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Self-perceived gait stability modulates the effect of daily life gait quality on prospective falls in older adults

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ABSTRACT

Background: Quality of gait during daily life activities and perceived gait stability are both independent risk factors for future falls in older adults.
Research question: We investigated whether perceived gait stability modulates the association between gait quality and falling in older adults.
Methods: In this prospective cohort study, we used one-week daily-life trunk acceleration data of 272 adults over 65 years of age. Sample entropy (SE) of the 3D acceleration signals was calculated to quantify daily life gait quality. To quantify perceived gait stability, the level of concern about falling was assessed using the Falls Efficacy Scale international (FES-I) questionnaire and step length, estimated from the accelerometer data. A fall calendar was used to record fall incidence during a six-month follow up period. Logistic regression analyses were performed to study the association between falling and SE, step length or FES-I score, and their interactions.
Results: High (i.e., poor) SE in vertical direction was significantly associated with falling. FES-I scores significantly modulated this association, whereas step length did not. Subgroup analyses based on FES-I scores showed that high SE in the vertical direction was a risk factor for falls only in older adults who had a high (i.e. poor) FES-I score. In conclusion, perceived gait stability modulates the association between gait quality and falls in older adults such that an association between gait quality and falling is only present when perceived gait stability is poor.
Significance: The results of the present study indicate that the effectiveness of interventions for fall prevention, aimed at improving gait quality, may be affected by a modulating effect of perceived gait stability. Results indicate that interventions to reduce falls in older adults might sort most effectiveness in populations with both a poor physiological and psychological status.

1. Introduction

Physiological and psychological risk factors have frequently and independently been associated with falls in the growing population of older adults [1,2]. A physiological risk factor for falling is gait quality [3], which can be assessed using accelerometers and can be quantified as the sample entropy (SE) of the acceleration signal during bouts of gait obtained in daily life [4,5]. SE in essence quantifies the degree of complexity of a time series. In gait, higher SE reflects a less predictable gait pattern and is associated with falls [6,7] and therefore a poor gait quality. SE is independent of gait velocity [8] and stride time [5] and since daily life gait velocity and stride time are influenced by psychological factors [9], SE may represent the physiological aspect of gait more exclusively than other measures.

Perceived gait stability can be defined as one's own belief in the ability to prevent balance loss during gait. It is a psychological risk factor for falling and can be quantified explicitly by questionnaires such as the Falls Efficacy Scale – International (FES-I) [10], though these scales are prone to ceiling effects [11]. An alternative and rather implicit measure of perceived gait stability might be step length (SL). In experimental conditions, people adapt their gait pattern in response to more risky environments (e.g. a slippery floor) by reducing their SL [12]. Furthermore, SL has been shown to be shorter in older adults who report a high concern for falling [13,14]. We, therefore, consider SL as a gait characteristic that can reflect perceived gait stability and that can be objectively obtained from daily life gait acceleration data.

The association of perceived gait stability with falling is less obvious than that of gait quality with falling. On the one hand, people with poor perceived gait stability often resort to a stiffening response and have reduced visual awareness [15], which may hamper balance control and recovery in dynamic tasks. On the other hand, they may expose themselves to fewer risky situations and therefore reduce the

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probability of falling. Moreover, perceived gait stability might interact with gait quality with respect to fall risk. It is not unlikely that the association between quality of gait and falling may be different depending on the level of perceived gait stability. For instance, for older adults that have a poor perceived gait stability having a poor gait quality may be of greater risk for falling than for older adults that perceive their gait stability as good. However, this may not be the case at all and it is conceivable that it may even be the other way around. Therefore, in the current study, we tested this modulating effect of perceived gait stability on the association between gait quality and falling in older adults and determined its direction. A better understanding of the interplay between gait quality and perceived gait stability may help health care professionals to reduce the prevalence of falls with targeted and personalized interventions.

