

Evaluation of Gait Characteristics and Ground Reaction Forces in Cognitively Declined Older Adults With an Emphasis on Slip-Induced Falls

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ABSTRACT The objective of the present study was to evaluate the relationship between gait adaptation and slip/fall risk of older adults with cognitive impairments. The study investigated the gait characteristics of six healthy older adults and five older adults with dementia. Participants walked on an instrumented walkway at their preferred walking speeds. After ensuring that the preferred walking speeds were consistent, participants' natural posture and ground reaction forces were measured. The results suggested that participants with dementia walked more cautiously yet demanded more friction at the shoe/floor interface at the time of heel contact, increasing the risk of slip initiation. To reduce the risk of slip-induced falls among older adults with dementia, specific gait training to reduce friction demand requirements by increasing the transfer speed of the whole body mass is suggested.

KEYWORDS aging, cognition, dementia, gait, slips and falls

INTRODUCTION

With longer life expectancy, an increasing number of older adults experience cognitive impairments and dementia (Verghese et al., 2002). Older adults with dementia fall twice as often as older adults without cognitive impairments (Shaw et al., 2003). Also, elderly people who suffer from impaired mental status (cognitively declined) such as dementia are mostly over 65 years of age (Verghese et al., 2002). Studies have suggested that impaired gait characteristics and balance profiles are major contributing factors to the greater fall rates of persons with dementia (Alexander et al., 1995; Caffarra, Salmaso, Viola, Scaglioni, & Malvezzi, 1990; Morris, Rubin, & Morris, 1987; Prudham & Evans, 1981; Rossor et al., 1999; Tinetti, Speechley, & Ginter, 1988; Verghese et al., 2002). The problem is quite prevalent; according to Verghese and colleagues (2002), elderly people with an odd gait (e.g., unsteady gait, frontal gait, neuropathic gait, apraxia gait) are three and a half times more likely to possess

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characteristics of dementia and experience more falls than the elderly without an odd gait and dementia.

Although epidemiological studies (Shaw et al., 2003; Van Dijk et al., 1993) have identified older adults with dementia as fall-prone individuals, biomechanical mechanisms associated with slip-induced falls among these individuals are lacking. Understanding the mechanisms of gait characteristics associated with cognitive impairments (e.g., dementia) may provide effective intervention strategies to reduce falls among older adults with dementia.

Often, slip-induced falls are predicted by the required coefficient of friction (RCOF), the ratio of the horizontal shear force (F_h) over the vertical normal force (F_v) (Perkins, 1978; Kim, Lockhart, & Yoon, 2005; Lockhart, Woldstad, & Smith, 2002, 2003). Most falls led by slips occur when the available frictional force (F_μ) opposing the movement of the foot at the shoe-floor interface is less than the horizontal shear force (F_h) at the foot during the heel contact phase of the gait cycle (Lockhart, Woldstad, & Smith, 2003). A number of studies have shown that horizontal shear force at the foot during heel contact phase of gait cycle are altered as heel contact velocity, step length, and walking velocity change (Kim et al., 2005; Lockhart, Woldstad, & Smith, 2002, 2003; Bunternghit, Lockhart, Woldstad, & Smith, 2000). Furthermore, studies suggest that age-related alterations found in heel contact velocity, step length, and walking velocity play a significant role in altering RCOF among older adults.

As indicated, a number of studies have been performed among the healthy older population to investigate age-related gait characteristics and foot dynamics (i.e., heel contact velocity, step length, and walking velocity) in slip-induced falls. However, there have been a few attempts to study the effects of gait characteristics and foot dynamics among cognitively declined older adults on slip-induced falls, and little is known about the causes of falls in spite of an increased rate of institutionalization of cognitively declined older adults due to falling (Morris et al., 1987). The present study targets a specific population of cognitively declined elderly people to investigate their gait characteristics and foot dynamics and significant relationships to RCOF.

