The Effects of Age on Stress and The Biomechanics of Slips and Falls

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ABSTRACT

A study was conducted to investigate if stress associated with a fear of falling contributes to the increased incidents of falls among older adults. The investigation compared physiological stress, with biomechanical parameters of walking for twenty-eight participants in two age groups: (18-35) and (65 or older). Both age groups were evaluated while walking over dry and slippery floor surfaces. Biomechanical parameters included: step length, required coefficient of friction (RCOF), slip distance, and heel contact velocity.

Overall, the results indicated that there were differences between older and younger adult’s biomechanical parameters of walking, and their physiological stress associated with an inadvertent slip. Younger adult’s normal RCOF was higher and their normal step length was longer compared to older adults. Older adult’s stress level after a slip was significantly higher than younger adults. Furthermore, younger and older adults modified their step length differently to avoid slipping, when walking over the slippery floor surface. It was concluded that for the participants in this study some anxiety and stress might be beneficial in reducing the occurrence of inadvertent slips and falls due to an increased awareness of their external environment.

Running Title: Stress and the Biomechanics of Slips and Falls

Key Words: Required Coefficient of Friction, Heel Contact Velocity, Step Length, Stress
The Effects of Age on Stress and The Biomechanics of Slips and Falls.
Lecture proposal: Thomas W. Davis and Thurmon E. Lockhart

INTRODUCTION
Injuries associated with slip and fall accidents continue to pose a significant problem to society, both in terms of human suffering and economic losses. There are an estimated 300,000 disabling injuries each year in the American workforce, resulting in 1,400 worker deaths. Slips, trips, and falls account for 15 to 20 percent of all workers’ compensation cost (Center for Disease Control, 2000). Also, the Center for Disease Control (2000) reported that older adults are hospitalized for fall-related injuries five times more often than they are for injuries from other causes. In addition, research has shown that the populations of older adults who have experienced a previous fall are 60-70% more likely to suffer future falls versus those who have not fallen previously (Carpenter, Frank, Silcher, and Peysar, 2001). This observation highlights the relationship between fear of falling and balance control. Fear of falling may be a result of deteriorated balance capabilities and decreased balance confidence. Alternatively, fear of falling may influence changes in strategy or execution of postural control, which could be indirectly related to decreased postural performance and gait characteristics that can negatively impact slip induced falls (Carpenter, Frank, Silcher, and Peysar, 2001).

Gait changes associated with aging may affect the outcome of slip and fall accidents. A review of the biomechanical literature indicates that there are several differences in the gait characteristics of older and younger people. Older adults tend to walk slower, have a shorter step length, and a broader walking base. This results in a gait cycle with a longer stance or double support time (Lockhart, Smith, Woldstad, and Lee, 2000a). On slippery floor surfaces, people of all ages tend to shorten their step length to reduce horizontal foot forces to reduce the likelihood of slipping (Cooper and Glaslow, 1963; Llewellyn and Nevola, 1992). Most slips that lead to falls occur when the frictional force (Fμ) opposing the movement of the foot is less than the shear force (Fh) of the foot immediately after the heel contacts the floor (Perkins and Wilson, 1983). Particularly, at the heel contact phase of the gait cycle, there is a forward thrust component of force on the swing foot against the floor. This results in a forward horizontal shear force (Fh) of the ground against the heel. Moreover, a vertical force (Fv) results as the body weight and the downward momentum of the swing foot (and leg) make contact against the ground (Lockhart et al., 2000a). The ratio (Fh/Fv) has been used to identify where in the gait cycle a slip is most likely to occur (slip initiation). Analyzing this ratio, Perkins found that dangerous forward slips were most likely to occur shortly after (< 50 –100 ms) the heel contact phase of the gait cycle (peak 3). Currently this ratio (Fh/Fv at peak 3) is termed “Required Coefficient of Friction (RCOF)” (Redfern and Andres, 1984).

