The Effects of Transitioning Between Different Floor Surfaces on Gait Characteristics of the Elderly

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ABSTRACT

Each year the rate of slip and fall accidents increases among older individuals. Most falls among the elderly occur indoors rather than outdoors, and of the falls that occur in the residential home, over 600,000 are due to floor covering materials. In particular, carpet and vinyl are common floor coverings used in the home today as the elderly often transition from carpet to vinyl and vice versa. When transitioning between two different floor surfaces, older adults may adjust their gait to avoid a slip, trip, or fall. Many studies have assessed gait parameters of elderly individuals on either carpet or vinyl. Yet, few have studied the effect of transitioning between two different floor surfaces on the gait of older individuals.

This study investigated the effect of transitioning between different floor coverings on the gait characteristics of the elderly. For this study, 14 elderly (65 years old and over) and 14 young (18 to 35 years old) individuals participated. All participants walked on different transitional floors, namely carpeted floors, vinyl floors, and floors covered with both vinyl and carpet. While the participants were walking on the walkway, different gait parameters were measured, including the required coefficient of friction, stride length, transitional acceleration of the whole body center-of-mass (COM), heel velocity at heel contact, perception of slipping/tripping, and toe clearance. It was hypothesized that older participant’s gait parameters would be different from their younger counterparts. Also, the older participant’s gait adaptation would increase the likelihood of a slip and trip propensity while transitioning between different floor surfaces compared to the younger participants. More specifically, for the elderly, transitioning from carpeted floor surfaces to vinyl floor surfaces would increase the slip propensity and transitioning from vinyl floor surfaces to carpeted floor surfaces would increase trip propensity, and therefore increase the likelihood of fall accidents.

In the present study, it was found that elderly individuals had greater toe clearance than their younger counterparts. Also, the elderly individuals had smaller toe clearance on the carpet than on the vinyl, which would increase the probability of a trip-induced fall when walking on the carpet.

Further, the propensity of a slip-induced fall accident increased on the vinyl shortly after transitioning from the carpet to the vinyl due to the slower transitional acceleration of the whole body COM and the increased friction demand, especially during the toe-off phase of the gait cycle, rather than heel contact phase of the gait cycle.

In addition, it was also found that an increase in heel contact velocity and step length increases the propensity of a slip-induced fall accident. Furthermore, this propensity is greater while transitioning from a carpet to a vinyl floor surface, especially for elderly individuals.

The results of the present study indicate that transitioning between different floor surfaces changes the biomechanical parameters of gait, especially for the elderly individuals. Although the increased likelihood of a slip or trip accident was found throughout the changes in biomechanical gait parameters, the elderly individuals who participated in this study did not perceive of slipping and tripping much. Therefore, elderly individuals should be made aware of the danger of slipping and tripping while transitioning between different floor surfaces.

DEDICATAION

I would like to dedicate this thesis to my family which has always supported me. Especially, I thank my grandmother, father, and mother who have made enormous sacrifices in their life for me. Their love made this thesis accomplished. I will always love and look up to all of you.

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1. INTRODUCTION

1.1 Background

The rate of increase of the elderly population is quite high. In 2000, the population of elderly people (65 years old and over) was 35 million in the United States (US Census Bureau, 2001). This statistic represents an increase in the elderly population by 12 percent between 1990 and 2000, and this segment of the population will continue to grow due to an increase in life expectancy (Rawsky, 1998). The number of elderly (65 years old and over) is expected to reach to 70 million by 2030 (Centers for Disease Control and Prevention, 2000). Furthermore, the fastest growing group among the elderly population is the oldest one (85 years and over) which increased by 38 percent, from 3.1 million in 1990 to 4.2 million in 2000 (US Census Bureau, 2001).

Fall accidents among the elderly are a serious problem. Over 1/3 of elderly people (65 years of age and older) fall each year (Hausdorff, Rios, & Edelberg, 2001; Hornbrook et al., 1994) and falls among the elderly are a leading cause of injury-related deaths (Murphy, 2000). Additionally, the cost of fall injuries among the elderly is expected to reach up to $32.4 billion by the year 2020 (Englander, Hodson, & Terregrossa, 1996). Thus, protecting the elderly from accidental falls should be a national concern.

Falls among the elderly are more likely to occur indoors than outdoors. According to Kochera (2002), the majority (55%) of fall injuries among the elderly occurred inside the house. Twenty tree percent happened outside and the rest occurred away from the home. Furthermore, the rate of indoor fall accidents increases with age. Such indoor falls should be examined for the elderly.

Carpet is the most common indoor floor covering as it covers seventy percent of the total flooring market in the United States and 1.6 billion square yards are shipped annually (Davidsen, 1995; Hedge, 2004). The most common places covered with carpet are the living room and bedroom where elderly people spend most of their time.

Although transitioning over different indoor floor surfaces occurs often in daily activities which may cause falls or fall-related injures (Bunterngchit, Lockhart, Woldstad, & Smith, 2000), few studies have investigated the effect of specific floor coverings on gait parameters during transitioning. Furthermore, the findings of the few studies show contradictive results in terms of biomechanical gait parameters (i.e., gait speed).

Willmott (1986) investigated the number of steps and gait speed of 58 elderly hospital patients (mean age 76.05 years) during walking on carpeted versus vinyl floor surfaces. The results suggested that gait speed and step length were significantly greater on a carpeted floor surface (mean gait speed 0.48 [m/s], S.D. 0.19; mean step length 33.72 [cm], S.D. 12.01) than on a vinyl floor surface (mean gait speed 0.40 [m/s], S.D. 0.17; mean step length 29.50 [cm], S.D. 12.32).

However, Dickinson et al. (2000) reported that older people walk slower on carpeted floors than on vinyl. They conducted the experiment with healthy community-dwelling older people (n=25) who were instructed to walk a 12-foot gait course covered with both carpet and vinyl floor surfaces. The participants walked slower on the carpeted floor than vinyl tile floor surfaces. Additionally, Stephens and Goldie (1999) noted that twenty four stroke patients walked slower on carpeted floor surfaces than vinyl floor surfaces.

Changes in gait speed and step length during ambulating over two different surfaces such as carpet and vinyl floor surfaces may influence the outcome of slips and falls especially for the elderly. In general, the shortened step length and the slower walking velocity of elderly people are considered a stable and safer gait pattern; however these gait changes may increase the likelihood of slip-induced fall accidents. According to previous studies (Kavanagh, Barrett, & Morrison, 2004; Judge, Davis, & Ounpuu, 1995; Judge et al., 1995), the elderly have less vigorous push-off power (2.478 W/kg) than younger people (3.266 W/kg). Elderly people who have less vigorous push-off power will have slower transitional acceleration of the whole body center-of-mass (COM) than younger people. Specifically, slower transitional acceleration of the whole body COM affects friction demand characteristics (RCOF) (Lockhart, Woldstad, & Smith, 2003), and may increase the likelihood of slip-induced fall accidents. When the elderly walk on a carpeted floor surface where compliance is high (i.e., less stiff), it will result in a much slower transitional acceleration of the whole body center-of-mass (Lockhart et al., 2003). Thus elderly people may have the increased rate of horizontal foot force to vertical foot force (i.e., RCOF). If walking over compliant carpeted floor surface reduces the transitional acceleration of the whole body COM, it is more likely to increase the friction demand among the elderly and, consequently, lead to a higher likelihood of slip-induced falls (Hanson, Redfern, & Mazumdar, 1999) when the elderly transition from a carpeted floor surface to a slippery floor surface (e.g., tiled bathroom or a linoleum kitchen area contaminated by oil, water, or other slippery materials). Furthermore, previous research (Bunterngchit et al., 2000) reported that elderly people can not adjust their gait in order to reduce RCOF on a slippery floor surface so that it might increase the possibility of slips or slip induced falls.

Additionally, elderly people could be more likely to trip during transitioning from vinyl to carpeted floors. Winter (1990) noted that toe clearance of elderly individuals is less than their younger counterparts. The elderly people’s toe clearance is about 1.12 cm but young people’s toe clearance is about 1.29cm. Furthermore, carpet is normally thicker than vinyl coverings. An older individual is more likely to catch their foot on a high pile carpeted floor. Thus, walking over carpeted floors or transitioning from vinyl floors to carpeted floors might increase the likelihood of trips among the elderly.

1.2 Statement of the Problem

Most studies on falls or balance have been conducted exclusively on either carpet or vinyl floor surfaces. Cham and Redfern (2002) measured elderly individual's gait characteristics on each of the two different floor conditions (i.e., a carpeted floor and vinyl floor). However, most of the research has not considered the effect of transitioning over two different floor coverings. Although a number of indoor falling accidents are reported (Kochera, 2002) and transitioning over different indoor floor coverings occurs often in daily activities, few studies have been conducted to investigate how transitioning (e.g., moving from carpet to vinyl or vice versa) over different floors affects gait characteristics.

1.3 Objective of the Study

The objective of this study was to investigate whether transitioning between different floor surfaces affects gait characteristics of the elderly. The gait characteristics being examined included 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, young and old individuals, were observed to determine age-related effects on gait characteristics. More specifically, an experiment was conducted to observe if slip propensity would be greater when transitioning from carpeted floor surfaces to vinyl floor surfaces, and also if trip propensity would be greater when transitioning from vinyl floor surfaces to carpeted floor surfaces.

2. LITERATURE REVIEW

2.1 Epidemiology

The proportion of elderly individuals in our society has been increasing (US Census Bureau, 2001) . The U.S. Census Bureau reported in 2001 that there was an increase in the population of 75 to 84-year-olds by 23 %, and the population of 65 to 74-year-olds by approximately 2 % between the years of 1999 and 2000. Further, according to these studies (American Geriatrics Society, British Geriatrics Society, & American Academy of Orthopaedic Surgeons Panel on Falls Prevention, 2001; Campbell, Reinken, Allan, & Martinez, 1981), the number of accidents due to falls increases with age.

Most falls among the elderly occur indoors (Kochera, 2002; Sjorgen & Bjornstig, 1991; Tinetti, Speechkey, & Ginter, 1988). Hornbrook et al. (1991) indicate that 56.6% of falls occur inside the home, 14.7% immediately outside the home, 17% away from the home in a familiar place, and 11.7% away from the home in an unfamiliar place. Additionally, Sjorgen et al. (1991) noted that most falls among the elderly occur indoors (71%) and the most common site (28%) for the falls are the living area such as the living room, hall ways, and other rooms rather than the kitchen (12%) and the bedroom (7.5%).

Indoor fall accidents are more likely to be caused by tripping, stepping wrongly, and intrinsic factors than are those that occur outdoors (Sjorgen et al., 1991). Indoor falls due to slipping are considered a small proportion of all falls (Sjorgen et al., 1991). On the other hand, the major reason of outdoor falls is slipping (Sjorgen et al., 1991).

The most common indoor floor covering, carpet, is considered a causative factor of indoor falls. According to Davidsen (1995), 70% of indoor floors in the United States are covered with carpet. Falls among the elderly predominantly occur indoors. Previous studies suggest that carpet could cause dangerous situations resulting in falls (Dickinson, Shroyer, & Elias, 2000; Gibson, 1998).

Although epidemiological studies suggest increases in fall accidents among the elderly indoors, mechanisms regarding these fall accidents remain elusive.

2.2 Gait Pattern

2.2.1 Gait Cycle

The gait cycle with one leg consists of two periods; namely, a stance and swing period. The stance is the time when the reference leg is on the ground; the swing is the time when the reference leg is off the ground.

He stance phase constitutes 60% of the gait cycle and the swing phase takes 40% of the gait cycle. The two phases are distinguished into several steps. The stance period consists of ground contact (0% of the normal gait cycle), foot flat (15%), heel off (40%), contralateral ground contact (50%), and toe off (60%). The swing period consists of early swing (60-75 %), mid swing (75-85 %), and late swing (85-100%).

2.2.2 Gait Parameter

2.2.2.1 Stride and Step Length

Step length is referred to as the distance from the heel contact of one foot to the following heel contact of the opposite foot (Oatis, 2004). Stride length is the distance from the heel contact of one foot to the following heel contact of the same foot (Oatis, 2004). Previous studies (Bunterngchit et al., 2000; Willmott, 1986) examined the stride and step length for steps taken on two different floor surfaces (e.g., a carpeted and vinyl floor hsurface). Both stride length and step length of the elderly walking on carpeted floor surfaces increased compared to walking on vinyl tile floor surfaces.

2.2.2.2 Toe Clearance

Foot clearance is defined as the height of markers on the heel or the toe from the ground (Bunterngchit et al., 2000; Gehlsen & Whaley, 1990). A considerable number of falls among the elderly are due to trips which occur when the foot contacts the floor during the swing phase (Tinetti et al., 1988). According to Startzell and Cavanagh (1999), the risk of a trip can be analyzed with the measurement of foot clearance in the sagittal plane during the swing phase of the gait cycle. A previous study (Winter, 1990) compared elderly participants' toe clearance with younger participants' toe clearance. The older participants in this study showed shorter toe clearance (1.12 cm) than their younger counterparts (1.29 cm).

2.2.2.3 Heel Contact Velocity over Different Floor Surfaces

According to previous studies (Karst, Hageman, Jones, & Bunner, 1999; Myung R. & Smith J.L., 1997; Winter, 1991), high horizontal heel contact velocity increases the likelihood of slipping. Cham and Redfern (2002) studied gait characteristics on different floor materials, such as vinyl and rough tile floor surfaces. They observed that heel velocity in the direction of motion at heel contact is greater on vinyl surfaces (mean velocity=0.19 m/s, S.D.=0.39) than on the rough floors (mean velocity=0.15 m/s, S.D.=0.31). However, in their study, age effects were not considered. On the other hand, Winter (1991) and Lockhart (1997) state that the elderly group have higher heel contact velocity in the horizontal direction than the younger group. It is worth noting, though, that they conducted the experiment without considering carpeted floor surfaces. Thus, in this study, the age and floor types will be considered for heel contact velocity in order to identify the relationship between heel horizontal contact velocity and slip-induced falls.

2.2.2.4 Velocity of the Whole Body Center-of-Mass (COM)

Sagittal and frontal 3-D link (14) segment models (Lockhart et al., 2003) are used to examine the velocity of the whole body center-of-mass (COM). Twenty- seven markers on landmarks of the body are utilized to define a whole body model. There is a contradictory result associated with walking velocity of the elderly. According to Willmott (1986), the elderly (mean 76.05 years of age) walk faster on a carpeted floor (mean velocity = 0.48 m/s, S.D. = 0.19) than on a vinyl floor (mean velocity = 0.40 m/s, S.D. = 0.17). However, Dickinson et al (2000) and Stephens et al (1999) suggest that elderly people walk slower on a carpeted floor than on a vinyl floor. McGibbon et al. (2001) examined gait patterns of the elderly (mean 70.67 years, S.D. = 8.66) on a 10m carpeted walkway. The gait speed of elderly participants was 1.13 ± 0.2 (m/s). On the other hand, the walking velocity of the elderly was 1.2 (m/s) on the vinyl floor (Kim, 2003). The elderly walked slower on the carpeted floor than the vinyl floor.

2.3 Tribology

Tribology is a study focusing on friction, wear, and lubrication of interacting surfaces in relative motion (Stachowiak & Batchelor, 2001). The slip resistance between shoe soles and floor surfaces is considered important in order to decrease the risk of slipping. For slip resistance, the coefficient of friction (COF), defined as the ratio of the foot’s horizontal shear force to the foot’s vertical normal force (Chaffin, Woldstad, & Trujillo, 1992), must be examined.

There are two kinds of COF, namely static COF and dynamic COF (Lockhart, Woldstad, Smith, & Ramsey, 2002b; Hanson et al., 1999; Redfern & Bidanda, 1994; Swensen, Purswell, & Schelegel, 1992). Static COF is referred to as the shear force required to initiate movement of an object on a floor divided by the vertical force on the object. On the other hand, dynamic COF is the shear force that is required to sustain movement of the object over the vertical force (Redfern et al., 1994).

RCOF represents the ratio of the horizontal foot force to the vertical foot force, indicating the minimum coefficient of friction available at the interface between shoe and floor to avoid initiation of slipping (Lockhart et al., 2002b). Foot slip can be avoided when the COF is higher than RCOF. McVay and Redfern (1994) noted that the peak RCOF is used to predict the slipperiness of the floor. Additionally, the peak RCOF has been employed to indicate the requirements of walking on various floor surfaces (Hanson et al., 1999; McVay & Redfern, 1994).

A previous study (Bunterngchit et al., 2000) investigated RCOF when participants walked on carpeted and soapy vinyl floor surfaces. The results indicate that the participants have higher RCOF values on a carpeted floor than on a soapy vinyl floor. Additionally, Lockhart et al. (2002b) observed that younger participants have higher RCOF values than older participants on a non-slippery floor surface.

2.4 Subjective Perception of Floor Slipperiness

Besides tribological effects, subjective perception of floor slipperiness is essential as well to prevent from a slip, trip, or fall accident (Li, Chang, Leamon, & Chen, 2004).When people walk on a slippery floor surface, they change their gait patterns to reduce the propensity of a slip.

Myung, Smith, and Leamon (1993) stated humans are able to distinguish floor slipperiness, which is reliable but risky. False subjective perception of slipperiness might lead to an inappropriate gait pattern, which results in higher probability of a slip-induced fall accident (Li et al., 2004).

2.5 Age-Related Changes in Gait Characteristics

The elderly show several gait adaptations, such as reductions in stance duration and loading speed on the supporting foot, and shorter stride length (Cham & Redfern, 2002; Edelstein, 1988). Additionally, studies (Cham et al., 2002; Dobbs et al., 1993; Winter, 1991; Edelstein, 1988) have found that walking velocity decreases with advancing age. Winter (1991) mentioned the lower walking velocity of the elderly, comparing levels of ankle plantar-flexor power during push-off. The elderly showed 2.478 W/kg at 1.29m/s while the young showed 3.266W/kg at 1.44m/s (Winter, 1991). These statistics indicate that the elderly have less vigorous push-off power (Kavanagh et al., 2004; Judge, Davis, III, & Ounpuu, 1996; Judge et al., 1995).

2.6 Summary

The elderly population who is more likely to suffer from a slip, trip, or fall is experiencing a rapid growth rate. The rate of indoor falls among the elderly is much higher than outdoor falls and many of theses falls are due to hazardous conditions associated with floor coverings. Seventy percent of indoor floor covering materials in the United States are covered with carpet (Davidsen, 1995) and the elderly spend most of their time indoors often encountering transitions from carpeted floors (e.g., bedroom and living room) to vinyl floors (e.g., kitchen and bathroom) or vice versa. There have been a number of studies trying to determine what factors affect older individuals in terms of balance and gait characteristics on vinyl or carpet. However few have tried to find the effect of transitioning over different floor surfaces on gait characteristics even though indoor falls exist predominantly. People exhibit several changes in gait characteristics (e.g., gait speed, stride length, toe clearance, heel contact velocity, walking velocity, and RCOF) when they walk over different floor surfaces (e.g., vinyl and carpeted floor surfaces). In conclusion, gait adaptations associated with different floor surfaces may influence the outcome of a slip, trip, or fall accident.

3. METHODS

3.1 Participants Population

Fourteen elderly (65 and over) and 14 younger individuals (18-35 years) participated in this experiment. For the determination of age for each age group, previous research of Lockhart et al (2002) was considered. Lockhart et al. (2002) found sensory changes in older participants increased the likelihood of slips and falls, compared to younger participants. For this study, the elderly were 65 years and above and the younger counterparts were between 18 and 35. The young participants were recruited from the general student population at Virginia Tech. The elderly participants were recruited from the local community. All participants were compensated for participating in this study. All participants were screened for health problems, using a medical history questionnaire (Appendix A). All participants had no restriction to physical activity and no history of musculoskeletal and neurological disease or no fall history.

