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Hilliness and the development of walking difficulties among community-dwelling older people

1. Introduction

Maintaining walking capability is important for older people in many areas of independent living and health, and hence the emergence of walking difficulties is a warning signal of a potential negative development in health and functioning. Among older adults, perceived walking difficulties is related to a decline in life-space mobility (Rantakokko, Portegijs, Viljanen, Iwarsson, & Rantanen, 2017), the development of new functional disabilities (Hardy, Kang, Studenski, & Degenholtz, 2010) and higher mortality risk (Frith, Addoh, Mann, Windham, & Loprinzi, 2017; Hardy et al., 2010). To be able to hinder the onset of mobility limitations, knowledge of the factors predicting their development is needed.

Walking difficulties have personal and environmental determinants. Multiple perceived environmental barriers to outdoor mobility (Rantakokko, Iwarsson, Mänty, Leinonen, & Rantanen, 2012) and low levels of walking (Simonsick, Guralnik, Volpato, Balfour, & Fried, 2005) predict incident walking difficulties among older people. Lower extremity capacity influences the association between perceived environmental barriers and reported walking difficulties (Sakari et al., 2017; Satariano et al., 2016). This interrelation between mobility capabilities, environmental barriers, and level of walking can be conceptualized in terms of the person - environment fit theory (Lawton M. P, Nahemow, L., 1973), according to which the state of balance between a person's capabilities and environmental challenges determines his or her performance in the environment.

Hilliness is a commonly perceived environmental barrier to outdoor mobility (Tsai et al., 2013), but precisely how it affects functional capabilities and health of older people is less clear. As a perceived environmental feature, greater neighborhood hilliness has been associated with lower self-reported health among older adults in a cross-sectional study (Tiernan et al., 2017). In contrast, greater hilliness, when measured objectively, may have beneficial effects as diabetes mellitus may be less prevalent (Villanueva et al., 2013) and better controlled (Fujiwara et al., 2017) in cross-sectional studies. Similarly to physical exercise (Nelson et al., 2007), mounting hills may provide a training stimulus to maintain physical fitness. To the best of our knowledge, prospective studies on associations between objective hilliness and incident walking difficulties have not been conducted.

Among older people, walking is the most commonly reported type of physical activity and is mostly practiced in close vicinity to the home (Chaudhury, Campo, Michael, & Mahmood, 2016). Frequent movement through the neighborhood compared to staying at home has been associated with higher step counts among older adults (Portegijs, Tsai, Rantanen, & Rantakokko, 2015; Tsai et al., 2016). Higher exposure to a hilly environment, that is, walking more frequently in and through the neighborhood, may potentially provide regular training and modify the perception of hills.

The purpose of this study is to investigate (1) whether objectively defined hilliness is associated with the prevalence and incidence of walking difficulties among community-dwelling older people during a two-year follow-up, and (2) whether the possible associations are fully or partially explained by frequency of moving through the neighborhood, perceived hilliness as a barrier to outdoor mobility, and/or health and socioeconomic factors. In line with earlier studies on hilliness and health we use cross-sectional analyses to determine the prevalence of walking difficulties and extend previous findings by conducting prospective analysis on the development of new walking difficulties, that is, the incidence of walking difficulties.

2. Methods

2.1 Study design

This study forms part of the project "Geographic characteristics, outdoor mobility and physical activity in old age" (GEOage) (Portegijs, Keskinen, Tsai, Rantanen, & Rantakokko, 2017). In the study we combine participant data, including self-reported walking difficulties and behavior-based variables of outdoor mobility in the neighborhood, with objectively defined hilliness in the participants' road network. Participant data for this study were obtained from the cohort study "Life-space mobility in old age" (LISPE), which has previously been described in detail (Rantanen et al., 2012).

