The influence of medio-lateral force in the calculation of required coefficient of friction (RCOF) during level walking in older people

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Abstract: Slipping is one of the major causes of falls in the elderly. The risk of slipping is often quantified by calculating the Required Coefficient of Friction (RCOF), the ratio of the horizontal and vertical force components applied to the ground. All ground reaction forces (GRF) can affect RCOF, however medio-lateral force ($F_x$) has often been ignored due to its low magnitude. A recent paper showed a significant effect of $F_x$ on RCOF in young as well as older adults up to the age of 60 years (Chang, Chang & Matz 2011). The risk of falling is significantly increased in older adults over the age of 65 years. The aim of this study was to investigate the effect of $F_x$ in the RCOF in older adults over 65 years of age. GRF data were recorded during continuous walking at self-selected normal and fast speeds. At both walking speeds there was a significant difference in the RCOF calculations in both young and older adults. The RCOF values were in general higher for all groups when including $F_x$ with a larger increase found for older people at both walking velocities.

Practitioner Summary: The medio-lateral ground reaction force ($F_x$) has often been ignored when calculating the required coefficient of friction. Its significant effect has recently been discussed and this study demonstrated the importance of including $F_x$ when calculating frictional properties of level walking in older adults over the age of 65 years. When quantifying gait characteristics and estimating falls related to slipping it is of importance to include all three ground reaction forces.

Keywords: Friction, slipping, calculation, walking velocity, ageing

1. Introduction

Worldwide, fall accidents are the second leading cause of fatalities. Approximately one third of community dwelling people over 65 years will fall at least once per year with the number of falls increasing with age and frailty (Blake et al. 1988; Gabell, Simons & Nayak 1985; Australian Institute 2004; Prudham & Evans 1981; World Health Organization 2007). Falls are the leading cause of accidental death in people over 75 years of age (Lilley, Arie & Chilver 1988; Buczek et al. 1990). In Australia the most common causes of injuries requiring hospitalisation are falls on the same level due to tripping, slipping or stumbling (Bradley 2013).

Walking is regarded safe when the available friction of the surface (COF, coefficient of friction) is greater than the ratio of the horizontal and vertical force components applied to the ground, the required coefficient of friction (RCOF). All three ground reaction forces (Vertical, $F_z$; Anterior-posterior, $F_y$; Medial-lateral, $F_x$) can affect RCOF, however there has been conflicting reports in the literature about the effect of $F_x$ on RCOF due to its low magnitude compared to the other two forces. Perkins (1978) presented RCOF as a measurement of slipping propensity without medio-lateral forces ($F_x$) while other authors included $F_x$ in the RCOF calculation (Buczek et al. 1990). However, the effect of $F_x$ has been shown to be significant in both young and older people of 60 years of age (Chang, Chang & Matz 2011). Studies on elderly fallers have also found that force increases in the medio-lateral direction (Gavin & Vardaxis 2002; Vardaxis, Cooper & Koceja 2001).

As people over 65 years of age have clearly been identified to be at a high risk of falls and with fallers identified to have increased $F_x$ forces, it is of interest to further investigate the underlying factors of slipping propensity in this cohort. Chang at al. (2011) identified the significant effects of $F_x$ in the RCOF calculation in people aged up to 60 years. This study will extend on Chang et al.’s findings by investigating the effect of $F_x$ in a larger sample group of older people aged over 65 years. The aim of this study is, therefore, to examine the effect of $F_x$ on RCOF during continuous walking in people over 65 years of age. A secondary aim is to investigate RCOF differences due to walking speed changes and between males and females.
1.1 Slipping

Slipping has been defined as “a sudden loss of grip, often in the presence of liquid or solid contaminants and resulting in sliding of the foot on a surface due to a lower coefficient of friction that that required for the momentary activity” (Grönqvist, R 1999). Slipping is important when analysing causality and prevention of falls. It has been reported that slips account for 25% of fall-related injuries (Berg et al. 1997). It has also been stated that 67% and 32% of the falls are caused by slips and trips in the elderly and young populations respectively (Lloyd & Stevenson 1992). Foot slippage has been reported to be the most common unforeseen factor triggering falls on the same level (Andersson and Lagerlöf 1983; Courtney et al. 2001).

1.1.1 Slipping in older people

Elderly gait has been described to differ from that of young adults in many ways such as lower walking velocity, increased step width, decreased step length, decreased cadence and increased time spent in double support during gait (Dobbs et al. 1993; Elble et al. 1991; Gavin & Vardaxis 2002; Grabiner, Biswas & Grabiner 2001; Imms & Edholm 1981; Prince et al. 1997; Winter 1991; Woo et al. 1995). These age related changes are present at both normal and fast self-selected walking velocities. Some gait changes associated with aging, such as a high horizontal heel velocity or a slow transition of the body's centre of mass (COM) may affect the initiation of slip-induced falls (Lockhart et al. 2003).

