Title

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Association between hilliness and walking speed in community-dwelling older Japanese adults: A cross-sectional study

Short running title: Hilliness and slow walking speed

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Highlights:

- Living in hilly environments was related to slower walking speed in older adults.
- Stratified analysis identified this association in non-drivers, but not drivers.
- Non-driving and living in hilly environments increased risks for slower walking speed.

Abstract

Purpose: This cross-sectional study investigated the association between hilliness and walking speed in community-dwelling older adults, and whether it varied according to their car-driving status.

Methods: Data were collected from 590 participants aged 65 and older living in Okinoshima Town, Shimane prefecture, Japan, in 2018. Comfortable walking speed (m/s) was objectively assessed. Hilliness was measured by the mean land slope (degree) within a 500-m or 1000-m network buffer around each participant's home using a geographic information system. A multiple linear regression examined whether the land slope was associated with walking speed, adjusted for sex, age, body mass index, smoking habits, alcohol consumption habits, exercise habits, chronic disease, and living arrangements. A stratified analysis by car-driving status was also conducted.

Results: After adjusting for all confounders, the land slope within the 500-m or 1000-m network buffer was negatively associated with walking speed (*B* = -0.007, 95% CI [-0.011, -0.002]; *B* = -0.007, 95% CI [-0.011, -0.003], respectively). The stratified analysis by car-driving status showed that living in a hilly area was negatively associated with walking speed among non-drivers in the 500-m or 1000-m network buffer (*B* = -0.011, 95% CI [-0.017, -0.004]; *B* = -0.012, 95% CI [-0.019, -0.006]), though there were no associations among drivers.

Conclusions: A hilly environment is positively associated with slow walking speed in community-dwelling older adults in Japan. Moreover, car-driving status potentially modifies the relationship between living in a hilly environment and slow walking speed.

Keywords: older adults; land slope; physical function; rural area

1. Introduction

The decline in walking speed as a physical function is a known important risk factor for disability and mortality among older adults (Shimada et al., 2021; Studenski et al., 2011). Preventing declining walking speed among older adults is a public health issue, and it is important to clarify its risk factors for creating age-friendly environments (Beard et al., 2016; Koohsari et al., 2018). Some studies have focused on the relationship between neighborhood environments and physical function among older adults (Brown et al., 2008; Koohsari et al., 2020; Michael et al., 2011; Soma et al., 2017). Those studies found a relationship between certain features of built environments (e.g., population density, number of community centers, and architectural features) and walking speed. However, they did not investigate the effect of the physical environment.

The physical environment of Japan is characterized by a hilly terrain (Koohsari et al., 2018). Its land area is predominantly (72.8%) mountainous or hilly, with the proportion of flat land (less than 3.0° land slope) accounting for only 14.0% of the total land area (Statistics Bureau of Japan, 2012). Previous studies have reported both positive and negative associations between hilliness and health outcomes (Okuyama et al., 2019; Tanaka et al., 2016; Villanueva et al., 2013; Buettner, 2015). Further, land slope, which is often used as a measure of hilliness, has been found to be a barrier for physical activities in older adults (Harada et al., 2018). In fact, older Japanese people living in areas with a high degree of land slope reported lower physical activity levels as compared to those living in areas with a low degree of land slope (Tanaka et al., 2016). Tanaka et al. (2016) reported that older people living in sloped areas had higher levels of quadriceps muscle force compared to those residing in non-sloped areas. Physical activity is known to maintain or improve physical function, including walking speed in older adults (Oliveira et al., 2020), the high-intensity activity of walking up and down slopes may have a positive effect on lower limb strength, despite a little amount of time spent participating in physical activity. Furthermore, few studies have examined the association between a hilly environment and walking speed; therefore, further research is required to address this issue.

