Article

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Brabants, Antoine, Tassin, Mederic, Debugne, Gauthier, Richards, James ORCID: 0000-0002-4004-3115, Kubonova, Eliska and Deschamps, Kevin (2019) Relationship between in-shoe pressure measurements and fear of falling among noncommunity- dwelling elderly: a pilot study. PRM+, 1 (3). pp. 67-72. ISSN 2489-8457

PRM+
JOURNAL OF QUANTITATIVE RESEARCH IN REHABILITATION MEDICINE

PRM+ (2018) Volume1 Issue 3 67-72
ISSN 2489-8457

Relationship between in-shoe pressure measurements and fear of falling among non-community-dwelling elderly: a pilot study

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Abstract

Objectives

To investigate the relationship between fear of falling indicators and pedobarographic variables among non-community-dwelling elderly.

Methods

Twenty-seven volunteers were recruited and assigned to three groups according to their level of fear of falling estimated using the Short FES-I score. The in-shoe foot pressure data were collected while walking 10 meters. The relative peak and mean force in different foot regions, functional gait tasks feature, and center of pressure displacement were measured. A Kruskal-Wallis test was performed to assess the differences between groups.

Results

The anterior-posterior displacement of pressure center was significantly different across the groups during weight acceptance and single limb advancement phases. The different pressure regions showed significant differences in relative mean (p=0.006) and peak forces (p=0.004) in hindfoot. The relative peak force was different for a hallux (p=0.042), a first metatarsal head (p=0.026), and a hindfoot (p=0.038).

Conclusions

In-shoe pressure measurement while walking may be important when assessing the risk and the fear of falling among elderly.

Keywords:
aged; geriatric assessment; foot; fall

ABBREVIATIONS

CoP: Centre of pressure patterns
RoI: Regions of interest
WA: Weight acceptance
SLS: Single limb support
SLA: Single limb advancement
MTH1: First metatarsal head
MTH2-3: Second and third metatarsal head
MTH4-5: Fourth and fifth metatarsal head
M-L: Medial/lateral
A-P: Anterior/posterior
GRF: Ground reaction forces
10-MWT: 10-meter walk test

INTRODUCTION

Annually, every third of community-dwelling elderly experience at least one fall (1). These falls may result in morbidity, a reduced level of independence, a poor quality of life, high levels of anxiety, and increased mortality rates (2). The prevalence of fear of falling has been reported up to 92% in people, who had already experienced falling (3), and from 20% to 55% in people without such an experience (4). The fear of falling may result in activity restrictions, increased risk of falling (5), accidental death (4), physical injuries (4), poor quality of life (6), and reduced social interaction (6).

The Short FES-I has been recommended for research and clinical use due to its good validity and reliability (7). The 7-item version has been considered more feasible than the original 16-item one (8). It has been validated among elderly with cognitive impairment (9) and to assess the risk of falling (10).

Plantar pressure measurements could be used when evaluating a balance during walking. The sensory input from plantar pressure plays an important role in standing balance and postural reflexes (11-13). Postural stability is associated with intrinsic foot muscle properties (14) which are active mainly during the stance phase of gait (15). A hallux plantar flexion strength measured by a peak pressure has been shown to be an independent risk factor for falling (16). Foot pressure analysis allows the assessment of foot placement – a predictive factor for falling (17). This

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Conflicts of interest: None to declare

