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Effects of Transitional Floor Surfaces and Visual Field Obstruction on Slips and Falls in the Elderly

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ABSTRACT

Among older persons falls are the leading cause of death resulting from injury. The research was conducted to investigate the effects of transitional floor surfaces and visual field obstruction on gait mechanisms in the elderly. Ten college students and ten elderly individuals participated in the experiment. The results indicated that walking on transitional floor surfaces and carrying a light load changed the elderly individuals biomechanical parameters of gait mechanisms more significantly than their younger counterparts in terms of slip severity. The result implies that the types of floor material placed in the homes of elderly individuals and in public places should minimize transitional floor surfaces and the elderly individuals should be made aware of the danger of slipping even when carrying a light load.

Keyword: Slips and Falls, Transitional Floor Surfaces

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1. Introduction

Among older persons, falls are becoming the leading cause of death resulting from injury in industry, public places, and homes. Jeong (1998) investigated work-related injuries in Korean industry. The study showed that, during the years 1991-1994, slips and falls were third leading cause of nonfatal injuries and fourth leading cause of death in Korean Industry. In terms of age, however, death occurred more frequently for older workers (over 45 years old). It is interesting to note some statistics related to slip and fall injury in the United States. The National Safety Council reported that in 1994, 13,300 Americans met their death by falling, of these deaths, 9,923 were people over 65 years of age (National Safety Council, 1995). Approximately 33% of the elderly population living at home will fall each year, and about 1 in 40 will be hospitalized (Campbell et al., 1981). Of those elderly admitted to the hospital after a fall, 5% to 25% will not survive for longer than three months (Brody, 1985), and only about 50% will survive for longer than a year (Overstall, 1978). In addition, falls and hip fractures among older persons rank as one of the most serious public health problems in the United States, with cost expected to escalate to over $16 billion by the year 2040 (Sattin, 1992; Cummings, Rubin, and Black, 1990).

A review of biomechanical investigations of gait mechanisms involved in walking for both young and elderly individuals has revealed that several functionally related gait mechanisms are different. In general, elderly individuals have a shorter step length and broader walking base with an increase in stance time and double support time (representing an adaptation to make their gait pattern safer) (Murray, et al., 1969; Gillis et al., 1986; Imms and Edholm, 1979; and Winter et al., 1990). However, this adaptation of safer gait pattern among elderly individuals may increase the possibility of slip-induced falls. Winter et al. (1990), reported that the heel velocity during the heel contact phase of the gait cycle was significantly higher for elderly individuals than younger individuals even though the walking velocity of older subjects was slower. This increase in heel velocity during a critical time of weight transfer might increase the possibility of slip-induced falls if the friction between the heel and the floor is reduced due to contamination of the floor surface. Lockhart et al. (1997) found that the Required Coefficient of Friction (RCOF) (i.e., the minimum coefficient of friction that must be available at the shoe-floor interface to prevent forward slipping at heel contact) was significantly higher for elderly individuals than for their younger counterparts. Furthermore, elderly individuals could not adjust their RCOF as well as younger subjects on very slippery floor surface (oily vinyl tile).

The RCOF also corresponds to the tangent of the angle between the leg and the vertical line (Sherman, 1986). In other words, increasing the step length (i.e. stride length) will increase RCOF (Perkins, 1978). Many researchers have observed that on slippery floor surfaces, subjects tended to shorten their stride length in order to reduce foot velocities and foot shear forces to maintain the body center of gravity so that a greater stability could be achieved (Cooper and Glassow, 1963; Ekkebus and Kelly, 1973; Swensen et al., 1992). Lockhart et al. (1997) found that younger subjects had longer stride lengths than older subjects and that floor slipperiness level affected stride length of both younger and older subjects.