Participants were community-dwelling older people aged 75-90 years at baseline and living in the neighboring municipalities of Jyväskylä and Muurame in Central Finland. The topography of the area combines lakes, hills, and relatively continuous areas of built environment surrounded by sparsely populated rural areas. A random, non-spatial sample of 2 550 people drawn from the national population register was informed about the study. Of these, 848 people were interviewed face-to-face at baseline in the year 2012 (exclusion criteria: not living independently, unable to communicate, residing outside recruitment area) and included in the cross-sectional analysis on prevalence of walking difficulty. Participants' home addresses at baseline were located on a map using the Digiroad dataset (Finnish Transport Agency, 2013) in Geographic Information System (GIS) software ArcMap 10.3. Follow-up interviews over the phone were conducted two years later (year 2014).

Of the 631 participants without walking difficulties at baseline, in total 80 participants were excluded from the prospective analysis due to a change in home address, communication difficulties, missing information on incident walking difficulties, non-respons or loss to follow-up, leaving 551 participants for the analysis on incident walking difficulties (Figure 1). Participants reporting no walking difficulties at baseline but not included in the follow-up were older (81.2 years vs. 79.8 years) and moved through their neighborhood less frequently (0-3 times a week 26% vs. 15%) than those, who were included.

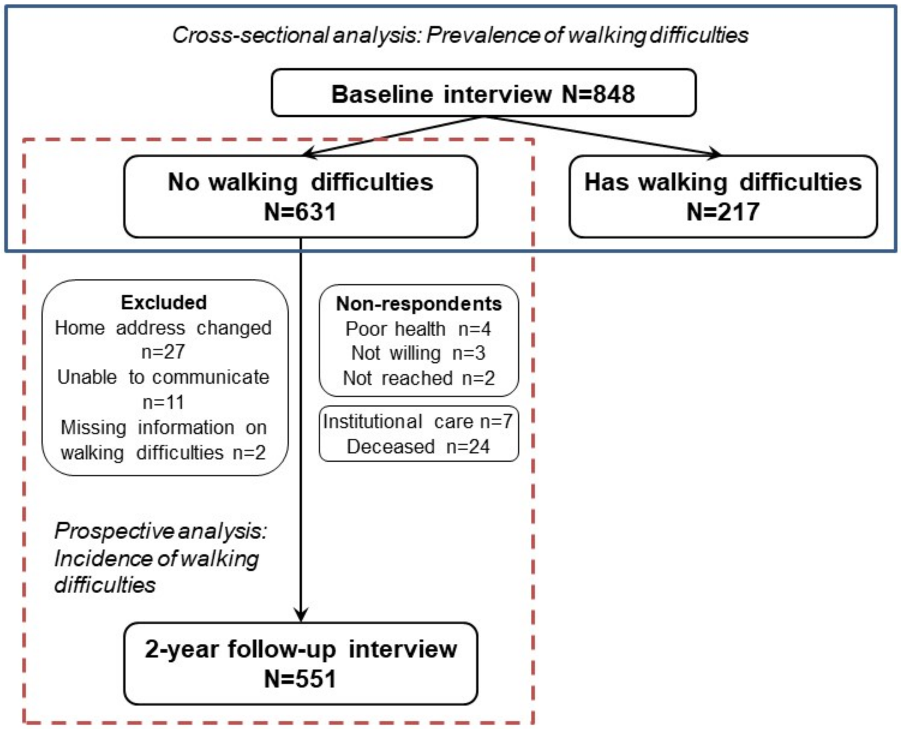

Figure 1. Participants for the cross-sectional analysis on prevalent walking difficulties at baseline and prospective analysis on incident walking difficulties at the two-year follow-up.

All participants signed a written informed consent before the baseline interview. Ethical approval for the LISPE project was granted on November 2nd 2011 and for the GEOage project on September 2nd 2014 by the Ethical Committee of the University of Jyväskylä, Finland.

2.2 Study measures

2.2.1 Self-reported walking difficulties (outcome variable)

Walking difficulties were self-reported at baseline and at the two-year follow-up in interviews. The participants were asked "Are you able to walk 500 meters?" and responses were categorized into no walking difficulties and walking difficulties (at least some difficulty - unable). Self-reported walking difficulties is a valid measure for evaluating mobility limitations in older people (Mänty, Minna et al., 2007a).