3.1.1 Sample Size

Estimation of required sample sizes for this study came from estimates of inter-subject variability in the heel velocity obtained from previous study (Lockhart, Woldstad, & Smith, 2002a). Power calculation was performed to ensure that sample sizes are large enough to identify differences between young and elderly participants with high probability. The standard two-sided t-test was considered as the general test statistic for two participant groups. The power of the test (Neter, Kutner, Nachtsheim, & Wasserman, 1996) were given by the formula below:

$$\text{Power} = p\ \{|t^*| > t\,(1-\alpha/2;\ n-2 \mid \delta)\}$$

In this formula, δ is the noncentrality parameter, or the distance between the means of elderly and young age groups' heel velocity (A and B). σ is the standard deviation of the distribution of the heel velocity. n was the number of participants in each age group.

$$\delta = |A - B| / \sigma\sqrt{(2/n)}$$

Results from a previous study of Lockhart et al. (2002a) indicated that the standard deviation (σ) of the heel velocity was approximately 15 cm/sec (α =0.05). The difference between A and B (or the minimum difference which is important to detect with high probability) of the heel velocity was assumed in this study to be 15cm/sec (Lockhart et al., 2002a). 14 participants in each of the age groups should be sufficient to see the specified differences in the heel contact velocity with risk of a Type I error of 0.05 and a Type II error of <0.3 (Power>0.7).

3.2 Apparatus

3.2.1 Simulated Floor

A linear walking track (1.5m x 15.5m) was utilized for walking trials. To produce different floor surface conditions, carpet and vinyl floor coverings commonly encountered indoors were used in this study. The specification of the vinyl and carpet used in this study meet ADA Accessibility Guidelines for Buildings and Facilities 2002 (US Architectural and Transportation Barriers Compliance Board, 2002) and the 2002 Annual Book of ASTM Standards (American Society for Testing & Materials, 2002).

Part of the walking track was covered with vinyl floor tile (Verde Tinos Floor Tile, VC0413131p). The selected residential carpet (cut pile, Nylon, 1/10 gauge, 0.28 inch pile height, total weight 60oz./sq.yd., pad thickness 3/8 inch) covered the other part of the walking track. The difference of height between the carpeted floor surface and the vinyl floor surface was treated as a condition seen in normal life. However, the changes in levels should be less than 6 mm according to 2002 Annual Book of ASTM Standards (American Society for Testing & Materials, 2002) and ADA Accessibility Guidelines for Buildings and Facilities 2002 (US Architectural and Transportation Barriers Compliance Board, 2002).

Each test surface incorporated two force plates (force plate 1: 24” x 48”, Advanced Mechanical Technology (AMTI), Inc., Watertown, MA and force plate 2: 18.25” x 20”, Bertec Corporation, Columbus, OH). Each force plate was covered with vinyl or carpet. Each test surface was mounted on wooden platforms (Figure 1).

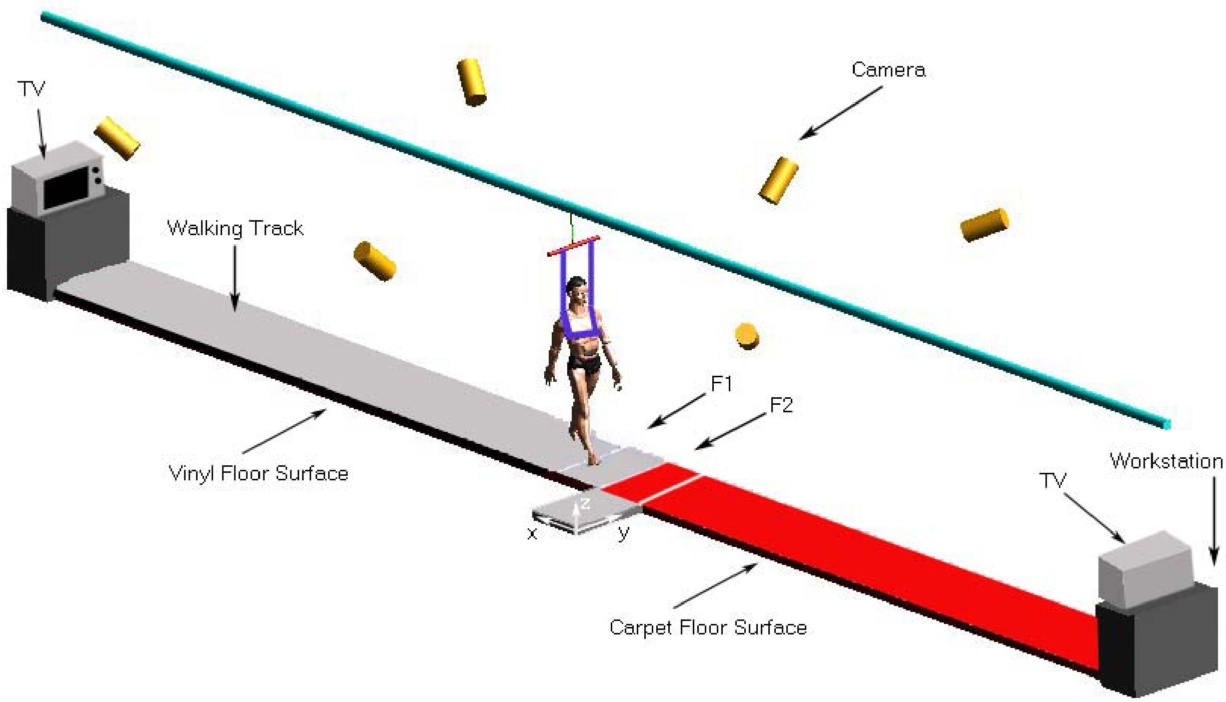

Figure 1. Walking track is installed with fall arresting harness, 6 cameras, two force plates, carpet and vinyl flooring.

3.2.2 Motion Analysis System

When participants walk over the force plates, their ground reaction force (GRF) was measured at a rate of 240 Hz. GRF signals were sampled and stored by the National Instrument™ hardware and LabVIEW system. Six camera motion analysis system (ProReflex, Qualisys Inc., East Windsor, CT) was used to capture three dimensional movement data of the participants with markers. Movement data was sampled and recorded at a rate of 120 Hz.

3.2.3 Fall Arresting Harness System

An overhead fall arresting harness system (Figure 1) was utilized to prevent participants from a trip that may cause fall-related injuries. Additionally, the harness was designed to permit participants to fall approximately 15cm before arresting the fall, and stopping any forward motion.

3.2.4 Experimental Shoes

All participants were provided with same type of athletic shoes in order to give the same resistance between a rubber sole of shoe and underfoot surfaces. Various sizes of shoes were prepared for all participants in order to provide them with the proper fit.

3.2.5 Questionnaire

All participants were asked to complete a set of questions (Appendix B) in order to provide feedback onn their fear of slipping and tripping. A 5 point Likert type scale (Figure 2) was used in this study. The questionnaire consisted of 5 questions. The first 4 questions were generated to investigate the participants' fear of slipping and tripping while transitioning between different floor surfaces. The last one was added as on open-ended question where participants could describe other comments related to the experiments. It was assumed that the distance between each anchor was the same.

1. My fear of slipping made me hesitate going forward during walking on the vinyl floor.

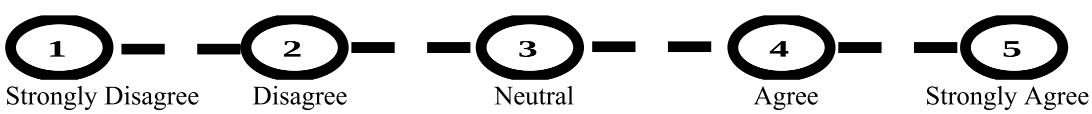

Figure 2. Example of the questionnaire using a 5 point Likert type scale

3.3 Procedure

Participants were scheduled to participate in two testing sessions: a preparation session, a walking test session, and a feedback session.

3.3.1 Preparation Session

Before performing the walking experiments, participants were asked to fill out the personal data form and medical history questionnaire (Appendix A). After participants completed the form, they reviewed the Virginia Polytechnic Institute and State University (Virginia Tech) IRB and signed the form. The participants were introduced to the experimental procedure through both written instruction (the IRB form) and verbally (by an experimenter). Additionally, all participants were guided to become familiar with the experiment equipment and procedure. Care was taken to ensure that verbal instruction was kept the same for all participants. An experimenter, for example, demonstrated the equipment wearing the harness and explained the procedure of the experiment. Therefore, participants might feel confident that the system would arrest a potential fall during the experiment. Additionally, participants' anthropometric data (e.g., body weight and height) were taken during this session.

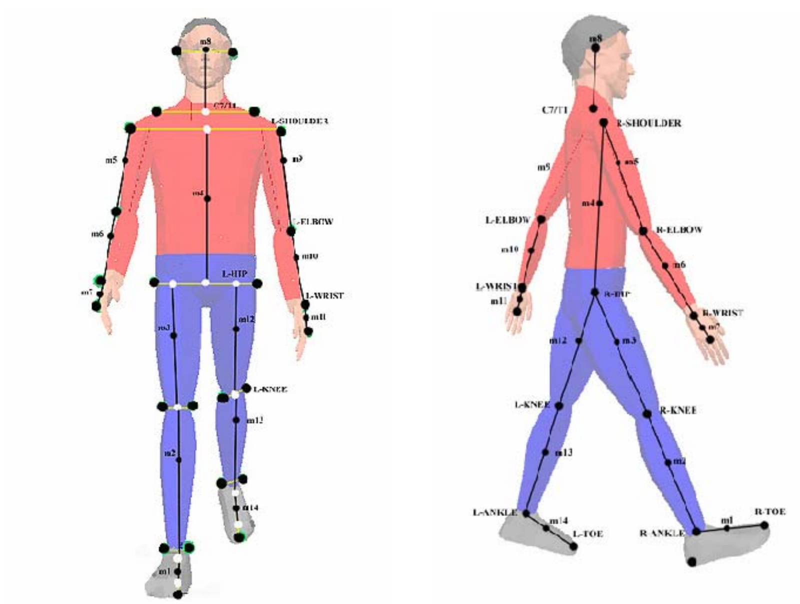

Figure 3. Points to which reflective markers will be attached (Lockhart, 2000)

3.3.2 Walking Test Session

All participants wore a safety harness and walked on the track while the Qualysis™ motion capture system records participants' posture and ground reaction forces. The length of the harness was adjusted for each participant. Therefore, it might protect against participants' hands contacting the floor in case they cannot recover from a slip. In this study, it was assumed that the harness would not affect upper or lower extremity motions. Additionally, all support cables were attached to the shoulders which were out of the subjects' field of vision. All participants were fitted with the experimental shoes to provide minimum variations due to footwear. Twenty seven reflective markers (Figure 3) were attached to the anatomically significant positions (Lockhart et al., 2003; Winter, 1991)

Participants were asked to complete some tasks in order to prevent them from concentrating on floor surfaces while walking. First, participants were required to focus their eyes on a TV that was located above the workstations (Figure 1). In addition, participants called out whenever the light from the TV screen was on or off.

During the experiment, the participants were asked to walk naturally on carpeted and vinyl floors. In addition, participants walked from a carpeted floor to a vinyl floor and vice versa. With different orders of treatment conditions, randomization was performed to balance out order effect, which is the effect of position in a series of treatments on performance.

Four different floors were prepared for this experiment. For the first floor set, vinyl floor coverings (Figure 4) which cover two force plates (i.e., F1 and F2) were tested. This floor setting was for assessing gait parameters on vinyl floor surfaces. Participants walked from a vinyl floor surface (4) to a vinyl floor surface (3 and 2). Walking on the carpeted floor surface (1) was not considered for data collection in this sequence so that only walking on the vinyl floor was investigated. When participants stepped on the vinyl floor surface (2) which covered force plate (F1), dependent variables (e.g., RCOF) were measured to investigate whether there was any change after the transition from a vinyl floor surface to another vinyl floor surface.

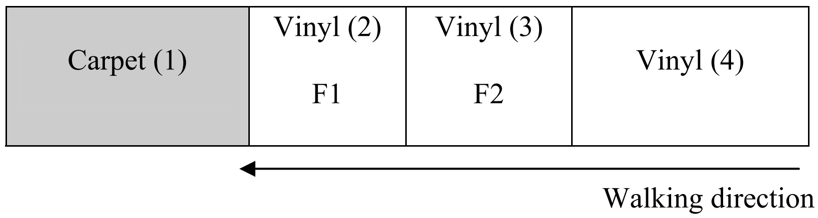

Figure 4. Two force plates (F1 and F2) are covered with vinyl.

For the second floor condition, two force plates (i.e., F1 and F2) were covered with carpet and vinyl (Figure 5 and Figure 6). The aim of this floor setting was to investigate changes in the values of gait parameters after transition. Participants walked from the carpeted floor surfaces (1 and 2) to the vinyl floor surfaces (3 and 4) in order to simulate the condition of transition from a carpeted floor surface to a vinyl floor surface (Figure 5). Once participants stepped on the second force plate (F2) covered with vinyl coverings (3), dependent variables (e.g., RCOF) were measured to investigate if there was any change after the transition from carpeted floor surfaces to vinyl floor surfaces. On the other hand, participants were instructed to walk from the vinyl floor surfaces (4 and 3) to the carpeted floor surfaces (2 and 1) in order to simulate the condition of transition from a vinyl floor surface to a carpeted floor surface (Figure 6). Once participants stepped on the first force plate (F1) covered with carpet (2), dependent variables (e.g., RCOF) were assessed to examine if there was any change after the transition from a vinyl floor surface to a carpeted floor surface.

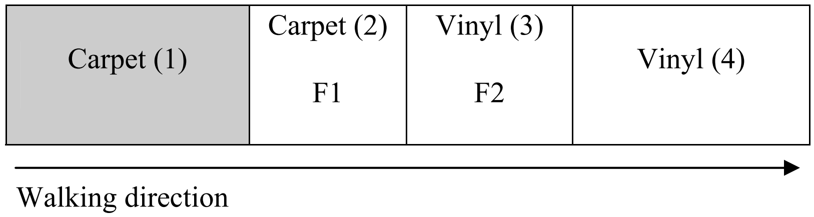

Figure 5. Two force plates (F1 and F2) are covered with carpet and vinyl to simulate the transition from carpet to vinyl floor surfaces.

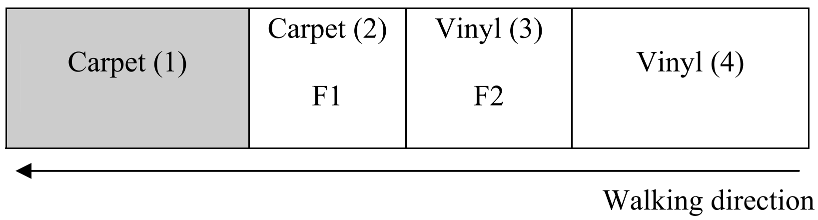

Figure 6. Two force plates (F1 and F2) are covered with carpet and vinyl to simulate the transition from vinyl to carpet floor surfaces.

Finally, two force plates were covered with carpet (Figure 7). The objective of this floor condition was to investigate gait characteristics on the carpeted floor surfaces. Participants walked from the carpeted floor (1) to the carpeted floor (2 and 3). Walking on the vinyl floor surface was not considered for data collection in this sequence so that only walking on the carpeted floor surfaces was investigated. When participants stepped on the second force plate (F2) which was covered with the carpet (3), dependent variables (e.g., RCOF) were measured to investigate whether there was any change after the transition from a carpeted floor surface to another carpeted floor surface.

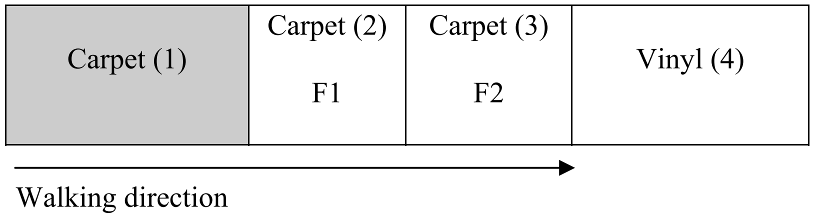

Figure 7. Two force plates (F1 and F2) are covered with carpet and vinyl.

3.3.3 Feedback Session

Participants were asked to complete a set of questions to provide their perception of slipping and tripping (Appendix B).

3.4 Experimental Variables

3.4.1 Independent Variables

3.4.1.1 Young and Old

Fourteen younger group members (18-35 years old) and 14 elderly group members (65 years old and over) participated in this study. They volunteered for this experiment and were compensated with $10 per hour.

3.4.1.2 Transitioning Floor Surface

All participants were asked to walk on the walkway that consisted of four different floor conditions (Figures 8,9,10, and 11).

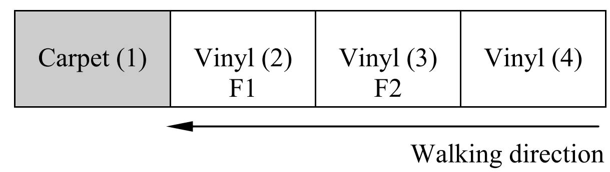

Figure 8. Walking on a vinyl floor surface

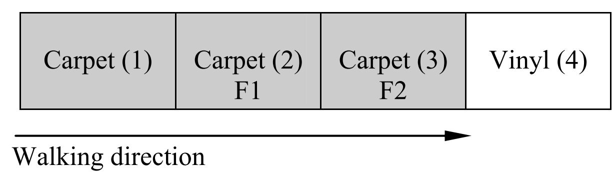

Figure 9. Walking on a carpeted floor surface

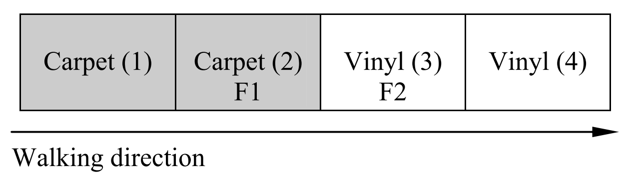

Figure 10. Transitioning from a carpeted to vinyl floor surface

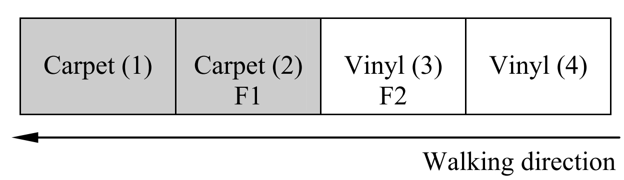

Figure 11. Transitioning from a vinyl to carpeted floor surface

3.4.2 Dependent Variables

3.4.2.1 Required Coefficient of Friction (RCOF)

The ratio of the horizontal ground reaction force over the vertical ground reaction force was calculated to get the RCOF (Perkins, 1978). The friction demand was measured and compared under the two different conditions (i.e., between and within transitioning floor conditions). First, the friction demands were compared "between" four different transitioning conditions in this study. For example, when participants transitioned from a carpeted to vinyl floor surface, they stepped on the carpet first and then the vinyl floor surface. The friction demand was measured when they stepped on the second floor, vinyl, after transitioning from the first floor, carpet. This friction demand was compared with the friction demands on the second floor condition for all the three transitioning conditions (i.e., "transitioning from a carpet to vinyl", "transitioning from a carpet to carpet", and "transitioning from a vinyl to vinyl"). All friction demands were calculated at the heel contact phase.