The objective of the present study was to evaluate if cognitively declined older adults had an increased tendency to experience slip-induced falls because of significantly different gait parameters and foot dynamics in

comparison to healthy older adults. The study attempted to study and identify differences in gait characteristics and friction demand characteristics (RCOF) among these healthy and cognitively declined older adults. We hypothesized that the cognitively impaired older adults' gait parameters and RCOF would be different than those of adults without cognitive impairments, potentially contributing to an increased likelihood of slip-induced falls among adults with dementia or other cognitive impairments.

METHODS

Participants

A total of 11 participants were selected and grouped either as (a) healthy older adults (mean age = 78 years, $SD = 4.56$) and (b) persons with dementia (mean age = 77.6 years, $SD = 13.76$). The group of healthy older adults consisted of 6 participants (3 male and 3 female), while the group of persons with dementia was composed of 5 participants (3 male and 2 female). Members of the healthy group were volunteers recruited from the community, and the group of persons with dementia was recruited from an adult day care service program serving community-dwelling individuals. Participation was voluntary, and participants were duly compensated for their participation; caregivers for persons with dementia signed an informed consent form for each subject.

The five individuals in the group of persons with dementia were diagnosed as having dementia by medical doctors prior to the study. Cognitive ability was also measured in this group using the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) in order to describe the severity of their cognitive impairment. The independently living participants in the healthy older adult group were assumed to have no symptoms of dementia; they had never been diagnosed as having dementia by a doctor, although they had seen their doctors on a regular basis. Therefore, the MMSE was not administered in the group of healthy older adults. The MMSE was administered by a trained research assistant at the adult day care service program. The MMSE consists of 11 questions, with possible scores ranging from 0 to 30; lower scores indicate greater levels of impairment (see Table 1). In the current sample, MMSE scores for persons with dementia ranged from 13 to 20, indicating mild to moderate cognitive impairment (see Table 2).

TABLE 1 MMSE score limits and implications for cognitive disability

MMSE score	Implication
<10	Severe
11–19	Moderate
20–26	Mild
>26	Normal

TABLE 2 MMSE scores for cognitively declined participants

Participant	Type	Gender	Age	MMSE score
1	CD	M	87	20
2	CD	M	80	N/A ^a
3	CD	F	92	17
4	CD	F	72	13
5	CD	M	57	17

^aMMSE score not usable because participant suffered recent heart attack.

Several gait characteristics were evaluated for adults with or without cognitive impairment using established methods (Kim et al., 2005) in Virginia Tech’s Locomotion Research Laboratory. Their gait characteristics were recorded while they walked across a track embedded

with force plates and monitored by an active-marker-auto-tracking camera system.

Apparatus

Walking trials were conducted on a linear track (20 m) embedded with force plates (Figure 1). The entire track was covered with vinyl tile. The test surface was mounted on a platform and connected to force plates (BERTEC #K80102, Type 45550-08, Bertec Corporation, Columbus, OH). A six-camera ProReflex system (Qualysis) was used to collect three-dimensional posture data on participants as they walked over the test floor surface. Kinematic data were sampled and recorded at 120 Hz. Ground reaction forces of participants walking over the test surfaces were measured using two force plates and sampled at a rate of 1200 Hz.

Procedure

Each participant’s gait characteristics were evaluated in the Locomotion Research Laboratory before the MMSE for persons with dementia was administered at

