a small proportion of our sample was found to have these diseases (e.g., stroke, Parkinson's disease, dementia, and cancer), a modified version of the Charlson Index of Comorbidity was calculated. All diseases received weights of 1, with the exception of renal disease and cancer, which received weights of 2.<sup>31</sup>

Mental health was assessed using the 5-item Brief Symptom Rating Scale (BSRS-5), which was developed to screen for psychiatric illnesses and disorders in non-psychiatric health settings. The BSRS-5 measures 5 symptoms (anxiety, depression, hostility, interpersonal sensitivity or inferiority, and insomnia) with higher scores indicating the presence of more symptoms.<sup>32</sup> The total score ranges from 0 to 20 and the cut-off point is suggested to be 8 for the community population.<sup>33</sup>

Exercise behaviors other than walking were also adjusted for in the analyses. In general, exercise is the umbrella term for all PAs including walking. However, in our study, participants were asked about walking behaviors first. Then they reported participating in other exercise behaviors except walking. The term "exercise" referred to formally organized activities such as Tai Chi and sports. These 2 variables (exercise and PA) are therefore regarded as discrete from each other in our study. Participants were asked to report exercise behaviors during the past 7 days at baseline. They were classified as "no exercise" if they did not participate in any exercise. Participants who engaged in some exercise (excluding walking) were classified as "yes".

### 2.3. Statistical analyses

Descriptive statistics for all covariates, walking parameters, and sleep difficulty at baseline were calculated to characterize the participants. Kruskal–Wallis tests were used to examine group differences in scores of sleep difficulty among the sample descriptors because of violations of normality. Given the scores of sleep difficulty were positively skewed and over-dispersed,<sup>34,35</sup> generalized estimating equations with negative binomial regressions were performed to analyze the prospective associations between baseline walking and subsequently sleep difficulty. Incident rate ratios were reported due to the nonlinearity of the negative binomial distribution.

Five separate negative binomial regressions were computed. The first regression examined the association between total walking volume at baseline and sleep difficulty after 2 years, with age, sex, education, marital status, living arrangement, smoking habits, alcohol consumption, Charlson Index, mental health, exercise, and sleep difficulty at baseline as covariates. Then 3 separate regressions were performed examining associations between each parameter of walking (frequency, duration, and speed) at baseline and subsequent sleep difficulty. Finally, to determine the relative contributions of walking parameters on subsequent sleep difficulty, the 3 parameters of walking were simultaneously entered as independent variables into 1 model. The interactions of walking volume  $\times$  exercise, walking volume  $\times$  sex, walking volume  $\times$  mental health, and walking volume  $\times$  Charlson Index were tested. The results showed no evidence of a significant interaction for each term ( $p = 0.879$ ,  $p = 0.606$ ,  $p = 0.371$ ,  $p = 0.072$ , respectively). Sensitivity analyses were performed to test whether similar results

would be observed if sleep difficulty was examined as a variable of changes in sleep scores over 2 years. All the analyses were performed with SPSS Statistics Version 22.0 (IBM Corp., Armonk, NY, USA) and a  $p$  value less than 0.05 was considered statistically significant.

### 3. Results

Descriptive characteristics of the study population at baseline are presented in Table 1. The mean  $\pm$  SD score of sleep difficulty was  $1.85 \pm 2.73$  in 2012 at baseline and  $1.45 \pm 2.98$  at follow-up. The prevalence of sleep difficulty was 15.5% at baseline and 19.6% after 2 years. The age of participants was  $73.73 \pm 5.69$  years, among whom 24.3% received more than 9 years of schooling. Less than 10% of them were current smokers and just over a quarter (25.1%) consumed alcohol. The proportion of poor mental health was 15.9% and more than 3 quarter of participants (75.5%) suffered at least 1 chronic disease. The walking volume was  $10.33 \pm 10.49$  MET-h/week. Some 32.3% of participants expended more than 10.5 MET-h/week in walking, whereas 36.7% of them expended less than 4.5 MET-h/week. The frequency of walking was  $4.88 \pm 2.54$  days per week and nearly half of the participants (48.7%) walked outdoors on a daily basis. The duration was  $36.53 \pm 30.09$  min per session, and the walking speed was  $2.73 \pm 0.74$  METs, which indicates an easy to average pace. Only 10.2% of participants walked with a brisk or very brisk pace ( $>3.5$  METs).