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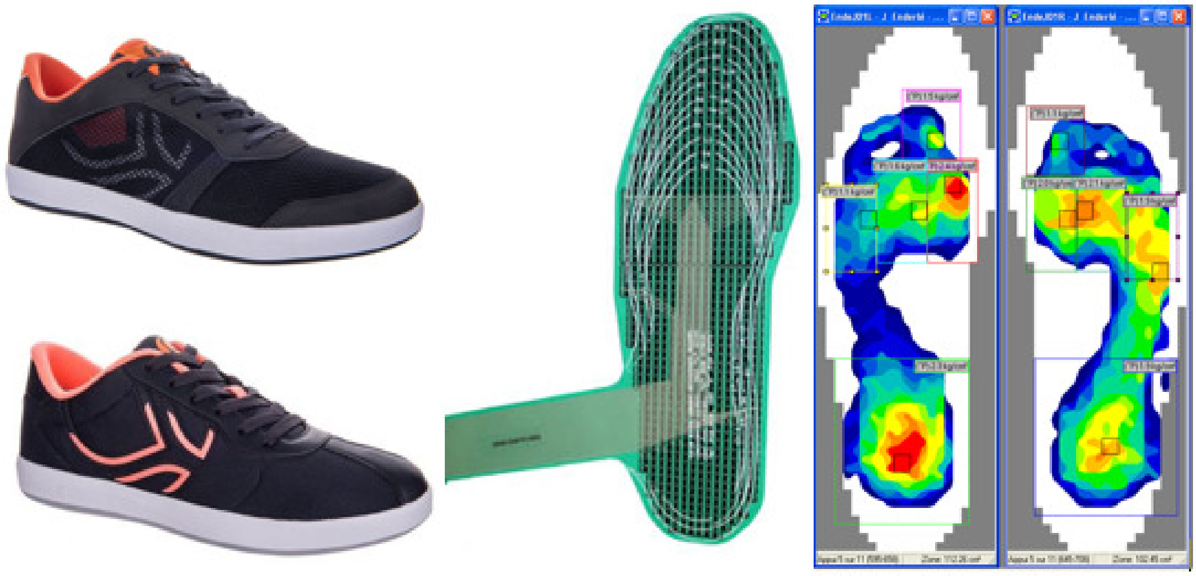
Figure 1. Footwear used and F-Scan® in-shoe pressure measurement insoles along with manual mapping of foot regions. Left image top – male model and bottom – female model.



quantifying approach may help to understand mechanisms involved in a risk and fear of falling (18–20). While some pressure-based measures to assess the risks or fear of falling have been studied, the Short FES-I has not been used for that purpose yet. Only two previous studies have investigated pedobarographic features related to walking and a risk of falling (18,21). While fall occurrence rates are higher among non-community-dwelling compared to community-dwelling populations (1,22), most of previous studies have focused on populations that are different from non-community dwelling elderly.

The objective of this study was to evaluate: pressure in different plantar regions, functional gait tasks, and pressure centering patterns within three groups that differed regarding the severity of fear of falling.

METHODS

The 27 non-community-dwelling elderly were recruited from three nursing homes in Brussels. All the participants were able to walk 10 meters without walking aids and to understand spoken and written French. People with history of stroke, surgery during the past 6 months, or major psychiatric disorders were excluded. All the participants provided written informed consent approved by an institutional medical ethics committee.

The initial part of protocol included the Swiss French version of Short FES-I questionnaire (23). Using the cut-off points suggested by Delbaere et al. (7), three groups were formed based on their level of fear of falling: low (7–8 points), moderately (9–13 points) and high (14–28 points) – here “low group”, “moderate group”, and “high group”. Within seven days all the subjects were given a pair of suitably sized and standardized gender-specific athletic shoes of a particular brand (Artengo TS730) (24) (Figure1). The qualitative assessment of male and female shoe types was performed using the Footwear Assessment Tool (25) (Table 2). The subjects were asked to wear them for a week until the next experimental session. The participants were excluded if not wearing the given shoes as reported by themselves or by healthcare professionals. After one week, the participants attended a final session and performed a 10-meter-walk test three times at their comfortable walking speed wearing standardized shoes with F-scan® in-shoe pressure measurement insoles (26) (Figure1). To restrict the effect of acceleration and deceleration on the gait speed calculation, the subjects began walking 1.2 meter before the 10 meters and stopped 1.2 meter after that. Based on the manufacturer manual, the pressure matrices were calibrated for each participant. The plantar pressure measurements were started approximatively one second before starting walking and they were collected for 15 seconds at sampling frequency of 80 Hz. An examiner recorded the time using a digital stopwatch.

