

EFFECTS OF COMPLIANT FLOORING ON DYNAMIC BALANCE AND GAIT CHARACTERISTICS OF COMMUNITY-DWELLING OLDER PERSONS

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Abstract: *Background:* Compliant flooring while providing the impact force attenuation in the event of falls, its low stiffness characteristic might impair balance and gait which consequently resulted in an increase in the risk of falling. *Objective:* To investigate the effects of compliant flooring on dynamic balance and gait performance of older adults under challenging conditions. *Design and participants:* A cross-sectional designed with repeated measured. Thirty five community-dwelling older adults (mean age 74.91 ± 6.51 yrs) participated in this study. *Measurement:* Modified Dynamic Gait Index (mDGI) and Timed Up and Go (TUG) were used to assess dynamic balance. Spatio-temporal gait parameters were measured under comfortable and maximal speed. All tests were administered on the vinyl and compliant flooring in random order. *Results:* The time taken to complete TUG and the mDGI scores were similar between the two flooring types ($p \geq 0.05$). Overall, gait characteristics were comparable when walking on the compliant and vinyl flooring for both speeds except for swing time, step time, and cadence. *Conclusion:* The present study demonstrated that compliant flooring did not significantly affect dynamic balance and had minimal effects on gait characteristics. The compliant flooring appears to be safe for installing in self-ambulating older adult's home.

Key words: Compliant flooring, dynamic balance, gait characteristics, community-dwelling older adults.

Introduction

Falls are a leading cause of injury and death among older people. Up to 30 % of community-dwelling people aged 65 years and over fall each year (1). Non-fatal falls are often followed by injuries such as soft tissue injury, head injury, and fracture which consequently lead to activities restriction, bed ridden, decrease sense of well-being, and poor quality of life (2, 3). In addition, falls also pose substantial financial burden. A systematic review on the international comparison of costs of falls reported that falls accounted for 3,476 USD per incident, 10,749 USD per injurious fall, and 26,483 USD per fall requiring hospitalization (4).

Causes of falls are multi-factorial. As for intrinsic factors, older people prone to fall because of age-related physiological changes as well as pathological diseases of various body systems that affect postural control (2, 5). Environmental hazards such as poor lighting, unsafe stairways, improper flooring have been identified as extrinsic factors associated with increased fall risk (2, 5). Several studies have been conducted to find effective fall prevention strategies. A systematic review that included 159 randomized trials with 79,193 participants concluded that exercise and home safety interventions are effective in reducing rate of falls and risk of falling in community-dwelling older people (6).

Compliant or shock absorbing flooring is an intervention approach aimed to attenuate the impact force in the event of a fall, resulting in reduction of the incidence and severity of fall-related injuries. Previous studies reported that the compliant floorings could attenuate hip impact forces by 16.4 to 51.2%

(7-9), head impact force by 20-80% compared to a rigid surface (10). While providing force attenuation, the low stiffness characteristic of the compliant flooring might impair balance and mobility performance, consequently increase risk of falling. Findings whether complaint flooring increases the risk of falling in older adults have been inconclusive (11-14). Warren and Hanger (14) found no difference in fall rates or fractures between carpet and vinyl flooring. In contrast, Donald et al (15) reported a significant higher incidence of falls on carpet as compared to vinyl flooring. In line with this finding, a pilot randomized controlled trial by Drahota et al (11) suggested that compliant flooring may reduce fall-related injuries but increase risk of falls.

A recent biomechanical efficacy review demonstrated that compliant flooring could reduce impact forces during simulated falls with minimal effects on balance and gait in self-ambulating individuals (16). Such findings were, however, derived from less challenging tasks such as standing balance and walking at comfortable speed. Evidence regarding the impact of compliant flooring on challenging dynamic balance and complex functional mobility is lacking. Results from a stakeholder symposium also indicated a need for future research to investigate the impact of compliant flooring on dynamic balance and challenging walking condition (3). To address this research gap, the present study aimed to examine the effects of compliant flooring on dynamic balance and gait performance under maximal speed and complex gait tasks. Findings from the present study would provide additional information beneficial for decision making on appropriate flooring for older people.

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Table 1
 Participant characteristics

	Mean ± SD	Frequency	Percent (%)
N	35	-	-
Age (years)	74.91 ± 6.51	-	-
Weight (kg)	48.71 ± 13.21	-	-
Height (cm)	152.06 ± 8.21	-	-
Gender (M:F)	-	13 : 22	37 : 63
At least 1 fall in the past 1 year	-	7	20
Exercise at least 3 days per week	-	16	46

SD = standard deviation; All values are means ± standard deviations except for gender, history of fall and exercise

Methods

Participants

Thirty five community-dwelling older adults aged 65 years or older participated in the study. Participants were included in the study if they were able to walk at least 10 meters without gait aid or assistance and comprehend instructions. The exclusion criteria included having neurological, musculoskeletal or other medical conditions (e.g. Parkinson’s disease, stroke, multiple sclerosis, severe arthritis, foot pain) that affect balance and gait performance. The study protocol was approved by the Human Ethical Review Board of the primary investigator’s institution (AMSEC-59EX-041). All participants signed a written informed consent form prior to participation.