2.2.2 Slope (independent variable)

To objectively define hilliness, the mean percentage slope (1 % -point = 0.45 degree inclination of terrain) in each participant's 500m road network was calculated using openly available datasets in GIS. First, roads eligible for walking year-round, excluding motorways, winter roads, trails, railways and ferry lines, were extracted from the road network dataset (National Land Survey of Finland, 2013). Then, intersecting with the road network, raster cells containing elevation values on a 2 x 2 meter grid were extracted from the Digital elevation model dataset (National Land Survey of Finland, 2012) and the maximum slope value defined for each extracted raster cell. Raster cell slope values higher than 15% were excluded as erroneous based on the national guidelines for road design (Ristikartano, Granlund, Räsänen, & Salmelin, 2012). Finally, the mean slope value in the participant's 500m road network was calculated; slope values ranged from 0.9 % to 4.6 %.

2.2.3 Self-reported behavior variables (independent variables)

Frequency of moving through the neighborhood was used as an indicator of outdoor mobility in the neighborhood. As part of the baseline life-space mobility assessment

(Baker, Bodner, & Allman, 2003), participants were asked on how many days a week during the previous four weeks they had moved through their neighborhood. Responses were dichotomized into 0-3 days a week versus 4-7 days a week as was done in earlier studies (Portegijs et al., 2015).

Perceived hilliness as a barrier to outdoor mobility at baseline was one item on the "Checklist for perceived environmental barriers to outdoor mobility" (PENBOM) (Rantakokko, Iwarsson, Portegijs, Viljanen, & Rantanen, 2015). Participants were asked whether they perceived hilliness in their neighborhood as a barrier to their outdoor mobility or not (yes vs. no).

2.2.4 Covariates

We selected age, sex, physical performance of the lower extremities, number of chronic conditions, and years of education for covariates as they have shown association with walking difficulty previously (Rantakokko, Portegijs, Viljanen, Iwarsson, & Rantanen, 2016; Sakari et al., 2017). Additionally, we used time in the current home to account for familiarity with and length of exposure to the neighborhood environment, and road network length to control for different route selection opportunities among study participants.

Age, sex, and the latest address change for calculating time in current home were derived from national population register data, road network length from GIS, and other covariates from the baseline home interview. Physical performance of the lower extremities was assessed with the Short Physical Performance Battery (SPPB) (Guralnik et al., 1994; Mänty, M., Sihvonen, Hulkko, & Lounamaa, 2007b). The SPPB score combines results from balance, walking speed over 2.44 meters, and chair rise tests, with higher values indicating better performance (range 0-12). A list of 22 physician-diagnosed chronic conditions and an additional open-ended question (Rantanen et al., 2012) was used to calculate the number of chronic conditions. Education, an indicator of socioeconomic status, was self-reported as number of years. Data were not imputed for participants with missing SPPB scores (n=9) or years of education (n=8). The average time in current home was calculated and imputed for participants (n=30) with missing information. Road network length was calculated as the total length of road segments in the participant's 500m road network.

2.3 Analyses

The Mann-Whitney U-test and Chi-Square test were used to compare baseline participant characteristics between those with and those without prevalent or incident difficulties in walking 500m. Moran's Index showed no noteworthy spatial clustering for prevalent or incident walking difficulties and thus traditional statistical methods could be applied to analyzing the data. The cross-sectional and prospective associations of difficulties in walking 500 meters with network slope, perceived hilliness as a barrier to outdoor mobility, and frequency of moving through the neighborhood were analyzed using binary logistic regression analysis. Five different models were constructed for both the cross-sectional and the prospective analysis. In the cross-sectional analyses, the first model tested the association between slope and the prevalence of walking difficulties at baseline (N=848) (Model 1). To ascertain the role of the behavior variables, the frequency of moving through the neighborhood (Model 2) and perceived hilliness as a barrier to outdoor mobility (Model 3) were added first separately and then simultaneously (Model 4) to the model. Finally, number of chronic conditions, years of education, and time at current address were included in the model (Model 5). The same models were created for the prospective analysis with incidence of walking difficulties at the two-year follow-up as outcome variable (N=551). All models were adjusted for age, sex, SPPB, and road network length. We also tested the interactions between the behavior variables (frequency of moving through the neighborhood and perceived hilliness as a barrier to outdoor mobility) and slope, but as no statistically significant associations were observed ($p \geq 0.156$), we did not include them in the final models. To investigate possible attrition bias, we conducted ancillary sensitivity analyses. The prospective analyses were rerun including those participants reporting no baseline walking difficulties who died or became institutionalized during the follow-up period (n=31), assigning them to incident walking difficulties. Associations between slope and incident walking difficulties were not markedly different from the results of the models 1-5 (data not shown).