Table 2 provides the results from the 5 negative binomial regressions with multivariable adjustments, including exercise (excluding walking). The first regression analysis (Model 1) showed that baseline total walking volume was associated with sleep difficulty 2 years later ( $p = 0.015$ ). Participants with low walking volume had higher scores of sleep difficulty than individuals with high walking volume ( $p = 0.004$ ).

Results of the 3 separate regressions (Models 2–4) featuring each walking parameter as an independent variable showed that participants with low levels of walking frequency ( $p = 0.045$ ), duration ( $p = 0.003$ ), or speed ( $p = 0.009$ ) had more subsequent sleep difficulty than those in the high-level groups. However, no significant difference in effects was found between moderate- and high-level groups in each walking parameter.

The final regression explored the relative contributions of the 3 walking parameters at baseline on subsequent sleep difficulty (Model 5). A significant association was found between baseline walking speed and subsequent sleep difficulty even after these substantial adjustments. The score of sleep difficulty among participants with low level of walking speed was 1.68 times of those with high level of walking speed ( $p = 0.045$ ). Neither walking frequency nor time remained significant in this fully adjusted model.

Apart from walking and sleep difficulty, other covariates, which include alcohol drinking, Charlson Index, exercise (excluding walking), and baseline sleep difficulty, were significantly associated with sleep difficulty at follow-up (all  $p < 0.05$ ). Education was also significantly associated with subsequent sleep difficulty, with the exception of the results in

Table 1  
Baseline descriptive statistics of participants with sleep difficulty at follow-up (mean  $\pm$  SD,  $n = 511$ ).

Variable	%	Sleep difficulty at follow-up	<i>p</i>
<b>Age (year)</b>			0.990
65–74	60.8	1.45 $\pm$ 3.06	
75+	39.2	1.47 $\pm$ 2.86	
<b>Sex</b>			0.008
Female	46.0	1.81 $\pm$ 3.38	
Male	54.0	1.14 $\pm$ 2.55	
<b>Education</b>			0.086
Schooling $\leq$ 9 years	75.7	1.53 $\pm$ 3.01	
Schooling > 9 years	24.3	1.19 $\pm$ 2.88	
<b>Marital status</b>			0.845
Married or cohabiting	74.2	1.42 $\pm$ 2.98	
Others	25.8	1.52 $\pm$ 2.98	
<b>Living arrangement</b>			0.776
Living with others	85.9	1.44 $\pm$ 2.97	
Alone	14.1	1.53 $\pm$ 3.04	
<b>Smoking</b>			0.739
No	90.8	1.45 $\pm$ 2.94	
Yes	9.2	1.49 $\pm$ 3.37	
<b>Alcohol drinking</b>			0.763
No	74.9	1.31 $\pm$ 2.63	
Yes	25.1	1.89 $\pm$ 3.82	
<b>Exercise (excluding walking)</b>			0.002
No	33.5	2.08 $\pm$ 3.57	
Yes	66.5	1.14 $\pm$ 2.58	
<b>Mental health</b>			0.583
Good	84.1	1.46 $\pm$ 3.00	
Poor	15.9	1.43 $\pm$ 2.87	
<b>Charlson Index</b>			<0.001
0	24.5	0.65 $\pm$ 2.14	
1	36.6	1.36 $\pm$ 2.73	
2+	38.9	2.04 $\pm$ 3.49	
<b>Walking volume/(MET-h/week)<sup>a</sup></b>			0.052
Low ( $\leq$ 4.5)	36.7	1.77 $\pm$ 3.16	
Moderate (4.6–10.5)	31.0	1.39 $\pm$ 2.88	
High (>10.5)	32.3	1.16 $\pm$ 2.85	
<b>Walking components</b>			0.049
<i>Frequency (day/week)</i>			
Low ( $\leq$ 3)	34.5	1.66 $\pm$ 3.16	
Moderate (4–6)	16.8	1.87 $\pm$ 3.35	
High (7)	48.7	1.16 $\pm$ 2.68	
<i>Duration (min)</i>			0.180
Low ( $\leq$ 20)	33.7	1.67 $\pm$ 3.05	
Moderate (21–40)	34.5	1.44 $\pm$ 2.93	
High (>40)	31.8	1.24 $\pm$ 2.97	
<i>Speed (MET)</i>			0.036
Low ( $\leq$ 2.5)	42.2	1.88 $\pm$ 3.34	
Moderate (2.6–3.5)	47.6	1.12 $\pm$ 2.56	
High (>3.5)	10.2	1.23 $\pm$ 3.07	

<sup>a</sup> The total walking volume in MET-h/week = walking frequency  $\times$  duration  $\times$  speed.