Outcome Measures

Outcome measures including balance and spatio-temporal gait parameters were assessed twice: on vinyl (serve as standard, rigid flooring) and compliant flooring. The order of the testing conditions (i.e. balance or gait, vinyl or compliant flooring) was randomized and counter balance across all participants. All tests were performed with bare feet to eliminate the influence of footwear. Structured instructions and demonstration of each test were given to the participants prior to testing. All outcomes were assessed by trained assessors.

Dynamic Gait Index (DGI) and Timed Up and Go test (TUG) were used to assess balance. The DGI is consisted of 8 functional walking tasks: 1) walk at normal speed, 2) change of walking speed, 3) walk with horizontal head turns, 4) walk with vertical head turns, 5) walk and pivot turns, 6) step over obstacle, 7) step around obstacles, and 8) walk up the stairs (17). Since the flooring was commonly installed in the room, the item “walk up the stairs” in the DGI was not tested in this study. Therefore, the total score for this modified Dynamic Gait Index (mDGI) was 21 points. For the TUG, participants were asked to stand up from a chair, walk at their maximal speed to the 3-meter line, turn 180 degrees, walk back, and sit down on a chair. A practice trial was performed, followed by two testing

trials with rest between each trial. The average time used to complete the two TUG trials was recorded (18).

Gait parameter outcomes including gait speed, cadence, step length, step width, step time, stance time and swing time were measured using the GaitRite® electronic walkway system (CIR systems Inc. Clifton, NJ). Validity of the GAITRite® system has been established (19). Each flooring type was placed over the GAITRite® mat and the participants were instructed to walk bare feet at their comfortable and maximal speed for 3 trials per gait speed with rest between each trial. The gait variables for each speed and flooring condition were averaged across the 3 trials.

Statistical Analysis

All statistical analyses were conducted using SPSS software (version 21.0, IBM Corporation, Chicago, IL, USA). Tests of data normality were performed using the Shapiro-Wilk test. Differences of outcome measures between the compliant and vinyl flooring were determined using student t-tests. The significance level was set at P < 0.05, 2-sided.

Results

Participant characteristics

Thirty five older adults aged between 65-87 years old (mean 74.91 ± 6.51 yr) participated in the study. Seven participants (20%) reported 1-2 falls during the past year. Participant demographic characteristics are illustrated in Table 1.

Balance Performance

Time taken to complete TUG was similar between the two flooring types (p = 0.19). The modified dynamic gait index (mDGI) score for the compliant flooring was slightly lower than that for the vinyl flooring with marginally significance (p = 0.05), Table 2.

Gait characteristics

Overall, gait characteristics were similar when walking on the compliant and vinyl flooring for both speeds except for

Table 2
 Balance performance while performing on the compliant and vinyl flooring

Balance Measure	Flooring type		p-value
	Vinyl flooring	Compliant flooring	
Timed Up and Go (s)	9.00 ± 2.06	9.19 ± 2.19	0.19
modified Dynamic Gait Index (total score 21 points)	15.46 ± 3.00	14.94 ± 2.88	0.05

All values are means ± standard deviations

Table 3
 Gait parameters while walking on the compliant and the vinyl flooring with comfortable and maximal speed

Gait parameters	Comfortable speed		p-value	Maximal speed		p-value
	Vinyl flooring	Compliant flooring		Vinyl flooring	Compliant flooring	
Gait speed (m/sec)	92.33 ± 17.46	92.45 ± 17.40	0.94	140.97 ± 23.98	143.04 ± 22.47	0.25
Cadence (steps/min)	83.98 ± 6.31	84.78 ± 6.91	0.21	100.29 ± 9.58	102.24 ± 10.41	0.02*
Step width (cm)	4.53 ± 5.38	4.53 ± 5.46	0.99	5.30 ± 6.76	5.29 ± 6.69	0.61
Step length (cm)	65.96 ± 11.14	65.54 ± 11.75	0.68	85.05 ± 16.41	85.03 ± 17.37	0.98
Step time (sec)	0.72 ± 0.06	0.71 ± 0.06	0.11	0.60 ± 0.06	0.59 ± 0.06	0.01*
Stance time (sec)	0.87 ± 0.07	0.87 ± 0.08	0.97	0.72 ± 0.08	0.72 ± 0.08	0.93
Swing time (sec)	0.63 ± 0.07	0.60 ± 0.07	0.01*	0.56 ± 0.07	0.54 ± 0.07	0.01*

All values are means ± standard deviations

swing time, step time, and cadence (Table 3). Swing time was significantly shorter when walked on the compliant flooring than the vinyl flooring for both comfortable and maximal speed ($p = 0.01$). Step time was significantly shorter ($p = 0.01$) and cadence was significantly greater ($p = 0.02$) when walked on the compliant flooring as compared to the vinyl flooring under the maximal gait speed condition.

