Abstract: As there is lack of understanding about the effect of transitioning between different flooring materials on the gait of older adults, this study investigated the effect of transitioning between a carpeted floor and a vinyl floor on the gait characteristics of older adults. Fourteen older (65 years old and over) and 14 younger (18 to 35 years old) adults walked on different transitional floors by measuring various gait parameters. While the older participants had greater toe clearance than their younger counterparts, the older participants had smaller toe clearance on a carpeted floor than on a vinyl floor, which would increase the probability of a trip-induced fall. Further, the study found the slower transitional acceleration of the whole body COM and the increased friction demand, especially during the toe-off phase, rather than heel contact phase, which will lead to a slip-induced fall on a vinyl floor shortly after transitioning from a carpeted floor to a vinyl floor. Although the increased likelihood of a slip or trip accident was found throughout the changes in gait parameters, the older participants did not perceive of slipping and tripping much. Therefore, older adults are recommended to be made aware of the danger of slipping and tripping while transitioning between different flooring materials.

Keywords: safety; ageing; falls; gait; home

1. Introduction

As people grow older, they are more likely to increase risk of falling and consequent injuries. In 2015, the number of people age 65 and older in the United States was 47.8 million, which accounted for 14.9 percent of the total population [1]. The older population is anticipated to more than double to over 98 million by 2060 [2]. It is well documented that falls are the leading cause of fatal and non-fatal injuries for older Americans [3], resulting in financial burden for treating fall injuries and loss of independence [4,5]. Fall-related injury is one of the 20 most expensive medical conditions among community-dwelling older adults [6]. The costs for treating fall injuries to Medicare totaled over $31 billion, and the number of falls and the costs to treat are likely to increase as the U.S. population is aging [7].

Falls among the elderly are more likely to occur indoors than outdoors. While the majority of older adults’ falls occur inside the house (e.g., stairs and rooms), approximately 23% of falls occur near the house (e.g., driveway, patio, and back yard) and the remaining 22% occur in public spaces (e.g., parking lots and sidewalks) [8,9]. Older adults would thus need more attention and support while staying at home. Carpet is the most common indoor floor covering as carpet represents more than 43% of the overall flooring market today [10]. The most common places covered with carpet are the living...
room and bedroom where elderly people spend most of their time. Vinyl is also widely used in the residential places. Vinyl sheet market has grown 2.8% going from $791 million in 2013 to $813.5 million in 2015 [10].

Although transitioning over different floor coverings occurs often in daily activities that may cause falls or fall-related injuries, little has been found about the effect of specific floor coverings on gait parameters, especially during transitioning between carpet and vinyl. Furthermore, the findings of the few studies show contradictive results in terms of biomechanical gait parameters. For example, Willmott [11] found that gait speed and step length were significantly greater on a carpeted floor than on a vinyl floor in 58 elderly hospital patients. Yet, Dickinson et al. [12] reported that community-dwelling older persons walked slower on a carpeted floor than on a vinyl floor. Additionally, Stephens and Goldie [13] noted that twenty-four stroke patients walked slower on a carpeted floor than a vinyl floor. On the other hand, a recent study by Kleiner et al. [14] reported no significant differences for gait speed between two groups of older and middle-aged individuals walking barefoot on a 9-m pathway of different flooring conditions including carpet and vinyl.

The objective of this study is to investigate the degree to which transitioning between different flooring materials affects gait characteristics of older adults. Various gait characteristics are examined including required coefficient of friction (RCOF), heel contact velocity, transitional acceleration of the whole body center-of-mass (COM), step length, and toe clearance. Both groups of younger and older individuals are observed to determine age-related effects on gait characteristics.

2. Methods

2.1. Experimental Variables

The study had two independent variables: Age and Floor. Younger and older adults participated in this study where they were instructed to walk on the walkway that was covered by different flooring materials (i.e., vinyl and carpet). The study had the following dependent variables: required coefficient of friction (RCOF), step length, transitional acceleration of the whole body center-of-mass (COM), heel velocity at heel contact, toe clearance, and subjective perception of slipping and tripping.