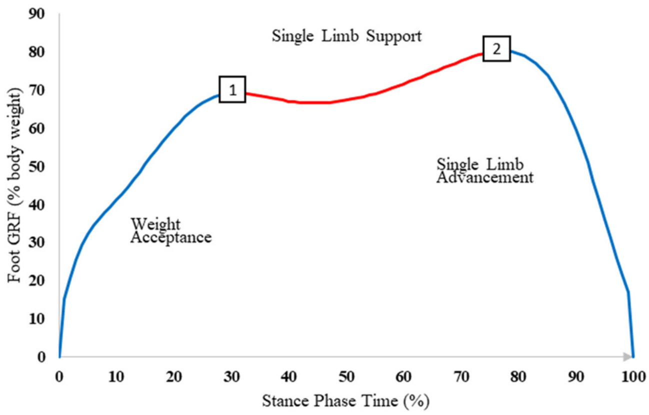
Data were processed using F-Scan Mobile Research 5.72® (26) and Microsoft Excel 2016® (27). Initially, three representative stance phases were selected for each walking session yielding nine representative trials per foot. After the vertical ground reaction force for each trial was extracted and normalized to 100% of stance phase and

Table 1: Baseline demographics

Variable	Fear of falling			*p*-value
	Low	Moderate	High	
	Mean (SD)	Mean (SD)	Mean (SD)	
n	7	10	10	
Age (SD), years [1]	80.1 (8.6)	80.4 (8.0)	84.1 (6.1)	0.064
Height (SD), cm [1]	167 (5.32)	159 (10.4)	161.3 (4.4)	0.9285
Weight (SD), kg [1]	67.9 (8.7)	68.7 (16.8)	87 (16.8)	0.0145
BMI (SD), kg/m^2 [1]	24.3 (2.0)	27.0 (4.9)	33.5 (6.9)	0.0011
10-MWT [3] (SD), sec [1]	15.3 (6.4)	15.8 (9.2)	23.5 (22.9)	0.1247
Men/women ratio [2]	6/1	4/6	1/9	0.0075

[1] Kruskal-Wallis test; [2] Chi-squared test; [3] 10-minute walk test

Figure 2. Determination of three phases in respect to the bilateral synergistic relationship of both limbs



body weight, an average pattern was calculated for each foot. The duration of the three sub-phases of stance phase were determined manually. Weight acceptance (WA) was defined as a phase between initial contact and first peak force. Single limb support (SLS) was defined as a phase between a first and a second peak force. Single limb advancement (SLA) was defined from a second peak and a toe-off (28) (Figure 2). This way, the duration of each phase (%), the total stance time, and the time to reach a first and a second peak force were obtained. In addition, several ROI from the in-shoe pressure recordings were analysed. The ROIs included; the hallux, first metatarsal head (MTH1), second and third metatarsal head (MTH2-3), fourth and fifth metatarsal head (MTH 4-5) and hind foot (Figure 1). For each of the regions, the relative peak force during WA, SLS and SLA, as well as the relative mean force during SLS and SLA were calculated and normalized based on a body weight. Finally, centers of pressure pattern and relative displacements in mediolateral and anteroposterior directions (%) during sub-phases were calculated.

Statistical analysis

The Kruskal-Wallis test was performed to determine the differences between groups. To correct for multiple comparisons, the α values were adjusted by a factor of 5 to α =0.01. The data from the right and left sides were well correlated (r>0.5 for 61% of the compared variables) and, therefore, the data obtained from the left side were used in the further analyses.