3. Results

At baseline, 26 % (n=217) of participants reported prevalent difficulties in walking 500m (Table 1). At the two-year follow-up, 16% (n=86) of the participants without walking difficulties at baseline reported difficulties in walking 500m. Perceived hilliness as a barrier to outdoor mobility and moving through the neighborhood only 0-3 times a week were associated with prevalent and incident walking difficulties while a steeper mean slope in the road network was associated with incident walking difficulties only. In addition, those with prevalent and incident difficulties in walking 500m were older, had a lower SPPB score, more chronic conditions, and fewer years of education. Prevalent walking difficulties were more common among women, but incident walking difficulties showed no gender differences.

Table 1. Baseline participant characteristics according to the prevalence and incidence of difficulties in walking 500m two years later.

	Baseline			2-year follow-up		
	Prevalent walking difficulties (n=217)	No walking difficulties (n=631)		Incident walking difficulties (n=86)	No walking difficulties (n=465)	
	Mean ± SD	*Mean ± SD*	*p-value*	*Mean ± SD*	*Mean ± SD*	*p-value*
Age (yrs)	82.4 ± 4.1	80.0 ± 4.1	**<0.001**[a]	81.4 ± 4.1	79.5 ± 3.9	**<0.001**[a]
SPPB	7.7 ± 3.2	10.3 ± 1.9	**<0.001**[a]	9.8 ± 2.0	10.4 ± 1.6	**0.007**[a]
Chronic conditions (n)	5.7 ± 2.4	3.9 ± 2.3	**<0.001**[a]	4.5 ± 2.4	3.8 ± 2.3	**0.008**[a]
Education (yrs)	8.6 ± 3.6	9.9 ± 4.3	**<0.001**[a]	9.4 ± 5.2	10.1 ± 4.2	**0.016**[a]
Time in home (yrs)	22.3 ± 15.0	23.2 ± 14.5	0.468[a]	24.5 ± 15.7	23.2 ± 14.7	0.476[a]
Slope (% rise)	2.2 ± 0.6	2.1 ± 0.6	0.458[a]	2.3 ± 0.7	2.1 ± 0.6	**0.031**[a]
Network (km)	5.8 ± 2.4	5.9 ± 2.5	0.973[a]	6.0 ± 2.5	5.9 ± 2.4	0.540[a]
Sex (women, %)	73	58	**<0.001**[b]	55	60	0.404[b]
Moving through neighborhood (0-3x/wk vs. 4-7x/wk, %)	54	17	**<0.001**[b]	35	12	**<0.001**[b]

Hilliness as barrier (yes vs. no, %)	39	18	**<0.001**[b]	27	17	**0.032**[b]

[a] Mann-Whitney U-test, Asymp. Sig. 2-sided; [b] Chi-Square test, Exact Sig. 2-sided; Bold indicate $p < 0.05$; SD = Standard Deviation

Cross-sectionally (Table 2), road network slope was not associated with prevalent difficulties in walking 500m, while moving through the neighborhood less often and perceiving hilliness as a barrier showed two-fold odds for prevalent walking difficulties. Adding more covariates into the model did not materially change the odds.

Table 2. Cross-sectional logistic regression estimating prevalent difficulties in walking 500m at baseline (n=848).

