Postural control while dressing on two surfaces in the elderly

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Received: 16 March 2009 / Accepted: 27 June 2010 / Published online: 15 July 2010
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Abstract Falling is a worldwide problem faced by the elderly, and it has serious consequences. The elderly falls in the bathroom very often, and this raises the concern of the connection between the high incidence of falls in the bathroom and postural control of putting on shorts. Because little is known about postural control while putting on shorts of any age group, this study investigated the effects of age and surface on postural control while putting on shorts. Healthy young adults ($n=15$; age range: 21–27 years) and the elderly participants ($n=15$; age range: 63–78 years) were compared in the temporal–spatial parameters, movement of center of mass (COM),

and its interactions with center of pressure (COP) and kinematic measures under two conditions: anti-slipping mat and tile. The results demonstrated that the elderly had lengthened cycle time, decreased single-limb-support ratio, decreased medial–lateral velocity of COM, decreased relative displacement between COM and COP, decreased hip abduction–adduction angle, knee flexion angle, and the height of foot elevation. The elderly demonstrated a conservative strategy that may reduce the mechanical load on the supporting limb but preserve medial–lateral balance during the task. The adopted strategy may be relevant to the reduction of muscle strength and proprioception loss during natural aging process. Although surface did not affect the motion patterns of participants while putting on shorts, the slippery surface should be avoided. Other environmental modification such as a grab bar and bright illumination may have advantages in reducing the risk of falls.

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Keywords Falling · Putting on shorts · Slippery · Lateral stability

Introduction

Falling is a serious problem faced by the older population because these accidents cause dramatic injuries and have significant impact in health care costs (Cali and Kiel 1995; Englander et al. 1996). Such accidents are most commonly seen in the elderly

(65 years and older) (Rawsky 1998; Wells and Evans 1996) and are the major cause of death for those older than 75 years (Baker and Harvey 1985; Rubenstein and Josephson 2002). Among falls, lateral falling is one major contributor to femoral fracture in the elderly and can result in subsequent complications including daily life dependency (Cumming and Klineberg 1994; Hayes et al. 1993; Nevitt and Cummings 1993). About 60% of indoor falls occur in the bathroom, based on a case series study of 319 patients (Yeh and Chou 2003). The epidemiology of falls, especially in the bathroom, raises the concern of why the elderly have falling accidents in the bathroom so often.

That different balance strategies are adopted by the young and the elderly in response to postural perturbation has been suggested (Rogers and Mille 2003). Young adults shift their center of mass (COM) in the direction opposite to the perturbation and take a sidestep to increase the base of support (BOS), whereas the elderly use the unloaded limb to take a crossover step in the direction of the perturbation to seek balance (Hahn and Chou 2004). The strategy used by the elderly, however, fails to retrieve balance and thus falls laterally. When stepping over an obstacle, older patients with imbalance show an increased medial–lateral COM motion positively correlated with increased medial–lateral range of motion of the swing foot trajectory (Chou et al. 2003). These workers suggested that increased motion in the frontal plane is a strategy to increase the BOS for the next step in older patients with imbalance. The medial–lateral COM movement is a sensitive measurement for dynamic instability (Hahn and Chou 2003), whereas the center of pressure (COP) is adjusted consistently to keep the projection of COM within the BOS (Lyon and Day 1997; Rogers and Pai 1990) and is considered as the neuromuscular response to COM imbalance (Winter 2005). Therefore, the relationship between COM and COP, rather than their individual values, may provide a valuable means for evaluating the dynamic stability of a subject.

The effect of floor surface on postural control during walking has been examined. A previous study reported that subjects show different gait parameters including step length, required coefficient of friction, and heel contact velocity on a slippery or dry floor surface (Lockhart et al. 2007). The subjects with

decreased values of these three parameters have a reduced likelihood of slipping. In addition, older subjects exhibit a more conservative pattern (with decreased cadence, step length, and shoe–floor angle at heel-strike) on an irregular or wet walking surface compared with a dry level surface (Menant et al. 2009). The elderly had a greater root mean square and maximum COP range in the anterior–posterior and medial–lateral directions in slippery than non-slippery gait termination (Oates et al. 2005). Furthermore, the displacement and velocity of COM to BOS became smaller from heel-strike to contralateral toe-off during a slipping perturbation (You et al. 2001). Therefore, subjects adopt a walking strategy that avoids slipping on a slippery surface. However, it is unclear how the slippery surface affects the movement pattern while putting on shorts.