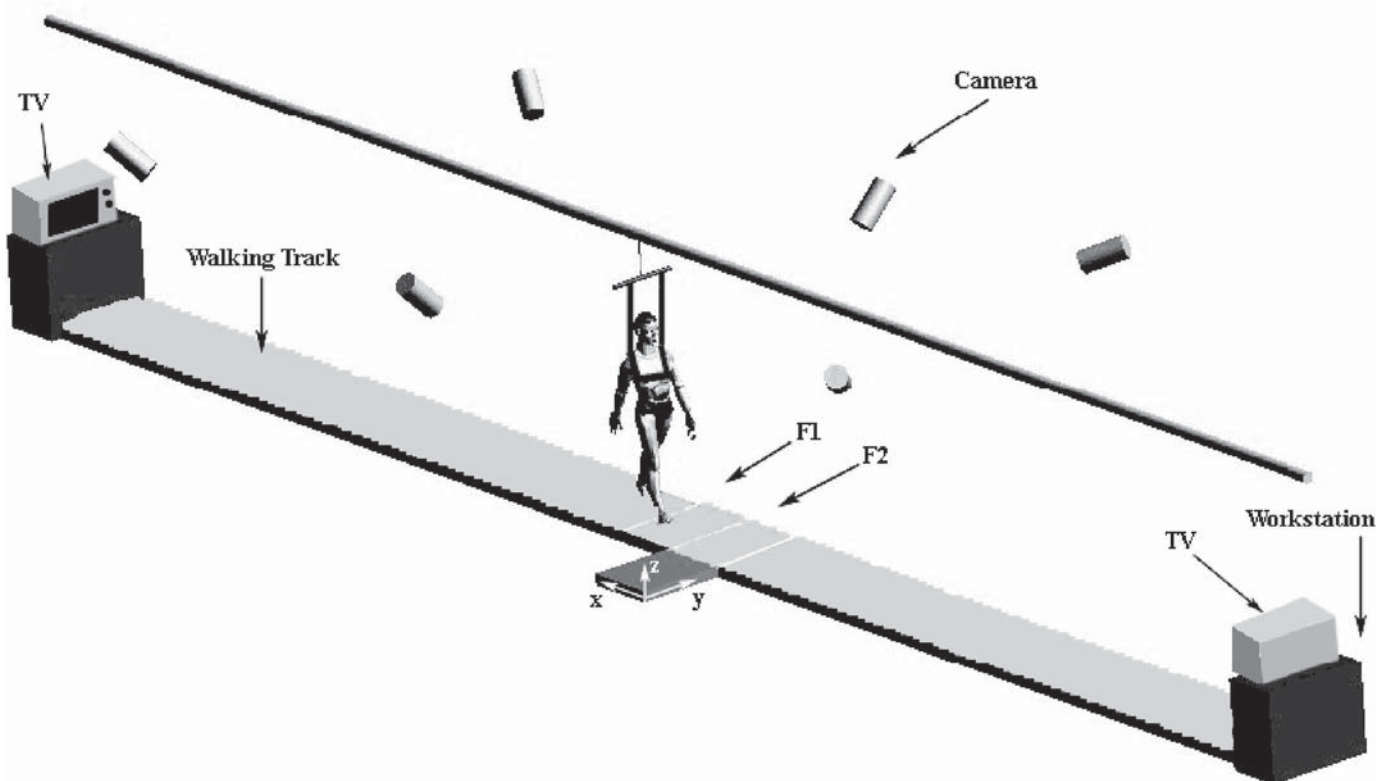


FIGURE 1 Field layout of the experimental set-up, including fall arresting system, infrared cameras (6), two force plate (F1 and F2), and workstations. X, Y, and Z = global references for force and position.

the adult day care service center (Center for Gerontology, Virginia Tech). A set of 12 markers were placed on participants' anthropometric landmarks (base of second toe, malleolus, epicondyle, and greater trochanter). Also, two markers were placed on the heel to assess heel contact velocity. Healthy participants walked across the vinyl floor surface for about 20 minutes, and participants with cognitive impairment walked approximately 5–10 minutes since they were only capable of following the instructions for that length of time. Each participant was asked to walk at his or her preferred walking speed. Participants' cadence was measured to ensure that their preferred walking speeds were consistent throughout the experiment. The point on the walking track where the participant started his or her walk was determined such that his or her left foot landed on the first force plate and was done in a manner so the participant did not know the intent. After ensuring that preferred walking speeds were consistent, participants' natural posture and ground reaction forces were measured.

Data Analysis

The coordinate data from ProReflex were used to calculate gait parameters such as walking velocity, heel contact velocity, and step length. Force plate data were used to determine RCOF and heel contact time. Ground reaction forces were measured using two force plates for 5 seconds at 1200 Hz and lowpass-Butterworth-filtered at 6 Hz. Kinematic data were recorded for 5 seconds at 120 Hz and lowpass-Butterworth-filtered at 12 Hz.