In addition to distinct terrain features between rural and urban Japan, there is a striking difference in the use of daily public transportation (Kikuchi et al., 2018). For example, older adults living in rural areas depend on their private cars more than those living in metropolitan areas (66.8% vs. 38.4%; Cabinet Office, 2018). Drivers and non-drivers living in rural areas of Japan tend to have different lifestyles because rural residents depend on private cars to carry out their activities of daily living (Amagasa et al., 2018). Further, Kamada et al. (2009) reported that car-driving status modified the relationship between neighborhood environments and physical activity among rural Japanese women. Attributes of neighborhood environments may be more important for health among older non-drivers because their physical activities are likely to be confined to the immediate environment. We hypothesized that older adults are dependent on and vulnerable to their neighborhood environment when they are unable to drive. Understanding the interactive effects of the immediate environment and car-driving status on walking speed can help identify disadvantaged population subgroups that face environmental barriers to healthy aging. However, to our knowledge, previous research has not focused on whether the relationship between hilliness, as a physical environment, and walking speed differs according to car-driving status among community-dwelling older adults.

Thus, the present study aimed at examining the association between hilliness and walking speed in community-dwelling older Japanese adults, and whether that relationship varied according to car-driving status (current drivers vs. non-drivers).

2. Methods

2.1. Study design

This cross-sectional study was conducted by the Center for Community-based Healthcare Research and Education (CoHRE), Shimane University, in collaboration with an annual health checkup program in Okinoshima town (population: 14,608; aging rate: 38.4%; area: 242.8 km^2; based on data from Japan's 2015 census) in Shimane prefecture in rural Japan. Annual health checkups conducted by a government agency are available once a year for residents in the prefecture who are covered by the National Health Insurance and aged 40 years and older. Data were collected during the health checkups from 11 to 22 June 2018. The checkups were conducted by trained nurses or public health nurses, as recommended by the Japanese Ministry of Health, Labour and Welfare (Ministry of Health, Labour and Welfare of Japan, 2013). These data included an additional health survey collected from the same participants during the health checkups. The study was conducted in accordance with the Declaration of Helsinki, and the study protocol was approved by the Ethics Committee of Shimane University (#2888). Written informed consent was obtained from all participants before enrollment.

2.2. Participants

Inclusion criteria were adults aged 65 or older, living in Okinoshima town, and participating in the health checkups. A total of 690 older adults participated in the study. We excluded the data of 100 participants from the statistical analyses due to missing information (i.e., exercise habits, n = 13; car-driving status, n = 1; walking speed, n = 11; geographic information system [GIS] coordinates [latitude, longitude], n = 75). Data from 590 participants were available for statistical analyses. There were no significant differences between participants with and without missing data in terms of sex (p = 0.30), age (p = 0.33), and body mass index (BMI; p = 0.50).

2.3. Walking speed

Comfortable walking speed was measured using a sheet-type pressure sensor (45.5 × 183 cm plate sensor; Healthwalk; Kao Corporation, Japan) placed in the center of a 5-meter walkway (Takayanagi et al., 2018). Participants were asked to walk freely along a 7-meter course and return to the starting point. On the course, acceleration and deceleration zones were set as 1-meter at both ends. The average walking speed (m/s) of one round trip (i.e., two times) was used for the analysis.

2.4. Hilliness

Based on the mean land slope, hilliness was the main exposure variable within a 500-meter and 1000-meter network buffer from each residential point for each participant. The land slope value (degree) was analyzed using ArcGIS 10.0 (Esri Inc., Redland, CA). A network buffer is a polygonal geometric space that approximates the daily activity space of each participant along with the actual street network. The buffer zones were computed along with the actual street network, which excluded non-habitable areas such as forests, rivers, and mountains. The degree of slope 5th mesh data consists of several 50 × 50 m grid squares, each of which stores the land slope value. We computed the mean land slope within each network buffer for the grid squares that intersect with a buffer. The mean land slope was calculated within the 500-meter and 1000-meter network buffer as a degree in the angular unit for each resident. These data were obtained from the National Land Numerical Information, publicly available GIS data administered by the National Land Information Division, National Spatial Planning, and the Regional Policy Bureau of Japan (National Land Information Division).