Abbreviation: MET = metabolic equivalent value.

Model 5, which almost achieved significance (Models 1 to 5:  $p = 0.048, 0.018, 0.030, 0.030, 0.056$ , respectively).

Sensitivity analyses yielded similar results for the associations between walking volume ( $p = 0.001$ ), walking duration ( $p = 0.001$ ), and walking speed ( $p = 0.041$ ) with sleep-score changes over 2 years. Participants with low walking volume ( $p < 0.001$ ), low duration ( $p = 0.001$ ), and low speed ( $p = 0.023$ )

at baseline had an increased sleep difficulty during this period when compared to the high-level groups. However, the association between walking frequency and sleep-score changes was only marginally significant ( $p = 0.064$ ) and walking duration emerged as a significant predictor ( $p = 0.012$ ) among 3 walking parameters (Table 3).

#### 4. Discussion

This study examined the association between outdoor walking and sleep difficulty 2 years later among older adults. The results showed that total walking volume was negatively associated with subsequent sleep difficulty. It suggests that high amounts of outdoor walking (>10.5 METs) in later life might help to reduce risk of sleep difficulties among older adults. Previous researchers have suggested that walking outdoor is typically performed in bright-light environments, which might have additive effects on sleep outcomes.<sup>36</sup> Moreover, participating in outdoor walking may increase endorphin secretion and induce elevated mood, which promotes good sleep. High amounts of outdoor walking deplete energy stores and stress the body, which may also facilitate sleep for recuperation of the body.<sup>11,20</sup>

To provide further insight into the possible mechanisms underpinning the impact of walking on risk of sleep difficulties, this study further explored the relative and independent contributions of walking parameters (frequency, duration, and speed) on subsequent sleep difficulty. Among the 3 parameters, walking speed emerged as the most salient independent parameter in the explanation of subsequent sleep difficulty. Higher speeds of walking may lead to higher metabolic turnover and higher levels of physical fatigue. From the hypotheses of energy conservation, one of the functions of sleep is to reduce energy expenditure. Sleep also provides the body a period of low metabolic demand and opportunity for tissue restoration.<sup>20</sup> It may be that higher speeds of walking are more effective in stimulating these mechanisms. Moreover, the group of faster walkers may have better physical fitness, function, and health, which in turn promote better sleep. Previous research has shown that fitness status is significantly related to sleep quality.<sup>37</sup>

There are no other prospective studies with which to directly compare. However, cross-sectional associations between walking speed and sleep-related breathing disorders, have shown slower walking speed to be independently associated with an increased risk of sleep-disorder breathing outcomes.<sup>30</sup> Previous research has also indicated that slow walking speed was associated with poor physical function, more medicated systems, and increased mortality risk.<sup>28</sup> This might partly explain the findings in this study, and suggest that those with faster walking speed might have better physical function and physical health, which may be at least in part an explanation for better sleep. Two cross-sectional studies examined the relationships between sleep quality and physical function (including walking speed) in older men. The results showed that nighttime awakening, multiple long wake episodes, prolonged sleep latency, and insomnia were associated with slower walking speed.<sup>38,39</sup> These findings suggested that the associations



Table 2  
Negative binomial regressions for predicting sleep difficulty after 2 years.

Baseline variable	Model 1			Model 2			Model 3			Model 4			Model 5		
	IRR	95%CI	<i>p</i>	IRR	95%CI	<i>p</i>	IRR	95%CI	<i>p</i>	IRR	95%CI	<i>p</i>	IRR	95%CI	<i>p</i>
<b>Walking volume (MET-h/week)<sup>a</sup></b>			0.015												
Low (≤4.5)	1.61	1.16–2.22	0.004												
Moderate (4.6–10.5)	1.24	0.88–1.74	0.228												
High (>10.5)	1														
<b>Walking components</b>															
<i>Frequency (day/week)</i>						0.120									0.820
Low (≤3)				1.34	1.01–1.80	0.045							1.10	0.81–1.51	0.540
Moderate (4–6)				1.05	0.73–1.51	0.803							1.01	0.70–1.46	0.943
High (7)				1									1		
<i>Duration (min)</i>										0.009					0.164
Low (≤20)							1.64	1.18–2.28	0.003				1.40	0.98–2.00	0.067
Moderate (21–40)							1.15	0.82–1.60	0.420				1.10	0.78–1.54	0.584
High (>40)							1						1		
<i>Speed (MET)</i>												0.002			0.050
Low (≤2.5)										1.92	1.18–3.14	0.009	1.68	1.01–2.80	0.045
Moderate (2.6–3.5)										1.27	0.77–2.09	0.353	1.25	0.76–2.07	0.379
High (>3.5)										1			1		