Heel Contact Velocity

Heel contact velocity (cm/s) was defined as an instantaneous heel velocity when the heel made contact with the ground in a gait cycle.

Required Coefficient of Friction

The coefficient of friction was defined as the ratio of ground reaction forces in the horizontal and vertical directions, after heel contact was achieved. The RCOF was defined as the maximum value of the ratio of F_h over F_z after the heel contacted the floor (Figure 2).

Step Length

Step length was defined as the linear distance in horizontal (X) direction from heel contact of left foot

to heel contact of right foot. Step length was calculated mainly to calculate walking velocity and was not used to draw any inferences.

Walking Velocity

Walking velocity was defined as the speed of the participant (cm/s). It was calculated using the following formula: $WV = [\text{Step Length}/\Delta t]$, where Δt = time taken from one foot's heel contact to the other foot's heel contact.

Group differences were evaluated using one-way analyses of variance (ANOVAs) with the between-subjects factor of presence/absence of dementia. Descriptive and inferential statistical analyses were performed with the JMP statistical packages (SAS Institute Inc., Cary, NC).

RESULTS

Table 3 summarizes parameter calculations for participants based on raw data measured during the experiment.

The ANOVA results (Table 4) indicated that, in comparison to the group of older adults with dementia, the healthy older adults had higher heel contact velocity, $F(1, 10) = 27.44$, $p = .0005$; longer step length, $F(1, 10) = 15.48$, $p = .003$; and faster walking velocity, $F(1, 10) = 47.37$, $p < .0001$. However, they exhibited lower RCOF, $F(1, 10) = 11.92$, $p = .007$.

DISCUSSION

Limited research (Prince, Corriveau, Hebert, & Winter, 1997; Woollacott & Shumway-Cook, 2002) suggests that cognitive impairments such as dementia play a moderate role in slips and falls, although age-related changes in intrinsic factors such as musculoskeletal and sensory degradations (Thompson & Brown, 1999; Lockhart, Woldstad, Smith, & Ramsey, 2002) are commonly believed to be the major cause of slips and falls among older adults. However, there have been only a few attempts to study gait characteristics of cognitively impaired older adults and their influence on the risk of slip-induced falls. The objective of our study was to evaluate fall risks related to gait characteristics and foot dynamics during ambulation among older adults with dementia.

Our results indicate that participants with dementia exhibited slower heel contact velocity, slower walking