So far, little is known about the postural control of the elderly during specific indoor functional activities. Most studies focus on balance during single-limb standing or obstacle crossing and show significant differences between young adults and the elderly (Hahn and Chou 2004) or differences between the elderly with and without imbalance during obstructed walking (Chou et al. 2003). Dressing, for example putting on shorts, requires the ability of weight shifting, unilateral stability, and movement coordination. Very few studies have investigated how the COM and COP changes while dressing and the mechanisms underlying this task. It is also important to understand the effect of bathroom floor surface on the postural control during dressing. Thus, the purposes of this study were to investigate the effects of age and surface properties on postural control while putting on shorts. We hypothesized that the elderly take longer to complete the dressing task (cycle time) with a shorter single-limb-support phase and with smaller COM displacement, velocity, and relative displacement between COM and COP than young adults. We also hypothesized that the task performed on an anti-slipping mat differs from that on tile in terms of COM displacement, velocity, and relative displacement between COM and COP.

Method

A group of 15 young adults (9 women, 6 men; age range: 21–27 years) and a group of 15 elderly

Table 1 Mean (SD) of subjects characteristics

	Young adults (<i>n</i> =15)	Elderly adults (<i>n</i> =15)	<i>P</i> value
Age (years)	23.85 (2.15)	68.23 (6.26)	<0.001
Height (m)	1.63 (0.08)	1.59 (0.08)	0.578
Body mass (kg)	57.65 (9.64)	63.23 (10.03)	0.701

participants (9 women, 6 men; age range: 63–78 years), free from neurological and musculoskeletal diseases or impairments that would affect daily activities and balance, participated in the study (Table 1). The elderly participants were recruited from local communities, had regular walking exercise, and did not have a history of falling in the past year. Subjects were excluded from the study if they had a history of vestibular problems or others that would affect balance, or if they were currently taking medication that would affect reaction and alertness. All subjects read and signed the informed consent approved by the university institutional review board.

A pair of specially made transparent plastic shorts designed to avoid concealing markers was given to subjects (Fig. 1a). Subjects were allowed time to practice how to put on these shorts, but no further instructions on the task were given. Subjects were asked to stand on the surface with each foot placed on one force plate and then put on the shorts as they habitually did. Two floor surfaces, a tile and an anti-slipping mat, were used. Eight 20×20 cm² tiles and

two 30×30 cm² anti-slipping mats were used to create an environment similar to a bathroom floor. Water was also spread on the tiles and anti-slipping mats to mimic usual conditions. The tiles or anti-slipping mats were securely fastened to the force plates just before data collection. Subjects performed five successful trials for each condition. Mats were placed around the force plates to protect subjects in case of falls. The order of the conditions was randomized.

Reflective markers were placed on the front, top, and back of the head, the seventh cervical vertebra, midpoint between the posterior superior iliac spines, and bilaterally on the shoulder acromions, lateral epicondyle of the humerus, and ulnar and radial styloid processes, anterior superior iliac spines, greater trochanters, lateral thighs, lateral knee joint lines, lateral shanks, lateral malleoli, heels, and metatarsal bases between the second and third metatarsals (Fig. 1b) by the same investigator. Each subject performed five successful trials of putting on shorts in two surface conditions and rested between each trial for 30 to 60 s. Two static standing trials

Fig. 1 (a) A pair of specially made transparent plastic shorts was designed to avoid markers concealment. (b) Subject with markers and shorts on

with an additional four markers were collected before performing the dynamic trials. These markers were placed bilaterally on the medial knee joint lines and medial malleoli. The same person placed the markers for all subjects.