	Model 1		Model 2		Model 3		Model 4		Model 5	
	OR	(95%CI)	OR	(95%CI)	OR	(95%CI)	OR	(95%CI)	OR	(95%CI)
Slope (% rise)	1.34	(0.99-1.81)	1.25	(0.92-1.70)	1.21	(0.89-1.65)	1.14	(0.83-1.57)	1.13	(0.82-1.57)
Moving through neighborhood										
0-3x/wk vs. 4-7x/wk			**2.73**	**(1.85-4.04)**			**2.58**	**(1.73-3.83)**	**2.41**	**(1.60-3.63)**
Hilliness as a barrier										
yes vs. no					**2.26**	**(1.52-3.37)**	**2.09**	**(1.39-3.15)**	**1.82**	**(1.19-2.76)**
Women vs.										
Men	**1.91**	**(1.29-2.83)**	**1.75**	**(1.17-2.63)**	**1.77**	**(1.19-2.65)**	**1.65**	**(1.09-2.49)**	1.52	(1.00-2.33)
Age (yrs)	**1.12**	**(1.07-1.17)**	**1.10**	**(1.05-1.15)**	**1.11**	**(1.06-1.16)**	**1.09**	**(1.05-1.15)**	**1.08**	**(1.03-1.14)**
SPPB	**0.67**	**(0.62-0.72)**	**0.70**	**(0.65-0.76)**	**0.67**	**(0.62-0.73)**	**0.71**	**(0.65-0.77)**	**0.73**	**(0.67-0.79)**
Network (km)	0.98	(0.90-1.05)	0.98	(0.91-1.06)	0.97	(0.90-1.05)	0.98	(0.91-1.06)	0.99	(0.91-1.07)
Chronic conditions (n)									**1.22**	**(1.13-1.33)**
Education (yrs)									0.98	(0.93-1.03)
Time in home (yrs)									1.00	(0.99-1.01)

OR= Odds Ratio; CI= Confidence Interval; SPPB = Short Physical Performance Battery; Bold indicate $p < 0.05$

Prospectively (Table 3), road network slope showed 1.7-fold odds for incident difficulties in walking 500m at the two-year follow-up. Moving through the neighborhood less often showed more than three-fold odds whereas perceiving hilliness as a barrier was not associated with incident walking difficulties. Introducing additional variables into the model did not markedly change the results.

Table 3. Prospective logistic regression estimating incident difficulties in walking 500m at two-year follow-up (n=551).

	Model 1		Model 2		Model 3		Model 4		Model 5	
	OR	(95%CI)	OR	(95%CI)	OR	(95%CI)	OR	(95%CI)	OR	(95%CI)
Slope (% rise)	**1.74**	**(1.17-2.59)**	**1.73**	**(1.15-2.61)**	**1.68**	**(1.12-2.52)**	**1.67**	**(1.10-2.53)**	**1.66**	**(1.09-2.51)**
Moving through neighborhood										
0-3x/wk vs. 4-7x/wk			**3.30**	**(1.87-5.82)**			**3.24**	**(1.83-5.73)**	**3.14**	**(1.77-5.58)**
Hilliness as a barrier										
yes vs. no					1.66	(0.94-2.94)	1.59	(0.88-2.86)	1.50	(0.83-2.71)
Women vs.										
Men	0.66	(0.41-1.09)	0.63	(0.38-1.04)	0.63	(0.38-1.04)	**0.60**	**(0.36-0.99)**	**0.59**	**(0.35-0.98)**
Age (yrs)	**1.12**	**(1.05-1.19)**	**1.10**	**(1.03-1.17)**	**1.11**	**(1.05-1.18)**	**1.09**	**(1.03-1.16)**	**1.09**	**(1.02-1.16)**
SPPB	**0.80**	**(0.71-0.92)**	**0.84**	**(0.74-0.96)**	**0.81**	**(0.71-0.92)**	**0.84**	**(0.74-0.97)**	**0.86**	**(0.75-0.98)**
Network (km)	1.04	(0.94-1.14)	1.06	(0.96-1.17)	1.04	(0.94-1.15)	1.06	(0.96-1.18)	1.07	(0.96-1.19)
Chronic conditions (n)									1.09	(0.98-1.22)
Education (yrs)									1.00	(0.94-1.06)
Time in home (yrs)									1.00	(0.98-1.02)