2.5. Car-driving status

Self-reported car-driving status was used to define drivers and non-drivers (Kamada et al., 2009). The question was "Do you have a car driving license?" Participants answered "yes: currently operate a car," "yes: currently do not operate a car," or "no." Drivers were defined as those who currently had a license to operate a car; non-drivers were defined as those who did not have a license to operate any motor vehicle or had a license but were not currently driving.

2.6. Covariates

Participants' demographics, including sex (male or female), age calculated using participant's birthdate, smoking habits (yes or no), and alcohol consumption habits (yes or no), were collected as part of the health checkups. Exercise habits were measured using the following item: "Do you engage in regular physical exercise or sports to improve your health (including agricultural activities)?" Participants responded "yes" or "no" (Satake et al., 2017). Chronic disease information (yes or no) was collected from a list of 13 items of self-reported physician-diagnosed chronic diseases (hypertension, hyperlipidemia, diabetes, hyperuricemia, stroke, heart disease, vascular disease, kidney disease, hepatic disease, gastrointestinal disease, endocrine disease, osseous disease, or cancer). Living arrangements were classified as single household (living alone) or non-single household (living with others). BMI was calculated from the objectively obtained health checkup data by dividing the body weight by the squared height (kg/m^2).

2.7. Statistical analyses

Descriptive statistics were calculated for all variables by car-driving status. The main analyses in this study used two models (a crude and an adjusted model) to examine whether land slope as the main exposure variable was associated with walking speed. Multiple linear regressions were conducted to estimate unstandardized regression coefficients (*B*), standard error (*SE*), and 95% confidence intervals (CIs) for walking speed as it related to the land slope. For the crude model, the analysis was conducted without any adjustments. For the adjusted model, the analysis was adjusted for sex, age, BMI, current smoking habits, current alcohol consumption habits, exercise habits, current chronic disease, and living arrangements. After a variance inflation factor (VIF) for each independent variable was calculated to evaluate an indicator of multicollinearity, we determined that multicollinearity was not each independent variable based on a cut-off (VIF <10.0). For testing car-driving status as a potential effect modifier of land slope and walking speed, the land slope was entered together with car-driving status and an interaction term of the two in the adjusted model. A stratified analysis was performed to clarify whether the relationship between land slope and walking speed differed depending on car-driving status. A multiple linear regression analysis was also used to examine walking speed with land slope by car-driving status. All statistical analyses were performed using IBM SPSS Statistics 24.0 for Windows (IBM Corp., Armonk, NY, USA). For all analyses, *p*-values less than 0.05 were considered statistically significant.

3. Results

Table 1 shows the differences in participant characteristics based on car-driving status. Of the 590 participants, 375 (59.2%) and 258 (40.8%) were drivers and non-drivers, respectively. The mean degree of land slope was 9.2 (*SD* = 3.8) in the 500-m network buffer and 10.2 (*SD* = 3.8) in the 1000-m network buffer, respectively. The mean walking speed was 1.1 m/s (*SD* = 0.2).

Table 1. Participants' characteristics.