Notes: Covariates are (from Model 1 to Model 5) age (*p* = 0.486, 0.419, 0.484, 0.491, 0.515, respectively), sex (*p* = 0.529, 0.510, 0.525, 0.595, 0.548, respectively), years of schooling (*p* = 0.048, 0.018, 0.030, 0.030, 0.056, respectively), marital status (*p* = 0.851, 0.730, 0.836, 0.957, 0.891, respectively), living arrangement (*p* = 0.132, 0.142, 0.202, 0.179, 0.315, respectively), smoking (*p* = 0.063, 0.089, 0.082, 0.091, 0.076, respectively), alcohol drinking (*p* = 0.001, 0.002, 0.001, 0.008, 0.004, respectively), Charlson Index (all *p* < 0.001), mental health (*p* = 0.112, 0.127, 0.164, 0.063, 0.098, respectively), exercise (excluding walking) (*p* = 0.020, 0.022, 0.019, 0.029, respectively), and sleep difficulty at baseline (all *p* < 0.001). *p* values for variables (walking volume, frequency, duration, and speed) are of comparison between baseline and follow-up; *p* values for levels (low and moderate) are of comparison with high level.

<sup>a</sup> The total walking volume in MET-h/week = walking frequency × duration × speed.

Abbreviations: CI = confidence interval; IRR = incident rate ratio; MET = metabolic equivalent value.

Table 3  
Sensitivity analyses for predicting changes in sleep scores over 2 years.

Baseline variable	Model 1			Model 2			Model 3			Model 4			Model 5		
	IRR	95%CI	<i>p</i>	IRR	95%CI	<i>p</i>	IRR	95%CI	<i>p</i>	IRR	95%CI	<i>p</i>	IRR	95%CI	<i>p</i>
<b>Walking volume (MET-h/week)<sup>a</sup></b>			0.001												
Low (≤4.5)	2.17	1.42–3.31	<0.001												
Moderate (4.6–10.5)	1.27	0.81–2.01	0.296												
High (>10.5)	1														
<b>Walking components</b>															
<i>Frequency (day/week)</i>						0.064									0.387
Low (≤3)				1.40	0.97–2.01	0.073							1.10	0.73–1.64	0.658
Moderate (4–6)				0.82	0.51–1.32	0.407							0.76	0.47–1.24	0.275
High (7)				1									1		
<i>Duration (min)</i>										0.001					0.012
Low (≤20)							2.08	1.37–3.17	0.001				1.94	1.21–3.09	0.006
Moderate (21–40)							1.16	0.74–1.82	0.514				1.16	0.73–1.83	0.528
High (>40)							1						1		
<i>Speed (MET)</i>												0.041			0.452
Low (≤2.5)										2.16	1.11–4.20	0.023	1.54	0.77–3.08	0.224
Moderate (2.6–3.5)										1.59	0.81–3.15	0.181	1.51	0.76–2.98	0.236
High (>3.5)										1			1		

Notes: Covariates are (from Model 1 to Model 5) age (*p* = 0.365, 0.286, 0.427, 0.390, 0.373 respectively), sex (*p* = 0.006, 0.007, 0.005, 0.012, 0.003, respectively), year of schooling (*p* = 0.329, 0.277, 0.491, 0.253, 0.595, respectively), marital status (*p* = 0.220, 0.214, 0.255, 0.332, 0.258, respectively), living arrangement (*p* = 0.006, 0.007, 0.005, 0.012, 0.003, respectively), smoking (*p* = 0.494, 0.751, 0.866, 0.913, 0.754, respectively), alcohol drinking (all *p* < 0.001), Charlson Index (all *p* < 0.001), mental health (*p* = 0.018, 0.021, 0.022, 0.010, 0.018, respectively), exercise (excluding walking) (*p* = 0.083, 0.087, 0.093, 0.050, 0.110, respectively). *p* values for variables (walking volume, frequency, duration, and speed) are of comparison between baseline and follow-up; *p* values for levels (low and moderate) are of comparison with high level.

<sup>a</sup> The total walking volume in MET-h/week = walking frequency × duration × speed.