Table2. Shoe assessment based on the Footwear Assessment Tool

Variable	Men (42)	Women (42)
General		
Age of shoe	0-6 months	0-6 months
Footwear style	Athletic shoes	Athletic shoes
Materials (upper)	Synthetic	Synthetic
Materials outsole	Rubber	Rubber
Weight	295 g/shoe	274 g/shoe
Length	28.8 cm	28.8 cm
Weight/length	10.24	9.51
General Structure		
Heel height	2.4 cm (0 - 2.5 cm)	2.7 cm (2.6 - 5.0 cm)
Forefoot height (at point of the 1st and MTPJs)	2.0 cm (1.0 – 2.0 cm)	2.0 cm (1.0 – 2.0 cm)
Longitudinal profile (heel – forefoot difference)	0.4 cm: flat (0 – 0.9 cm)	0.7 cm: flat (0 – 0.9 cm)
Last (centre goniometer at 50% shoe length)	10°: semi-curved (5° - 15°)	10°: semi-curved (5° - 15°)
Fixation of upper to sole	Slip-lasted	Slip-lasted
Forefoot sole flexion point	Proximal to 1st MTPJ	Proximal to 1st MTPJ
Motion Control Properties Scale		
Midsole density layers	Single density	Single density
Fixation (upper to foot)	Laces	Laces
Heel counter stiffness	Moderate (<45°)	Moderate (<45°)
Midfoot sagittal stability	Moderate (<45°)	Moderate (<45°)
Midfoot torsional stability	Moderate (<45°)	Moderate (<45°)
Motion control score	6/11	6/11
Cushioning		
Presence	None	None
Lateral Midsole hardness	Hard	Hard
Medial Midsole hardness	Hard	Hard
Heel sole hardness (centre of inside heel shoe	Firm	Firm

RESULTS

Of the participants, 16 were women and 11 were men. The average age was 82.0 (7.4) years, the average height 161.7 (7.7) cm, and the average weight was 74.4 (16.5) kg. Of the 27 participants, 7 belonged to a group with low fear of falling, 10 to a moderate group, and 10 belonged to a group with high fear of falling (Table 1). There were not significant differences between groups in age, height, or self-selected speed. The weight (p=0.014) and body mass index (p=0.001) were significantly higher in a high group comparing to a low group. Additionally, the men/women ratios within groups were significantly different (p=0.0075) (Table 1).

The relative mean (p=0.006) and peak force (p=0.004) of hindfoot during SLA were significantly higher in a high group than in a moderate group (Table 3). The relative peak force during WA tended to be greater in a low than in a high group for hallux (p=0.042). Reversely, for a MTH1 (p=0.026) and a hindfoot (p=0.038) it was greater in a high than in a low group (Table 3). The low and moderate groups demonstrated a significantly shorter WA relative duration comparing to a high group (p=0.003). Except for that, the sub-phases of gait stance phase did not differ between three groups (Table 4). In WA phase, the estimates of the center of pressure were significantly smaller in a low than in a high group for mediolateral (p=0.004) and anteroposterior displacement (p=0.00613) (Table 4).

DISCUSSION

The in-shoe pressure measurements demonstrated that WA duration and the anterior-posterior displacement of WA and SLA varied between groups with different severity of fear of falling. There were significant differences in hindfoot centers of pressure regarding relative mean and peak forces during SLA. Relative peak forces during WA were different in hallux, MTH1, and in hindfoot.

While previous studies have mostly focused on the duration of stance phase, the present study was the first one that extended its focus on the relative duration of WA suggesting a relationship between a prolonged double limb support time and a fear of falling among elderly (19,29). It may be speculated that people with higher level of fear of falling may find achieving initial limb stability being more difficult and, thus, they may compensate their impaired balance by needing more time in that subphase (28). These time differences may probably also be explained by the differences seen in regional displacements reflecting the lack of stability in WA.

Force measurements in different regions showed differences in relative pressure under MTH1, hallux, and hindfoot with higher estimates observed in a high group compared to a low group. The findings are in line with previous studies highlighting the role of hallux flexor strength measurements (measured as a relative peak force) when evaluating the risk of falling (16). Peak forces in midfoot and lesser toes may also play an important part when evaluating a risk of falling among elderly (16,21).