Second, the friction demands were compared "within" the transitioning conditions in the present study. For example, when participants transitioned from a carpeted to vinyl floor surface, they stepped on the carpet first then the vinyl floor surface. The friction demand was measured at the first floor, the carpet and also at the second floor, the vinyl. The two friction demands were compared to see if there was any difference at the moment of transitioning. All friction demands were calculated at the heel contact phase. Besides the friction demand at the heel contact phase, the friction demand was measured at the toe-off phase as well.

3.4.2.2 Step Length

The step length was considered as the linear distance between the first heel contact (X_1, Y_1) of one foot and the following heel contact (X_2, Y_2) of the same foot (Lockhart et al., 2003).

$$\text{Step Length (cm)} = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$$

3.4.2.3 Transitional Acceleration of the Whole Body COM

A 3-D link (14) segment model was used to calculate positions (Table 1) and velocities of the whole body COM. This model utilized the 14-component link-segment system defined by MacKinnon and Winter (1993) and the anthropometric model (Winter 1990). Twenty-seven reflective markers were used to define a whole body model (Figure 3). Utilizing the whole body COM model, averaged horizontal velocities of the five frames before and after the heel contact phase of the gait cycle were computed utilizing the time integrations of the positions of the whole body COM. The relative horizontal COM difference between COM velocity before heel contact and after heel contact was calculated for the transitional acceleration of the whole body COM.

According to Lockhart et al. (2003), the relative horizontal COM velocity of the whole body was calculated by considering the mean of the displacement over 3 time intervals (50 ms) of the instantaneous COM velocity before heel contact (ICOMVB) and after heel contact (ICOMVA) using the formula below.

Velocity of the whole body COM before heel contact phase:

$$ICOMVB_{k-i} = [X_{(k-i+1)} - X_{(k-i-1)}]/2\Delta t \quad \text{where, k=heel contact frame}$$

$$V_{COM}b = \sum_{i=1}^{N} ICOMVB_{k-i} / N \quad \text{where, N=3 (total frame)}$$

Velocity of the whole body COM after heel contact phase:

$$ICOMVA_{k+i} = [X_{(k+i+1)} - X_{(k+i-1)}]/2\Delta t \quad \text{where, k=heel contact frame}$$

$$V_{COMa} = \sum_{i=1}^{N} ICOMVA_{k-i} / N \quad \text{where, N=3 (total frame)}$$

Thus, transitional acceleration of the whole body COM ($\dot{v}_{COM}$) was calculated using the formula below:

$$\dot{v}_{COM} = (v_{COMb} - v_{COMa}) / \Delta t$$

Table 1. Definition of 14 segments and the location of center-of-mass of the segments in 3-D (Lockhart et al., 2000).

Segment	Segment Definition	Total Weight (% of Body Weight)	COM Location
Foot (m1, m14)	Extrapolating down 1.9 cm and perpendicular to the midpoint of the line between midpoint of markers placed on the lateral and medial malleolus (Subtalar) and the head metatarsal II	0.0145	Midpoint of the line between midpoint of markers placed on the lateral and medial malleolus and the head metatarsal II
Leg (m2, m13)	Mid point between medial and lateral femoral condyles / Subtalar	0.0465	43.3 % below femoral condyle markers
Thigh (m3, m12)	Extrapolating medially 19.7% of the distance between the right and left greater trochanter (HIP)/ Mid point between medial and lateral femoral condyles	0.1000	43.3 % below hip markers
Trunk (m4)	Mid point between the right and left hip markers/Mid point between the right and left shoulder markers	0.497	Midpoint between the line intersecting hip and shoulder
Upper arm (m5, m9)	Glenohumeral axis/elbow axis	0.028	43.6 % below glenohumeral axis
Forearm (m6, m10)	Elbow axis /ulnar styloid	0.016	43.0% below elbow axis
Hand (m7, m11)	Wrist axis / knuckle II middle finger	0.006	49.4 % above knuckle II middle finger
Head and Neck (m8)	Mid point between the right and left acromion of scapula (C7/T1)/ Mid point between the right and left 1st rib/ear markers	0.081	At the 1st rib/ear canal

3.4.2.4 Heel Velocity at Heel Contact

Heel contact velocity was calculated using the formula below.

$$\text{Heel contact velocity (cm/sec)} = \left| \frac{(X_{i+1} - X_{i-1})}{2\Delta t} \right|$$

In this formula, heel position in the horizontal direction (X) at the foot displacement of 1/120 second before and after the heel contact phase of the gait cycle was referred. Heel contact was defined as the time when vertical ground reaction force (GRF) exceeds more than 7N after the heel contacts the ground (Kim & Lockhart, 2003).

3.4.2.5 Toe Clearance

The distance (Figure 12) between the toe maker at its lowest point in mid swing and the ground was referred to as foot clearance (Gehlsen et al., 1990; Winter, Patla, Frank, & Walt, 1990).

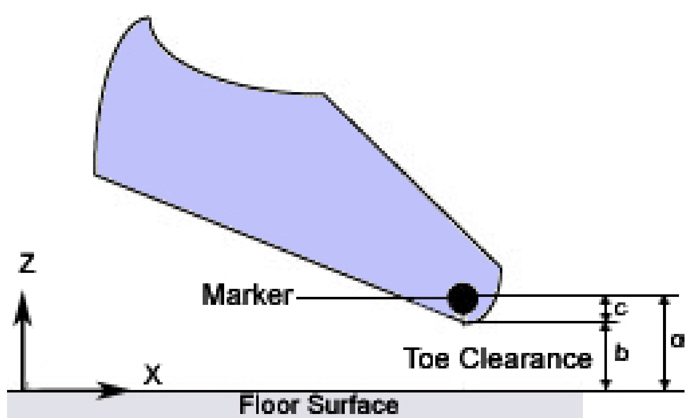

Figure 12. The measurement of toe clearance

Due to the difficulty of locating a marker at the bottom of a shoe, the marker in this study was placed approximately 2cm from the bottom of the shoe sole. The gap between a shoe sole and the center of the maker was considered to calculate toe clearance.

Toe clearance (b) = a – c

where, a = distance from a floor surface to the center of a marker, b = toe clearance, c = distance from a shoe sole to the center of a marker.

3.4.2.6 Subjective Perception of Floor Slipperiness

A subjective evaluation questionnaire using a 5 point Likert-type rating scale (Figure 13) was used to measure participants' perception of slipping and tripping during transitioning over different floor surfaces. After the transitioning experiment, participants were asked to complete the subjective evaluation sheet (APPENDIX B). The anchors consisted of 5 points. Each one was referred to degree of perception of slipping and tripping while transitioning between different floor surfaces. For example, point 1 indicated that the participant strongly disagreed with the question.

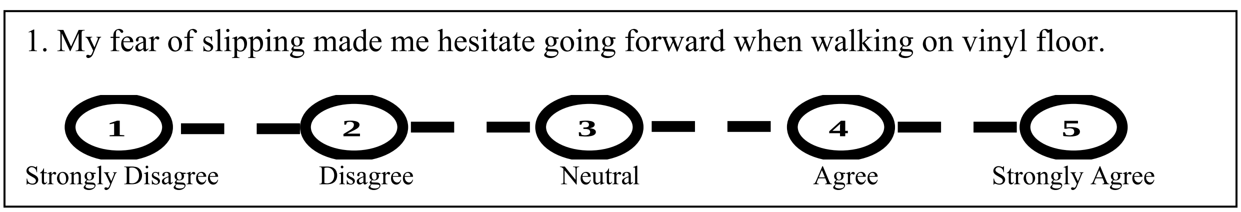

Figure 13. Example of the questionnaire using 5 point Likert type scale

3.5 Data Analysis

A 2x4 (age x floor) two-way repeated measures analysis of variance (ANOVA) was performed on each dependent variable with $\alpha \leq .05$ to test whether the main effects and interaction effects were statistically significant. Independent variables were age (young and old) and floor surface conditions for gait (i.e., walking on a carpeted floor surface, walking on a vinyl floor surface, transiting from a carpeted floor surface to a vinyl floor surface and transiting from a vinyl floor surface to a carpeted floor surface). Dependent variables were step length, required coefficient of friction (RCOF), transitional acceleration of the whole body center-of-mass (COM), heel contact velocity, toe clearance and subjective feedback.

3.5.1 Structural Model

Observation = Population Mean + Main Effect + Interaction + Random Error

$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_{k(i)} + \alpha\beta_{ij} + \beta\gamma_{jk(i)} + \varepsilon_{l(ijk)}$

α_i = fixed effect of the age groups (factor A)

β_j = fixed effect of the floor surface conditions (factor B)

$\gamma_{k(i)}$ = effect of the participant (random) in each group

$\alpha\beta_{ij}$ = interaction effects of the age groups and floor surface conditions

$\beta\gamma_{jk(i)}$ = effect of a particular level of repeated measures factor B on the particular individual nested within the group

$\varepsilon_{l(ijk)}$ = random effect of the k^{th} participant receiving the i^{th} age group followed by the j^{th} floor condition

Given the structural model, mixed-factor design (Table 2) was used to calculate sum of squares (SS), expected mean square (MS), and F ratio. The mixed-factor design consisted of between factor A, two age groups, and within factor B, four floor conditions.

Table 2. Matrix of Mixed-Factors Design

			Factor B				Sum	Sum
			carpet(b_1)	vinyl(b_2)	carpet to vinyl(b_3)	vinyl to carpet(b_4)		
Factor A	Young(a_1)	S_1	ABS_{111}	ABS_{121}	ABS_{131}	ABS_{141}	$\mathbf{AS_{1.1}}$	$\mathbf{A_{1..}}$
		S_2	ABS_{112}	ABS_{122}	ABS_{132}	ABS_{142}	$\mathbf{AS_{1.2}}$	
		S_3	ABS_{113}	ABS_{123}	ABS_{133}	ABS_{143}	$\mathbf{AS_{1.3}}$	
		S_4	ABS_{114}	ABS_{124}	ABS_{134}	ABS_{144}	$\mathbf{AS_{1.4}}$	
		S_5	ABS_{115}	ABS_{125}	ABS_{135}	ABS_{145}	$\mathbf{AS_{1.5}}$	
		S_6	ABS_{116}	ABS_{126}	ABS_{136}	ABS_{146}	$\mathbf{AS_{1.6}}$	
		S_7	ABS_{117}	ABS_{127}	ABS_{137}	ABS_{147}	$\mathbf{AS_{1.7}}$	
		S_8	ABS_{118}	ABS_{128}	ABS_{138}	ABS_{148}	$\mathbf{AS_{1.8}}$	
		S_9	ABS_{119}	ABS_{129}	ABS_{139}	ABS_{149}	$\mathbf{AS_{1.9}}$	
		S_{10}	ABS_{1110}	ABS_{1210}	ABS_{1310}	ABS_{1410}	$\mathbf{AS_{1.10}}$	
		S_{11}	ABS_{1111}	ABS_{1211}	ABS_{1311}	ABS_{1411}	$\mathbf{AS_{1.11}}$	
		S_{12}	ABS_{1112}	ABS_{1212}	ABS_{1312}	ABS_{1412}	$\mathbf{AS_{1.12}}$	
		S_{13}	ABS_{1113}	ABS_{1213}	ABS_{1313}	ABS_{1413}	$\mathbf{AS_{1.13}}$	
		S_{14}	ABS_{1114}	ABS_{1214}	ABS_{1314}	ABS_{1414}	$\mathbf{AS_{1.14}}$	
			[$AB_{11.}$]	**[$AB_{12.}$]**	**[$AB_{13.}$]**	**[$AB_{14.}$]**		
	Old(a_2)	S_{15}	ABS_{211}	ABS_{221}	ABS_{231}	ABS_{241}	$\mathbf{AS_{2.1}}$	$\mathbf{A_{2..}}$
		S_{16}	ABS_{212}	ABS_{222}	ABS_{232}	ABS_{242}	$\mathbf{AS_{2.2}}$	
		S_{17}	ABS_{213}	ABS_{223}	ABS_{233}	ABS_{243}	$\mathbf{AS_{2.3}}$	
		S_{18}	ABS_{214}	ABS_{224}	ABS_{234}	ABS_{244}	$\mathbf{AS_{2.4}}$	
		S_{19}	ABS_{215}	ABS_{225}	ABS_{235}	ABS_{245}	$\mathbf{AS_{2.5}}$	
		S_{20}	ABS_{216}	ABS_{226}	ABS_{236}	ABS_{246}	$\mathbf{AS_{2.6}}$	
		S_{21}	ABS_{217}	ABS_{227}	ABS_{237}	ABS_{247}	$\mathbf{AS_{2.7}}$	
		S_{22}	ABS_{218}	ABS_{228}	ABS_{238}	ABS_{248}	$\mathbf{AS_{2.8}}$	
		S_{23}	ABS_{219}	ABS_{229}	ABS_{239}	ABS_{249}	$\mathbf{AS_{2.9}}$	
		S_{24}	ABS_{2110}	ABS_{2210}	ABS_{2310}	ABS_{2410}	$\mathbf{AS_{2.10}}$	
		S_{25}	ABS_{2111}	ABS_{2211}	ABS_{2311}	ABS_{2411}	$\mathbf{AS_{2.11}}$	
		S_{26}	ABS_{2112}	ABS_{2212}	ABS_{2312}	ABS_{2412}	$\mathbf{AS_{2.12}}$	
		S_{27}	ABS_{2113}	ABS_{2213}	ABS_{2313}	ABS_{2413}	$\mathbf{AS_{2.13}}$	
		S_{28}	ABS_{2114}	ABS_{2214}	ABS_{2314}	ABS_{2414}	$\mathbf{AS_{2.14}}$	
Sum			**[$AB_{21.}$]**	**[$AB_{22.}$]**	**[$AB_{23.}$]**	**[$AB_{24.}$]**		
Sum			$\mathbf{B_{.1.}}$	$\mathbf{B_{.2.}}$	$\mathbf{B_{.3.}}$	$\mathbf{B_{.4.}}$		**[T…]**

3.5.2 Sum of Squares

Sum of squares in this study was shown below.

where, a = the number of levels of factor A, b = the number of levels of factor B, and n = the number of participants.

$SS_A = (\sum A_{i..}^2/bn) - (T_{...}^2/abn)$

$SS_{S/A} = (\sum AS_{i.k}^2/b) - (\sum A_{i..}^2/bn)$

$SS_B = (\sum B_{.j.}^2/an) - (T_{...}^2/abn)$

$SS_{BxA} = (\sum AB_{ij.}^2/n) - (\sum A_{i..}^2/bn) - (\sum B_{.j.}^2/an) - (T_{...}^2/abn)$

$SS_{BxS/A} = (\sum ABS_{ijk}^2) - (\sum AB_{ij.}^2/n) - (\sum AS_{i.k}^2/b) + (\sum A_{i..}^2/bn)$

3.5.3 Expected Mean Square, E (MS)

Expected Mean Square is listed below.

$E(MS_A) = bn\sigma_\alpha^2 + b\sigma_\gamma^2 + \sigma_\varepsilon^2$

$E(MS_B) = an\sigma_\beta^2 + \sigma_\gamma^2 + \sigma_\varepsilon^2$

$E(MS_{S/A}) = b\sigma_\gamma^2 + \sigma_\varepsilon^2$

$E(MS_{BxA}) = n\sigma_\alpha^2 + \sigma\beta_{\beta\gamma}^2 + \sigma_\varepsilon^2$

$E(MS_{BxS/A}) = \sigma_{\beta\gamma}^2 + \sigma_\varepsilon^2$

3.5.4 F ratio

$F_A = bn\sigma_\alpha^2 + b\sigma_\gamma^2 + \sigma_\varepsilon^2 / b\sigma_\gamma^2 + \sigma_\varepsilon^2 = MS_A / MS_{S/A}$

$F_B = an\sigma_\beta^2 + \sigma_\gamma^2 + \sigma_\varepsilon^2 / \sigma_{\beta\gamma}^2 + \sigma_\varepsilon^2 = MS_B / MS_{BxS/A}$

$F_{BxA} = n\sigma_\alpha^2 + \sigma\beta_{\beta\gamma}^2 + \sigma_\varepsilon^2 / \sigma_{\beta\gamma}^2 + \sigma_\varepsilon^2 = MS_{BxA} / MS_{BxS/A}$

3.5.5 ANOVA Summary Table

Table 3. ANOVA summary table

Source	df	Ss	MS	F
Between				
A	a-1	SS_A	MS_A	$MS_A/MS_{S/A}$
S/A	a(n-1)	$SS_{S/A}$	$MS_{S/A}$	
Within				
B	b-1	SS_B	MS_B	$MS_B/MS_{BxS/A}$
BxA	(a-1)(b-1)	SS_{BxA}	MS_{BxA}	$MS_{BxA}/MS_{BxS/A}$
BxS/A	(b-1)a(n-1)	$SS_{BxS/A}$	$MS_{BxS/A}$	
Total	abn-1	SS_{total}		

3.5.6 Hypothesis Testing

F-ratio was calculated to test whether there is a statistically significant difference among group means.

$F_A = MS_A / MS_{S/A}$

* Test: difference among means

Format: H_0: $\sigma_A^2 = 0$ (There is no significant difference among means of age group)

H_i: $\sigma_A^2 \neq 0$ (There is significant difference among means of age group)

(α=0.05) significance level

Decision Rule: I reject H_0 if $F_{observed} > F_{tabled}$

Note: $F_{observed=}$ $MS_A/MS_{S/A,}$ $F_{tabled=}$ $(df_A, df_{S/A})$

$F_B = MS_B / MS_{BxS/A}$

* Test: difference among means

Format: H_0: $\sigma_B^2 = 0$

(There is no significant difference among means of floor conditions group)

H_i: $\sigma_B^2 \neq 0$

(There is significant difference among means of floor conditions group)

(α=0.05) significance level

Decision Rule: I reject H_0 if $F_{observed} > F_{tabled}$

Note: $F_{observed=}$ $MS_B/MS_{BXS/A,}$ $F_{tabled=}$ $(df_B, df_{BXS/A})$

$F_{BXA} = MS_{BxA}/MS_{BxS/A}$

* Test: difference among means

Format: H_0: $\sigma_{BXA}^2 = 0$

(There is no significant interaction between age and floor conditions groups)

H_i: $\sigma_{BXA}^2 \neq 0$

(There is significant interaction between age and floor conditions groups)

(α=0.05) significance level

Decision Rule: I reject H_0 if $F_{observed} > F_{tabled}$

Note: $F_{observed=}$ $MS_{BxA}/MS_{BxS/A,}$ $F_{tabled=}$ $(df_{BxA}, df_{BXS/A})$

Hypotheses in this study were that gait parameters of older participants were different from younger participants, which affected the gait adaptation and increased the likelihood of a slip and trip accident during the transition between different floor surfaces.

4. RESULTS

4.1 Data Analysis

Dependent measures of gait parameters (RCOF, transitional acceleration of the whole body COM, toe clearance, step length, and heel contact velocity) and subjective assessment were analyzed using 2x4 (age x floor) two-way mixed analysis of variance (ANOVA) design. Tukey-Kramer Least Significant Difference post hoc test was performed on all significant differences (age, floor condition, and interactions). Supplement 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 to vinyl floor surface and vise 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, Paired-Comparison t-Test was performed to test whether there was a statistically significant difference between the two friction demands on the carpeted and vinyl floor surfaces.

4.2 ANOVA Results

The results of normality test (alpha=0.05) indicated that the data in this study was adequately normal to perform a parametric test. The results of the two-way ANOVA indicated statistically ($p < 0.05$) significant difference among means of floor condition groups in heel contact velocity ($F_{3,73} = 6.25$, P=0.0008) and toe clearance ($F_{3,75} = 22.23$, P<0.0001). There is no statistically significant age effect on all dependent variables except toe clearance ($F_{1,26} = 4.68$, P = 0.0399). The subjective assessment showed that there is no statistically significant difference among means of age and floor condition groups in all questions. Summary of gait parameters are listed on Table 4.