OR= Odds Ratio; CI= Confidence Interval; SPPB = Short Physical Performance Battery; Bold indicate $p < 0.05$

4. Discussion

To our knowledge, this is the first study on the association between objectively defined network slope and the development of walking difficulties among older adults. In the present sample, a steeper mean slope in the living environment was associated with a higher incidence of walking difficulties. Frequency of moving through the neighborhood, perceived hilliness as a barrier to outdoor mobility, and adjustments for health and socioeconomic factors did not attenuate the association between slope and incident difficulties in walking 500m. In the cross-sectional analysis, an association between slope and prevalent walking difficulties was not observed.

The risk associated with high hilliness is noteworthy, as a one unit increase in the mean network slope, which ranged from 0.9% to 4.6% among the study participants, increased the likelihood for reporting incident walking difficulties by about 70 %. These results are in line with the person-environment fit theory (Lawton M. P, Nahemow, L., 1973). Age-related decline in the capacity of neural, sensory and motor systems may underlie the development of walking difficulties in older adults. In uphill walking, older adults' muscles are more heavily recruited than those of younger people (Franz & Kram, 2013). Besides exhaustion, using muscles near to maximum capacity may bring on fear of falling and subsequent avoidance behavior. These mechanisms may also explain why we did not find a statistically significant association between slope and prevalent walking difficulties at baseline. Current behavior and health status may serve as better correlates for prevalent walking difficulties than objective neighborhood hilliness.

In line with previous research (Brown & Flood, 2013), lower mobility in the neighborhood was associated with reporting walking difficulties (cross-sectionally and prospectively) but did not affect the association between slope and walking difficulty. When an older adult is capable of walking in a hilly environment, frequent walks in such a neighborhood may provide exercise for maintaining walking capability. Perceiving hilliness as a barrier was not associated with the incidence of walking difficulties at the two-year follow-up, similarly as reported earlier (Rantakokko et al., 2012), but an association with the prevalence of walking difficulties at baseline existed. This finding might suggests that once hills are perceived as a barrier, a person may already be experiencing mobility decline. Perceived hilliness did not attenuate the association between slope and incident walking difficulties. In an area with high hills, avoiding them by choosing alternative routes might be a beneficial adaptation enabling the maintenance of walking ability. Such adaptations, also called mobility modifications, have been shown to attenuate the effect of perceived environmental barriers on the incidence of walking difficulties (Rantakokko et al., 2016).

The strengths of our study include the use of objective elevation data in the form of a detailed 2m x 2m grid, which enabled us to accurately define slope in each participant's 500m road network. However, the use of mean road network slope in our analysis might not totally reflect participant's exposure to hills and the actual routes participants take. Anyhow, this information on the association between higher slope and higher incidence of walking difficulties may be of value in road network planning and evaluation on the local level. Our sample was population-based, rather large, and had little drop-out at the two-year follow-up and few missing data. The use of rather crude self-reported measures for walking difficulties and frequency of moving through the neighborhood, used as a surrogate for outdoor mobility, may be considered limitations in our study. However, measures based on one's own experience are suitable to describe one's mobility behavior and capabilities in relation to his or her environment (Portegijs et al., 2017). Although participants with communication difficulties were excluded from the study, cognitive limitations may have affected the quality of responses (Poranen-Clark et al., 2018; Tian, An, Resnick, & Studenski, 2017). It is also possible that health conditions have emerged after baseline and affected participants' walking capability during the two-year follow-up period.

5. Conclusions

Our study yielded novel information on the association between objectively defined road network hilliness and the development of walking difficulties among older adults. The results show that a higher mean slope across the road network is associated with a higher likelihood for developing walking difficulties, even after adjusting for behavioral, health-related, and socio-economic factors. Our study suggests that a more steeply sloping road network is a risk factor for the incidence of walking difficulties among older people. However, perceived hilliness as a barrier rather than objective hilliness was associated with prevalent walking difficulty at baseline. The findings indicate that in hilly areas the route network should be able to offer alternative routes with lower slopes and/or benches for resting. The underlying mechanisms and potential intervention targets require further research.

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