2. Methods

2.1. Study design and study population

We re-analyzed data from 416 participants from the *FA*ll-*R*isk *A*ssessment in *O*lder adults (FARAO) study [3]. The overall aim of this study was to develop and test a new system to predict fall risk, based on ambulatory monitoring. Participants were community dwelling or living in a residential home and were recruited in Amsterdam (the Netherlands) and the surrounding area between 2012 and 2014, via general practitioners, pharmacies, hospitals and residential care facilities. Participants were included in the prospective cohort study if they were 65 years of age or older, if their Mini Mental State Exam [16] score exceeded 18 out of 30 points, and if they were able to walk at least 20 m (with walking aid if needed). The medical ethical committee of the VU medical center approved the protocol (#2010/290) and all participants signed an informed consent.

2.2. Fall outcome

Prospective fall data were collected during a six-month follow-up through monthly telephone contact in addition to a daily fall diary. A fall was defined as an unintentional change in position resulting in coming to rest at a lower level or on the ground. Participants were classified as faller if they fell once or more during the follow-up period.

2.3. Predictors

Participants wore a tri-axial accelerometer (DynaPort MoveMonitor, McRoberts, The Hague, the Netherlands) with a sample rate of 100 samples/s and a range from −6 g to +6 g, for 8 consecutive days. The accelerometer was placed dorsally on the trunk at the level of L5 using an elastic belt. Participants were instructed to wear it at all times except during aquatic activities such as showering. The first and final 6 h of data were discarded to account for artifacts caused by transportation of the device to and from the participant's home. Raw acceleration data were realigned with the anatomical axes based on the sensor's orientation with respect to gravity and optimized for left–right symmetry [17,18]. Locomotion bouts were detected using activity classification algorithms developed by McRoberts the manufacturer of the accelerometers McRoberts (McRoberts, The Hague, the Netherlands) [19]. Acceleration data were analyzed using MATLAB R2014a (MathWorks, Natick, MA, USA) for all locomotion bouts that exceeded 10 s. Per locomotion bout the average SE and SL was determined over all 10-s gait epochs, to improve stationarity and to avoid effects of differences in data series length on subsequent analyses.

Gait quality was assessed using the SE of the acceleration signal in vertical (vt) and anteroposterior (ap) direction with embedding dimension 5 and tolerance 0.3 [20]. SE represents gait quality more uniquely than other gait quality measures that have shown associations with falls [6], due to its independence from stride time [5] and gait velocity [8]. Rispens et al. showed that high values for the median (p50) SE in vt and for the 10th percentile (p10) SE in vt and ap over all locomotion bouts obtained during one week predicted falling in a univariate model [6]. Hence, we used SEvt_p50 and SEvt _p10 and SEap_p10 as measures of gait quality.

Perceived gait stability based on daily life gait was quantified as SL, which was determined from the vertical acceleration component of the 10-s gait epochs, normalized for the participant's body height [21].

Perceived gait stability was also assessed by the FES-I [10]. The FES-I measures the level of concern for falling during daily activities on a scale between 16 and 64, with 16 indicating no concern and 64 indicating the highest level of concern. The Dutch version of the FES-I showed to be unidimensional, internally consistent (Chronbach $\alpha = 0.96$) and reliable (intra class correlation coefficient = 0.82) and also the construct validity was found to be sufficient [22].

To avoid having to make assumptions about (non-)linearity, we dichotomized the predictor variables. We split the sample in three sub-samples for each predictor (the 0th–40th percentile, 40th–60th percentile and 60th–100th percentile), excluded the middle sub-sample from the analyses and compared the remaining sub-samples. The exclusion was applied because participants close to the median are more likely to be misclassified.

2.4. Confounders

Besides controlling for the descriptive confounders age, gender, body weight and body height, we also assessed the following confounders which are known to be associated with both the outcome and at least one of the predictors [23]: symptoms of depression, as measured with the 30-item geriatric depression scale (GDS) [24], executive functioning, as measured with the trail making test (TMT) [25], and fall history.

2.5. Statistical analysis

Statistical analyses were performed in R (R Core Team (2015), Vienna, Austria). Descriptive analyses were used to describe the demographic characteristics among the study population. Because we performed secondary analyses of data that were collected in a study that was not designed for our specific research question and because we decreased the sample size and associated power by excluding the middle 20%, we used a 90% confidence interval (CI) to determine statistical significance in order to prevent possibly relevant findings from being omitted.