Table 4. Summary of Gait Parameters

Variable	Age	Carpet	Vinyl	Carpet to Vinyl	Vinyl to Carpet
RCOF (Fx/Fz)	Young	0.17(0.03)	0.19(0.03)	0.17(0.02)	0.19(0.02)
	Old	0.15(0.06)	0.18(0.05)	0.18(0.05)	0.18(0.02)
Step Length (cm)	Young	72.15(6.45)	73.17(5.94)	72.47(7.16)	76.06(4.72)
	Old	66.13(10.38)	68.65(3.36)	66.17(10.44)	68.15(6.90)
Transitional Acceleration of the Whole body COM(cm/s^2)	Young	153.82(40.78)	150.82(34.37)	144.23(32.65)	158.60(44.06)
	Old	124.76(45.98)	134.50(41.34)	141.33(45.98)	155.06(33.40)
HCV(cm/s)	Young	72.29(9.18)	83.58(18.40)	78.03(15.92)	75.18(16.26)
	Old	80.33(18.50)	106.50(18.21)	98.45(22.06)	86.91(18.80)
*Toe Clearance (cm)	Young	1.21(0.78)	2.85(0.69)	1.57(0.76)	3.33(0.71)
	Old	1.55(0.65)	3.23(0.69)	1.67(0.81)	3.76(0.83)
Subjective Assessment	Young	1.47(0.88)	1.40(0.80)	1.33(0.60)	1.53(0.88)
	Old	1.40(0.65)	1.53(0.65)	1.47(0.74)	1.60(0.85)

* significant difference between age groups

4.2.1 Required Coefficient of Friction (RCOF) at heel contact

4.2.1.1 Age Comparisons

The ANOVA results indicated no statistically significant differences ($F_{1,26}$=0.84, P =0.368) between the two age groups (Table 5 and Figure 14).

Table 5. Descriptive summary of RCOF on main effect age

Age	Mean	S.D.
Young	0.18	0.03
Old	0.17	0.04

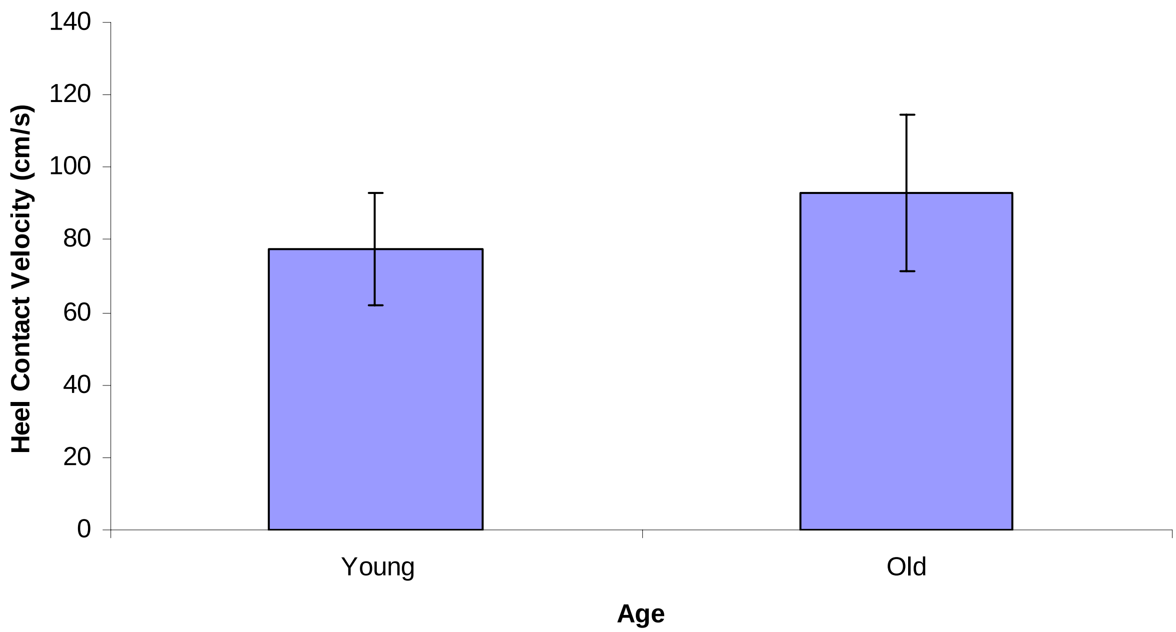

Figure 14. Age effect on RCOF

4.2.1.2 Floor Comparisons

The ANOVA results indicated no statistically significant differences ($F_{3,70}$=0.55, P =0.6503) between the four different floor conditions (Table 6 and Figure 15).

Table 6. Descriptive summary of RCOF on main effect floor

RCOF	Carpet	Vinyl	Carpet to Vinyl	Vinyl to Carpet
Mean	0.16	0.19	0.17	0.18
SD	0.05	0.02	0.04	0.02

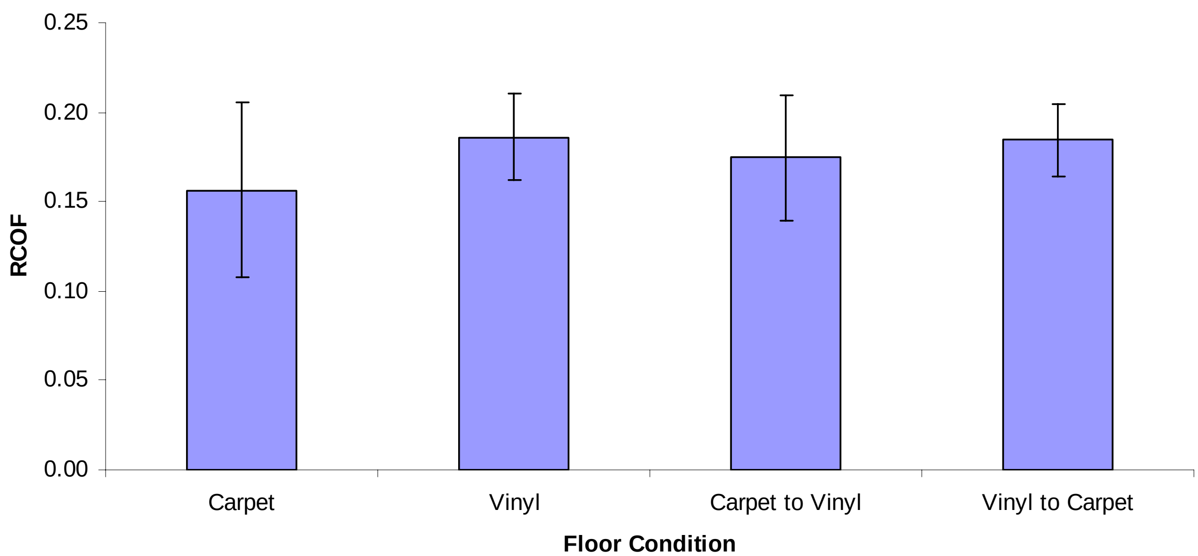

Figure 15. Floor effect on RCOF

4.2.1.3 Interactions

The ANOVA results indicated no statistically significant age and floor interactions ($F_{3,70}$=2.31, P =0.084) (Table 7 and Figure 16).

Table 7. Descriptive summary of RCOF on age and floor interactions

Mean(SD)	Carpet	Vinyl	Carpet to Vinyl	Vinyl to Carpet
Young	0.17(0.03)	0.19(0.03)	0.17(0.02)	0.19(0.02)
Old	0.15(0.06)	0.18(0.02)	0.18(0.05)	0.18(0.02)

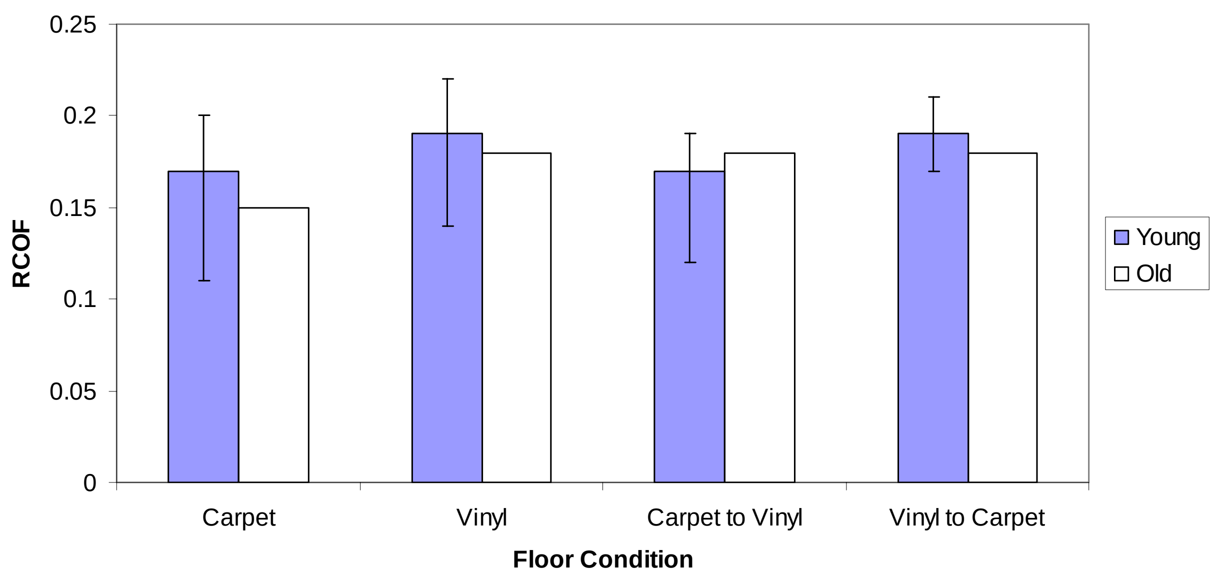

Figure 16. Interactions effect on RCOF

4.2.2 Step Length

4.2.2.1 Age Comparisons

The ANOVA results indicated no statistically significant differences ($F_{1,26}$=2.77, P =0.1080) between the two age groups (Table 8 and Figure 17).

Table 8. Descriptive summary of step length on main effect age

Step Length(cm)	Mean	S.D.
Young	73.46	6.17
Old	67.27	8.23

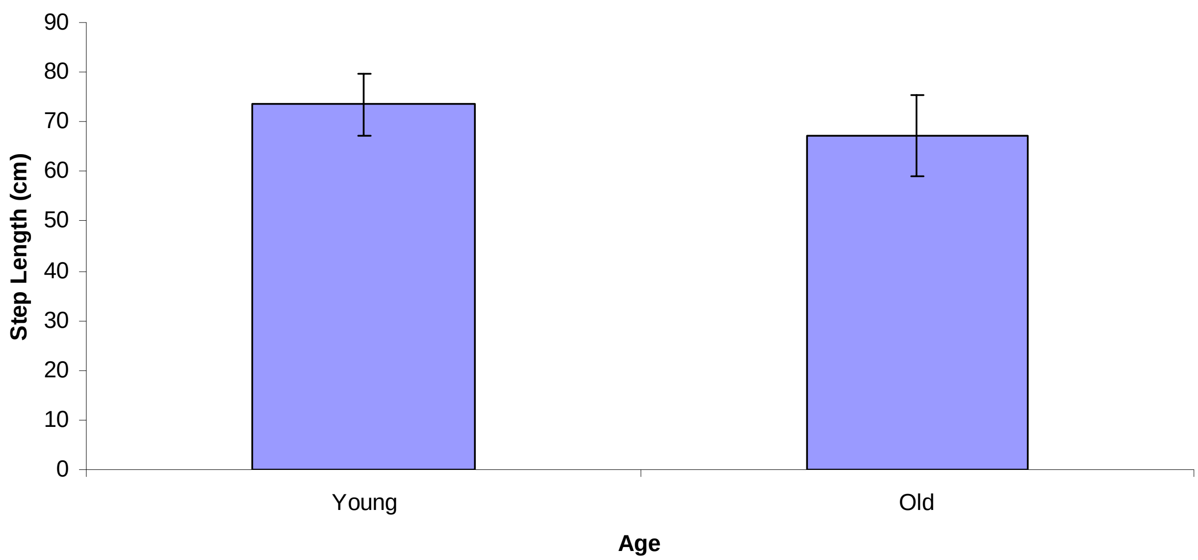

Figure 17. Age effect of step length

4.2.2.2 Floor Comparisons

The ANOVA results indicated no statistically significant differences ($F_{3,73}$=0.26, P =0.8560) between the four different floor conditions (Table 9 and Figure 18).

Table 9. Descriptive summary of step length on main effect floor

Step Length(cm)	Carpet	Vinyl	Carpet to Vinyl	Vinyl to Carpet
Mean	69.03	71.08	69.43	71.96
SD	9.08	5.35	9.28	7.09

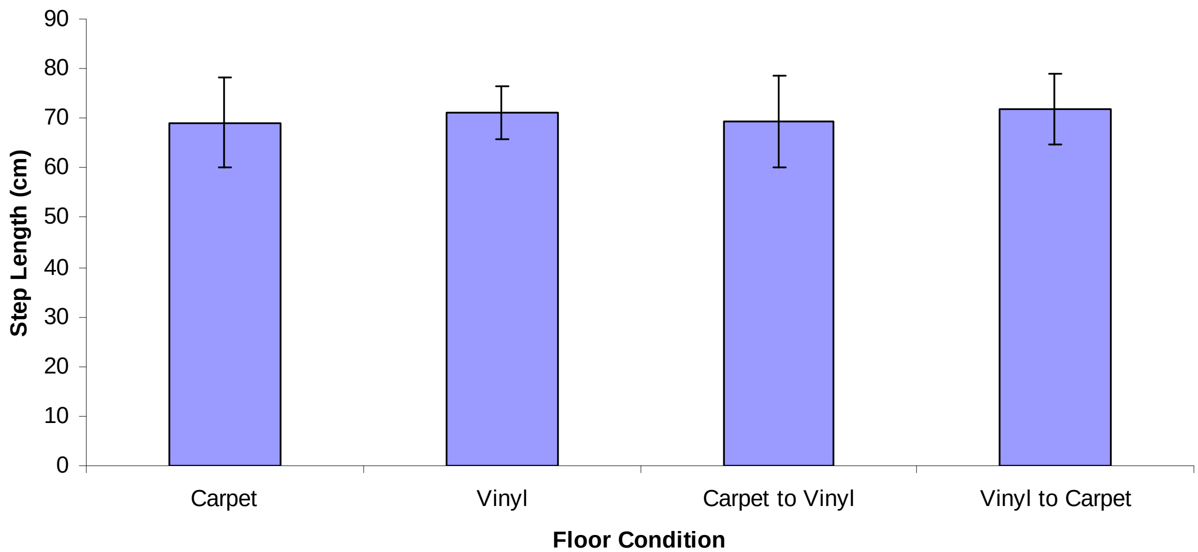

Figure 18. Floor effect on step length

4.2.2.3 Interactions

The ANOVA results indicated no statistically significant age and floor interactions ($F_{3,73}$=1.19, P =0.3206) (Table 10 and Figure 19)

Table 10. Descriptive summary of step length on age and interactions

Step Length(cm)	Carpet	Vinyl	Carpet to Vinyl	Vinyl to Carpet
Young	72.15(6.45)	73.17(5.94)	72.47(7.16)	76.06(4.72)
Old	66.13(10.38)	68.65(3.36)	66.17(10.44)	68.15(6.90)

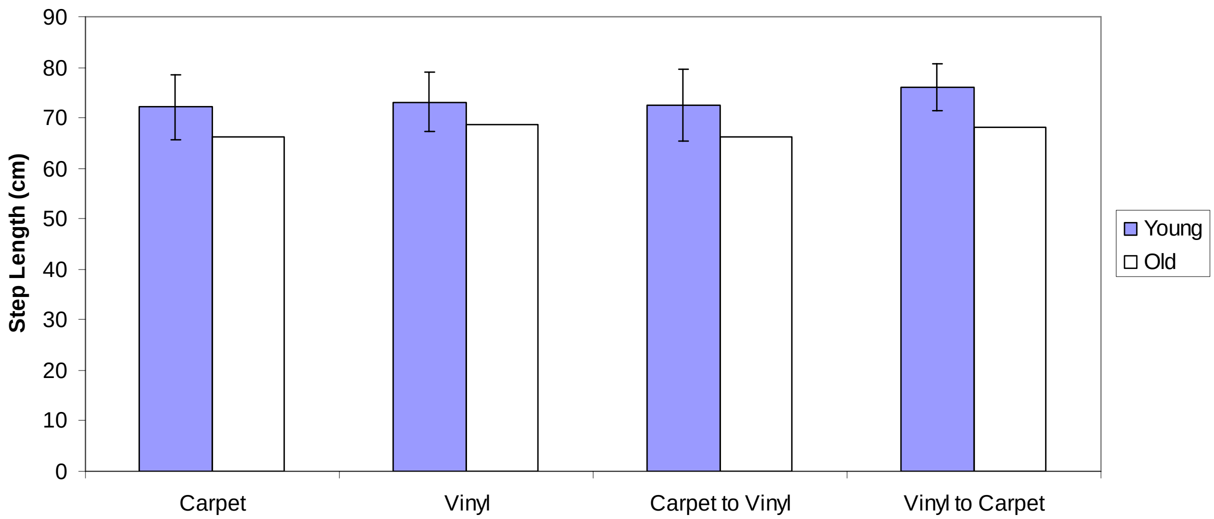

Figure 19. Interactions effect on step length

4 2 3 Transitional Acceleration of the Whole Body COM

4.2.3.1 Age Comparisons

The ANOVA results indicated no statistically significant differences ($F_{1,26}$=0.54, P =0.4702) between the two age groups (Table 11 and Figure 20).

Table 11. Descriptive summary of transitional acceleration of the whole body COM on main effect age

Transitional Acceleration of the Whole Body COM(cm/s^2)	Mean	S.D.
Young	151.71	37.35
Old	138.91	40.53

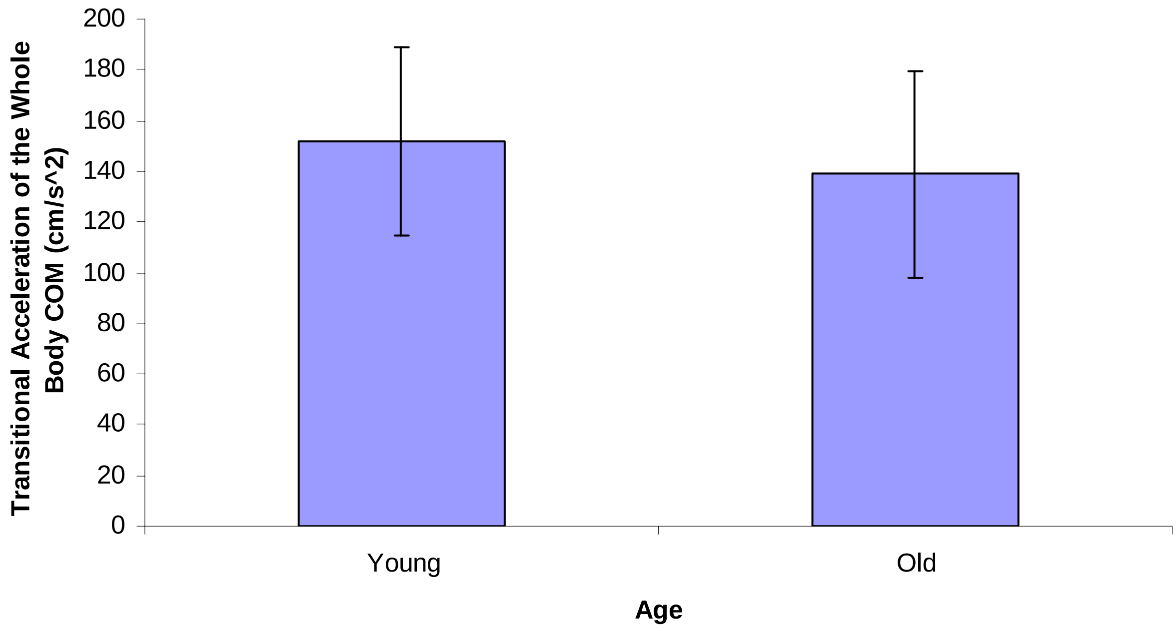

Figure 20. Age effect on transitional acceleration of the whole body COM

4.2.3.2 Floor Comparisons

The ANOVA results indicated no statistically significant differences ($F_{3,73}$=0.83, P =0.4808) between the four different floor conditions (Table 12 and Figure 21).