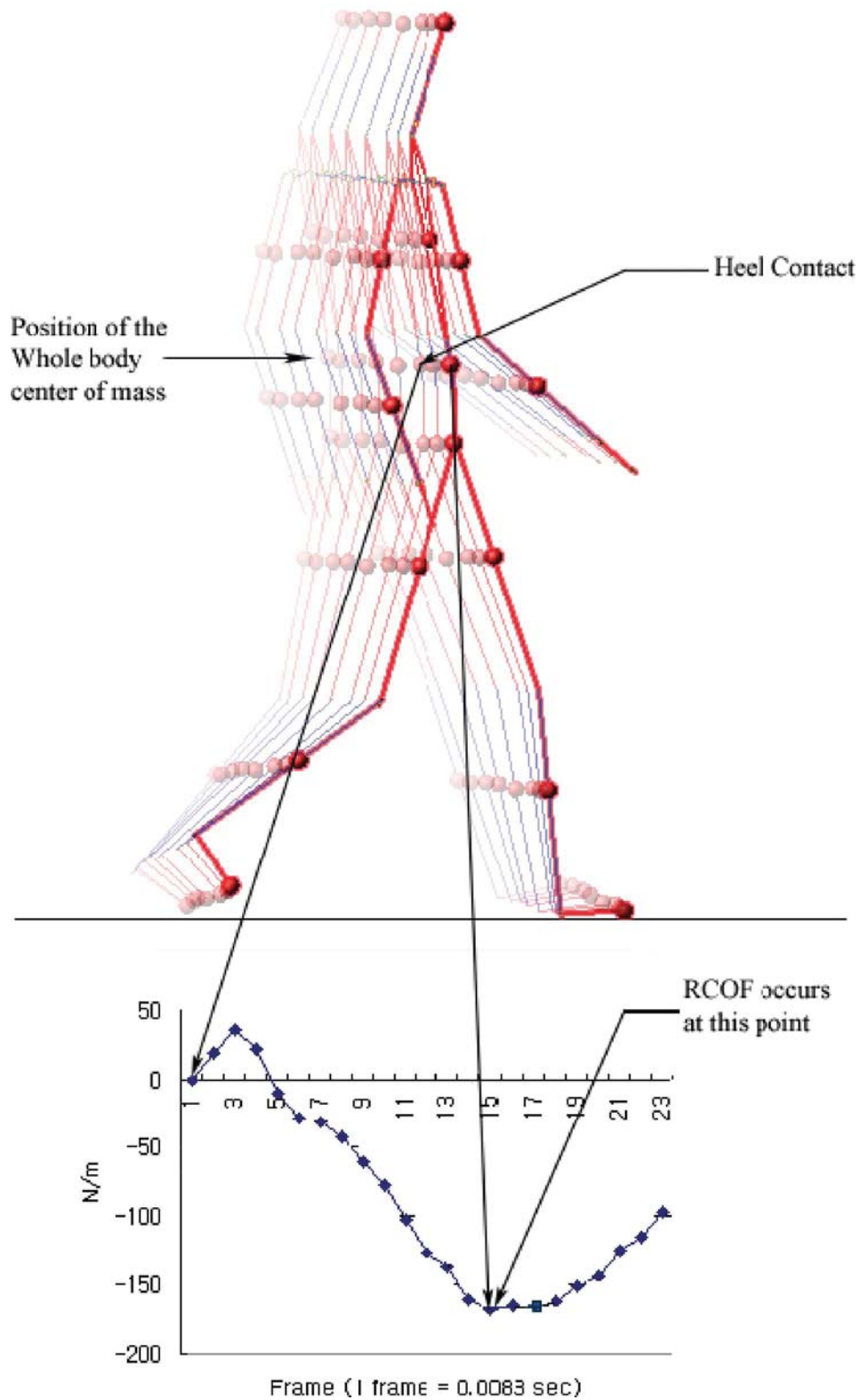


FIGURE 2 Positions of the whole body COM and the synchronized graphical indication of RCOF (F_x/F_z) (adapted from Kim et al., 2005) after heel contact.

velocities, and shorter step length, similar to Alexander and colleagues' findings (1995) (i.e., walking velocity of 0.80 cm/s vs. 1.40 cm/s and step length of 49.68 cm vs. 65.55 cm for older persons with dementia and

healthy older adults, respectively). In terms of friction demand (RCOF), participants with dementia exhibited higher RCOF during walking than the healthy older participants. As a result, risk for slip-induced

TABLE 3 Parameter results for participants

Participant type	Age	Gender	Heel contact velocity (cm/s)	Required coefficient of friction	Walking velocity (cm/s)	Step length (cm)
O	86	M	65.97	0.174	131.98	63.29
O	76	M	92.36	0.168	133.16	73.30
O	78	M	81.78	0.153	132.96	74.55
O	78	F	50.26	0.184	121.54	67.86
O	78	F	63.53	0.114	106.48	53.24
O	72	F	82.05	0.162	143.72	58.68
CD	87	M	41.15	0.25	78.3	46.98
CD	80	M	40.7	0.19	48.5	40.4
CD	92	F	28.9	0.25	41.7	33.41
CD	72	F	24.78	0.2	27	26.58
CD	57	M	20.93	0.193	76.59	57.58

TABLE 4 ANOVA results and means for all parameters

	O mean (SD)	CD mean (SD)	ANOVA α
Heel contact velocity	72.65 (5.32)	31.29 (9.23)	.05
RCOF	0.16 (0.01)	0.22 (0.03)	.05
Walking velocity	128.31 (7.23)	54.41 (22.41)	.05
Step length	65.15 (4.14)	40.99 (12.00)	.05

Note. All ANOVA values were significant.

falls among the participants with dementia in this study may be higher than that of their healthy counterparts.