Logistic regression analyses were performed to explore the ability of gait quality (i.e., SEvt and SEap) and perceived gait stability (i.e., SL and FES-I score) to predict falls. We reported the resulting odds ratios (OR) and their 90% CI [26]. After testing the association of gait quality or perceived gait stability with falling, we tested the modulating effect of perceived gait stability (of either SL or FES-I scores) on the association between gait quality and falling. Hence, the latter models included the interaction between perceived gait stability and gait quality. Next, subgroup analyses were done by exploring the association of gait quality with falls in people with either low or high perceived gait stability.

Age, gender, body weight, depression symptoms (GDS score), executive functioning (TMT score) and fall history were only included in the regression analyses to control for confounding if they were not highly correlated (correlation coefficient < = 0.6) with the predictors and if they changed the regression coefficient of the interaction term of gait quality and perceived gait stability by more than 10% [27].

3. Results

Of the 416 participants available in the FARAO database, we excluded a total of 144 people due to incomplete fall data over 6 months

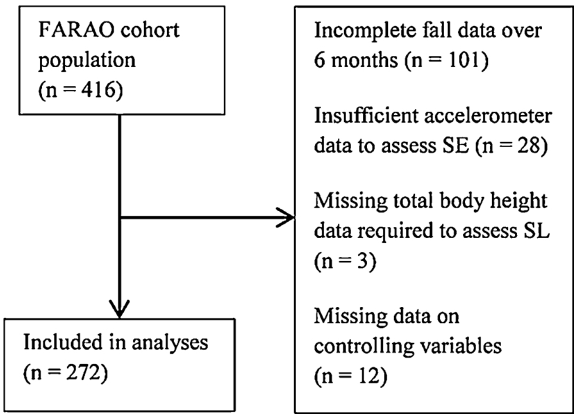

Fig. 1. Flow chart of data inclusion and exclusion. Fall data were considered incomplete when one or more months of fall data were missing. Accelerometer data were insufficient when too few 10-s gait epochs (< 50) were registered during one whole week. To determine SL, data on total body height were required.

Table 1
Participants' general characteristics, predictors and fall incidence before exclusion of the middle 20%. Values represent means with (SD) unless noted otherwise. Handgrip strength is presented as left and right combined.

Variable	Total (N = 272)
General characteristics	
Age, years	75.2 (6.9)
Female, n (%)	138 (50.7)
Body weight, kg	74.0 (13.3)
Body height, cm	170.6 (9.0)
Hand grip strength, kg	53.7 (20.5)
Use of walking aids, n (%)	77 (28.3)
Living status	
Independent, n (%)	226 (83.1)
Assisted living, n (%)	19 (7.0)
Care home, n (%)	27 (9.9)
Cognitive status	
Trial making test, Δs, median (IQR)	51.0 (34.5–79.3)
GDS score, median (IQR)	3 (1.0–6.3)
Predictors	
FES-I, median (IQR)	19 (17–22)
SL/body height, arb. unit	0.6 (0.1)
Outcome	
Fallen, n (%)	91 (33.5)

(n = 101), insufficient accelerometer data to assess SE (n = 28) or SL (n = 3) and missing data on confounding variables (n = 12) (Fig. 1), leaving 272 participants for our analysis. The number of eligible participants per regression model is shown in Table 2. Demographics of the eligible participants are shown in Table 1. About one third of the participants fell more than once in the subsequent 6 months. Fig. 2 presents the percentages of fallers in four groups classified based on both their gait quality and perceived gait stability. It shows that gait quality and perceived gait stability did not necessarily have an additive effect in predicting future falls. There were relatively more people that fell with a poor gait quality than with a good gait quality within the poor FES-I group. However, this association was only observed for SEvt and not for SL.

3.1. Association between predictors and falling

We started by testing the association between the five predictors (i.e., three gait quality and two perceived gait stability measures) and falling in logistic regression models, while controlling for the potential confounding effects of age, gender, body weight, depression symptoms, executive functioning and fall history. Falling was associated with high (i.e., poor) SEvt_p50 (adjusted OR: 1.81, 90% CI [1.12, 2.96]) and short SL (adjusted OR: 1.75, 90% CI [1.05, 2.94]). We found no significant associations between falling and SEvt_p10, SEap_p10, or FES-I (Table 2).