Table 12. Descriptive summary of Transition Acceleration of the Whole Body COM on main effect floor

Transitional Acceleration of the Whole Body COM(cm/s^2)	Carpet	Vinyl	Carpet to Vinyl	Vinyl to Carpet
Mean	138.75	143.29	142.84	156.76
SD	45.20	37.88	34.96	37.88

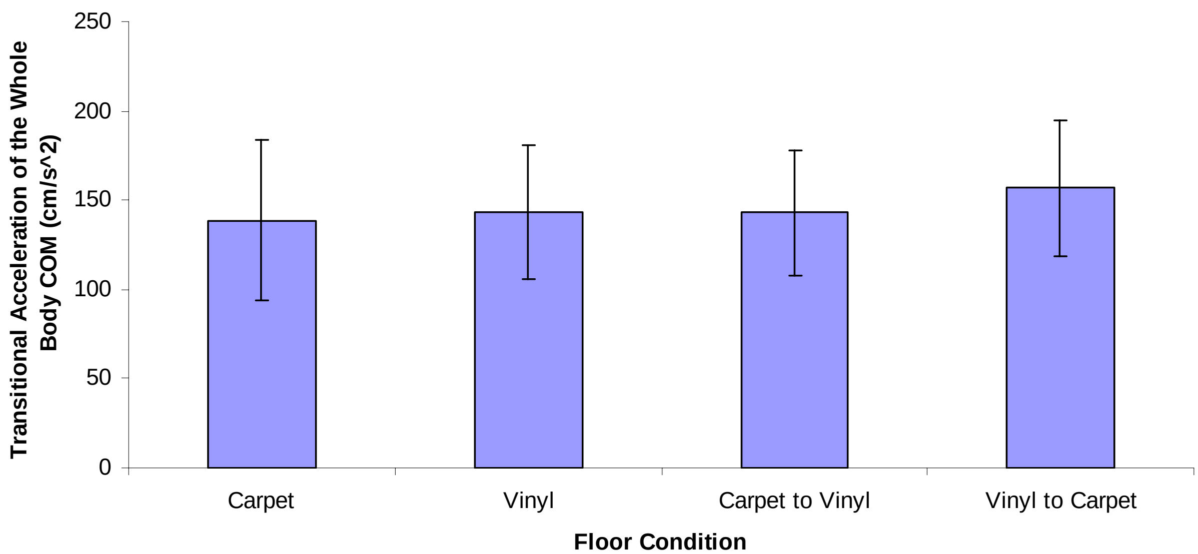

Figure 21. Floor effect on transitional acceleration of the whole body COM

4.2.3.3 Interactions

The ANOVA results indicated no statistically significant age and floor interactions ($F_{3,73}$=0.32, P =0.8106) (Table 13 and Figure 22).

Table 13. Descriptive summary of transitional acceleration of the whole body COM on age and floor interactions

Transitional Acceleration of the Whole Body COM(cm/s^2)	Carpet	Vinyl	Carpet to Vinyl	Vinyl to Carpet
Young	153.82(40.78)	150.82(34.37)	144.23(32.65)	158.60(44.06)
Old	124.76(45.98)	134.50(41.34)	141.33(45.98)	155.06(33.40)

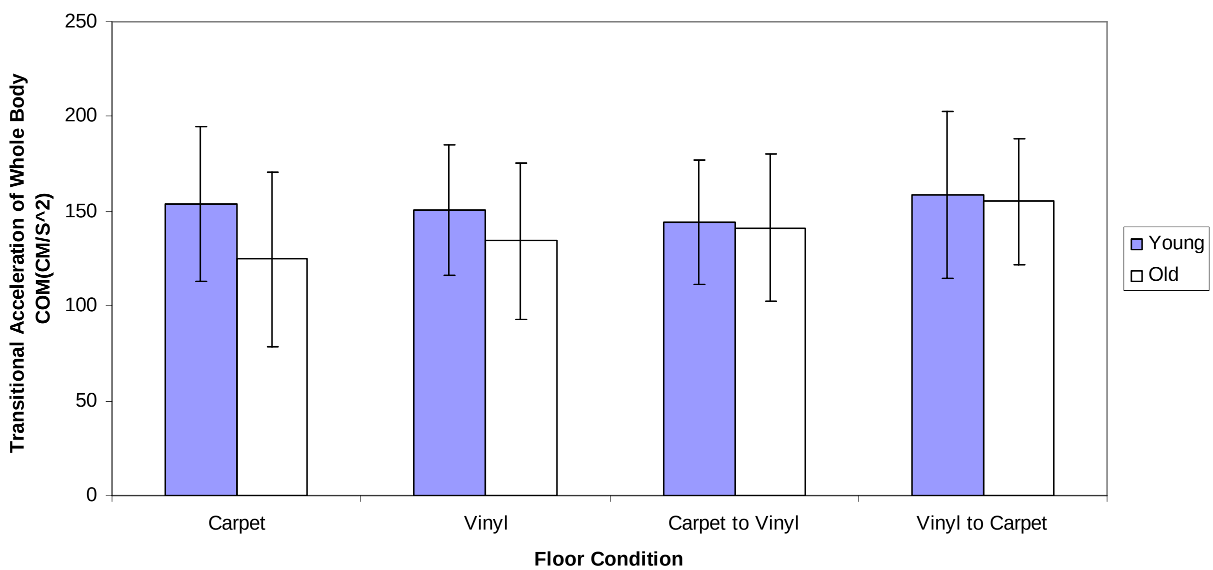

Figure 22. Interactions effects on transitional acceleration of the whole body COM

4.2.4 Heel Contact Velocity

4.2.4.1 Age Comparisons

The ANOVA results indicated no statistically significant differences ($F_{1,26}$=3.03, P =0.0935) between the two age groups (Table 14 and Figure 23)

Table 14. Descriptive summary of heel contact velocity on main effect age

Heel Contact Velocity(cm/s)	Mean	S.D.
Young	77.46	15.65
Old	93.05	21.48

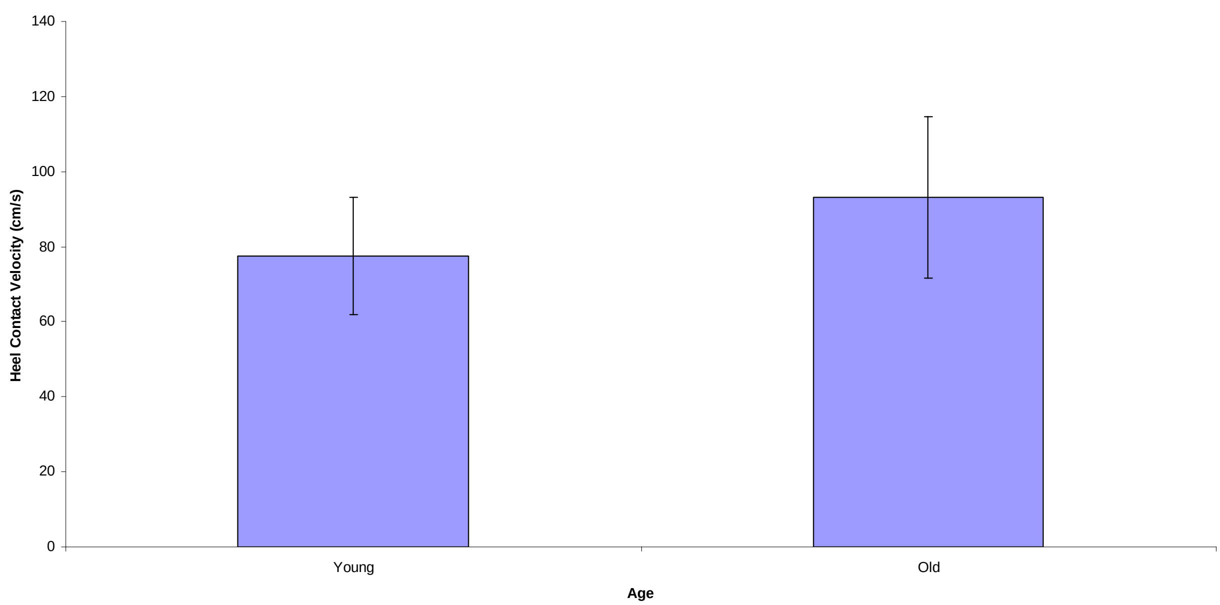

Figure 23. Age effect on heel contact velocity

4.2.4.2 Floor Comparisons

The ANOVA results indicated statistically significant differences ($F_{3,73}$=6.25, P =0.0008) between the four different floor conditions (Table 15 and Figure 24). Tukey-Kramer post-hoc test indicated significant differences between 1) carpet and vinyl, 2) carpet and carpet to vinyl, and 3) vinyl and vinyl to carpet.

Heel contact velocity is higher on a vinyl than carpeted floor. An increase in heel contact velocity was observed during transitioning from a carpet to vinyl rather than walking on a carpeted floor. In addition, heel contact velocity was significantly higher on the vinyl floor as compared to the transitioning from a vinyl to carpeted floor.

Table 15. Descriptive summary of heel contact velocity on main effect floor

Heel Contact Velocity(cm/s)	Carpet	Vinyl	Carpet to Vinyl	Vinyl to Carpet
Mean	76.62	94.62	87.86	80.83
SD	15.22	21.41	21.44	18.19

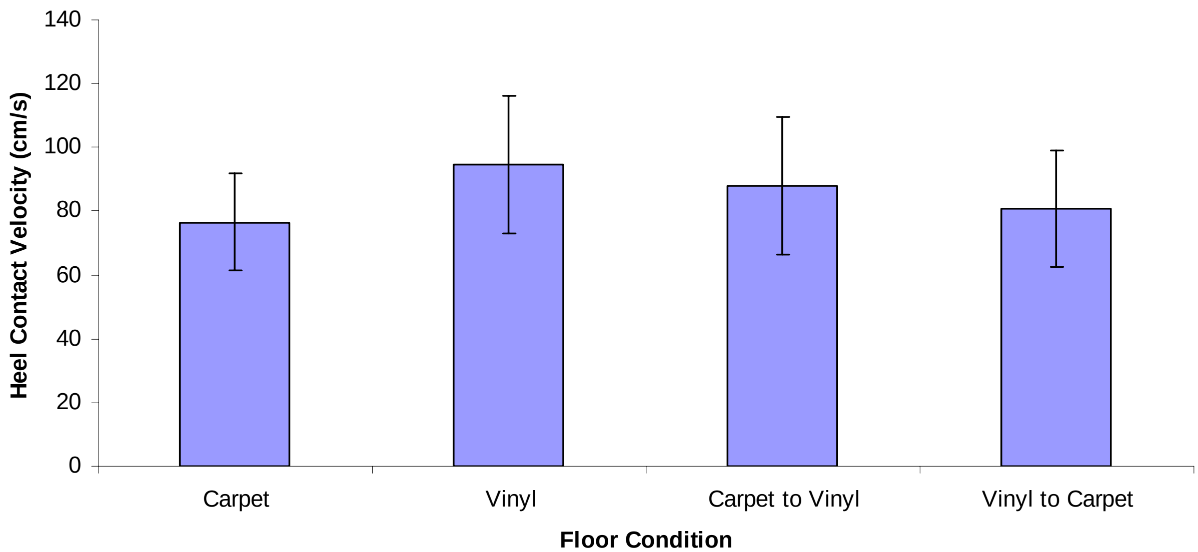

Figure 24. Floor effect on heel contact velocity

4.2.4.3 Interactions

The ANOVA results indicated no statistically significant age and floor interactions ($F_{3,73}$=1.86, P =0.1437) (Table 16 and Figure 25)

Table 16. Descriptive summary of heel contact velocity on age and floor interaction

Heel Contact Velocity(cm/s)	Carpet	Vinyl	Carpet to Vinyl	Vinyl to Carpet
Young	72.29(9.18)	83.58(18.40)	78.03(15.92)	75.18(16.26)
Old	80.33(18.50)	106.50(18.21)	98.45(22.06)	86.91(18.80)

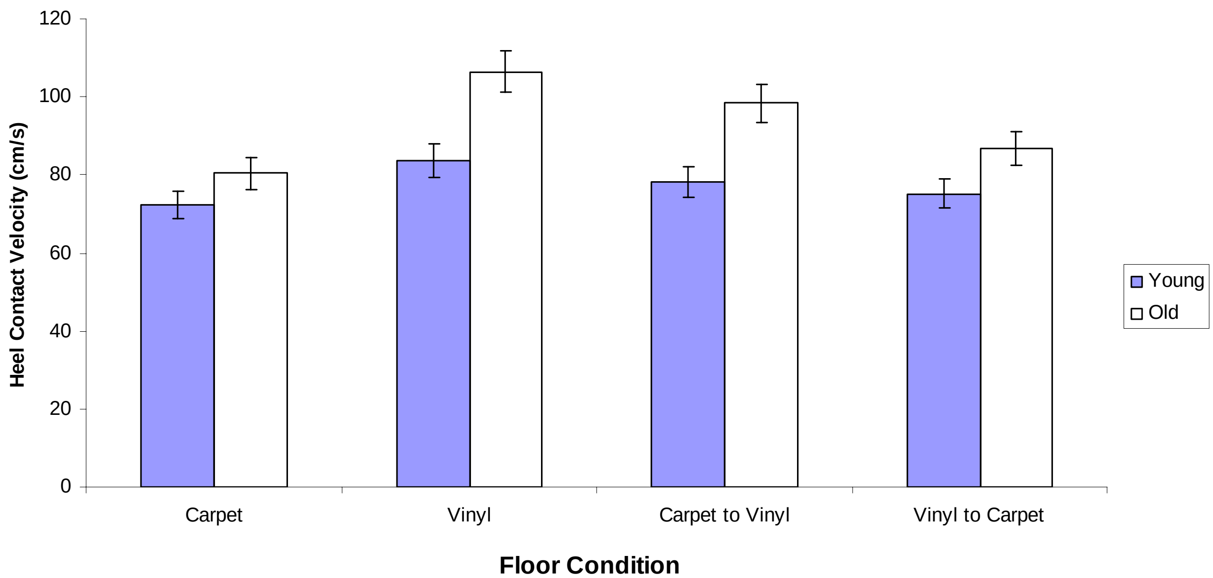

Figure 25. Interactions effect on heel contact velocity

4.2.5 Toe Clearance

4.2.5.1 Age Comparisons

The ANOVA results indicated statistically significant differences ($F_{1,26}$=4.50, P =0.0435) between the two age groups. In general, older individuals' toe clearance was higher than their younger counterparts (Table 17 and Figure 26).

Table 17. Descriptive summary of toe clearance on main effect age

Toe Clearance(cm)	Mean	S.D.
Young	2.26	1.14
Old	2.55	1.21

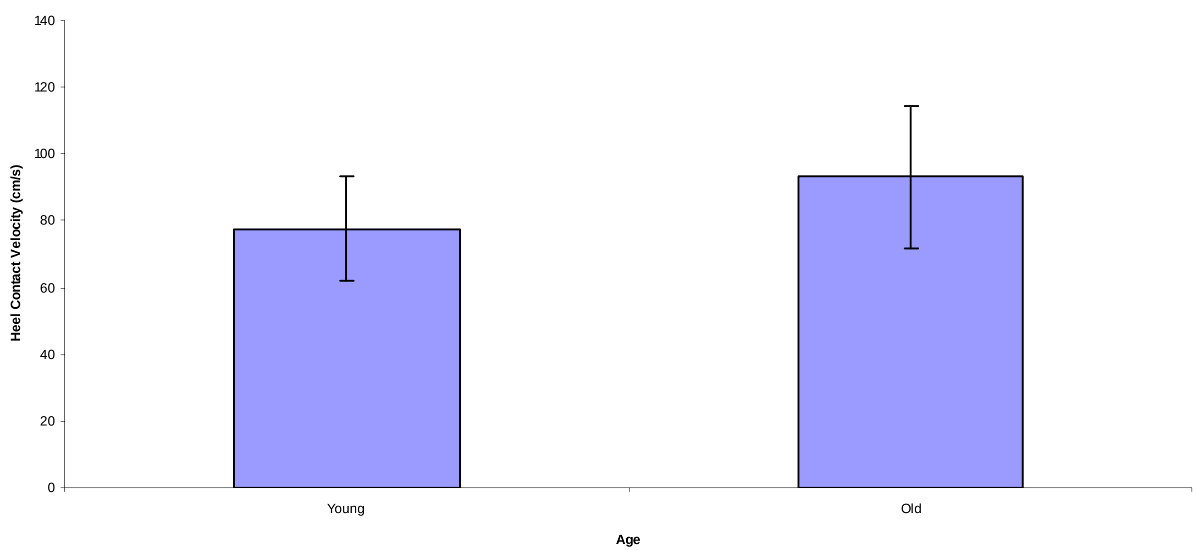

Figure 26. Age effect on toe clearance

4.2.5.2 Floor Comparisons

The ANOVA results indicated statistically significant differences ($F_{3,75}$=21.94, P < 0.0001) between the four different floor conditions (Table 18 and Figure 27). Tukey-Kramer post-hoc test indicated significant differences between 1) carpet and vinyl, 2) carpet and carpet to vinyl, and 3) vinyl and vinyl to carpet, 4) carpet to vinyl and vinyl to carpet, 5) carpet to vinyl and vinyl.

An increase in toe clearance was observed on a vinyl floor as compared to on a carpeted floor. Additionally, participants generated higher toe clearance after transitioning from a vinyl floor.