2.2. Participants

Estimation of required sample sizes for this study came from estimates of inter-subject variability in the heel velocity obtained from the author’s previous study [15]. Power calculation [16] was performed to ensure that sample sizes are large enough to identify differences between younger and older participants with high probability. Fourteen participants per group should be sufficient to see the specified differences in the gait parameter heel contact velocity with risk of a type I error of 0.05 and a type II error of < 0.3 (power > 0.7). A convenience sampling method recruited fourteen older (65 years old and over) and 14 younger adults (18 to 35 years old) meeting the criteria: community-dwelling, no restriction to physical activity, no history of musculoskeletal and neurological disease, and no fall history.

2.3. Equipment and Materials

A linear walking track (1.5 m × 15.5 m) was used for walking trials. To produce different floor surface conditions, this study used the floor coverings commonly encountered indoors – i.e., carpet (cut pile, Nylon, 1/10 gauge, 0.28 inch pile height, total weight 60 oz./sq. yd., and pad thickness 3/8 inch) and vinyl (Verde Tinos Floor Tile, VC0413131p). The specifications of the vinyl and carpet used in this study meet ADA Accessibility Guidelines for Buildings and Facilities [17]. Each test surface incorporated two force plates (force plate #1: 24” × 48”, Advanced Mechanical Technology, Inc., Watertown, MA and force plate #2: 18.25” × 20”, Bertec Corporation, Columbus, OH). A six-camera motion analysis system (ProReflex, Qualisys Inc., East Windsor, CT) was used to capture three-dimensional movement data of the participants while wearing an overhead fall arresting harness. All participants were provided
with the same type of athletic shoes in order to give the same resistance between a rubber sole and underfoot surface. This study used a 5-point Likert scale (Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree) to investigate the participants’ fear of slipping and tripping while transitioning between different floor surfaces (e.g., “My fear of slipping made me hesitating going forward during walking on vinyl floor”, “My fear of tripping made me hesitating going forward during walking on carpeted floor”, “My fear of slipping made me hesitating going forward during the transition from carpeted to vinyl floor”, and “My fear of tripping made me hesitating going forward during the transition from vinyl to carpeted floor”).

2.4. Procedure

The experiment consisted of a preparation session, a walking test session, and a feedback session. For the preparation session, the participants were guided to become familiar with the experiment equipment and procedure. For instance, an experimenter demonstrated the walking test equipment by wearing the harness and also explained the procedure of the walking test. Twenty-seven reflective markers were attached to the anatomically significant positions. The participants wore a safety harness and walked on the track while the Qualysis\textsuperscript{TM} motion capture system recorded the participant’s posture and ground reaction forces. All participants were fitted with the experimental shoes to provide minimum variations due to footwear. To prevent the participants from concentrating on floor surfaces while walking, they were required to focus their eyes on TVs that were located at each side of the walkway, and they should call out whenever the light from the TV screen was on or off. The participants were instructed to walk on the walkway that consisted of four different floor conditions; that is, (1) walking on a vinyl floor; (2) walking on a carpeted floor; (3) transitioning from a carpeted floor to a vinyl floor; and (4) transitioning from a vinyl floor to a carpeted floor. With different orders of treatment conditions, randomization was performed to balance out order effect. After the walking test session, participants were asked to answer a set of questions to provide their perception of slipping and tripping.