Overstall et al. (1977), in a study of 240 subjects 60 years and over, revealed that the most common cause of falls was tripping (47%). The result is consistent with Sheldon's (1960) finding that the tripping (45%) was the major cause of accidental falls. The toe is last to leave the ground during normal level walking, and because of the angular relationship between the leg and foot the toe rises to no more than 2.5 cm above the ground (Winter, 1991). This toe clearance occurs at the most dangerous phase of the toe trajectory (when the horizontal velocity is at its maximum). Furthermore, the location of the center of gravity at this time is at or ahead of the toe of the contralateral support foot (Ruder, 1989; MacKinnon, 1990; Shimba, 1984). Thus, with the forward momentum of the body at that instant it is impossible to recover with the contralateral limb, and consequently, the only recovery that is possible is with the swing limb. Winter et al. (1990), in a study of walking pattern changes in the fit and healthy elderly, revealed that elderly subjects had shorter toe clearance than younger subjects.

Most current efforts to reduce the incidence of slip and fall accidents in elderly people have focused on physiological disabilities of the elderly. Changes in human sensory and motor abilities with age have been well documented (Tinetti and Speechley, 1989; Goldman, 1986; Cohn and Lasley, 1985; Tobis, Reinsh, Swanson, Byrd, and Scharf, 1985; Stelmach and Worringham, 1985). In addition, many studies have documented the decline of postural control (increased sway) due to sensory degradation among elderly individuals (Sheldon, 1963; Wollacott, Sumway-Cook and Nashner, 1982). This decline of postural control is believed to be an integrative process associated with a greater risk of falling (Isaacs, 1985; Brocklehurst et al., 1982; Overstall et al., 1977).

Compensatory postural control and the alerting process to an imminent fall may be initiated and maintained by proprioception, vision, and the vestibular system (Lacour, Vidal, and Xerri, 1983; Nashner, 1982). However, any age-related deterioration in visual, proprioceptive, and vestibular signals concerning balance may produce a central signal detection problem, and to detect a peripheral stimulus correctly, a longer sampling period might be necessary (Clarkson, 1978; Gottsdanker, 1980; Kroll and Clarkson, 1978; Loveless, 1980). In addition, inputs from these systems may not be conformable for the elderly. For example, visual information (such as walking on two different floor surfaces [slippery and non-slippery] with same color and contrast) may be in conflict with proprioceptive and vestibular information. Many studies have shown that sensory conflict conditions have a greater effect on the sway pattern for elderly subjects as compared to their younger counterparts (Woollacott, 1986; Teasdale, Stelmach, and Breunig, 1991; Redfern et al., 1997). Therefore, in a situation where sensory conflicts exist due to the environment (e.g. transitional floor surfaces), sensory degradation among elderly individuals may increase the likelihood of slip and fall accidents.

Recently, Redfern et al., (1997) reported that the postural stability of elderly individuals was more affected by moving visual environments than for younger individuals. They also concluded that postural instability was most likely due to a function of the sensitivity of older people to visual and proprioceptive inputs and of their difficulty in handling sensory conflicts to the postural control system. Thus, a combination of gait instability and sensory conflicts to the postural control system could influence the likelihood of slip and fall accidents. The degradation of sensitivity of older people to visual and proprioceptive inputs and their difficulty in handling sensory conflicts during dynamic visual environments such as walking on two different (slippery and non-slippery) floor surfaces with the same color and contrast may further increase the likelihood of slip and fall accidents by the elderly.

The effects of transitional floor surfaces and immediate visual field obstruction on biomechanical gait parameters have not been studied in the context of slips and falls in the elderly. The purpose of this study was to investigate the biomechanical parameters of gait mechanisms (such as the stride length, RCOF, and minimum toe clearance) during transition from a slippery to a non-slippery floor surface and vice versa. The effects of the obstruction of the immediate visual field of floor surface area on the biomechanical parameters of walking and ground reaction forces was also of interest in this experiment. It was hypothesized that the load condition (obstruction of immediate visual field of the floor) and the effect of transitional floor would affect the gait pattern of older subjects more than their younger counterparts in terms of slip severity.