Table 18. Descriptive summary of toe clearance on main effect age

Toe Clearance(cm)	Carpet	Vinyl	Carpet to Vinyl	Vinyl to Carpet
Mean	1.38	3.04	1.54	3.62
SD	0.73	0.71	0.78	0.78

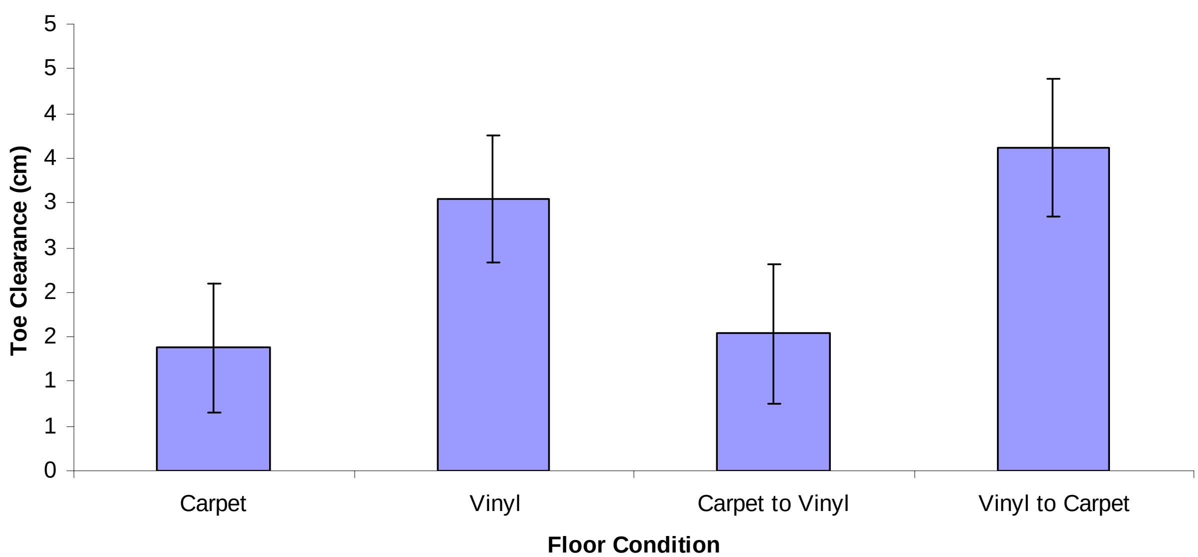

Figure 27. Floor effect on toe clearance

4.2.5.3 Interactions

The ANOVA results indicated no statistically significant age and floor interactions ($F_{3,73}$=0.22, P =0.8801) (Table 19 and Figure 28).

Table 19. Descriptive summary of toe clearance on age and floor interactions

Toe Clearance(cm)	Carpet	Vinyl	Carpet to Vinyl	Vinyl to Carpet
Young	1.21(0.78)	2.85(0.69)	1.57(0.76)	3.33(0.71)
Old	1.55(0.65)	3.23(0.69)	1.67(0.81)	3.76(0.83)

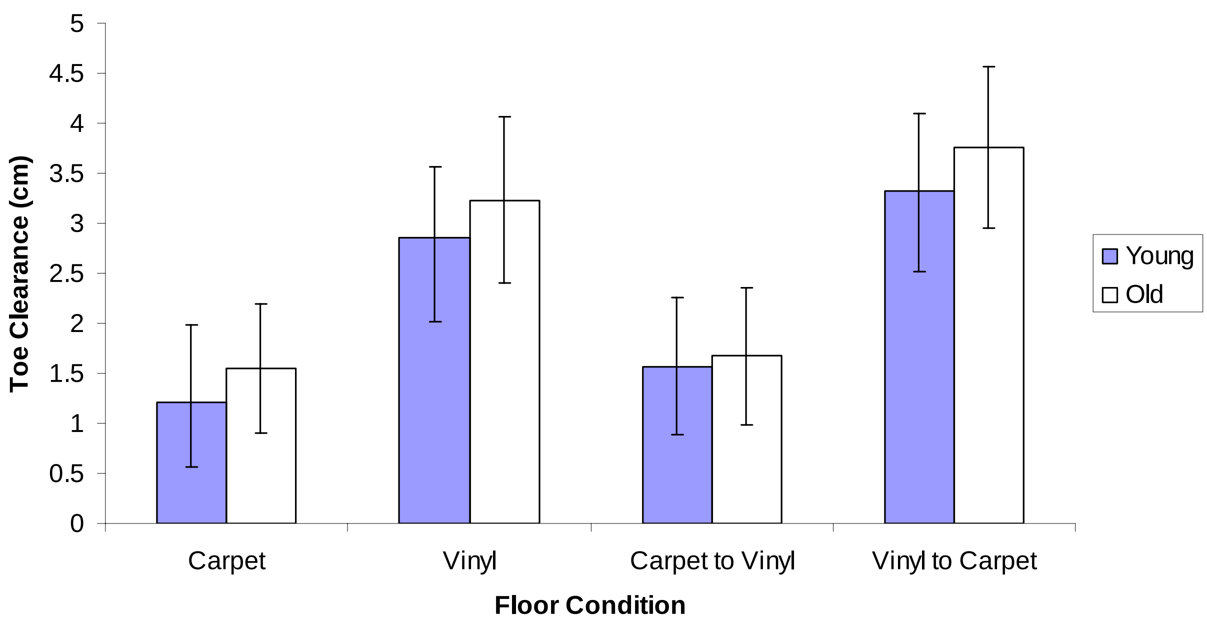

Figure 28. Interactions effect on toe clearance

4.2.6 Subjective perception of slipping and tripping

For the open-ended question, there were no comments directly related with this study. Their comments, for example, were the request to join future experiments, compliments for the research, etc.

4.2.6.1 Age Comparisons

The ANOVA results indicated no statistically significant differences ($F_{1,26}$=0.11, P =0.7402) between the two age groups (Table 20 and Figure 29).

Table 20. Descriptive summary of subjective perception

Rating	Mean	S.D.
Young	1.36	0.72
Old	1.43	0.71

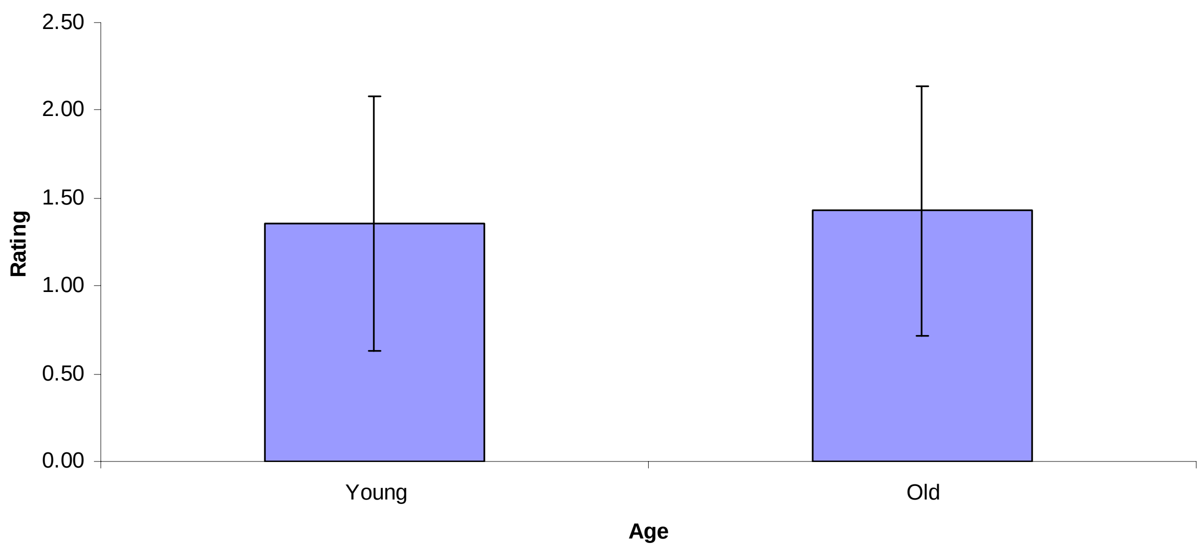

Figure 29. Age effect on subjective perception

4.2.6.2 Floor Comparisons

The ANOVA results indicated no statistically significant differences ($F_{3,78}$=0.33, P =0.8051) between the four different floor conditions (Table 21 and Figure 30).

Table 21. Descriptive summary of subjective perception on main effect floor

Rating	1	2	3	4
Mean	1.46	1.39	1.39	1.32
SD	0.79	0.63	0.79	0.67

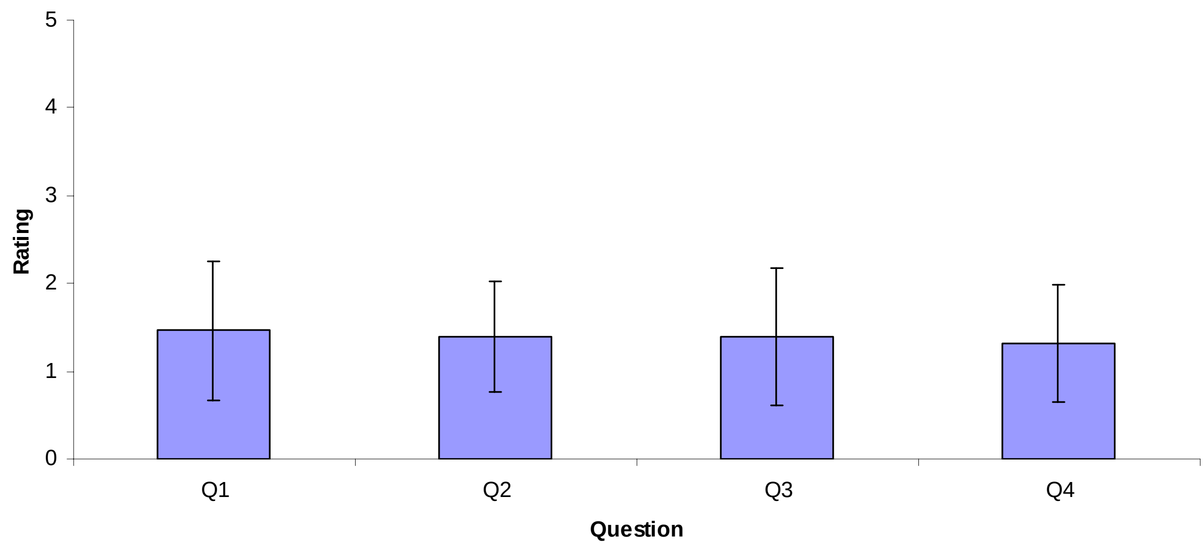

Figure 30. Floor effect on subjective perception

4.2.6.3 Interactions

The ANOVA results indicated no statistically significant age and floor interactions ($F_{3,78}$=0.66, P =0.5815) (Table 22 and Figure 31).

Table 22. Descriptive summary of subjective perception on age and floor interactions

Rating	Carpet	Vinyl	Carpet to Vinyl	Vinyl to Carpet
Young	1.47(0.88)	1.33(0.60)	1.53(0.88)	1.40(0.80)
Old	1.40(0.65)	1.53(0.65)	1.47(0.74)	1.60(0.85)

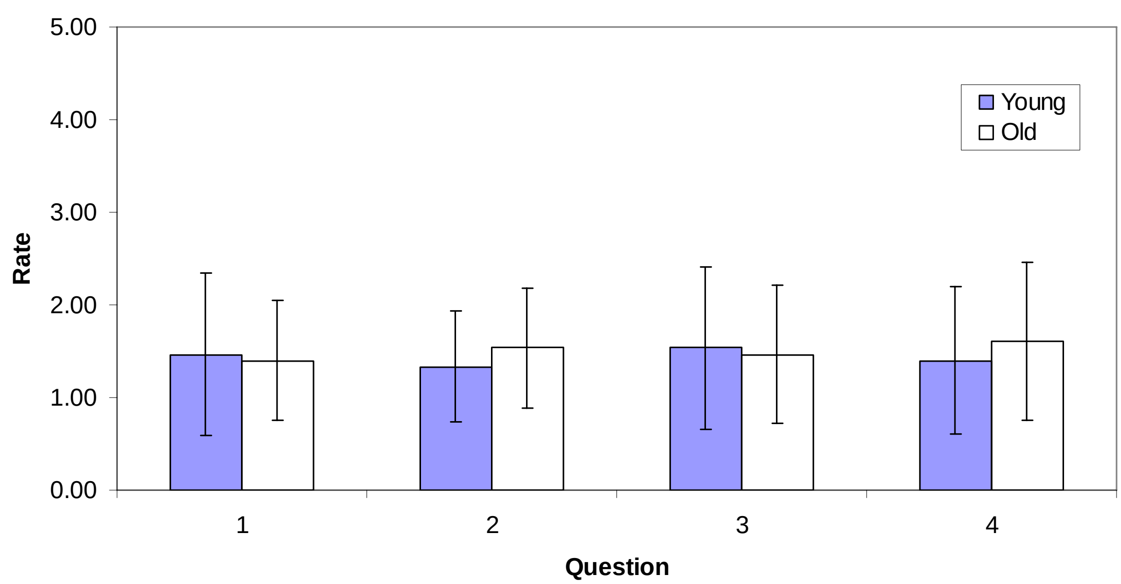

Figure 31. Interactions effect on subjective perception

4.3 Paired-Comparison t-Test

Paired-Comparison t-Test was performed to test whether there was statistically significant difference between the two friction demands on the carpeted and vinyl floor surfaces at the moment of transitioning (Table 23).

Table 23. Summary of Paired-Comparison t-Test

Variable	Age	Carpet to Vinyl		t-Test
		Carpet	Vinyl	
RCOF (Fx/Fz)	Young	0.19(0.03)	0.17(0.02)	*
	Old	0.18(0.02)	0.16(0.03)	*
PPOFD (Fx/Fz)	Young	0.29(0.06)	0.87(0.30)	*
	Old	0.28(0.02)	0.71(0.65)	*

Variable	Age	Vinyl to Carpet		t-Test
		Vinyl	Carpet	
RCOF (Fx/Fz)	Young	0.14(0.03)	0.18(0.02)	*
	Old	0.12(0.02)	0.18(0.02)	*
PPOFD (Fx/Fz)	Young	0.42(0.10)	0.36(0.10)	
	Old	0.30(0.08)	0.28(0.05)	

* significant difference between friction demands

4.3.1 Friction Demand at the First and the Following Second Heel Contact

The results of the Paired-Comparison t-Test indicated statistically ($p<0.05$) significant differences between friction demands at the first heel contact and at the second heel contact except the floor condition of transitioning from a carpet to vinyl surface for the younger participants (Table 24 and Figure 32). The friction demand at the heel contact was lower on the vinyl than carpet for each age group and also each transition condition.

<u>Younger participants</u>

Carpet to Vinyl: $t(12)=2.55$, $p=0.2256$

Vinyl to Carpet: $t(12)=-5.68$, $p<0.0001$*

<u>Older participants</u>

Carpet to Vinyl: $t(9)=2.89$, $p=0.0179$*

Vinyl to Carpet; $t(11)=-9.71$, $p<0.0001$*

Table 24. Descriptive summary of RCOF at heel contact on each floor surface

Age	Carpet to Vinyl		Vinyl to Carpet	
	Carpet	Vinyl	Vinyl	Carpet
Young	0.19(0.03)	0.17(0.02)	0.14(0.03)	0.18(0.02)
Old	0.18(0.02)	0.16(0.03)	0.12(0.02)	0.18(0.02)

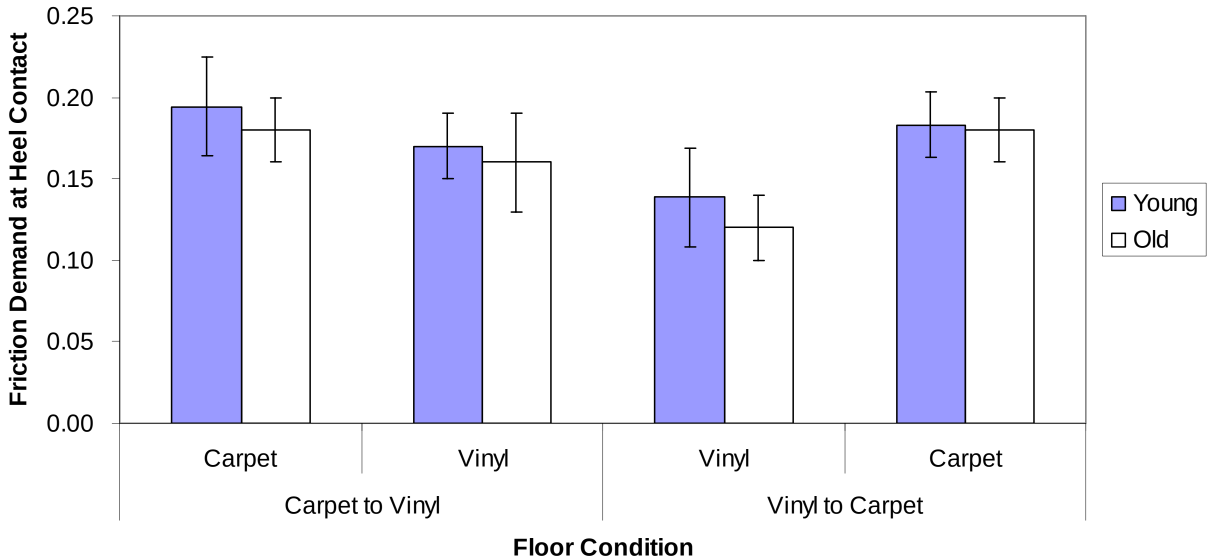

Figure 32. RCOF on each floor surface during transitioning.

4.3.2 Peak Push-Off Friction Demand (PPOFD)

The results of the Paired-Comparison t-Test indicated statistically ($P<0.05$) significant differences between the friction demand for a carpeted and vinyl floor surface during transitioning from a carpeted to vinyl floor surface for all age groups (Table 25 and Figure 33). PPOFD was higher for a vinyl floor surface than a carpeted floor surface.

<u>Younger participants</u>

Carpet to Vinyl: $t(11)=6.84$, $p<0.001$*

Vinyl to Carpet: $t(12)=-1.51$, $p=0.1580$

<u>Older participants</u>

Carpet to Vinyl: $t(11)=-2.29$, $p=0.0425$*

Vinyl to Carpet: $t(12)=-1.02$, $p=0.3278$

Table 25. Descriptive summary of PPOFD at push-off on each floor surface

PPOFD	Carpet to Vinyl		Vinyl to Carpet	
	Carpet	Vinyl	Vinyl	Carpet
Young	0.29(0.06)	0.87(0.30)	0.42(0.10)	0.36(0.10)
Old	0.28(0.02)	0.71(0.65)	0.3(0.08)	0.28(0.05)

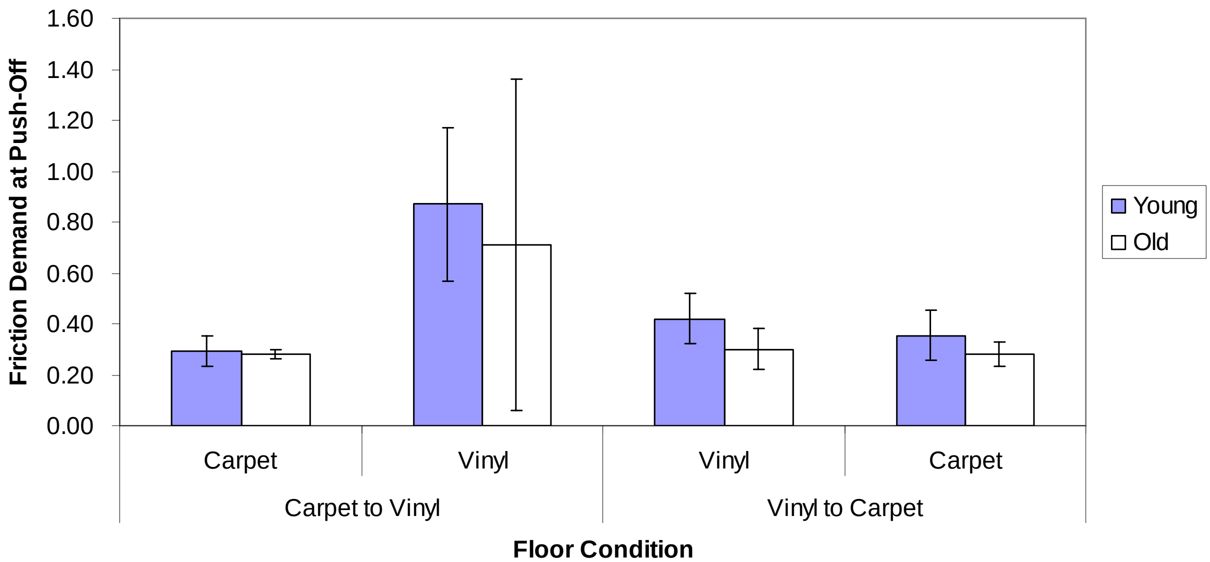

Figure 33. PPOFD on each floor surface during transitioning.