Table 2
Logistic regression results for models with one predictor and models with two predictors and their interaction. Adjusted Odds Ratios (OR) are presented, corrected for age, gender, body weight, depressive symptoms (GDS score), executive functioning (TMT score) and fall history when appropriate (see Methods for selection). N shows the number of participants included in each model after exclusion of the middle 20%. *p < 0.1.

	N		OR	90%CI
Without interaction				
SEvtP10	218	Good quality	1	
		Poor quality	1.58	0.98–2.55
SEapP10	218	Good quality	1	
		Poor quality	1.31	0.80–2.14
SEvtP50	218	Good quality	1	
		Poor quality	1.81	1.12–2.96*
SL	218	Good perceived gait stability	1	
		Poor perceived gait stability	1.75	1.05–2.94*
FES-I	228	Good perceived gait stability	1	
		Poor perceived gait stability	1.03	0.60–1.75
Interaction SE × SL				
SEvtP10 × SL	180	Poor × Poor	1.19	0.38–3.82
SEapP10 × SL	178	Poor × Poor	0.85	0.26–2.93
SEvtP50 × SL	178	Poor × Poor	1.37	0.42–4.62
Interaction SE × FES-I				
SEvtP10 × FES-I	182	Poor × Poor	3.27	1.13–9.65*
SEapP10 × FES-I	180	Poor × Poor	0.54	0.18–1.63
SEvtP50 × FES-I	182	Poor × Poor	4.00	1.33–12.43*

3.2. Modulating effect of perceived gait stability on gait quality

Next, we tested the modulating effect of perceived gait stability, as defined by SL or FES-I scores, on the association between SE and falling. To this end, we included the interaction of these perceived gait stability measures with SE in the logistic regression model. SL did not modulate the association between falling and any of the SE measures. However, FES-I score did significantly modulate the association between falling and SEvt_p10 (adjusted interaction OR: 3.27, 90% CI [1.13, 9.65]) and falling and SEvt_p50 (adjusted interaction OR: 4.00, 90% CI [1.33, 12.43]) (Table 2). Hence, the associations between these gait quality measures and falling was stronger for people with high (i.e. poor) FES-I scores than for people with low (i.e. good) FES-I scores. FES-I did not modulate the association between SEap_p10 and falling.

Finally, we explored the associations between falling and SEvt_p10 and falling and SEvt_p50 within the groups of people with either high (i.e. poor) or low (i.e. good) FES-I scores. For people with a low FES-I score there was no association between falling and SEvt_p10 (adjusted OR: 1.02, 90% CI [0.49, 2.13]) or SEvt_p50 (adjusted OR: 1.08, 90% CI [0.51, 2.28]). For people with a high FES-I score there was a significant association between falling and SEvt_p10 (adjusted OR: 3.33, 90% CI [1.52, 7.29]) and between falling and SEvt_p50 (OR: 4.33, 90% CI [1.89, 9.91]). This indicates that among older adults with a high concern for falling (high FES-I score), those with poor gait quality (SEvt_p10 or SEvt_p50) are 3.33–4.33 times more likely to fall in the upcoming six months than those with a good gait quality. Unadjusted models, 95%CI and models with the middle 20 percentage included and dichotomized at the median are presented in Tables S1 and S2.