2.5. Data Analysis

Dependent measures of gait parameters (i.e., RCOF, transitional acceleration of the whole body COM, toe clearance, step length, and heel contact velocity) and subjective assessment were analyzed using $2 \times 4$ (age $\times$ floor) two-way mixed analysis of variance (ANOVA) design ($\alpha \leq 0.05$) to test whether the main effects and interaction effects were statistically significant. Tukey post hoc test was also performed on all significant differences (i.e., age, floor condition, and interactions). Supplemental data analysis was performed to compare Peak Push-Off Friction Demand (PPOFD) between the first toe-off and the second toe-off during transitioning from a carpeted floor to a vinyl floor and vice versa. Additionally, friction demands were investigated between the first heel contact and the second heel contact. Since two samples from the first toe-off/heel contact and the second toe-off/heel contact are dependent, the Paired-Comparison $t$-Test was performed to examine whether there was a statistically significant difference between the two friction demands on a carpeted floor and a vinyl floor.

3. Results

3.1. Effects of Age Conditions

Toe clearance. With the exception of toe clearance, there was no statistically significant age effect on any of the gait parameters in this study. The ANOVA results indicated statistically significant differences ($F_{1,26} = 4.50, P = 0.0435, \eta^2=0.046$) in toe clearance between the two age groups. The older participants’ toe clearance was higher than their younger counterparts (see Table 1).
3.2. Effects of Floor Conditions

Toe clearance. The ANOVA results indicated statistically significant differences ($F_{3,75} = 21.94$, $P < 0.0001$, $\eta^2 = 0.62$) between the different floor conditions. Tukey post-hoc test indicated significant differences between (1) Carpet vs. Vinyl, (2) Carpet vs. Carpet-to-Vinyl, (3) Vinyl vs. Vinyl-to-Carpet, (4) Carpet-to-Vinyl vs. Vinyl-to-Carpet, and (5) Carpet-to-Vinyl vs. Vinyl. As shown in Table 2, an increase in toe clearance was observed on a vinyl floor as compared to on a carpeted floor. Additionally, the participants generated higher toe clearance after transitioning from a vinyl floor to a carpeted floor.

3.3. Paired-Comparison t-Test for Friction Demands

Paired-Comparison t-Test was performed to test on the two friction demands on carpet and vinyl during transitioning.

Friction demand at the first and the following second heel contact. The Paired-Comparison t-Test indicated statistically significant differences between friction demands at the first heel contact and the second heel contact except the floor condition of transitioning from a carpeted floor to a vinyl floor for the younger participants (see Table 4). The friction demand at the heel contact was lower on a vinyl floor than a carpeted floor for each age group and also each transition condition (i.e., younger participants transitioning from carpet to vinyl: $t(12) = 2.55$, $p = 0.0256$, $d = 0.78$ and from vinyl to carpet: $t(12) = -5.68$, $p < 0.0001$, $d = 1.57$; older participants transitioning from carpet to vinyl: $t(9) = 2.89$, $p = 0.0179$, $d = 0.78$ and from vinyl to Carpet: $t(11) = -9.71$, $p < 0.0001$, $d = 3.0$).

Peak push-off friction demand (PPOFD). The Paired-Comparison t-Test indicated statistically significant differences between the friction demand for a carpeted floor and a vinyl floor during
transitioning from a carpeted floor to a vinyl floor for all age groups (see Table 5). Peak Push-Off Friction Demand (PPOFD) was higher for a vinyl floor than a carpeted floor (i.e., younger participants transitioning from carpet to vinyl: \( t(11) = 6.84, p < 0.001, d = 2.68 \) and from vinyl to carpet: \( t(12) = -1.51, p = 0.1580, d = 0.6 \); older participants transitioning from carpet to vinyl: \( t(11) = -2.29, p = 0.0425, d = 0.94 \) and from vinyl to carpet: \( t(12) = -1.02, p = 0.3278, d = 0.3 \).

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<th>Friction Demand</th>
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<td>On Carpet (1st Heel Contact)</td>
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<td>Younger</td>
<td>( 0.19 \pm 0.03 )</td>
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<th>PPOFD</th>
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<td>Younger</td>
<td>( 0.29 \pm 0.06 )</td>
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<td>Older</td>
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3.4. Perception of Slipping and Tripping

There was no statistically significant difference between the younger and older participants in the perception of slipping and tripping over transitioning between different floors; both age groups reported low levels of the perception of slipping and tripping (Younger Mean = 1.36, SD = 0.72; Older Mean = 1.43, SD = 0.71).