2. Methods

2.1 Subjects

Ten college students (5 males and 5 females), and 10 elderly individuals (5 males and 5 females) participated in this experiment. The college students averaged 26 years of age, 166 cm in height, and 55 kg in weight. The elderly subjects (restricted to 65 years or older) averaged 72 years of age, 170 cm in height, and 77 kg in weight. They were compensated for their participation.

2.2 Apparatus

Two commonly used floor materials were used in this experiment: outdoor carpet and vinyl tile. The dynamic coefficient of friction for each surface of the floor material was measured using a standard 4.54 kg horizontal pull slipmeter with a rubber sole material and found to be: outdoor carpet (1.80) and soapy vinyl tile (0.13). For the load condition (i.e., the condition for the obstruction of visual field), an empty foam box (0.6kg in weight and 51cm x 46cm x 15cm in dimensions) was used. Walking trials were conducted on a circular track using an overhead fall arresting rig as shown in Figure 1. The circular wooden track was approximately 0.9 m wide and 20 m in circumference. The test surface of the simulated floor material covered approximately one-half of the circumference of the track. A fall arresting rig was used to protect subjects from falling during the experiment. The rig consists of a full-body parachute harness attached to an automated overhead suspension arm. The rig was designed to permit the subject to fall approximately 15 cm before arresting the fall and stopping the forward motion. To collect the three-dimensional posture of the subjects as they walked over the test surface, an ExpertVision Motion Analysis System was used with three cameras. Retro-reflectors were attached to the anatomically significant body positions of the subject: toe, heel, ankle, knee, and hip of the subject's left side (see Figure 2). Posture data were sampled and recorded at a rate of 180 Hz. The ground reaction forces of the subjects walking over the test surfaces were collected using two Bertec force plates. Force platform

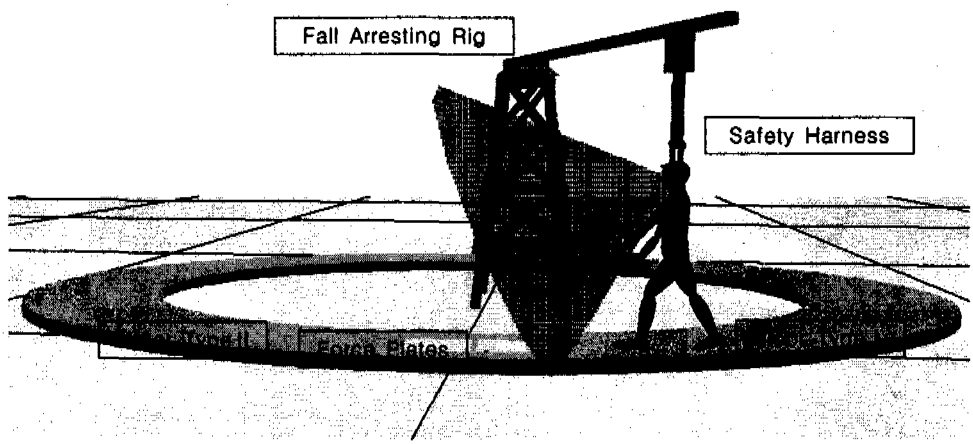

Figure 1. Field layout of the experiment including: Fall arresting rig, safety harness, force plates, transitional floor type materials (e.g., carpet to vinyl), and field of vision.

data were collected and recorded on a microcomputer at a rate of 180 Hz.