Lockhart et al. (2002) reported that the average RCOF in the elderly was not significantly different to that of young and middle-aged adults. Burnfield and Powers (2002) studied the effect of age and gender on the RCOF and found that females had higher RCOF values when walking at slow speed whilst men had higher values when walking at faster speeds. Kim et al. (2005) showed that older adults walked with a slower velocity and a decreased heel contact velocity, and thus created a lower RCOF when compared to young adults. Another study on both dry and randomly slippery surfaces reported no difference between the RCOF values of young and older adults. (Lockhart, Woldstad & Smith 2003). Maki et al. (1994) studied quiet standing in the elderly and found that lateral stability was decreased in elderly fallers. Vardaxis et al. (2001) stated that the older subjects had increased amplitude and variability in the peak medio-lateral ground reaction forces during walking.

It is clear from past research that medio-lateral forces play a role in the gait of older adults, especially those prone to falling. It is of interest to further investigate the effect of Fx during gait, including slipping propensity.

1.1.2 Calculation of Required Coefficient of Friction (RCOF)

The calculation of the required coefficient of friction (RCOF) as a measurement of slipperiness was discussed by Perkins in the 1970s (Perkins 1978). Perkins proposed that the ratio of horizontal force and vertical force was the way to quantify friction and to define if a slip is likely to happen. Perkins talked about the “Horizontal force” yet in reality he only used the antero-posterior force (Fx). It was suggested that the contribution of the medio-lateral force (Fx) was relatively small to the horizontal anterior-posterior force when walking (Perkins 1978, p. 73) and thus could be ignored. Many subsequent studies ignored Fx.

However, some authors have started to add the medio-lateral (Fx) force to the calculation (Buczek et al. 1990, Grönqvist et al. 2003), whilst in many cases it is not clearly identified if the Fx has been included in the calculation (Kim et al. 2005, Lockhart et al., 2003). Chang et al. (2011) studied the effect of the Fx at different walking velocities and found a significant difference for every subject at every walking condition, with the medio-lateral force component increasing the RCOF value by more than 10% in 7.2 % of all foot-strikes. This research included 40 people (equal number of both genders) divided in to three age groups. The group of older people included 13 people, aged 59.5 ± 3.48 years. It is of importance to further investigate Fx effects on RCOF in a larger group of older people (65 years and over) not included in the previous research.

Increased age relates to an increased risk of falls and changes in medio-lateral forces have been linked to falling in older adults. This study will investigate the role of Fx in the RCOF calculation in older people walking at two different speeds.
2. Methodology

One hundred participants, 50 healthy young (28.7 ± 4.7 years) and 50 healthy older (72.0 ± 5.2 years) adults with no falls history; equal number of both genders, took part in the study. The participants wore their own comfortable walking shoes, all with flat and rounded heel. They walked on a round carpet covered walkway continuously for 30 minutes at their self-selected normal speed and 15 min at self-selected fast walking speed. Two AMTI® force plates embedded in the middle of the walkway allowed for three dimensional ground reaction forces (GRF) to be recorded at 4000 Hz for two consecutive steps. Most participants completed approximately 100 strides over the force plates at self-selected normal walking speed and another 50 strides at self-selected fast walking speed. Only steps with a clear heel contact on the force plate were included. Heel contact was identified when initial vertical force exceeded 10 N and an increase of force was observed in the consecutive data samples. The data was processed using a 4th order Butterworth filter with a 36 Hz cut-off frequency. RCOF for every step was calculated from the recorded three dimensional forces using two different calculations:

\[
\text{RCOF1} = \frac{F_y}{F_z} \quad \text{excluding medio-lateral force (} F_x \text{).}
\]

\[
\text{RCOF2} = \frac{\sqrt{F_y^2 + F_x^2}}{F_z} \quad \text{including } F_x \text{ in the calculation.}
\]

To avoid issues with bilateral asymmetry only the data of right feet were used in this study. SPANOVA was used to examine statistical differences in RCOF (95th percentile value) between the two calculation methods: RCOF1 \((F_x \text{ excluded})\) and RCOF2 \((F_x \text{ included})\). 95th percentile rather than the mean RCOF was used as it was considered a better indicator of the utilized RCOF and slipping risk during walking. The independent variables were age, gender and walking velocity.

3. Results

The results (table 2) indicate that a significant difference exists between the two calculations in every group and at both walking speeds. At both walking speeds there was a significant difference in the RCOF calculations between the age groups but no gender effect could be noted. The RCOF values were in general higher for all groups when \(F_x\) was included with a larger increase seen for older people at both walking velocities. The largest difference between the two calculations was seen in older male adults when walking at normal walking velocity. Female groups had higher RCOF values in all scenarios with highest RCOF values observed with older females at normal walking speed. This is interesting as this group also had the slowest walking velocity (table 1) indicating that a slow walking velocity does not necessarily make walking safer when discussing slipping propensity – the ratio of horizontal to vertical forces influences frictional demand of walking.