4. Discussion

This study helped to obtain a deeper understanding of various gait characteristics of older adults transitioning between carpet and vinyl floors.

Toe Clearance. With regard to aging effects, only one gait parameter, i.e., toe clearance, among the other gait parameters (RCOF, transitional acceleration of the whole-body COM, step length, and heel contact velocity) revealed a statistically significant difference between the two age groups. Older participants’ toe clearance was significantly higher than that of their younger counterparts for all four different floor conditions. There is a possibility that the older participants in this study might have a smaller angle of ankle than the younger individuals. A recent study [20] found that older adults are more likely to have a weaker and smaller joint range of movement as compared to younger individuals. Thus, the older participants’ higher toe clearance might have been induced by their smaller joint range of movement. The measurement of ankle angle was not considered due to the technical limitation of this current study. However, future research should investigate further how a change in the angle of ankle influences the toe clearance, especially while transitioning between different floor coverings.

With regard to floor effects, the older participants showed the highest toe clearance during transitioning from a vinyl floor to a carpeted floor than for all the other floor conditions, yet the transition from a carpet floor to a vinyl floor generated a decrease in toe clearance. This result was observed not only among the older participants but also among their younger counterparts. We argue that the possible reason for the decrease in toe clearance during transitioning from a carpeted floor to a vinyl floor might be explained by considering the floor material’s inherent elasticity (i.e., the property of returning to an initial shape or state following deformation) and resilience, instead of merely considering the difference in their levels only. For example, the lower toe clearance was observed after transitioning from a carpeted floor to a vinyl floor rather than from a vinyl floor to a carpeted floor. The reduced toe clearance might be due to the weak elasticity of the carpet. There is evidence [21] that a floor covering, such as carpet, significantly reduces the impact forces, so greater
energy absorption is likely to be observed. Thus, when the participants stepped on a carpeted floor and tried to take their toe off, the energy to push off might have been absorbed due to the higher compliance of the carpet. Thus, the shortage of the energy available to push off from the carpet might lead to reduction in toe clearance during transitioning from a carpeted floor to other floors. It is recommended that people pay more attention to transitioning from a carpeted floor to a vinyl floor to avoid a fall accident.

Heel Contact Velocity. The older participants had higher heel contact velocity than did their younger counterparts while transitioning from a carpeted floor to a vinyl floor. Heel contact velocity was considered as a factor that would increase the likelihood of slip-induced falls [18]. Therefore, the higher heel contact velocity of an older person while transitioning from a carpeted floor to a vinyl floor would increase the likelihood of slip-induced falls.

Friction Demand. This study found that the elderly participants had smaller friction demand at the heel contact phase than did their younger counterparts, which is consistent with previous research [22]. Furthermore, the smaller friction demand was found for all transitioning floor conditions except one, i.e., transitioning from a carpeted floor to a vinyl floor. Thus, the older participants have a higher probability of a slip-induced fall accident when they transition from a carpeted floor to a vinyl floor.

The friction demands were further investigated to examine if there was any significant difference when older participants stepped on the first floor (i.e., carpet), and then on the second floor (i.e., vinyl). For the heel contact phase, the friction demand significantly decreased on the vinyl floor for older participants; however, for the toe-off phase, the friction demand significantly increased. This implies that the risk of a slip-induced fall accident would significantly increase for older individuals during the toe off on the vinyl floor after transitioning from the carpeted floor to the vinyl floor. Therefore, there is a greater chance of slipping when older individuals have their toe off rather than heel contact for transitioning from a carpeted floor to a vinyl floor surface (e.g., a slippery vinyl floor surface). Older adults are recommended to be properly warned of these specific risk conditions.