Previous studies suggest that heel contact velocity, walking velocity, and step length are directly proportional to horizontal force and vertical force at the contacting heel (Bunternghit et al., 2000; Lockhart et al., 2002). As such, decreases in heel contact, walking velocity, and step length should reduce friction demand (i.e., RCOF) among older adults with dementia. However, in this study, gait parameter measures of participants with dementia were significantly lower than healthy older adults, and friction demand (RCOF) was higher. In other words, participants with dementia walked more cautiously yet had a higher tendency to slip at the time of heel contact. Lockhart and colleagues (2003) indicated a negative relationship between RCOF and transitional accelerations of the whole body center of mass (COM) (i.e., the slower the transition, the higher the RCOF). To illustrate this phenomenon, the whole body COM is projected

perpendicularly in Figure 2. Projected angle θ decreases from heel contact to shortly after heel contact as whole body COM progresses forward. The Lockhart et al. (2003) study suggested that RCOF decreased from θ_1 to θ_2 due to a decreased horizontal ground reaction force, thereby resulting in larger RCOF at θ_1 in comparison to θ_2 .

This illustration further supports the finding of the present study that higher RCOF was associated with slower walking velocity. In the current study, participants with dementia seemed to adapt their gait (slower heel contact and walking velocity and shorter step length) in an attempt to increase dynamic stability. However, in doing so, friction demand characteristics (RCOF) at the shoe/floor interface were altered due to slow transitional acceleration of the whole body mass, which consequently increased the risk of slip initiation. In conclusion, our findings indicate that older adults with cognitive impairment are at a greater risk of slips as measured by RCOF, even though they walk slower and have slower heel contact velocity and shorter step length.

Research data (Van Dijk et al., 1993) suggest that multifactorial interventions after a fall are less effective in older persons with dementia than in cognitively normal older adults. This might be due to the fact that people with dementia show progressive deterioration in their intellectual properties, such as memory, attention, calculation, abstract thinking, and judgment (Office of Technology Assessment, 1987). These deficits further imply that people with dementia will have difficulty in acquiring skills to avoid slips and falls. In addition, many studies have found that typical physical exercise

interventions do not improve ability to perform basic daily activities in people with dementia (Panella, Lilliston, Brush, & McDowell, 1984). These studies suggest that people with dementia require repetitive practice with feedback from multiple sensory systems with less cognitive involvement (McEvoy & Patterson, 1986; Tappen, 1994).

Mechanisms involving increased risk of slip-induced falls among older adults with dementia could be attributed to a higher RCOF and slower transition of the whole body mass. An appropriate intervention should focus more on gait training; more specifically, gait training to increase transitional acceleration of the whole body mass to reduce friction demand characteristics (Kim et al., 2005) and decrease heel contact velocity (Lockhart & Kim, 2006) should be employed. A wide variety of therapeutic gait training methods are available in neurological rehabilitation (Mauritz, 2002). Gait training has been found to be effective in restoring gait patterns in people with neurological disorders and to be essential to those wanting to regain an independent living style (Mauritz, 2002; Pohl, Rockstroh, Rückriem, Mrass, & Mehrholz, 2003), and it would be an essential part of the rehabilitation process for older adults with dementia in improving their gait characteristics. In addition, gait training for people with dementia should involve repetitive practice with more emphasis on physical or functional skill acquisition and a deemphasis on cognitive involvement.

Nurses and caregivers were found to play a key role in preventing excess disability and assisting people with dementia to perform their daily activities more successfully (Dawson, Wells, & Kline, 1993). Therefore, nurses' or caregivers' ability to focus on functional skill training (Tappen, 1994) such as gait training rather than a general exercise intervention could be a prominent factor in successful improvements in the functioning of people with dementia. This suggests that nurses and caregivers should be trained in skills and techniques that would allow them to systematically implement these interventions.

In addition to gait training, shoe surface materials that provide higher available frictional force opposing the movement of the foot at the shoe-floor interface should be considered for use by people with dementia during gait training. This would result in alleviating their RCOF at heel contact while walking.

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