Discussion

This study aimed to investigate the effects of compliant flooring on dynamic balance and gait performance of older adults under challenging conditions. Timed Up and Go at fastest speed and mDGI were used to assess dynamic balance. The TUG has been widely used to identify balance deficit and predict fall risk in healthy older adults and individuals with various medical diagnoses (18, 20, 21). Functional mobility included in the TUG (i.e. gait, turning, transitional tasks from sit to stand to walk and reverse) represents those activities for which fall incidence is often occurred (22). A previous study found that the time taken to complete TUG at self-selected speed was not different between the compliant (SmartCells, SoftTile) and vinyl flooring (9). The present study further demonstrated that the TUG performance at maximal speed on the compliant flooring was also comparable to that on the vinyl flooring.

The DGI was designed to assess balance not only during steady state walking, but also walking in response to changes in speeds, directions, and environments (23). Although the statistical analysis indicated marginally significant difference for the mDGI score between the compliant and vinyl flooring, this difference is unlikely to have clinical meaningfulness as the mean difference (0.52 ± 1.5) of mDGI score was not greater than the minimal detectable change value. It has been reported that a change of 2.9 points in the DGI is required to be 95% confident that the true change has occurred (24). Thus, our finding indicated that balance control was not compromised by the compliant flooring even when the participants had to modify their gait under different circumstances. Such finding is practically valuable as in everyday life. It is common for a person to be walking while concurrently engaging in other activities such as turning the head to look at different directions or negotiating obstacles. Collectively, the results from TUG and mDGI suggested that the compliant flooring did not compromise dynamic balance of self-ambulating older persons.

In the present study, swing time was affected by the compliant flooring regardless of the walking speed, whereas step time and cadence was affected only under the maximal gait speed condition. However, these differences were small and did not affect gait speed or spatial parameters such as step length and step width (Table 3). Gait speed and step length have been demonstrated to be significant discriminators for

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high and low fall risk elderly (25). In contrast to a previous study that demonstrated decreased gait speed when walking on soft surface (5), this was not observed in the present study. Previous findings regarding the impact of compliant flooring on gait parameters were inconclusive. Both positive and negative attributes of compliant flooring on gait performance have been reported (16). The discrepancy between these findings might be partly due to the difference in degree of the floor's stiffness. It has been demonstrated that lower stiffness of the surface was associated with poorer balance and gait performance. However, available evidence suggested that the stiffness of most commercial compliant floorings were not lower than the threshold required to cause significant impairments (16).

The main strength of this study was that it provided further evidence for the impact of compliant flooring on challenging dynamic balance and gait tasks. The functional activities observed in the present study were clinically relevant as fall incidence has often been reported during these activities. Certain study limitations also need to be considered. First, because participants in the present study were healthy community-dwelling older adults, it is not known how the compliant flooring would affect balance and gait of those with physical limitations or neurological dysfunction. Future studies are warranted to examine the impact of compliant flooring in these populations as they are at high risk of falls and serve as the target user group. Second, as each flooring type has different properties, the findings may not be generalized to other flooring types.

Conclusion

The present study demonstrated that compliant flooring, when tested under challenging conditions, was non-inferior to the standard, rigid flooring for balance and gait performance, suggesting that the compliant flooring was safe for self-ambulating older persons.

Acknowledgements: This work was funded in part by a grant from The Siam Cement Group. The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Declaration of Conflicting Interests: The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethics standard: Ethical approval number AMSEC-59EX-041

References

1. Campbell AJ, Borrie MJ, Spears GF, Jackson SL, Brown JS, Fitzgerald JL. Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. *Age Ageing*. 1990;19(2):136-41.
2. Ambrose AF, Paul G, Hausdorff JM. Risk factors for falls among older adults: a review of the literature. *Maturitas*. 2013;75(1):51-61.