Previous studies have reported the relationship between gait variability and a risk and fear of falling among elderly (18–20). Most of these studies have investigated a spatiotemporal variability in gait. In addition, a recent study has examined the variability of absolute displacement of center of pressure in mediolateral and anteroposterior directions finding a significant relationship between a risk of falling and fluctuations in that displacements during a pre-swing phase at a defined speed task (18). In the present study, the variability of anteroposterior relative displacement during WA and SLA subphases was associated with a Short FES-I score without such a relationship between a Short FES-I score and mediolateral relative displacement.

The differences between the present results and previous research might lay in differences between community-dwelling and non-community-dwelling populations or in differences that appear when using a force plate (barefoot) versus in-shoe pressure measurements. Diversities in displacement calculation schemes (absolute versus relative), settings (self-selected versus predefined walking speed), or in the measures of risk of falling (history of falls versus Short FES-I) might also explain dissimilar results. The differences between groups might be explicated by a possibility that relative displacements in center of pressure may be influenced by different relative durations of subphases and, thus, may reflect the dissimilarities in foot kinematics.

The study sample was small. The Swiss French version of Short FES-I questionnaire has yet to validated. While the Short FES-I Questionnaire is able to assess the risk and the fear of falling, the cutoffs used in this study were those for the fear of falling and not for the risk of falls. Some demographic differences between groups might influence the results.

Further research may amplify the ability of foot pressure measurements to predict falls. The respective assessment of foot intrinsic muscles may reveal their role in maintaining postural stability.

CONCLUSIONS

In-shoe pressure measurement while walking may be important when assessing the risk and the fear of falling among elderly.

Table 3. Loadings in different regions

Relative force (%body weight)	Loadings			p
	Low group	Moderate group	High group	
Weight acceptance				
Peak Hallux	0.33 (0.42)[3]	0.91 (0.67)	1.72 (1.47)[1]	0.042
Peak MTH 1	2.27 (0.95)[3]	3.30 (3.15)[3]	5.86 (4.64)[1,2]	0.026
Peak MTH 2-3	3.05 (1.73)	3.64 (3.93)	5.45 (2.53)	0.187
Peak MTH 4-5	3.71 (2.22)	3.06 (2.88)	4.60 (2.07)	0.34
Peak Hindfoot	61.59 (9.75)[3]	61.38 (15.99)[3]	47.34 (9.32)[1,2]	0.038
Peak GRF	73.84 (6.55)	76.10 (17.24)	71.39 (10.58)	0.932
Single limb support				
Peak Hallux	3.42 (2.83)	8.48 (4.52)	5.38 (4.19)	0.096
Peak MTH 1	19.41 (8.19)	24.64 (10.30)	14.70 (7.45)	0.084
Peak MTH 2-3	28.89 (7.79)	30.73 (11.41)	19.81 (9.83)	0.095
Peak MTH 4-5	18.25 (5.95)	18.25 (5.95)	10.87 (5.66)	0.077
Peak Hindfoot	59.43 (11.34)	58.04 (16.26)	45.80 (9.97)	0.083
Peak GRF	87.12 (10.06)	95.61 (23.62)	80.16 (11.99)	0.128
Mean Hallux	1.19 (1.04)[3]	3.03 (1.49)[3]	2.95 (2.36)[1,2]	0.091
Mean MTH 1	9.35 (4.09)	12.18 (5.70)	9.35 (4.40)	0.462
Mean MTH 2-3	12.94 (4.8)	14.22 (6.95)	11.56 (4.98)	0.666
Mean MTH 4-5	10.00 (4.00)	9.80 (4.49)	7.79 (3.89)	0.507
Mean Hindfoot	29.15 (13.37)	22.54 (5.51)	32.37 (14.35)	0.222
Mean GRF	72.02 (7.09)	73.90 (19.33)	74.82 (10.35)	0.622
Single limb advancement				
Peak Hallux	5.71 (4.84)	14.02 (10.58)	7.55 (4.20)	0.075
Peak MTH 1	20.03 (7.60)	24.17 (9.60)	15.47 (6.13)	0.12
Peak MTH 2-3	30.57 (7.07)	31.39 (10.51)	22.17 (7.62)	0.097
Peak MTH 4-5	17.76 (6.83)	16.98 (8.31)	11.62 (4.42)	0.178
Peak Hindfoot	1.56 (2.17)	0.83 (1.22)[3]	17.54 (19.67)[2]	0.004
Peak GRF	80.90 (16.46)	93.67 (25.74)	78.52 (12.12)	0.112
Mean Hallux	4.53 (3.86)	11.06 (7.68)	5.92 (3.49)	0.083
Mean MTH 1	13.76 (4.86)	14.26 (6.13)	10.12 (3.30)	0.308
Mean MTH 2-3	19.79 (5.12)	19.32 (6.83)	14.64 (4.51)	0.217
Mean MTH 4-5	10.41 (5.33)	9.12 (5.41)	6.69 (1.98)	0.258
Mean Hindfoot	0.42 (0.51)	0.25 (0.29)[3]	6.03 (7.40)[2]	0.006
Mean GRF	54.85 (11.89)	62.75 (16.66)	50.57 (8.84)	0.135