Abbreviations: CI = confidence interval; IRR = incident rate ratio; MET = metabolic equivalent value.

between walking speed and sleep might be bi-directional. Therefore, we further analyzed our data with baseline sleep difficulty as the exposure variable and subsequent walking speed as the outcome variable adjusting for baseline walking speed and other covariates. However, no significant association was found (data not shown). It is not possible to fully establish the causal relationship with our observational study during follow-up. More research is needed to compare effects of different speeds of walking on these parameters.

Walking duration emerged as the only significant predictor among 3 walking parameters in the sensitivity analyses with sleep-score changes as the dependent variable. Another study also found a significant bivariate association between level of daily walking time and insomnia prevalence, though it became nonsignificant after entering other forms of PA and covariates.<sup>40</sup> Spending more time on walking will place greater demand on energy stores, which in turn will require more sleep as compensation. We further analyzed walking duration between participants with insomnia and those without. Individuals with insomnia spent less time in walking (mean difference 5.1 min) and had significant lower total walking volume than those without insomnia (mean difference 2.9 METs).

This is the first study to look at the effect of different walking parameters on sleep, though it is a descriptive observational work. Descriptive data that indicate the strengths of relationships between independent and dependent variables are necessary to provide a preliminary indication of possible mechanisms. This research was designed to investigate the strengths of associations between each of the parameters of walking and sleep with a view to identifying which were most likely to contribute to any effect on sleep quality. The findings that higher intensity walking produces stronger associations will help direct future research to consider the physiological and psychological mechanisms triggered by high-intensity activity that underpin sleep improvement.

No significant difference was found between mental health (depressive symptoms) and sleep difficulty in the univariate analysis. This finding is inconsistent with previous research among older adults, showing significant associations between depressive symptom and poor subjective sleep quality, though weaker associations have been found with objective measures.<sup>41,42</sup> Our result might be due to the various subjective sleep measures used and the relatively small proportion of participants with poor mental health (15.9%,  $n = 81$ ), both of which could contribute to the lack of statistical power to detect the significance.

There are limitations to this study. Older adults tend to have poorer memories; therefore, the use of self-reported information on walking and sleep measures might be influenced by recall bias. Moreover, there may be problems of sample representativeness given that participants of this study were recruited from a free hospital health examination. Those with severe health conditions may have difficulties in attending the health examination. Participants in our study are physically healthier than a Chinese study with a nationally representative sample<sup>24</sup> (Charlson Index  $\geq 3$ : 17.2% vs. 25.8%). The prevalence of sleep difficulty in this study was much lower than that in previous

research that used the same measure in older adults (15.5%–19.6% vs. 41.4%–43.5%).<sup>43,44</sup> It is difficult to directly compare the proportion of participants with poor mental health to other studies due to the large range of measures and cut-off points used. However, a review study showed that the prevalence of depressive disorders (depressive symptoms) with a range of measures in the older population has been estimated to be 17.1%.<sup>45</sup> These suggest that our sample may also be mentally healthier than the general older populations. Therefore, the present findings should be interpreted with caution as they might not fully generalize to all older adults. Because less walking activity and poor sleep quality tend to be common among the subgroups with poor physical and mental health, any selection bias may underestimate the association between walking and sleep difficulty in our study.

The heterogeneity of the sample is also an issue. Our sample is not big enough to divide the participants into different subgroups based on exercise, sex, mental health, or physical health, though it is not one of our research objectives. However, the interactions of walking volume and the above variables were tested, showing no evidence of a significant interaction in each term. Finally, this study only used 1 wave data of walking parameters at baseline. Subsequent changes in waking habits in the years before follow-up may yield different results. Well-designed randomized control trials and large-scale cohort studies with more repeated measures are encouraged to confirm these findings.

## 5. Conclusion

The prospective design of this study, adjusting for several potential confounders, provides more confidence than cross-sectional studies that show walking (especially faster walking and longer duration) is associated with lower levels of sleep difficulty after 2 years. This study provides further support for walking programs for older adults that involve working with at least moderate intensity and for more than 20 min as a means of improving sleep quality.

## Authors' contributions

LJC and PWK designed the study, performed the statistical analyses, and drafted the manuscript; KRF conceived of the study, participated in its design, and helped to draft the manuscript; WJS collected the data and helped to revise the manuscript; DC carried out the study, participated in its coordination, helped to revise the manuscript; PST participated in its design and data analyses and helped to revise the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

## Competing interests

The authors declare that they have no competing interests.

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