Three-dimensional (3-D) videographic data were collected for each subject while putting on shorts. A videographic acquisition system with eight Eagle CCD cameras (Motion Analysis Corporation, Santa Rosa, CA, USA) was used to record the real-time 3-D trajectories of the reflective markers on the subject at 100 frames per second. Two Type 9281B Kistler force plates (Kistler Instrument Corp., Winterthur, Switzerland) were used to collect the ground reaction force (GRF) signals at 1,000 samples per second. The videographic and ground reaction force signals were recorded using the Motion Analysis videographic and analog data acquisition system. The videographic and force plate data collection were time-synchronized to 1,000 Hz using a linear interpolation method.

The raw 3-D coordinates of the markers in each trial were processed through a GCVSPL (Woltring 1986) with a second-order low-pass filter at cutoff frequency 6 Hz. The GCVSPL is a FORTRAN package for generalized, cross-validatory spline smoothing and differentiation (Woltring 1986). The markers and estimated joint centers were used to calculate the 3-D motion of each segment and the segment COM. Each segment COM was adjusted by the anthropometric data (Winter 2005). The position of the whole-body COM was calculated as the weighted sum of each body segment, a total of 15 segments representing the whole body: head–neck, trunk, pelvis, bilateral upper arms, forearms, hands, thighs, shanks, and feet. The point of application of GRF defines the COP position. The cycle time was the duration of putting on shorts and was defined as the time from the initiation of head marker movement to task completion. Each trial was defined as the single-limb-support phase (SLS) and the double-limb-support phase (DLS). The SLS was determined as the time when the vertical component of ground reaction force in one force plate became zero. The single-limb-support ratio was defined as the duration of SLS divided by the cycle time of the corresponding trial. All data reduction was completed with a custom-made algorithm using MATLAB computer programming language version 7.0 (The Mathworks Inc., Natick, MA, USA).

The variables of interest were the cycle time, COM displacement, and COM peak velocity in the medial–lateral, anterior–posterior, and vertical directions, relative displacement between COM and COP in the medial–lateral direction and anterior–posterior directions during the task. The kinematic parameters of the trunk and lower extremity (trunk forward lean angle, trunk side-bending angle, maximal hip flexion angle, maximal range of hip abduction–adduction motion, maximal knee flexion angle, and maximal foot elevation height) were measured to define the movement patterns during the task. The hip flexion angle was defined as the flexion angle of the thigh segment relative to the pelvis segment. The trunk forward lean angle was defined as the forward flexion angle of the trunk segment relative to the global coordinate system. The maximal foot elevation was determined as the greatest displacement of the heel marker in the vertical direction.

The independent *t*-test and descriptive statistics were used to detect differences in demographic data between groups. Data from five successful trials of each subject under each condition were used for analysis. Two-way analyses of variance was used to assess differences between age and surface conditions for the following dependent variables: cycle time; COM displacement and peak velocity in the vertical, anterior–posterior, and medial–lateral directions; relative displacement between COM and COP in the anterior–posterior and medial–lateral directions; trunk forward lean angle; trunk side-bending angle; maximal hip flexion angle; maximal range of hip abduction–adduction motion; maximal knee flexion angle; and maximal height of foot elevation. In cases where a significant interaction of a given dependent variable was found, one-way analysis of variance was conducted to determine the significance of differences between conditions in this variable. A type I error rate of 0.05 was used as an indication of statistical significance for each analysis of variance. The power was greater than 0.8 with 15 subjects. All statistical analyses were performed using SPSS 13.0 (SPSS for Windows, Chicago, IL, USA).

Results

No interaction effect between age and surface was found for all the parameters in this study.