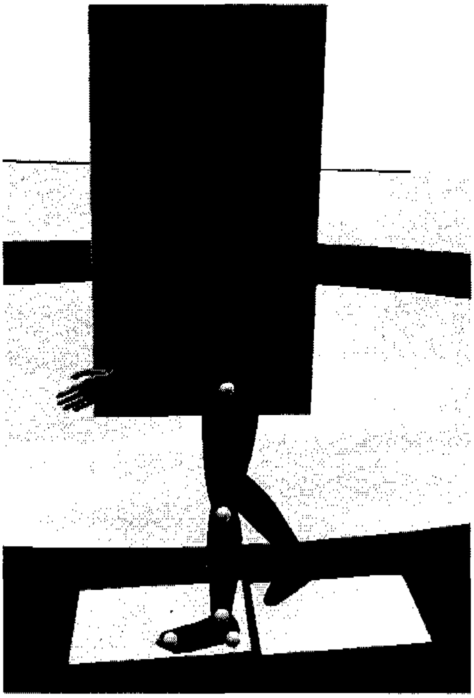

Figure 2. Retro-reflectors placement to the anatomically significant body positions.

2.3 Procedure

The subjects attended a familiarization session before the experiment. During this session, the fall arresting system and the walking conditions were introduced to the subjects. During the experiment, the subjects walked across each floor (combination of 4 floor levels) for 5 minutes with and without the load (two load conditions). Within the 5 minute trial, 2 robust measurements of subject's posture and ground reaction force were recorded. Walking velocity for the experiment was based on cadence of 100 steps per minute (average cadence based on Meserlian (1995)). A metronome provided an audible cue of 100 beats per minute. To reduce the learning effect, each subject walked on a different floor surface on each of four different days separated by at least one day. Trials were ordered based on decreasing DCOF (carpet to vinyl tile) values with the outdoor carpet surface on the first day, soapy vinyl tile surface on second day, combination of outdoor carpet - soapy vinyl tile surface on third day, and finally, combination of soapy vinyl tile surface - outdoor carpet surface on the fourth day. The first two floor surfaces provided base line measurements for the gait parameters, and the last two combinations of floor surfaces provided information concerning the effect of transitional floor surfaces on slips. Therefore, for each trial, a subject walked total of 10 minutes (5 minutes for each load condition). Standard shoes with rubber soles were supplied to all subjects to maintain constant COF levels.

2.4 Treatment of the Data

The converted coordinate data from the Motion Analysis and LabView System were smoothed by utilizing digital filtering techniques (Butterworth fourth-order, zero lag low-pass). Residual analyses of the difference between filtered and unfiltered signals over three different ranges of cutoff frequencies (6, 10, and 12 Hz) determined 6 Hz as the preferred cutoff frequency.

The gait parameters and ground reaction force data were analyzed by utilizing a 2 x 2 x 4 x 2 (age x gender x floor x load) four-way repeated measures design with the RCOF, stride length (SL) and minimum toe clearance (MTC) as dependent variables. Descriptive and inferential statistical analyses were performed on a PC using SAS statistical package (SAS Institute). A computer algorithm was written in the Mathematica 3.0 software to objectively assess SL, and MTC.

3. Results

Stride length (SL) was calculated from the difference between consecutive positions of the heel contacting the floor. The younger subject's SL (127.60 cm) was longer, on the average ($p<0.01$), than the SL of older subjects (115.29 cm). Also, SL was

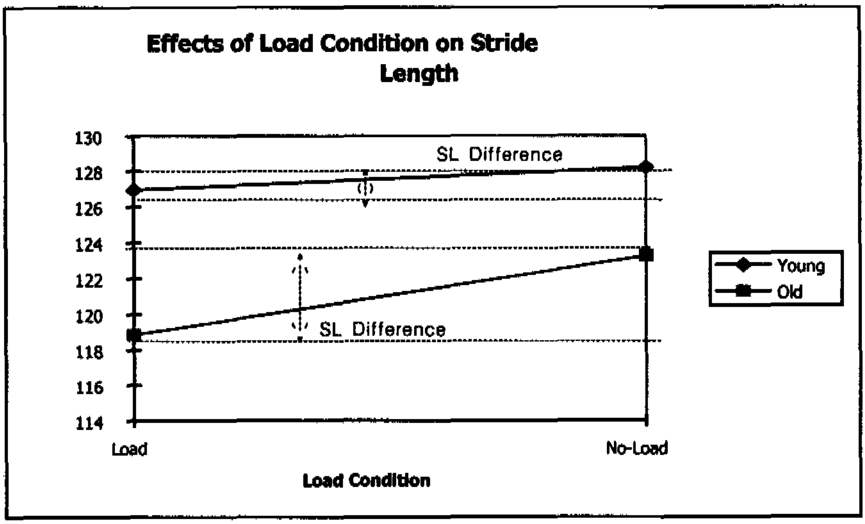

Figure 3. The effects of the load condition on stride length of young and old subjects.