4.4 Summary of Results

4.4.1 Age Main Effect

The results of ANOVA indicated that with the exception of toe clearance there was no statistically significant age effect on any of the gait parameters. In general, older individuals had higher toe clearance than their younger counterparts. Additionally, there was no statistically significant difference between the young and older groups in the perception of slipping and tripping over transitioning between different floor surfaces; both age groups stated similar levels of the perception of slipping and tripping. More specifically, their perceptions of slipping and tripping were quite low.

4.4.2 Floor Main Effect

The results of ANOVA indicated a statistically significant difference among means of floor condition in heel contact velocity and toe clearance. An increase in heel contact velocity was observed for walking on a vinyl floor, and walking on a vinyl floor after transitioning from a carpeted floor to a vinyl floor as compared to the walking on a carpeted floor and the walking on a carpeted floor after transitioning from a vinyl floor to a carpeted floor. An increase in toe clearance was observed while walking on the vinyl floor, as well as while walking on a carpeted floor after a vinyl floor surface in comparison to the walking on a carpeted floor and walking on a vinyl floor after a carpeted floor. In addition, there was no statistically significant difference between the four questions for the perception of slipping and tripping. According to the results of the Paired-Comparison t-Test, friction demand at toe-off significantly increased at the moment of transitioning from a carpeted to vinyl floor for both age groups. More specifically, the friction demand for the vinyl was over twice as much as for the carpet.

4.4.3 Interaction Effect

There was no statistically significant age and floor interaction for the gait parameters. In addition, the results of ANOVA indicated no statistically significant difference in the four different questions which investigated the perception of slipping and tripping.

5. DISCUSSION AND CONCLUSION

5.1 Hypotheses and Experimental Findings

5.1.1 Hypothesis #1

"During transitioning, older participants' gait parameters will be different from younger participants, which may increase the propensity of a slip, trip, or fall."

Only one gait parameter, toe clearance, among the others (RCOF, transitional acceleration of the whole body COM, step length, and heel contact velocity) revealed a statistically significant difference among the two age groups. In contrast with the previous research (Winter, 1990), older individuals' toe clearance was significantly higher than that of their younger counterparts for all four different floor conditions. There is a possibility that the older individuals in this study might have a smaller angle of ankle than the younger individuals (Figure 34). A recent study conducted by Lark, Buckley, Jones & Sargeant (2004) found that older people are more likely to have a smaller and weaker joint range of movement as compared to younger individuals. Thus, the older participants' higher toe clearance could be induced by their smaller joint range of movement. The ankle angle was not considered due to the technical limitation of this current study. However, further research should investigate whether a change in the angle of ankle influences the toe clearance, especially while transitioning between different floor surfaces.

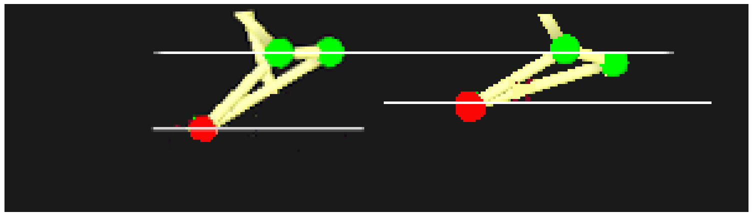

Figure 34. Different angle of ankle

In agreement with previous research (Lockhart et al, 2002), older participants had smaller friction demand at the heel contact phase than did their younger counterparts for all transitioning floor conditions except one: transitioning from a carpet to a vinyl floor. In other words, the older individuals had a higher friction demand than their younger counterparts while transitioning from a carpeted to vinyl floor; consequently, older individuals have a higher probability of a slip-induced fall accident when they step on the vinyl floor.

The transitioning floor condition above was investigated further by comparing the friction demands at the toe-off phase and heel contact phase. The friction demands were measured to see if there was any significant difference when the older participants stepped on the first floor, the carpet, and then on the second floor, the vinyl. For the heel contact phase, the friction demand significantly decreased on the vinyl floor for the older individuals. 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 the vinyl floor after transitioning from the carpeted floor to vinyl floor. Therefore, there is a greater chance of slipping when older individuals have their toe off rather than heel contact when transitioning from a carpeted to a vinyl floor surface, especially a slippery vinyl floor surface. Furthermore, older individuals should be properly warned of these specific risk conditions.

The present study found that elderly individuals had higher heel contact velocity than did their younger counterparts while transitioning from a carpeted to vinyl floor surface. Heel contact velocity was considered as a factor which would increase the likelihood of slip-induced falls (Karst et al., 1999; Myung R. et al., 1997; Winter, 1991) because an increase in heel contact velocity would lead to an increase in RCOF (Lockhart, 1997; Perkins & Wilson, 1983). Therefore, the higher heel contact velocity of an older person while transitioning from a carpeted to vinyl floor would increase the probability of slip-induced falls, especially for the older group.

Consistent with the previous research (Lockhart et al., 2003), the present study indicated that older participants had slower transitional acceleration of the whole body center-of-mass than their younger counterparts for all floor conditions. This result supports the assumption for hypothesis #3 that slower transitional acceleration of the whole body COM occurs for the older individuals due to their less vigorous push-off power than occurs for younger individuals (Kavanagh, et al., 2004; Judge et al., 1995).

In disagreement with previous research (Bunterngchit et al., 2000; Willmott, 1986), the older participants in the present study had shorter step length than their younger counterparts for all floor conditions. Some studies have pointed to the fact that people are more likely to shorten their step length in order to reduce friction demand and avoid a slip-induced fall (Edmison, Jones, Lockhart, & Martin, 2003). Thus, shorter step length might have helped older participants in this study to lower friction demand as compared to younger individuals. However, their likelihood of slip-induced fall accidents would increase while transitioning different floor surfaces. The older participants had longer step length on the vinyl than on the carpet. In addition, the longer step length was observed on the vinyl after transitioning from the carpet rather than on the carpet after transitioning from a vinyl. In other words, older individuals have longer step length on the vinyl, which would lead to a higher probability for a slip-induced fall accident.

Finally, a majority of both the younger and older participants responded that they did not perceive much danger of tripping and slipping. Additionally, the perception of tripping and slipping was not significantly different between different transitioning conditions. Therefore, their gait would not be influenced much by fear of slipping and tripping. However, there is one possible factor which might have influenced their response about the perception. For protection purpose, all participants wore a fall-arresting harness to prevent them from tripping while transitioning from a vinyl to carpeted floor. Thus, the harness might have made the participants feel safe and comfortable regarding a possible trip-induced fall. Thus, further research might be conducted without the harness to compare their perception with the findings of this study, because, according to the results of this study, none had a trip-induced fall and older participants had higher toe clearance than their younger counterparts.

In summary, some of the factors related to age effects were not statistically significant. This may be due to the fact that the older people who participated in the present study were in good physical shape and relatively younger than other older groups in previous research. The older individual's average age in this study was 70 years, which is young in comparison to other participants in the research referred to the present study. Furthermore, some of older participants in this study exercised regularly.

5.1.2 Hypothesis #2

"The likelihood of a trip as measured by toe clearance will increase during transitioning from a vinyl floor surface to carpeted floor surface."

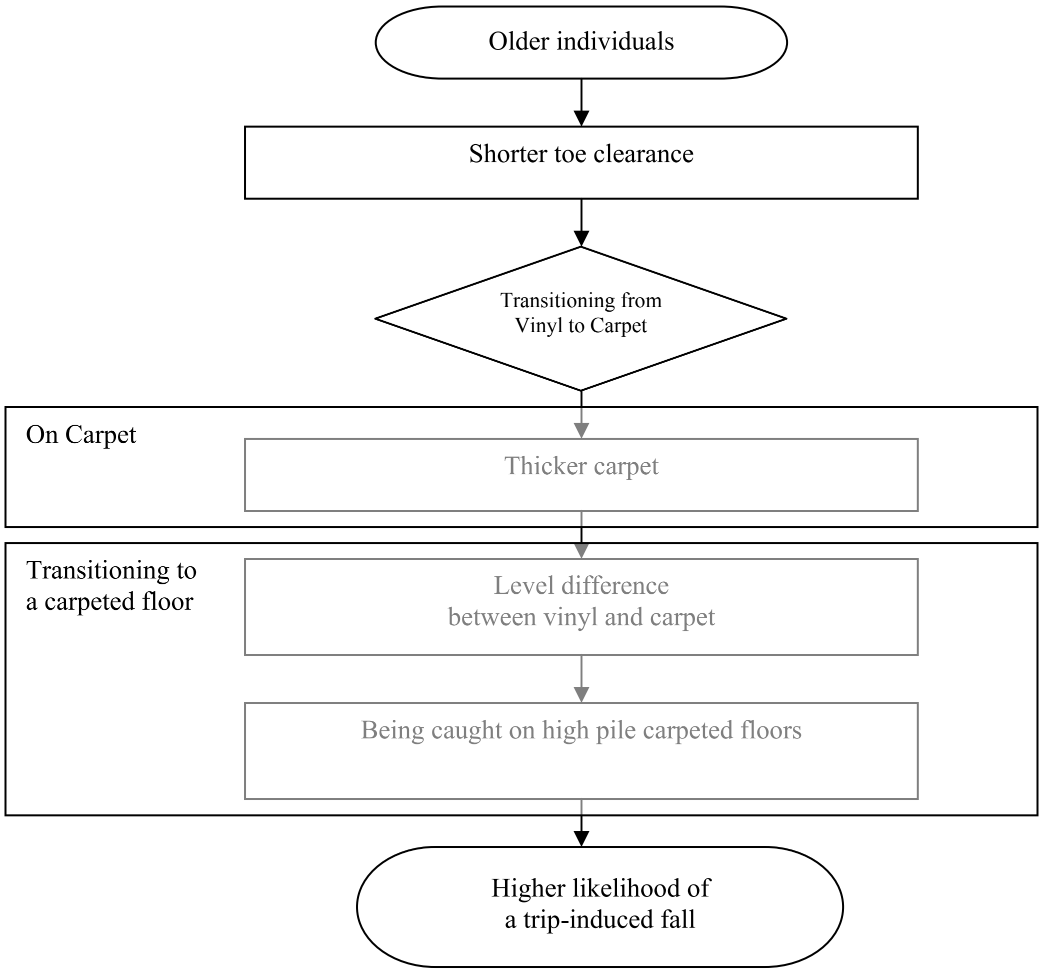

Figure 35. Schematic flow diagram for the transitioning effects on trip accidents

In disagreement with hypothesis 2 (Figure 35), old participants had the highest toe clearance while transitioning from a vinyl to carpeted floor than for all the other floor conditions. Therefore, a reduction in the likelihood of a trip was observed for the older individuals. On the other hand, transitioning from a carpet to vinyl floor generated a decrease in toe clearance. This result was observed not only among older participants but also among their younger counterparts.

The possible reason for the changes in toe clearance during transitioning might be explained in another way by considering the inherent elasticity (the property of returning to an initial shape or state following deformation) and resilience of the floor coverings such as carpet and vinyl, instead of the difference in their levels. Based on the results, in short, lower toe clearance was observed after transitioning from a carpeted floor to others (i.e., another carpet or a vinyl) rather than from a vinyl floor to other surfaces (i.e., another vinyl or a carpet).

The reduced toe clearance might be due to the weak elasticity of the carpet. A recent study conducted by Nabhani & Bamford (2004) found that a floor covering, such as carpet, significantly reduced the impact forces, so greater energy absorption was observed. Due to this, when the participants stepped on the carpet 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.

Hence, walking on a carpeted floor generates lower toe clearance as compared to walking on a vinyl floor. Therefore, people should be made aware of a possible trip-induced fall accident while walking on the carpeted floor.

5.1.3 Hypothesis #3

"The likelihood of slip as measured by RCOF will increase during transitioning from a carpeted floor surface to vinyl floor surface."

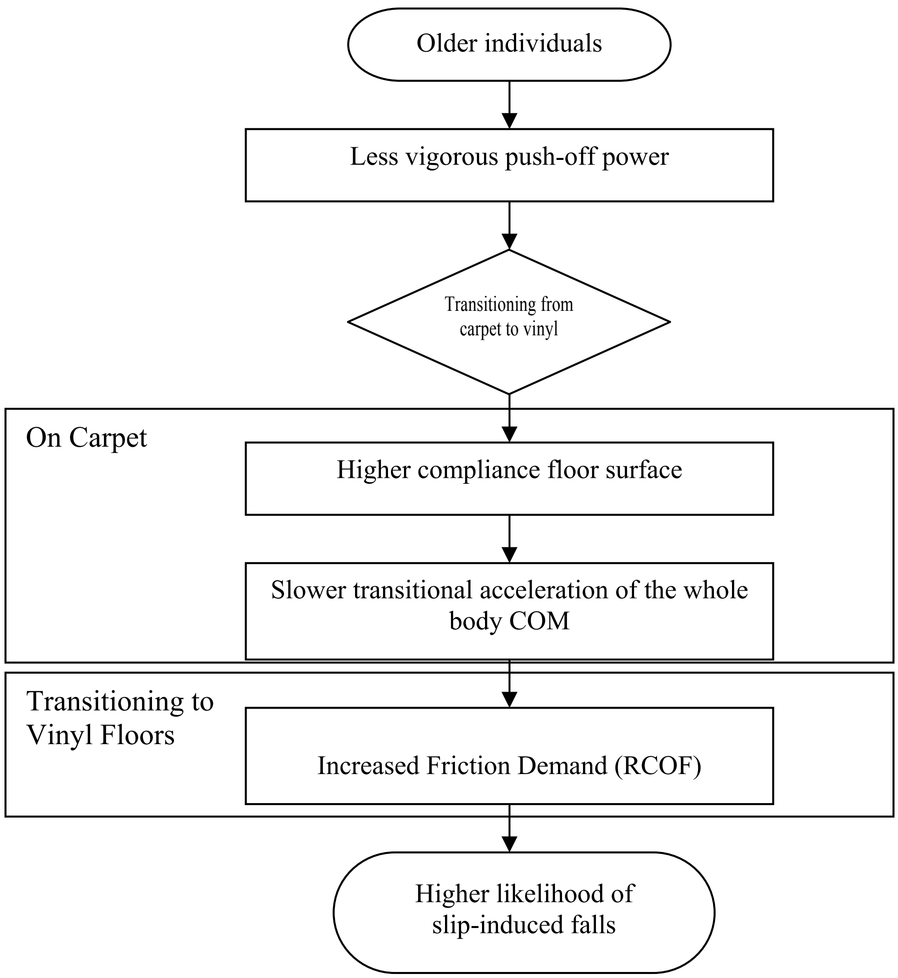

Figure 36. Schematic flow diagram for the transitioning effects on slip accidents

According to the results of the present study, hypothesis 3 (Figure 36) was valid. In general, the older individuals have less vigorous push-off power than did their younger counterparts (Kavanagh, et al., 2004; Judge et al., 1995). This resulted in the reduced transitional acceleration of the whole body COM while transitioning from a carpeted to vinyl floor. This may be due to the higher compliance of the carpeted floor surface.

For transitioning floor conditions, RCOF was not significantly different in this study. Therefore, as a supplemental data analysis, Peak Push-Off Friction Demand (PPOFD) was investigated to compare friction demands at the push-off phase and at the heel contact phase within the transitioning floor condition (e.g., transition from a carpeted to vinyl floor). For example, when participants transited from a carpeted to a vinyl floor, they stepped on the carpet first and then on the vinyl floor. The friction demand was calculated at the first floor, the carpet. Additionally, the friction demand was measured at the second floor, the vinyl. The two friction demands were compared to see if there was any significant difference at the moment of transitioning. In high contrast to friction demand at the heel contact phase, friction demand at the push-off phase dramatically increased on the vinyl floor as compared to the carpeted floor. Thus, the likelihood of a slip-induced fall accident will be greater on the vinyl floor at the push-off phase rather than the heel contact phase when transitioning from a carpeted to a vinyl floor surface.

When we look at the friction demands of each participant (Table 26), significantly different friction demands were observed among the older participants. Some participants (named Group A) had significantly higher friction demands than other participants (named Group B). There was no age effect because the average age of both groups A and B was similar: group A (Mean 71, SD 4.7) and group B (Mean 69, SD 9.4). In addition, a review of the medical history questionnaire revealed no important considerations. Most of participants in both group A and B were healthy. Future research might be extended to investigate why, given good health, the older participants in group A had significantly higher friction demands at the toe-off phase.

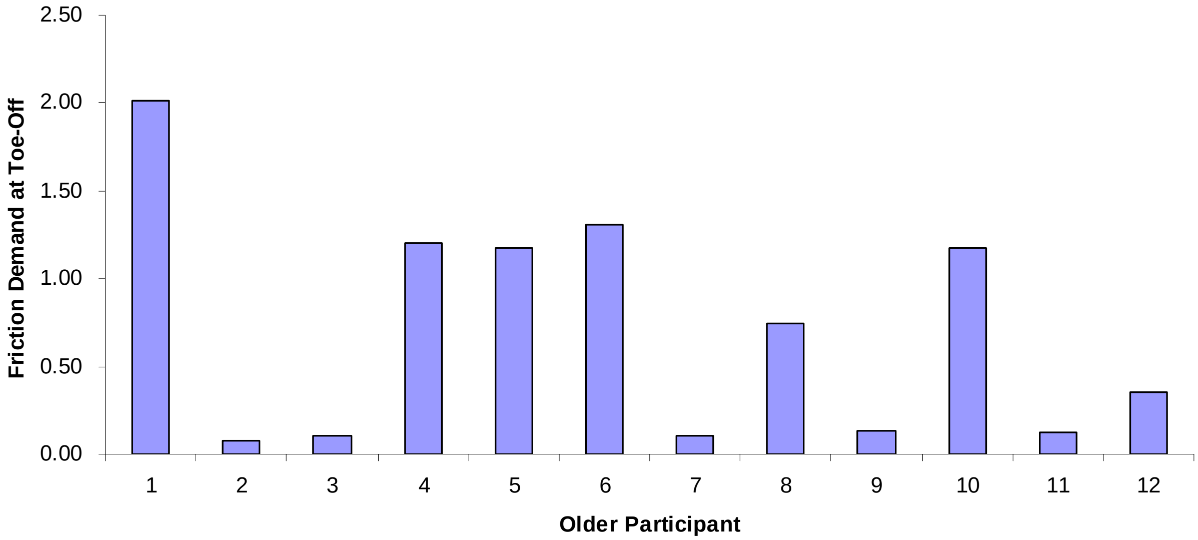

Table 26. Friction demands at toe-off phase for older participants

In addition, this study was focused on whether transitioning could affect the probability of tripping/slipping; however, recovery after tripping/slipping was not considered in the present study. When people try to recover from a slip, trip, or fall, they could also encounter a fall accident. Thus, recovery reaction might be investigated for future research, especially while transitioning across different floor surfaces.

In conclusion, the third hypothesis was based on two assumptions. First, it was assumed that transitional acceleration of the whole body COM would be slower on carpeted floors. Second, it was assumed that friction demand would be decreased, especially at the push-off phase, on vinyl floors. Both of these assumptions were satisfied based on the observations that when older individuals transit from a living room covered with carpet to a kitchen/bathroom covered with vinyl, their probability of a slip-induced fall may be higher.