3. Lachance CC, Mackey DC. Feasibility of compliant flooring in long-term care: results from a stakeholder symposium. *Can J Aging*. 2018;37(1):84-94.
4. Davis JC, Robertson MC, Ashe MC, Liu-Ambrose T, Khan KM, Marra CA. International comparison of cost of falls in older adults living in the community: a systematic review. *Osteoporos Int*. 2010;21(8):1295-306.
5. Demura S, Shin S, Takahashi S, Yamaji S. Relationships between gait properties on soft surfaces, physical function, and fall risk for the elderly. *Adv Aging Res*. 2013;2:57-64.
6. Gillespie LD, Robertson MC, Gillespie WJ, Sherrington C, Gates S, Clemson LM, et al. Interventions for preventing falls in older people living in the community. *Cochrane Database Syst Rev*. 2012(9):Cd007146. doi: 10.1002/14651858.CD007146.pub3.
7. Bhan S, Levine IC, Laing AC. Energy absorption during impact on the proximal femur is affected by body mass index and flooring surface. *J Biomech*. 2014;47(10):2391-7.
8. Glinka MN, Karakolis T, Callaghan JP, Laing AC. Characterization of the protective capacity of flooring systems using force-deflection profiling. *Med Eng Phys*. 2013;35(1):108-15.
9. Laing AC, Robinovitch SN. Low stiffness floors can attenuate fall-related femoral impact forces by up to 50% without substantially impairing balance in older women. *Accid Anal Prev*. 2009;41(3):642-50.
10. Wright AD, Laing AC. The influence of headform orientation and flooring systems on impact dynamics during simulated fall-related head impacts. *Med Eng Phys*. 2012;34(8):1071-8.
11. Drahota AK, Ward D, Udell JE, Soilemezi D, Ogollah R, Higgins B, et al. Pilot cluster randomised controlled trial of flooring to reduce injuries from falls in wards for older people. *Age Ageing*. 2013;42(5):633-40.
12. Gustavsson J, Bonander C, Andersson R, Nilsson F. Investigating the fall-injury reducing effect of impact absorbing flooring among female nursing home residents: initial results. *Inj Prev*. 2015;21(5):320-4.
13. Simpson AH, Lamb S, Roberts PJ, Gardner TN, Evans JG. Does the type of flooring affect the risk of hip fracture?. *Age Ageing*. 2004;33(3):242-6.
14. Warren CJ, Hanger HC. Fall and fracture rates following a change from carpet to vinyl floor coverings in a geriatric rehabilitation hospital. A longitudinal, observational study. *Clin Rehabil*. 2013;27(3):258-63.
15. Donald IP, Pitt K, Armstrong E, Shuttleworth H. Preventing falls on an elderly care rehabilitation ward. *Clin Rehabil*. 2000;14(2):178-85.
16. Lachance CC, Jurkowski MP, Dymarz AC, Robinovitch SN, Feldman F, Laing AC, et al. Compliant flooring to prevent fall-related injuries in older adults: a scoping review of biomechanical efficacy, clinical effectiveness, cost-effectiveness, and workplace safety. *PLoS ONE*. 2017;12(2):e0171652. doi: 10.1371/journal.pone.0171652.
17. Herman T, Inbar-Borovsky N, Brozogl M, Giladi N, Hausdorff JM. The Dynamic Gait Index in healthy older adults: the role of stair climbing, fear of falling and gender. *Gait Posture*. 2009;29(2):237-41.
18. Shumway-Cook A, Brauer S, Woollacott M. Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. *Phys Ther*. 2000;80(9):896-903.
19. Bilney B, Morris M, Webster K. Concurrent related validity of the GAITRite walkway system for quantification of the spatial and temporal parameters of gait. *Gait Posture*. 2003;17(1):68-74.
20. Flansbjerg UB, Holmback AM, Downham D, Patten C, Lexell J. Reliability of gait performance tests in men and women with hemiparesis after stroke. *J Rehabil Med*. 2005;37(2):75-82.
21. Huang SL, Hsieh CL, Wu RM, Tai CH, Lin CH, Lu WS. Minimal detectable change of the Timed "Up & Go" test and the dynamic gait index in people with Parkinson disease. *Phys Ther*. 2011;91(1):114-21.
22. Topper AK, Maki BE, Holliday PJ. Are activity-based assessments of balance and gait in the elderly predictive of risk of falling and/or type of fall?. *J Am Geriatr Soc*. 1993;41(5):479-87.
23. Shumway-Cook A, Baldwin M, Polissar NL, Gruber W. Predicting the probability for falls in community-dwelling older adults. *Phys Ther*. 1997;77(8):812-9.
24. Romero S, Bishop MD, Vellozo CA, Light K. Minimum detectable change of the Berg Balance Scale and Dynamic Gait Index in older persons at risk for falling. *J Geriatr Phys Ther*. 2011;34(3):131-7.
25. Senden R, Savelberg HH, Grimm B, Heyligers IC, Meijer K. Accelerometry-based gait analysis, an additional objective approach to screen subjects at risk for falling. *Gait Posture*. 2012;36(2):296-300.