Variables	Total	Car-driving status	
		Drivers	Non-drivers
	(*N* = 590)	*n* = 375 (59.2%)	*n* = 258 (40.8%)
Sex, *n* (%)			
Male	216 (36.6)	184 (54.9)	32 (12.5)
Female	374 (63.4)	151 (45.1)	223 (87.5)
Age (years), *M* (*SD*)	75.8 (6.3)	73.9 (5.7)	78.2 (6.3)
Body mass index (kg/m^2), *M* (*SD*)	23. 0 (3.2)	23.2 (3.1)	22.8 (3.2)
Smoking habits, *n* (%)			
No	565 (95.8)	314 (93.7)	251 (98.4)
Yes	25 (4.2)	21 (6.3)	4 (1.6)
Alcohol consumption habits, *n* (%)			
No	406 (68.8)	188 (56.1)	218 (85.5)
Yes	184 (31.2)	147 (44.9)	37 (14.5)
Exercise habits, *n* (%)			
No	160 (27.1)	96 (28.7)	64 (25.1)
Yes	430 (72.9)	239 (71.3)	191 (74.9)
Chronic disease, *n* (%)			
No	110 (18.6)	69 (20.6)	41 (16.1)
Yes	480 (81.4)	266 (79.4)	214 (83.9)
Living arrangement, *n* (%)			
With partner or others	479 (81.2)	290 (86.6)	189 (74.1)
Alone	111 (18.8)	45 (13.4)	66 (25.9)
Land slope (degree), *M* (*SD*)			
500-m network buffer	9.2 (3.8)	8.8 (3.5)	9.6 (4.1)
1000-m network buffer	10.2 (3.8)	9.8 (3.5)	10.7 (4.0)
Walking speed (m/s), *M* (*SD*)	1.1 (0.2)	1.2 (0.2)	1.0 (0.2)

Note. M, mean; *SD*, standard deviation

Table 2 shows the associations between land slope and walking speed. Land slope in the 500-m network buffer was negatively associated with walking speed in both the crude model (B = -0.007; SE = 0.002; 95% CI [-0.012, -0.002], p = 0.003) and the adjusted model (B = -0.007; SE = 0.002; 95% CI [-0.011, -0.002], p = 0.002). The p-value for the interaction was 0.019. Land slope in the 1000-m network buffer was negatively associated with walking speed in both the crude model (B = -0.008; SE = 0.002; 95% CI [-0.012, -0.003], p = 0.001) and the adjusted model (B = -0.007; SE = 0.002; 95% CI [-0.011, -0.003], p = 0.001). The p-value for the interaction was 0.005.

Table 2. Multiple linear regression for the association between land slope and walking speed.

Network buffer	Land slope								p-value for interaction ‡
	Crude model				Adjusted model †				
	B	*SE*	95% CI	*p*-value	*B*	*SE*	95% CI	*p*-value	
500-m	-0.007	0.002	(-0.012, -0.002)	0.003	-0.007	0.002	(-0.011, -0.002)	0.002	0.019
1000-m	-0.008	0.002	(-0.012, -0.003)	0.001	-0.007	0.002	(-0.011, -0.003)	0.001	0.005

Note. B, unstandardized regression coefficient; *SE*, standard error; CI, confidence interval; each land slope buffer was examined separately.

† Sex, age, body mass index, smoking habits, alcohol consumption habits, exercise habits, chronic disease, and living arrangements were adjusted for.

‡ *P-value* of interaction with car-driving status.

Table 3 shows the association between land slope and walking speed by car-driving status. Among current drivers, the adjusted model showed no significant association between land slope in the 500-m (p = 0.703) or 1000-m network buffer (p = 0.857) and walking speed. Among the non-drivers, land slope in the 500-m (B = -0.011; SE = 0.003; 95% CI [-0.017, -0.004], p = 0.002) or 1000-m network buffer (B = -0.012; SE = 0.003; 95% CI [-0.019, -0.006], p < .001) was more likely to be associated with slow walking speed.

Table 3. The association between land slope and walking speed by car-driving status.

Network buffer	Land slope							
	Crude model				Adjusted model†			
	B	*SE*	95% CI	*p*-value	*B*	*SE*	95% CI	*p*-value
Drivers (n = 375)								
500-m	-0.001	0.003	(-0.007, 0.005)	0.814	-0.001	0.003	(-0.007, 0.005)	0.703
1000-m	0.000	0.003	(-0.006, 0.006)	0.951	-0.001	0.003	(-0.006, 0.005)	0.857
Non-drivers (n = 258)								
500-m	-0.011	0.004	(-0.018, -0.004)	0.003	-0.011	0.003	(-0.017, -0.004)	0.002
1000-m	-0.013	0.004	(-0.020, -0.006)	<0.001	-0.012	0.003	(-0.019, -0.006)	<0.001

Note. B, unstandardized regression coefficient; *SE*, standard error; CI, confidence interval; each land slope buffer was examined separately.