Research indicates that older adults who fell previously modify their gait patterns (shorter step lengths, slower heel contact velocity, and reduced RCOF) in an attempt not to fall (Lockhart, 1997). This change in gait characteristics suggests that older adults who have previously fallen should be less likely to fall. However, epidemiology findings clearly indicate that this is not the case. Therefore, the relationship between older adults...
who have fallen versus older adults who have not fallen needs to be examined. Additionally, the effects of stress associated with a fear of falling needs to be investigated to identify if stress is a factor that contributes to older adults who have fallen being more likely to fall again. Therefore, in order to effectively reduce slip and fall accidents in society and industry, there is a need to examine the behavior and psychological characteristics of humans walking on a slippery floor surface to ascertain if there is a relationship between stress, biomechanics of the gait, and the occurrence of slips and falls. It was hypothesized: (1) older adults would have a higher level of stress after slipping and/or falling than their younger counterparts. (2) Older adults would have a higher level of stress when standing still on the test track looking at the known slippery floor surface prior to walking back over it than their younger counterparts. (3) Older adults would modify their gait characteristics in a way that would adversely affect slip-induced falls, specifically higher heel contact velocity and higher RCOF.

METHOD

Fourteen younger (18-35 years) adults (7 male and 7 female) – [mean height 172.81 cm] and [mean weight 72.52 Kg] and 14 older (65 and over) adults (7 male and 7 female) – [mean height 168.49 cm] and [mean weight 72.59 Kg] participated in this experiment. Prior to participating in the experiment, participants were required to have had a medical exam to ensure that they had no physical problems, which may lead to further injury from participation in the study. During the experiment, the participants walked across the baseline floor surface (vinyl tile) for 10 – 15 minutes. Within a subsequent 10-minute session, slippery conditions were randomly introduced by changing the floor surface utilizing a manual floor changer, and measurement of the participant’s posture and ground reaction forces were recorded. First trial data was used for the data analysis. These parameters were measured utilizing a 6-camera 3-D motion analysis system, 2-force plates, analogue-to-digital converter and microcomputer, and a fall arresting rig. Physiological stress level was measured through Salivary Amylase (SA). Amylase is an enzyme that hydrolyzes starch to oligosaccharides and then slowly to maltose and glucose. Salivary amylase concentrations are predictive of plasma catecholamine levels and can be used as a measure of stress (Chatterton, Ellman, Hudgens, Lu, & Vogelsong, 1996). Four saliva samples were collected from each participant [baseline, pre-slip, slip, and post-slip] as follows: baseline was collected prior to the participants walking on the test track; pre-slip was collected prior to introducing the slippery floor surface; slip was collected immediately after the participants slipped; and post-slip was collected as the participants stood on the test track looking at the floor surface they previously slipped on prior to starting the adjusted gait phase of the study. Additionally, for the baseline and pre-slip samples, the participants were not aware of the alternate slippery floor surface. Standard shoes with rubber soles were supplied to each participant to control for coefficient of friction (COF). Normal heel contact velocity and adjusted heel contact were calculated as follows: The horizontal velocity (x) of the heel before the heel contacts the floor was measured. The position data was used to calculate the heel velocity. \( V_x \) of a sequence of data was obtained using the finite difference method. The linear finite difference equation is using the difference of the foot displacements of last 1/120 second (\( \Delta t \)) before and after the heel contact divided by the elapsed time (2\( \Delta t \)). Normal RCOF was calculated from the ratio between the horizontal
and vertical ground reaction force ($F_h/F_v$) was calculated at peak 3 (Perkins, 1978) on the non-oily vinyl floor surface with the Lab View data collection software system. This ratio indicates where in the walking step a slip is most likely to occur (slip initiation). Adjusted RCOF was calculated from the graphed kinematic data (Figure 1). The ($F_x$) for force plate two was used to determine the point of heel contact, and based on this point of contact, the relationship between the horizontal and vertical ground reaction forces were calculated by the ratio ($F_h/F_x$) for force plate two. Slip Distance (SD): The horizontal distance traveled by the foot after contact with the floor was measured utilizing the Lab View data collection software system. Saliva samples were sent to the Department of Ob/GYN at Northwestern University to be analyzed. Measurement of amylase concentration in saliva includes the observation of chemical color changes according to standard photometric procedures developed by Northwestern (Chatterton et al., 1996). The concentration of amylase is then determined from a table of values relating time and temperature to amylase activity. The SA levels were analyzed using a 2x2 two-way (age x gender) multivariate analysis of variance (MANOVA). Additionally, separate ANOVA was performed on all significant variables. Dependent measures (e.g., heel contact velocity, RCOF, slip distance, step length) were analyzed by 2x2 two-way (age x gender) repeated measures analyses of variance (ANOVA).