According to Bunterngchit et al. (2002), older people are less able to adjust their gait to reduce friction demand on a slippery floor surface. Thus, when the older individuals transit from a carpeted to vinyl floor, especially one which is contaminated by oil, water, or other slippery agents., their propensity for a slip-induced fall accident is greater.

5.2 Conclusions

The aging population is increasing and is expected to reach 70 million by 2030 (Centers for Disease Control and Prevention, 2000). Recent research (Hausdorff et al., 2001; Hornbrook et al., 1994) indicates that over a third of the older population is involved in slip and fall accidents each year that limit their mobility in daily activities (Alexander, Rivara, & Wolf, 1992). Additionally, a recent study conducted by Kochera (2002) found that the majority (55%) of fall accidents among older people occurred inside the house. Considering that older individuals spend most of their time inside the house, transitioning from carpet to vinyl and visa versa occurs often in their daily activities. Most of the residential floors in the United States are carpeted. It covers seventy percent of the total flooring market in the US and 1.6 billion square yards are shipped annually (Hedge, 2004; Davidsen, 1995). Although considerable indoor fall accidents are reported and transitioning between different floor surfaces could cause falls or fall-related injuries (Bunterngchit et al., 2000), few studies have investigated the effects of specific residential floor coverings on gait characteristics during transitioning.

The objective of the present study was to investigate whether transitioning between different floor surfaces affects gait parameters, especially for the senior population. The gait characteristics examined were required coefficient of friction (RCOF), heel contact velocity, transitional acceleration of the whole body center-of-mass (COM), step length, and toe clearance. In addition, a subjective evaluation was conducted after the experiment to examine the participants' fear of slipping and tripping during transitioning.

More specifically, this study was conducted to observe whether slip probability would be greater when transitioning from carpeted floor surfaces to vinyl floor surfaces, and also whether trip probability would be greater when transitioning from vinyl floor surfaces to carpeted floor surfaces.

A statistically significant increase in toe clearance was observed among older individuals as compared with younger counterparts. Even though the results of the present study indicated that they have lower probability of a trip-induced fall than younger individuals, it was found that older adults still have a shorter toe clearance on the carpet than on the vinyl, which would increase the probability of a trip-induced fall while they walk on the carpet.

Considering the slip propensity, older individuals are more vulnerable to a slip-induced fall while they are transitioning from a carpeted to vinyl floor surface than with other floor conditions. Furthermore, within the risky floor condition stated above, the propensity of a slip-induced fall increases on the vinyl shortly after transitioning from the carpet to the vinyl due to an increased friction demand, especially during the toe-off phase of the gait cycle rather than the heel contact phase. According to Bunterngchit (2000), older individuals can not adjust their gait to reduce friction demand on a slippery floor surface. Therefore, when older individuals transit from a carpeted floor surface to a slippery vinyl floor surface, the probability of a slip-induced fall would be higher, particularly at the toe-off phase.

In addition, one of the findings from the present study is that there are other factors which would influence the propensity of a slip-induced fall besides both the effects of the slower transitional acceleration of the whole body COM and an increase in RCOF. It was found that both heel contact velocity and step length were increased during transitioning from a carpet to a vinyl floor surface among older individuals, and in accordance with previous studies (Edmison et al., 2003; Karst et al., 1999; Myung R. et al., 1997; Winter, 1991), the increase in these two factors observed in this study might contribute to an increase in the probability of a slip-induced fall as well.

Older people are advised to exercise caution while transitioning between floor surfaces. The results of the present study indicate that transitioning between different floor surfaces changes the biomechanical parameters of gait, especially for the older individuals. Furthermore, care must be taken while installing indoor floor coverings, keeping the transitioning floor surfaces in homes and public places to a minimum, especially for older people. Although the increasing probability of a slip or trip accident was found throughout the changes in biomechanical gait parameters, older individuals who participated in this study were not aware of the danger posed by transitioning between floor surfaces as indicated by their subjective ratings. Therefore, older individuals should be made aware of the danger of slipping and tripping while transitioning between different floor surfaces, perhaps through use of a caution sign. For future research, it would be beneficial to investigate how much the caution sign influences the gait parameters and the perception of danger during transitioning. In addition, such a study could be extended to investigate the transitioning effect with various compliances of the pad and carpet, because the elasticity of floor coverings was found as one of the critical factors to the trip and slip-induced fall. In this study, only carpet and vinyl were investigated; however, future research could consider other floor coverings such as wood and ceramic tile.

5.3 Design Guidelines/Design Recommendation

1. Walking on a carpeted floor (trip-induced fall accidents)

If the carpet is installed by means of the stretch-in installing which is the common method to install a residential carpet, it should be securely attached without any gap between the carpet and ground. According to the results of this study, the older individuals have shorter toe clearance on the carpeted floor than the vinyl floor. Thus, the securely attached carpet would prevent the elderly individuals from a trip-induced fall accident. Additionally, the lowest toe clearance among the two age groups was 16mm for the younger individuals so that it satisfied the ADA & ASTM standards (i.e., changes in level up to 6mm; pile height should be less than 13mm). However it may be recommended to install low carpet piles with smaller level differences to prevent a possible trip-induced fall. Additionally, in terms of maintenance, care should be taken to ensure that there are no obstacles on the floor surface.

2. Subjective perception of slipping/tripping

Training could be considered to make people aware of the danger of slipping and tripping while transitioning between different floor surfaces. According to the results of this study, both age groups, young and old, underestimated the probability of a slip/trip-induced fall accident while transitioning between different floor surfaces. By helping people to become aware of possible fall accidents through training, the likelihood of the fall accidents while transitioning between different floor surfaces might be reduced.

3. Higher friction demand on the vinyl floor after the carpeted floor (slip-induced fall accidents)

In order to prevent a slip-induced fall accident, the friction demand should be reduced at the push-off phase on the vinyl floor, especially after transitioning from the carpeted floor to the vinyl floor. For example, transitioning from a living room covered with the carpet to a kitchen/bathroom covered with the vinyl could occur often in daily activities. The kitchen and bathroom are the places which are more likely to be contaminated by oil, water, etc. so the probability of the slip-induced fall accident increases. Thus, the contamination should be cleaned so that when people transition from the carpeted floor to the vinyl floor, they could have lower friction demand on the vinyl floor. In addition, such a slip-resistant vinyl floor covering or a rubber mat near the boundary between the carpet and vinyl floor could reduce the probability of the slip-induced fall accident.

5.4 Limitations and Assumptions

One of the limitations in this study was the identification of the ground level (on the Z axis). More specifically, the pile height of the carpet was not constant due to the soft fiber. Furthermore, the thickness of the carpet decreased throughout the study 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. The data collection for this experiment lasted around two months. Additionally, younger individuals participated in the first month, and the older individuals were studied in the second month. Therefore, older individuals might have been exposed to different floor conditions, such as a lower height of the carpet. Additionally, glue was heavily used directly under the carpet in order to attach it to the pad, and this contributed to contraction of the carpet and pad. The difference was approximately 10 mm. This might have led to the appearance of higher toe clearance among older participants. Furthermore, plywood (Figure 39) was used to keep a difference of 6mm or less between the levels of floor coverings, according to prescribed guidelines (US Architectural and Transportation Barriers Compliance Board, 2002; 2002 ASTM Book of Standards). Both vinyl and carpet surfaces were glued to the plywood and the glue may have caused distortion of the plywood thickness. This would also have affected the ground level of both vinyl and carpet surfaces. But in the analyses, it was assumed that ground level was constant throughout the experiment.

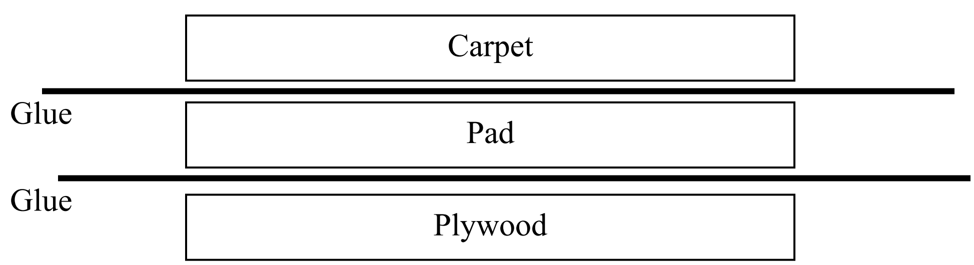

Figure 37. Install of carpeted floor using pad, plywood, and glue

Secondly, the safety harness used in the present study was quite heavy. It 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 seconds after the start of the participants' walking. Even so, this might have affected the data collected during the beginning of the gait cycle. Additionally, the safety harness might have led to a sense of safety and consequently might have altered the gait characteristics and the perceptions associated with risk of fallings.

Thirdly, grammar on the subjective evaluation might be one issue which could have swayed the results. For example, the first question was "My fear of slipping made me hesitating going forward during walking on the vinyl floor.” We should have used “hesitate” instead of “hesitating”.

Finally, the carpet specification (cut pile, Nylon, 1/10 gauge, 0.28 inch pile height, total weight 60oz./sq.yd., pad thickness 3/8 inch) used in this study was not a commonly specified carpet for the residential home in U.S. We failed to consult RBI (Reg Burnett Incorporated) International Carpet Consultants which is the largest carpet consulting firm in the U.S.; therefore, we chose the carpet in regard with guidelines for residential carpet such as ADA Accessibility Guidelines Americans with Disabilities Act (2002) and 2002 Annual Book of ASTM Standards (2002).

5.5 Summary of Future Research

Future studies might be extended to consider the following issues.

1. Angle of ankle

The older participants’ angle of ankle should be investigated, especially while they transition different floor surfaces. One finding of the present study is that the older individuals have higher toe clearance than the younger individuals (Figure 34). According to previous research (Lark, Buckley, Jones, & Sargeant, 2004), smaller and weaker joint range of movement (ROM) was observed among older people in comparison to younger individuals. Thus, if the older participants keep the smaller joint range of movement, especially when the toe clearance is measured, they might have the higher toe clearance due to the smaller joint range of movement. Therefore, future research could investigate whether the change in angle of ankle influences the toe clearance, especially while transitioning between different floor surfaces.

2. Safety Harness

The biomechanical gait parameters might be different if participants walk without a safety harness. In this study, all participants wore the fall-arresting harness to prevent themselves from a possible trip-induced fall while transitioning from a vinyl floor to a carpeted floor. However, any trip-induced fall was not observed during the transitioning; furthermore, the elderly individuals indicated higher toe clearance than their younger counterparts. As opposed to the initial expectation in this study, the probability of the trip-induced fall is quite low; thus, the safety harness would be unnecessary.

In addition, the participants' gait might be altered especially at the initiation of their gait due to the heavy harness in this study. Therefore, if they do not wear the heavy harness, participants might walk more naturally; therefore, results might be more reliable.

Moreover, the safety harness might have influenced participants' response about the perception and their gait pattern. The fall-arresting harness might have made the participants feel safe regarding a possible trip-induced fall accident. Thus, their gait pattern might be altered during the transitioning. Hence, future research might be conducted without the harness to investigate the gait parameters and the perception of tripping/slipping.

3. Carpet

The most commonly used residential carpet in U.S. should be utilized for the future research. The carpet specification (cut pile, Nylon, 1/10 gauge, 0.28 inch pile height, total weight 60oz./sq.yd., pad thickness 3/8 inch) in this study might not represent the commonly specified carpet for the residential home in U.S. although the present study adheres to the standards for the residential floor coverings such as ADA Accessibility Guidelines Americans with Disabilities Act (2002) and 2002 Annual Book of ASTM Standards (2002). For future research, we might contact a large carpet consulting firm in the U.S. such as RBI (Reg Burnett Incorporated) International Carpet Consultants to find the most commonly used residential carpet's specification in the United States. Furthermore, the carpet in the present study is usually used for both a residential and commercial floor (e.g., bank). Future research might utilize the carpet which is used mainly for the residential floor covering.

Additionally, for future research, the carpet might be installed without using the glue. According to the Air Force Center for Environmental Excellence (2004), installations using adhesive are appropriate for heavy rolling traffic conditions and a large area. On the other hand, the stretch-in installation is usually common in most residential settings. Therefore, the future research might consider the stretch-in installation instead of using the glue.

In the present study, carpet and vinyl were investigated regardless of other residential floor coverings such as hard wood, laminate, ceramic, etc. These floor coverings might also be investigated under the transitioning condition.

4. Participants

More comprehensive age range of participants should be considered, especially for the older participants. In the present study, the results indicated no age effects for most of the gait parameters. The older participants' average age was 70 years, which is younger in comparison to other previous research referred to in this study. Seventy nine percent of older participants in this study were between 65 and 75 years. The older participants in this study might not be representative of elderly population. Future research might broaden the older participants' age range.

5. Recovery vs. Initiation Dynamic

Recovery from a trip/slip might be considered for further research. The present study primarily focused on the initiation dynamic; thus, it investigated whether the transitioning initiated the slipping/tripping. While people try to recover from a slip or trip, they might also encounter a fall accident. Thus, recovery reaction might be investigated for future research, especially while transitioning across different floor surfaces.

6. Friction Demand at push-off phase

Half of the older participants (Group A) had significantly higher friction demand at their push-off phase; on the other hands, the rest of the older participants (Group B) had significantly lower friction demand at their push-off phase. Their age and medical history did not reveal any relationship between the two groups and the friction demands. Both groups show similar age; Group A (Mean 71, SD 4.7) and Group B (Mean 69, SD 9.4). In addition, the medical history questionnaire among the two groups showed no interesting information. Most of them were quite healthy and they did not have any history of serious disease. Future studies might be extended to discover other possible factors in regard to the higher/lower friction demands at push-off phase among the older participants.

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APPENDIX A: Personal Data and Medical History

Personal Data and Medical History
Grado Department of Industrial and Systems Engineering
Virginia Polytechnic Institute and State University

Research Title: The Effects of Transitioning Between Difference Floor Surfaces on Gait Characteristics of the Elderly

Date: _____/______/______

Persoal Data

Name :		Age :
Gender: Male( ) Female ( )	Height (cm):	Weight (kg):
In case of emergency contact information	Name:	Phone:

Medical History

1. Please check if susceptible to

( ) Shortness of breath ( ) Fatigue ( ) Headaches
( ) Dizziness ( ) Pain in arm, shoulder or chest

If you check any of the items above, please explain:

____

2. Please answer these question (Yes or No)

a. Have you ever had a heart attack? Yes ( ) No ( )
If so, please explain ____________________
b. Are you currently taking any type of medication? Yes ( ) No ( )
*If so, please explain*____________________
c. Have you had or do you now have any problems with your blood pressure? Yes ( ) No ( )
If so, please explain ____________________
d. In the last 6 month, have you had any back pain? Yes ( ) No ( )
*If so, please explain*____________________
e. Have you had or do you now have a hernia? Yes ( ) No ( )
*If so, please explain*____________________
f. Have you had or do you now have any problems with ankle, knee, or hip (surgery, injuries, and replacements)? Yes ( ) No ( )
If so, please explain ____________
g. Have you currently had osteoporosis or treated with osteoporosis? Yes ( ) No ( )
*If so, please explain*____________________
h. Have you had or do you now have any inner ear or balance problems? Yes ( ) No ( )
If so, please explain ____________________
i. Have you experienced slips and falls? Yes ( ) No ( )
If so, please explain ____________________
j. Have you had visual problems? Yes ( ) No ( )
If so, please explain ____________________

APPENDIX B: Subjective Evaluation

Subjective Evaluation
Grado Department of Industrial Systems Engineering
Virginia Polytechnic and Institute and State University

Name (Capital Letter)	
Age	
Gender	Male ( ) Female ( )
Date (mm/dd/yyyy)	

Please indicate how you felt during an experiment.

1. My fear of slipping made me hesitating going forward during walking on vinyl floor.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

2. My fear of tripping made me hesitating going forward during walking on carpeted floor.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3. My fear of slipping made me hesitating going forward during the transition from carpeted to vinyl floor.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

4. My fear of tripping made me hesitating going forward during the transition from vinyl to carpeted floor.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Are there any comments you would like to report?

APPENDIX C: Informed Consent Form

Informed Consent for Participants of Investigative Projects
Grado Department of Industrial and Systems Engineering
Virginia Tech

TITLE: The Effects of Transitioning Between Different Floor Surfaces on Gait Characteristics of the Elderly

PRINCIPAL INVESTIGATOR: Thurmon E. Lockhart Ph.D.

PURPOSE

Each year the rate of slip and fall accidents increases among older individuals. Most falls among the elderly occur indoors rather than outdoors, and of the falls that occur in the residential home, over 600,000 are due to floor covering materials. In particular, carpet and vinyl are common floor coverings used in the home today as the elderly often transition from carpet to vinyl and vice versa. When transitioning between two different floor surfaces, their gait will be adjusted to avoid a slip, trip, or fall. Many studies have assessed gait parameters of elderly individuals on either carpet or vinyl. Yet, few have studied the effect of transitioning between two different floor surfaces on the gait of older individuals.

This study will investigate the effect of transitioning between different floor coverings on the gait characteristics of the elderly.

PROCEDURE

The study will last one day consisting of a familiarization session and walking test session. You will be required to participate in the experiment and a familiarization session. Prior to this experiment, you will be given an opportunity to walk around the laboratory wearing a harness to familiarize yourself with the equipment (fall arresting rig), and floor surfaces. On the second session, you will be asked to transit between floor surfaces (i.e., transition from carpet to vinyl floor surface, transition from vinyl to carpet floor surface, transition from carpet to another carpet floor surface, and transition from vinyl to another vinyl floor surface). While you are walking along the path, please keep your eyes looking straight ahead and try to maintain the speed that you practiced.

After the familiarization session, you will be asked to walk on four different floor conditions. As you experienced in the familiarization session, the harness system will protect you if you slip or fall. The fall arresting rig will stop the motion of the tracking device and allow you to fall or slip only 3 or 4 inches.

RISKS OF PARTICIPATION

Minor back muscle sprain and possible ankle, knee and hip sprains, if you lose balance while walking on the floors.

BENEFITS and COMPENSATION

The benefits to you are a better understanding of floor surface slipperiness which could lead to preventing slips and falls. Additionally, monetary compensation will be provided ($10 per hour).

ANOYNMITY AND CONFIDENTIALITY

The data from this study will be kept strictly confidential. No data will be released to anyone but the principal investigator and graduate students involved in the project without written consent of the subject. Data will be identified by subject number.

FREEDOM TO WITHDRAW

You are free to withdraw at any time from the study for any reason. Circumstances may come up that the researcher will determine that you should not continue as a subject in the study. For example, an illness could be a reason to have the researchers stops your participation in the study.

APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Tech, and by the Grado Department of Industrial and Systems Engineering. You will receive a copy of this form to take with you.

SUBJECT PERMISSION

I have read the informed consent and fully understand the procedures and conditions of the project. I have had all my questions answered, and I hereby give my voluntary consent to be a participant in this research study. I agree to abide by the rules of the project. I understand that I may withdraw from the study at any time.

If I have questions, I will contact:

Principal Investigator: **Thurmon E. Lockhart**, Assistant Professor, Grado Department of Industrial and Systems Engineering, 231-9088.

Chairman, Institutional Review Board for Research Involving Human Subjects:
David Moore, 231-4991.

Signature of Subject:
____ Date: ____________

Signature of Project Director of his Authorized Representative:
____ Date: ____________

Signature of Witness of Oral Presentation:
____ Date: ____________