Table 1. Participant group characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>Normal velocity (m/s)</th>
<th>Fast velocity (m/s)</th>
<th>% increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>adults</td>
<td>Female</td>
<td>27.92 ± 4.6</td>
<td>1.36 ± 0.16</td>
<td>1.67 ± 0.17</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>29.5 ± 4.7</td>
<td>1.31 ± 0.15</td>
<td>1.69 ± 0.18</td>
</tr>
<tr>
<td>Older</td>
<td>Female</td>
<td>71.4 ± 5.4</td>
<td>1.19 ± 0.18</td>
<td>1.43 ± 0.16</td>
</tr>
<tr>
<td>adults</td>
<td>Male</td>
<td>72.3 ± 5.0</td>
<td>1.25 ± 0.17</td>
<td>1.55 ± 0.23</td>
</tr>
</tbody>
</table>


Proceedings 19th Triennial Congress of the IEA, Melbourne 9-14 August 2015

Table 2. Required Coefficient of Friction (RCOF) results using two calculations (RCOF1 & RCOF2), young and older adults at normal and fast walking speeds (RCOF 95th percentile value indicated).

<table>
<thead>
<tr>
<th>RCOF Descriptives - Group Mean values of 95%</th>
<th>Normal Velocity</th>
<th>Fast Velocity</th>
<th>diff</th>
<th>RCOF1</th>
<th>RCOF2</th>
<th>diff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RCOF1</td>
<td>RCOF2</td>
<td></td>
<td>RCOF1</td>
<td>RCOF2</td>
<td></td>
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<tr>
<td>Young adults</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>.222 ± .029</td>
<td>.228 ± .029</td>
<td>.006</td>
<td>.240 ± .028</td>
<td>.244 ± .028</td>
<td>.004 (1.7%)</td>
</tr>
<tr>
<td>Male</td>
<td>.216 ± .022</td>
<td>.225 ± .022</td>
<td>.009</td>
<td>.238 ± .022</td>
<td>.244 ± .020</td>
<td>.006 (2.5%)</td>
</tr>
<tr>
<td>Older adults</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>.250 ± .111</td>
<td>.262 ± .110</td>
<td>.012</td>
<td>.231 ± .056</td>
<td>.242 ± .058</td>
<td>.011 (4.8%)</td>
</tr>
<tr>
<td>Male</td>
<td>.228 ± .103</td>
<td>.245 ± .102</td>
<td>.017</td>
<td>.229 ± .068</td>
<td>.241 ± .067</td>
<td>.012 (5.2%)</td>
</tr>
</tbody>
</table>

Statistics

<table>
<thead>
<tr>
<th>RCOF calculation</th>
<th>p = .000 *</th>
<th>p = .000 *</th>
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</thead>
<tbody>
<tr>
<td>RCOF calculation*</td>
<td>p = .150</td>
<td>p = .493</td>
</tr>
<tr>
<td>RCOF calculation</td>
<td>p = .023 *</td>
<td>p = .007 *</td>
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</table>

Figure 1. Graphical representation showing the effect of $F_x$ on RCOF results. A significant difference between the two calculations was seen in all groups in both conditions. A significant difference was seen between the age groups but not between genders. With both velocities the groups of older adults had a larger increase of RCOF when including $F_x$. The group of older males walking at normal velocity have higher RCOF values that the other groups.
4. Discussion

A number of past researches have ignored the inclusion of medio-lateral forces (Fx) while calculating RCOF to assess slipping risk during walking. A recent paper reported the effect of Fx in the RCOF calculation and found significant differences for old and young individuals at both normal and fast walking velocities (Chang, Chang & Matz 2011). Chang et al.’s study included adults aged up to approximately 60 years. However, the age group most prominent for falls are those over 65 years of age.

The present study with older adults (mean age 72 years) showed similar effects as reported by Chang et al. (2011). As expected, RCOF values were higher when RCOF was calculated including Fx in all groups at both walking velocities. At both walking velocities the groups of older adults had a larger increase in RCOF when Fx was included in the calculation. The findings at normal walking velocities were similar to Burnfield (2002), however, we also found the females had higher RCOF values than males at both walking velocities. It was though interesting that the highest RCOF values were seen in the older female group (0.262) during their normal walking velocity. Older adults showed a larger variability in the RCOF at both velocities but especially during normal walking velocity. The group of young adults had higher RCOF values at fast walking velocity whilst the values in the older group were decreased.

The inclusion of Fx in the RCOF calculation showed a significant increase in RCOF in all participant groups but especially in older adults. This study showed that it is of high importance to include all ground reaction forces when calculating RCOF, especially when investigating older adults at risk of slips and falls. It would be interesting to further investigate the data of those at a higher risk of falling or with previous falls as the literature suggests alterations specifically in the medio-lateral forces.

5. Conclusions

Slipping is one of the major causes of falls in the elderly. Slipping propensity has been evaluated using the ground reaction forces during walking. The results of this study confirm the findings of Chang et al. (2011) verifying the significant difference in the calculation results when including Fx during continuous walking in older adults aged over 65 years walking at both self selected normal and fast speeds. This study also shows that the inclusion of Fx has a higher impact in the calculation when assessing older people verifying the effect of the medio-lateral forces. The study supports the inclusion of Fx in RCOF calculation in young and older people.

References