Step Length. The older participants had longer step length on the vinyl floor than on the carpeted floor. In addition, the longer step length was observed on the vinyl floor after transitioning from the carpeted floor as compared to that on the carpeted floor after transitioning from a vinyl floor. Thus, the older participants’ longer step length on the vinyl floor would lead to a higher probability for a slip-induced fall accident.

With regard to aging effect, in agreement with previous research [23], the older participants in this study had shorter step length than their younger counterparts, which was observed for all floor conditions. There is evidence that people are more likely to shorten their step length in order to reduce friction demand and avoid a slip-induced fall [24]. Thus, shorter step length might have helped the older participants to lower friction demand as compared to the younger participants.

Whole Body COM. Consistent with the previous research [25], the older participants had slower transitional acceleration of the whole body center-of-mass (COM) than their younger counterparts, especially for all floor conditions. This result supports the assertion that slower transitional acceleration of the whole body COM occurs for older individuals due to their less vigorous push-off power than younger individuals, which may be influenced by age-related sensory degradation [22].

Subjective Perception. A majority of both the younger and older participants responded that they did not perceive much danger of tripping and slipping during walking trials. Additionally, the perception of tripping and slipping was not significantly different between different transitioning conditions. Therefore, their gait would not much be influenced by fear of slipping and tripping.

Safety Recommendations for Older Adults. The results of the present study indicate that transitioning between different floor coverings changes the gait parameters, especially for older adults. Furthermore, care must be taken while installing indoor floor coverings, keeping the “transitioning” different floor coverings in homes and public places to a minimum, especially for older adults at risk of falling (e.g., those living in nursing homes and assisted living facilities). Although the increasing
probability of a slip or trip accident was found throughout the changes in gait parameters, the older participants were not aware of the danger posed by transitioning between floor surfaces as indicated by their subjective ratings (i.e., perception of slipping, tripping and falling). Therefore, older adults should be made aware of the danger of slipping and tripping while transitioning between different floor surfaces, perhaps through use of a caution sign or exercise programs. For future research, it would be beneficial to investigate how much the safety interventions (e.g., a caution sign and training) influence the gait parameters and the perception of danger during transitioning. As this study investigated only carpet and vinyl, a future research study could also consider other floor coverings such as wood and ceramic tile.

Limitations. The thickness of the carpet might have decreased throughout the study period as each participant kept walking on the carpet for the entire experiment period, thus compacting both the underlying padding and the elasticity of fibers of the carpet itself. Yet, we found that the difference was within approximately 1 cm, and we also used plywood to keep a difference of 6 mm or less between the levels of floor coverings as recommended in the literature [17]. In addition, the safety harness worn by the participants may be heavy and have, thus, created a backward force on the participants' body, especially during the initiation of gait. To overcome this effect, the data collection was started at 5–10 s after the start of the participants' walking.

5. Conclusions

The study investigated the degree to which the transitioning between different floor coverings affects gait characteristics of older adults. More specifically, this study was interested in examining whether slip probability would be greater when transitioning from a carpeted floor to a vinyl floor, and also whether trip probability would be greater when transitioning from a vinyl floor to a carpeted floor in older adults in the home. The older participants’ toe clearance was significantly higher than that of their younger counterparts for all four different floor conditions. Even though the results imply that the older participants have lower probability of a trip-induced fall than younger individuals, the older participants still have a shorter toe clearance on the carpet than on a vinyl floor, which would increase the probability of a trip-induced fall while they walk on a carpeted floor and they walk on a carpeted floor after a vinyl floor. Considering the slip propensity, the study found that the older participants are more vulnerable to a slip-induced fall while they are transitioning from a carpeted floor to a vinyl floor than with other floor conditions. Furthermore, the propensity of a slip-induced fall increases on a vinyl floor shortly after transitioning from the carpeted floor to a vinyl floor due to an increased friction demand, especially during the toe-off phase of the gait cycle rather than the heel contact phase.

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References


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