†Sex, age, body mass index, smoking habits, alcohol consumption habits, exercise habits, chronic disease, and living arrangements were adjusted.

4. Discussion

This study is the first to examine whether hilliness is related to walking speed in Japanese community-dwelling older adults. Two main findings are noteworthy. First, a higher land slope was negatively associated with walking speed in the crude and full adjusted models for both 500-m and 1000-m network buffers. In the 500-m network buffer, the B was same in the crude and adjusted models. The hilliness of the 500-m area from home may be more appropriate as a size of neighborhoods for actual daily activities than the 1000-m area. Second, the stratified analyses by car-driving status showed that a higher land slope was negatively associated with walking speed in non-drivers only. Hence, we found that a hilly environment is the neighborhood environmental correlate of slow walking speed among older adults living in a rural area in Japan. Additionally, car-driving status was found to be a potential modifying factor of the association between land slope and slow walking speed. Our results highlight the importance of considering hilliness as a physical environmental feature and car-driving status when establishing promotion strategies to maintain physical function among older adults living in rural areas.

Previous studies have found that walkable environments are positively associated with physical function in older adults (Brown et al., 2008; Koohsari et al., 2020; Michael et al., 2011; Soma et al., 2017). Especially, Soma et al.'s study showed that population density and number of community centers were positively associated with walking speed in older Japanese men and women (Soma et al., 2017). Focusing on land slope, Tanaka et al. (2016) compared quadriceps muscle force among older women living in sloped and non-sloped areas. Older women living in sloped areas had higher levels of quadriceps muscle force compared to those residing in non-sloped areas.

Further, Keskinen et al.'s (2020) longitudinal study showed that hilliness in the home neighborhood predicted the development of self-reported walking difficulties among Finnish older adults. Our results, therefore, advance the existing debate regarding the association between neighborhood physical environments and physical performance among community-dwelling older adults.

The mechanism of the relationship between living in a hilly rural environment and slow walking speed can be explained as follows. A previous study has shown that rural Japanese adults living in higher elevations had knee pain (Hamano et al., 2014). Daily activities in a hilly area may cause knee pain through the mechanical load for a long time (Sakakibara et al., 1996). Knee pain, as a physical factor, might be one reason for the decline in walking speed among older adults (Kitayuguchi et al., 2016). In addition, previous studies reported that the perceived neighborhood environments (e.g. walkability, accumulation of garbage, crime rate, drainage ditches, or broken sidewalks) affected fall efficacy or fear of falling among older adults (Canever et al., 2021; Curl et al., 2020; Lee et al., 2018). Older adults living in neighborhoods with hilly environments also may have fear of falling, and avoid going outdoors (Wijlhuizen et al., 2007). Fear of falling is one of the psychological factors related to reducing physical performance (Chamberlin et al., 2005; Delbaere et al., 2004). Thus, living in a hilly environment may be conducive to physical or psychological problems, which might lead to deteriorated walking performance in older adults.

The stratified analyses by car-driving status showed that a higher land slope was positively associated with slow walking speed only in non-drivers; there were no associations found for drivers. These results suggest that walking performance among older non-drivers living in a hilly environment might decline more than for drivers.

Marottioli et al. (2000) reported that driving cessation was strongly associated with decreased out-of-home activities. It seems difficult to go to the hospital for knee-pain treatment among non-drivers. In addition, Gomi et al. (2021) reported an association between living far away from food stores and low diet variety among rural older adults. They especially reported a low frequency of meat consumption among residents living in an area far from food stores. Non-drivers might have difficulty with out-of-home activities like going to the hospital or shopping for food; therefore, they might lack the chance for nutrients for the maintenance of physical health. Our study provided information helpful for rural public health on disadvantaged subgroups of the population facing environmental barriers to healthy aging. For example, transportation services may have an important role in the maintenance of a healthy lifestyle among non-drivers (Kamada et al. 2009; Crombie et al., 2004). Policymakers should support providing alternative transportation services (e.g., convenient bus service) for non-drivers, to promote out-of-home activities (e.g., going to the hospital or shopping; Beard et al., 2016). Moreover, health education about the maintenance of physical performance is needed for older adults living in hilly areas. In particular, because hilly environment is not easy to change, policymakers should provide residents with opportunities to learn about a modifiable healthy lifestyle.