4. Discussion

The aim of our study was to investigate whether perceived gait stability modulates the association between daily-life gait quality and

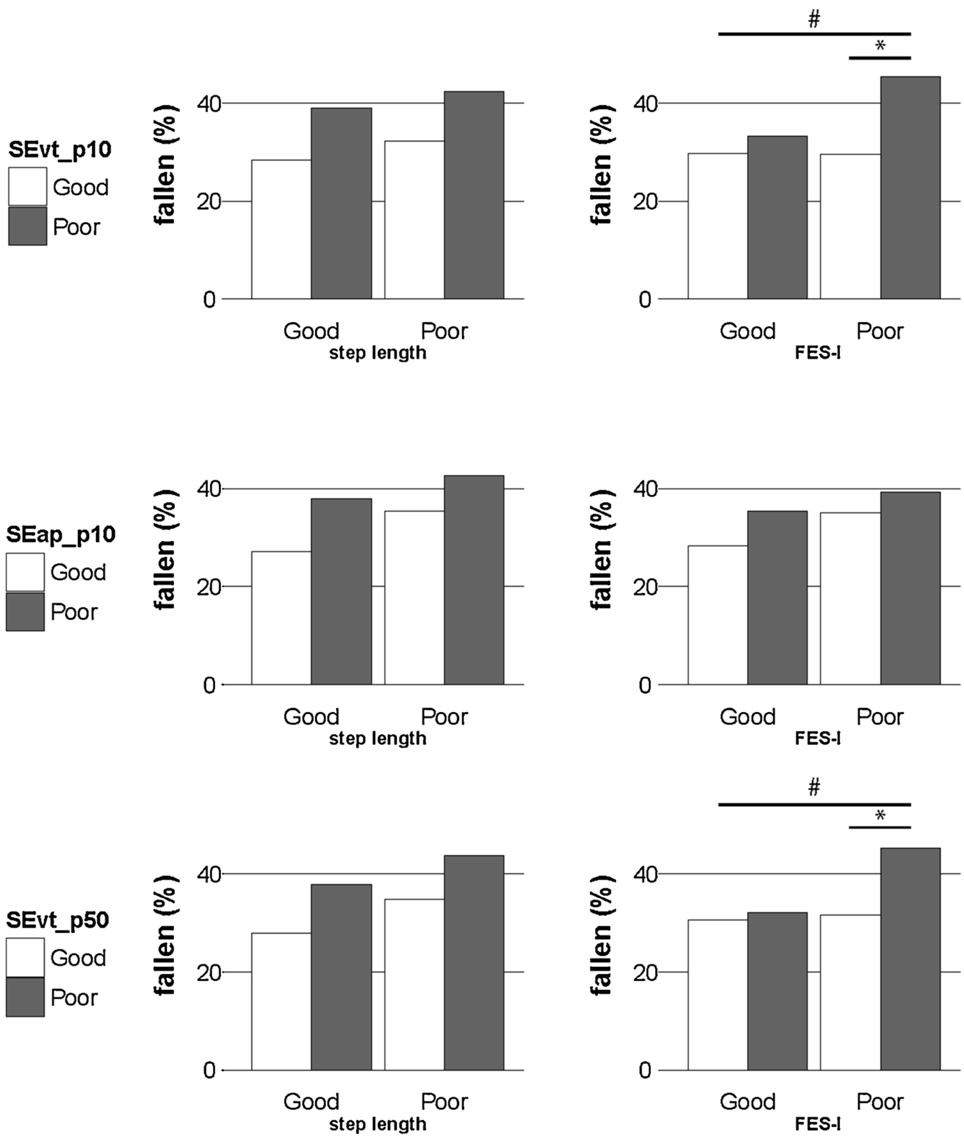

Fig. 2. Percentages of people within a classification group that fell at least once during six months follow-up. Groups were based on sample entropy (SE) and perceived gait stability as measured by step length (SL) (left panels) or FES-I (right panels). Rows represent stratification based on median and 10th percentiles of SE in vertical and anteroposterior direction (10th percentile vertical (vtP10), 10th percentile anteroposterior (apP10) and median vertical (vtP50)). # interaction effect between gait quality and perceived gait stability ($p < 0.1$). * association between SE and falling once or more in the subsequent year ($p < 0.1$), only determined in models with a significant interaction effect.

falling in older adults. We expected that better gait quality would result in fewer falls, but that this effect might be different for people with poor as opposed to good perceived gait stability. We used three SE measures derived from daily life accelerometry data to reflect gait quality, and two measures of perceived gait stability – FES-I as an explicit measure obtained with a questionnaire and SL as an implicit measure recorded during daily life. We found that FES-I modulates the association between gait quality (SEvtP10 and SEvtP50) and falling, whereas SL did not. Specifically, the results show that good gait quality is associated with fewer falls and this association is only present in older adults with a high (i.e. poor) FES-I score.