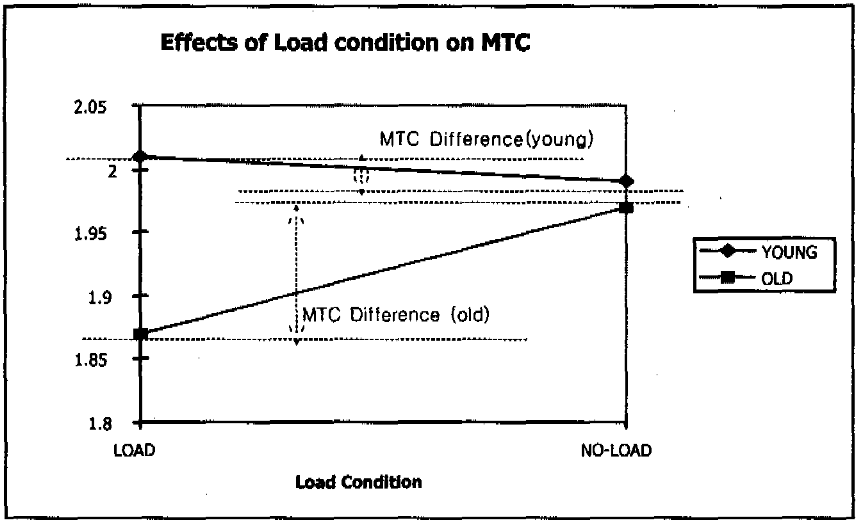

Figure 4. The effects of the load condition on MTC of young and old subjects.

longer for the no load condition (125.76 cm) than the load condition (122.89 cm). The SL effect of load levels upon age group indicated that the SL of young individuals changed less (1.28 cm) than for older individuals SL (4.44 cm) (Figure 3).

The required coefficient of friction (RCOF) was obtained by dividing the horizontal ground reaction force by the vertical ground reaction force at the heel contact phase of the gait cycle (peak 3 as defined by Perkins and Wilson, 1983). Overall, there was no significant difference between young and old individuals in terms of RCOF. However, analysis of transitional floor effects between the base line floor (carpet) and transitional floor (carpet to vinyl) surfaces indicated significant RCOF differences ($p<0.01$) between young and old subject (young: 0.12, old: 0.14 on carpet to vinyl transitional floor level). In addition, RCOF was higher for load condition (0.16) than the no load condition (0.15) for the elderly individuals.

The overall relationship between the stride length and RCOF was quite low in this study ($r=0.27$, $p<0.001$). Furthermore, the correlation between the stride length and RCOF ($r=0.23$, $p<0.001$) for older individuals was lower than for their younger counterparts ($r=0.38$, $p<0.001$).

The minimum toe clearance (MTC) was calculated utilizing toe coordinates during the mid stride of the gait cycle to provide information concerning the tripping hazard. The younger subject's

MTC (2.00 cm) was higher, on the average ($p<0.01$), than the MTC of older subjects (1.92 cm). Also, MTC was higher for no load condition (1.98 cm) than the load condition (1.94 cm). However, the MTC effect of load levels upon age group indicated that the younger individuals MTC changed less (0.02 cm) than older individuals MTC (0.10 cm) (Figure 4). In addition, male subjects MTC (2.10 cm) was higher, on the average ($p<0.01$), than the MTC of female subjects (1.81 cm).