Table 2 Mean (SD) of cycle time and percentage of single-limb support

	Tile		Anti-slipping mat	
	Young	Elderly	Young	Elderly
Cycle time (s) *	7.17 (1.54)	11.09 (3.78)	6.09 (1.43)	10.54 (3.23)
SLS time ratio (%)*	58.28 (10.23)	41.19 (13.96)	55.29 (9.03)	42.99 (11.72)

* $P<0.05$, significant main effect for age

Age effect

Age had a main effect on the cycle time ($P<0.001$), the COM medial–lateral velocity ($P<0.001$), the relative displacement of COM to COP in the medial–lateral direction ($P<0.001$), the maximum range of hip abduction–adduction motion ($P<0.01$), knee flexion angle ($P<0.05$), and the height of foot elevation ($P<0.001$). The elderly participants took significantly longer to complete the task of putting on shorts but had a shorter SLS in either condition of tile or anti-slipping mat ($P<0.001$; Table 2). Young adults had a greater medial–lateral velocity of COM ($P<0.05$, Table 3) and a greater relative displacement of COM to COP in the medial–lateral direction than elderly participants ($P<0.001$; Table 4, Figs. 2, 3 and 4). The elderly participants used a smaller range of hip abduction–adduction angle, knee flexion angle, and height of foot elevation to complete the task (Fig. 5). No significant difference was found in the trunk forward lean angle and trunk side-bending angle between elderly participants and young adults.

Surface effect

Surface had an effect on the vertical velocity of COM ($P<0.05$) and the height of foot elevation ($P<0.05$). The vertical velocity of COM was greater in the condition of anti-slipping mat than of tile. A higher foot elevation occurred with anti-slipping mat than tile. No significant differences in cycle time and

single-limb-support time ratio was found between tile and anti-slipping mat ($P=0.57$, $P=0.66$). Surface did not have a significant effect on the relative displacement of COM to COP in the medial–lateral direction ($P=0.06$).

A trend of greater maximum COM displacement and maximum COM velocity in the medial–lateral direction than that in the vertical and anterior–posterior directions for either elderly participants or young adults was observed (Tables 3 and 5).

Discussion

This study sought to determine whether age and surface affect the balance performance and motion pattern during a dressing task and attempted to determine why the risk of a fall in the bathroom is high by analyzing the motion patterns while putting on shorts. Our findings revealed that age do affect the postural control and motion patterns during this task, but the effect of surface on the postural control and motion patterns is minimal.

Age effect

Putting on shorts is a continuous dynamic motion that shifts the body from a two-footed base of support to a single-limb support while the other leg is moved. The narrow base of support challenges the individual's ability to maintain balance. Meanwhile, the single-

Table 3 Mean (SD) of maximum COM velocity (m/s) in the tile and anti-slipping mat conditions

	Tile			Anti-slipping mat		
	Med.–Lat.*	Ant.–Post.	Vertical**	Med.–Lat.*	Ant.–Post.	Vertical**
Young	0.47 (0.08)	0.10 (0.05)	0.18 (0.03)	0.53 (0.30)	0.11 (0.03)	0.22 (0.06)
Elderly	0.39 (0.19)	0.10 (0.06)	0.20 (0.05)	0.37 (0.12)	0.10 (0.04)	0.23 (0.06)

* $P<0.05$, significant main effect for age

** $P<0.05$, significant main effect for surface

Table 4 Mean (SD) of maximal relative displacement of COM to COP (cm) in the tile and anti-slipping mat conditions

	Tile		Anti-slipping mat	
	Med.–Lat.*	Ant.–Post.	Med.–Lat.*	Ant.–Post.
Young	12.51 (2.25)	9.48 (2.26)	14.04 (1.23)	8.59 (1.77)
Elderly	10.00 (3.68)	10.30 (3.98)	13.37 (5.44)	10.82 (2.96)

* $P < 0.001$, significant main effect for age

limb support exposes the hip muscles to a greater challenge than in a two-footed stance. Elderly participants are known to show decreased vestibular function, proprioception, and muscle strength (Camicioli et al. 1997; Liang and Cameron Chumlea 1998; Pai et al. 1997). The decline in physiological functions slows the movement time in the elderly and exposes them to a greater risk of falling due to the lack of sufficient proprioceptive inputs and muscle strength compared

with young adults. A study of 254 women aged 20 to 80 years showed that they could be grouped into stable or unstable, based on balance tests (eyes closed, eyes open, standing on firm or soft surface) (Choy et al. 2008). About 35% of the women aged 70 to 80 years were in the unstable group on the basis of failing all trials in three of the balance tests. The women categorized as unstable had weaker hip muscles, greater joint positioning errors, and higher vibration thresholds (representing poor peripheral sensory nerve function) as well as decreased dynamic visual acuity than women in the stable group. They also found that the unstable group consisted of a large proportion of elderly participants.