Using a similar approach, Delbaere et al. [28] studied disparities between psychological and physiological fall risk with the FES-I and the physiological profile assessment (PPA). Generally, the results of our studies are in line, showing that gait quality and perceived gait stability interact in a way that is non-additive. However, our data indicate that with more concern for falling poor gait quality is a stronger risk factor for falling, whereas their data suggest (without statistical confirmation) that with less concern for falling, good physiological status is more protective of falling. So a good physiological status, SE or PPA, was associated with fewer falls in both studies, but the FES-I group in which this became (most) apparent differed. A possible explanation for this difference in findings could be the different ranges of FES-I scores that defined the groups of low and high concern for falling in both studies after dichotomization. This was probably due to a generally smaller and lower total range of FES-I scores observed within our study population compared to that of Delbaere et al. [28]. As a result, it is possible that the modulating effect of perceived gait stability observed in both studies was due to a stronger effect of gait quality in the subgroups defined as ‘poor’ FES-I scores in our study and ‘good’ FES-I scores in the study of Delbaere et al., as FES-I scores for these ‘poor’ and ‘good’ groups had some amount of overlap.

Our study population had relatively low (i.e. good) FES-I scores (IQR: 17–22) compared to literature which reports scores of 16–22 to be low [29]. This could partly be due to the fact that we scored lowest values (i.e. not concerned) for activities in the questionnaire that people indicated not to perform. However, SL divided by body height, which has shown to be associated with the FES-I score [13,14], was also higher (0.6) compared to literature (0.4) [13,30]. Therefore, we find it more likely that the overall perceived gait stability of our sample was relatively high with respect to the general population of older adults.

SL may reflect more than just perceived gait stability, as it can also be affected by a decreased range of motion, reduced muscle strength, and a sedentary lifestyle [30]. By normalizing SL to each subject’s body height and by using acceleration data over a seven days period, the normalized SL can be assumed to be a walking characteristic of each subject. We found a weak but significant negative association between FES-I and SL ($rho_s = -0.19, p < 0.002$), which suggests that FES-I and SL contain, at least to some degree, similar information. We recommend future research on other methods to implicitly measure perceived gait stability during daily life.

It can be argued that we could have quantified gait quality by using SE of the signal in all three directions at p10 and p50. However, to avoid making too many comparisons and thereby increasing the likelihood of type I errors, we deliberately picked versions of SE that had previously shown to be associated, as continuous parameters, with prospective falls in univariate models by Rispens et al. [6]. Despite that our models showed no significant association for two of the three dichotomized measures of SE, we still believe that a theoretical basis was the best procedure to select potential candidates to quantify gait quality.

A possible underlying mechanism for the observed modulation is found in Young and Williams [15]. They show that based on increased stiffening behavior, possibly associated with a poor perceived gait stability, older adults may be more at risk of falling during complex tasks as opposed to simpler tasks. Task complexity depends on the task constraints and on a person's ability at performing the task. Hence, older adults with good gait quality may encounter fewer complex tasks in daily life as older adults with poor gait quality. If older adults with good gait quality were to revert to stiffening behavior due to a poor perceived gait stability, the association with falls would not be as strong as for older adults with poor gait quality, who encounter more complex tasks in daily life.

The results of the present study indicate that the effectiveness of interventions for fall prevention, aimed at improving gait quality, may be affected by a modulating effect of perceived gait stability. Results indicate that interventions to reduce falls in older adults might sort most effectiveness in populations with both a poor physiological and psychological status. Moreover, multimodal therapies, focusing on both physiological and psychological factors are recommended as both might be important for preventing falls, even though causal relations in working mechanisms need further research.

We conclude that perceived gait stability modulates the association between gait quality and falls in older adults such that an association between gait quality and falling is only present when perceived gait stability is poor.

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Conflict of interest

No further conflict of interest is declared by the authors.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.gaitpost.2018.04.002.

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