4. Discussion

This research was undertaken to provide a better understanding of how transitional effects of floor surfaces and obstruction of the immediate visual field of the floor surface area affect biomechanical parameters of walking and ground reaction forces. Consistent with recent findings of Winter et al. (1990), younger subjects' stride length (SL) was longer than older subjects. SL was also longer for the no load condition than for the load condition, and younger subjects SL changed less than that of older subjects (during the load condition). These data suggest that subjects changed their SL in order to compensate for the loss of immediate visual field information regarding the floor surface area and/or awkward laden gait (arms holding an object). However, it seems that the load condition affected the gait pattern (SL) of older subjects more than their younger counterparts.

Overall, there was no significant difference between young and older individuals in terms of the required coefficient of friction (RCOF).

However, the analysis of transitional floor effect (between the base line floor and transitional floor levels) indicated significant RCOF differences between young and old subjects. This result suggests that the elderly subjects may have encountered more difficulty in making gait (COF) adjustment due to the sensory degradation and the sensitivity of older people to visual and proprioceptive inputs during dynamic visual environments such as walking on two different (slippery and non-slippery) floor surfaces with the same color and contrast. Furthermore, elderly individuals RCOF of outdoor carpet to soapy vinyl tile floor level was higher than the available dynamic coefficient of friction (ADCOF). This potentially dangerous situation (due to forward slipping tendency at heel contact when RCOF exceeds the

ADCOF) may have resulted when elderly individuals tried to adjust their gait pattern to achieve greater stability (i.e., shorter stride length). RCOF was also higher for the load condition than the no load condition suggesting gait pattern adjustment due to the effect of the load conditions.

Previous research evaluating RCOF and SL (Perkins, 1978) revealed that RCOF increased with stride length during level walking. Contrary to Perkins study, the overall relationship between the stride length and RCOF was quite low in this study. Furthermore, the correlation between the stride length and RCOF for older individuals was lower than for their younger counterparts (i.e., elderly individuals had shorter stride length and higher RCOF). In general, the RCOF is task and task performance method dependent. In other words, for tasks such as pushing or pulling carts, the RCOF may be higher than normal level walking. However, the correlation between stride length and RCOF in this study suggests that there may be some other factors influencing the RCOF. One possible contributing factor to low correlation between the stride length and RCOF for elderly individuals may be due to the higher heel velocity. Winter (1990) reported higher heel contact velocity in the horizontal direction for the elderly individuals even though walking velocity was slower than their younger counterparts. Higher heel velocity in the horizontal direction may increase horizontal force output and consequently, may increase RCOF.

In terms of minimum toe clearance (MTC), consistent with recent findings of Winter et al. (1990), younger subjects had higher MTC than older subjects. Furthermore, the MTC was higher for no load condition than the load condition. As discussed previously, Overstall et al., (1977) revealed that the most common cause of fall for the elderly individuals was due to tripping (47%). The MTC result suggests that the during the load condition (light load) this tripping hazard is increased for elderly individuals due to the feet not being lifted high as during normal level walking.

One implication of the results of present study is that the type of floors (especially the transitional floor surfaces) and carrying a light load may increase the possibility of slip induced falls. The environment has been implicated in one third to one half of all falls or fall-related injuries (Lucht, 1971; Haddon and Baker, 1981). In daily activities, transitions are made between very different floor surfaces. For example, walking from a carpeted area to a tiled bathroom area or a linoleum kitchen area. In addition, carrying a light load such as pillows and blankets is a common daily routine for elderly individuals. The results of present study indicated that walking on transitional floor surfaces and carrying a light load changed the elderly individuals biomechanical parameters of gait mechanisms more significantly than their younger counterparts in terms of slip and fall severity. This implies that the types of floors placed in the homes of elderly individuals and in public places should minimize transitional floor surfaces. The elderly individuals should be made aware of the danger of slipping even when carrying a light load such as pillows.

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