RESULTS

In the interest of space, only age related effects will be presented. Consistent with previous finding (Lockhart, 1997), results show that older adults reduced their step length. In general, the result of the two-way ANOVA indicated a statistically significant ($p \leq 0.05$) SL difference between the age groups: normal gait ($F_{3, 24} = 3.1702, p = 0.0139$) and adjusted gait ($F_{3, 24} = 4.9265, p = 0.0362$). Additionally, there was a significant difference between the two groups normal gait RCOF ($F_{3, 24} = 11.0666, p = 0.0028$) however, the adjusted gait RCOF was not significantly different between the two age groups ($F_{3, 24} = 0.0379, p = 0.8473$). Although older adults heel contact velocity was slower than their younger counterpart, the two-way ANOVA indicated no statistically significant difference between the age groups: normal gait ($F_{3, 24} = 1.2450, p = 0.2756$) and adjusted gait ($F_{3, 24} = 1.8841, p = 0.1831$). Table 1 summarizes the mean values and standard deviations for each of the biomechanical dependent measures as a function of age.

Additionally, the results of the SA test indicated that older adults had a statistically significantly higher stress level after a slip than their younger counterpart ($F_{3, 24} = 5.7894, p = 0.0242$) as shown in Figure 2. Additionally, older adults had a statistically significant higher stress level than their younger counterpart prior to walking over the known slippery floor surface [adjusted gait] ($F_{3, 24} = 6.4170, p = 0.0183$) as shown in Figure 3. As expected, there was no statistically significant difference between the two groups pre-slip stress level ($F_{3, 24} = 0.5309, p = 0.4733$) or baseline stress level ($F_{3, 24} = 2.1954, p = 0.1514$). Figure 4 illustrates the difference in the groups SA mean level for each measurement.
DISCUSSION

The purpose of this study was to investigate mechanisms associated with slips and falls among older adults. Specifically, this study analyzed factors influencing the initiation phase of inadvertent slips and/or falls utilizing friction demand characteristics of old and young adults. Additionally, the effects of age on stress level after incurring a slip and/or fall, and the effects of stress on gait characteristics were evaluated.

The findings from this study indicated that both younger and older adults are susceptible to inadvertent slips when a slippery floor surface is randomly introduced. However, older adults had a significantly higher-level of stress as measured by salivary amylase. Salivary amylase level was significantly related to slip severity, and should increase as slip distance increase. However, this was not the case, older adults slipped less than younger adults, but their salivary amylase level was higher. This may be due to other factors; one factor may be a fear of falling. Previous studies indicated that older adults are more fearful of falling than younger adults (Brown et. al, 2002; Lachman et. al, 1998; Tinetti et. al, 1988).

Additionally, older adults significantly shorten their step length while walking across the slippery floor surface compared to younger adults. However, their friction demand characteristics were similar to that of younger adults. This may be due to other factors (e.g., muscle degradation, push off torque, hamstring activation rate,). Lockhart et. al. (2000a), indicated that the deterioration of lower extremity muscular strength among elderly adults affected the process of initiation and recovery of inadvertent slips and falls. Winter et. al. (1990), indicated that hamstring activation rate is related to heel contact velocity, and may affect the initiation process of inadvertent slips and falls. Additionally, Khuvasanont and Lockhart (2002), indicated that older adults push off torque was lower than younger adults, and may affect the initiation phase of inadvertent slips and falls.