[1-3] Kruskal-Wallis test with post-hoc (Tukey-Kramer) correction for multiple comparison – significantly different than the low[1], moderate[2], or high[3] group

Table 4. Functional gait tasks and centers of pressure

Tasks	Estimates			p value
	Low group	Moderate group	High group	
Relative duration (% stance duration) of reaching				
1st peak force	25.86 (3.48)[3]	27.60 (5.06)[3]	35.20 (4.71)[12]	0.003
2nd peak force	79.71 (3.65)	80.20 (3.12)	74.70 (5.92)	0.07
WA	25.86 (3.48)[3]	27.60 (5.06)[3]	35.20 (4.71)[12]	0.003
SLS	53.86 (4.67)	52.60 (6.07)	39.50 (9.97)	0.004
SLA	20.29 (3.65)	19.80 (3.12)	25.30 (5.92)	0.07
M-L relative displacement (% total displacement)				
WA	18.63 (10.75)[3]	26.04 (12.52)	36.44 (9.05)[1]	0.0036
SLS	36.32 (11.93)	34.81 (15.87)	18.72 (8.99)	0.1462
SLA	43.32 (15.45)	39.15 (15.48)	44.84 (13.40)	0.2238
A-P relative displacement (% total displacement)				
WA	16.74 (7.71)[3]	21.16 (10.94)	29.31 (8.86)[1]	0.00613
SLS	72.33 (10.99)	63.85 (13.30)	37.17 (19.19)	0.052
SLA	10.93 (5.55)[3]	14.99 (9.13)	33.51 (25.42)[1]	0.0112
M-L relative displacement mean variability (SD)				
WA	0.32 (0.04)	0.36 (0.18)	0.47 (0.16)	0.0607
SLS	0.96 (0.36)	1.30 (0.45)	0.88 (0.35)	0.0345
SLA	0.88 (0.31)	1.03 (0.22)	0.89 (0.52)	0.1281
A-P relative displacement mean variability (SD)				
WA	1.18 (0.46)[3]	1.50 (0.83)	2.25 (0.71)[1]	0.0046
SLS	3.13 (0.97)	3.68 (1.07)	3.75 (1.04)	0.0803
SLA	0.97 (0.73)[3]	1.02 (0.50)	1.70 (0.97)[1]	0.0086

[1-3] Kruskal-Wallis test with post-hoc (Tukey-Kramer) correction for multiple comparison – significantly different than the low[1], moderate[2], or high[3] group

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ACKNOWLEDGMENTS

None to declare