In Japan, older drivers are required to voluntarily give up their licenses if they are unable to safely drive a vehicle due to aging. The National Police Agency has imposed mandatory driving lessons, including cognitive screenings, for drivers aged 75 and over since March 2017 (National Police Agency, 2017). Further, if older drivers are diagnosed with dementia, their licenses are revoked. In our study, non-drivers were older and had more chronic diseases than drivers. Additionally, driving status may be associated with socioeconomic status, such as education or income. Thus, the modified effect of being a non-driver indicated in our results might be related to cognitive decline that occurs with aging or socioeconomic status, which we could not incorporate in the analyses. Moreover, lower socioeconomic status may affect lower health literacy and health behaviors in older adults. As a result, the possibility of an association between socioeconomic status and reduced walking performance among non-drivers cannot be denied (Stringhini et al., 2018).

There are some limitations to the present study. First, the use of a cross-sectional design precludes any conclusion regarding causal relationships. Therefore, future observational longitudinal studies are needed for further investigation. Second, the study sample included participants who completed annual health checkups across multiple centers in a municipality. This could have led to a selection bias, as individuals who did not have the means to visit a center or lacked motivation were not included. Third, we could not account for the influence of any unmeasured variables, such as socioeconomic status (Stringhini et al., 2018); fall efficacy, including fear of falling (Chamberlin et al., 2005; Delbaere et al., 2004); or other neighborhood environmental factors (Brown et al., 2008; Koohsari et al., 2020; Michael et al., 2011; Soma et al., 2017; Buettner, 2015; Gomi et al. 2021), which may have affected the relationships between environmental variables, slow walking speed, and car-driving status. Finally, since our sample was collected in one town of rural area in Japan, we could not examine differences among older adults between urban, suburban, and rural areas. These differences may affect older adults' neighborhood environment and lifestyles. Future research is needed to examine the associations based on these differences.

In conclusion, the present study found that a hilly environment is associated with reduced walking speed in community-dwelling older adults in Japan. Especially, car-driving status potentially modifies the relationship between living in a hilly environment and slow walking speed. Thus, our findings highlight that non-driving older adults living in a rural hilly environment may be at high risk for slow walking speed.

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Declarations of interest: none.

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Table 2. Multiple linear regression for the association between land slope and walking speed.

Network buffer	Land slope				
	Crude model				
	B	*SE*	95% CI	*p*- value	*B*
500-m	-0.007	0.002	(-0.012, -0.002)	0.003	-0.007
1000-m	-0.008	0.002	(-0.012, -0.003)	0.001	-0.007

Note. B , unstandardized regression coefficients; SE, standard error; CI, confidence interval; each land slope buffe
†Sex, age, body mass index, smoking habits, alcohol consumption habits, exercise habits, chronic disease, and liv
‡P value of interaction with car driving status.

Table 3. The association between land slope and walking speed among drivers and non-driv

Network buffer	Land s			
	Crude model			
	B	*SE*	95% CI	*p*- value
Drivers (n = 375)				
500-m	-0.001	0.003	(-0.007, 0.005)	0.814
1000-m	0.000	0.003	(-0.006, 0.006)	0.951
Non-drivers (n = 258)				
500-m	-0.011	0.004	(-0.018, -0.004)	0.003
1000-m	-0.013	0.004	(-0.020, -0.006)	<0.001

Note. B , unstandardized regression coefficients; SE, standard error; CI, confidence interval;

†Sex, age, body mass index, smoking habits, alcohol consumption habits, exercise habits, cl