In addition, it should be noted that the older adults in this study appeared to be in superb physical condition. Most of them indicated that they exercised daily (i.e., walking, jogging, water aerobics, weight lifting). However, they had a significantly higher level of stress after a slip than younger adults. It can be suggested that older adults
who are living in assisted living environments would have an even higher level of stress. Therefore, additional studies should be conducted to investigate the effects of stress on the initiation and recovery of inadvertent slips and falls in the population of older adults who are sedentary or less active than the older adults in this study.

In conclusion, the results suggest that for the participants in this study, some stress may be beneficial, in that, it lead to an increased awareness of their surroundings, and appeared to help facilitate appropriate gait adaptation when hazardous conditions were encountered. Additionally, based on the observation of older participants in this study, regular exercise and muscle strengthening may play a vital role in helping older adults prevent slip and fall accidents, or reduce the severity of slip and fall accidents.

ACKNOWLEDGEMENTS

This publication was supported by Cooperative Agreement Number UR6/CCU617968 from Centers for Disease Control and Prevention (CDC/NIOSH, K01-OH07450), and Jeffress Foundation (J604). Its contents are solely the responsibility of the authors and do not necessarily represent the official views of CDC/NIOSH and Jeffress Foundation.

The authors would like to thank the Army Research Laboratory’s Human Research and Engineering Directorate for its support of this research.

The contributions of Tanavadee Khuvasanont, Jeremy Spaulding, and Sukwon Kim are gratefully acknowledged.

REFERENCES


Figure 1. Adjusted gait kinematic profile data.

Table 1. Summary of ANOVA Means and Standard Deviations.

<table>
<thead>
<tr>
<th>Variables (unit)</th>
<th>Young Mean (SD)</th>
<th>Old Mean (SD)</th>
<th>P- Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Step Length Normal Gait (cm)</td>
<td>66.98 (6.03)</td>
<td>61.43 (4.95)</td>
<td>0.0139</td>
</tr>
<tr>
<td>*Step Length Adjusted Gait (cm)</td>
<td>64.19 (20.00)</td>
<td>51.16 (8.76)</td>
<td>0.0362</td>
</tr>
<tr>
<td>*RCOF Normal Gait</td>
<td>0.18 (0.02)</td>
<td>0.15 (0.03)</td>
<td>0.0028</td>
</tr>
<tr>
<td>RCOF Adjusted Gait</td>
<td>0.07 (0.04)</td>
<td>0.06 (0.03)</td>
<td>0.8473</td>
</tr>
<tr>
<td>Heel Velocity Normal Gait (cm/s)</td>
<td>69.74 (13.42)</td>
<td>60.91 (13.06)</td>
<td>0.2756</td>
</tr>
<tr>
<td>Heel Velocity Adjusted Gait (cm/s)</td>
<td>19.58 (16.49)</td>
<td>12.35 (12.73)</td>
<td>0.1831</td>
</tr>
<tr>
<td>Slip Distance 1 (cm)</td>
<td>1.93 (1.49)</td>
<td>1.382 (1.54)</td>
<td>0.3784</td>
</tr>
<tr>
<td>*Slip Distance 2 (cm)</td>
<td>8.08 (5.97)</td>
<td>3.97 (4.34)</td>
<td>0.0559</td>
</tr>
<tr>
<td>Total Slip Distance (cm)</td>
<td>10.73 (7.27)</td>
<td>5.35 (5.60)</td>
<td>0.0757</td>
</tr>
</tbody>
</table>

*Denotes significant differences between age groups.
Figure 2. Age effect on SA slip level.

Figure 3. Age effect on SA post-slip level.
Figure 4. Age effect on overall SA means.