Different movement strategies used in old and young adults affect balance performance and motion pattern. The elderly participants used a conservative strategy to complete the task (Fig. 2a). They flexed the knee of the supporting limb to lower the COM and increase stability, then reduced the distance

Fig. 2 COM displacement in the (a) anterior/posterior, (b) medial/lateral, and (c) superior/inferior directions during the task. An example of one young adult and one elderly in the tile condition

Fig. 3 COM velocity in the (a) anterior/posterior, (b) medial/lateral, and (c) superior/inferior directions during the task. An example of one young adult and one elderly in the tile condition

Fig. 4 Relative COM–COP displacement in the left single-leg-standing phase in the (a) anterior–posterior and (b) medial–lateral directions during the task. The positive value indicates that COM is anterior to COP (a) or COM is lateral to COP (b). An example of one young adult and one elderly in the tile condition

Fig. 5 Movement strategies adopted by (a) the elderly participants and (b) young adults while putting on shorts. The elderly participants used a conservative strategy to accomplish the task. The conservative strategy includes knee bending to lower their trunk and COM, lowering the pants near the ground, transferring COM slowly, and having a smaller hip flexion angle of the non-supporting limb. The point of application of ground reaction force (GRF) defines the COP position

between shorts and floor to shorten the single-limb stance phase, followed by weight shifting to the supporting limb and raising the unloaded limb to put it into the shorts. This movement strategy allowed the elderly participants to have a lower COM velocity, a smaller relative displacement between COM and COP, and a smaller hip motion in the medial–lateral direction; knee flexion angle and height of foot elevation were lower, but COM velocity in the vertical direction was higher. The elderly participants took time in transferring COM in the medial–lateral direction to ensure the single-limb stance stability and therefore lengthened the cycle time. This result to a degree is consistent with the results of gait analysis in the elderly showing that they have a shorter single stance phase than young adults (Shkuratova et al. 2004). A shorter single stance phase means that the time of a small base of support is shorter, and this

may protect the elderly from an unsafe condition such as slipping or falling. This lengthened cycle time is consistent with the finding of Blaszczyk et al. (1997) in which a “slowness strategy” was found in a cyclic pull-and-push arm movement.

The relative displacement between COM and COP in the medial–lateral direction may be affected by the reduced muscle strength due to aging. The reduced muscle strength in the elderly (Choy et al. 2008; Iverson et al. 1990; Johnson et al. 2004), especially the hip abductors, may be a reason why they have a smaller relative displacement between COM and COP in the medial–lateral direction than that of the young group (Hahn and Chou 2004). The smaller relative displacement between COM and COP in the medial–lateral direction resulted in a stiffer posture being adopted by the elderly participants to maintain the steadiness of posture. A smaller relative displacement between COM and COP indicates a reduction of the mechanical load on the supporting limb, and this may be explained by the reduction of muscle strength (Hahn and Chou 2004). In addition, anticipatory postural adjustment (APA) may affect the relative displacement between COM and COP. APA is a feed-forward postural adjustment against anticipated destabilization (Horak 2006; Massion 1992). For example, during forward stepping, the COM moves toward the supported leg before the other leg lifts off. This mechanism enables COM to travel above the base of support successfully and helps individuals maintain stability during the weight-transferring span. However, APA has been reported to be reduced in magnitude and delayed in onset in elderly participants (Inglin and Woollacott 1988; Woollacott et al. 1988). This may contribute to the reduced relative displacement between COM and COP observed in our elderly participants.

Surface effect

The dynamic postural control while putting on shorts adopted by the participants was similar on the two surfaces, i.e., the anti-slipping mat did not modify

Table 5 Mean (SD) of COM displacement (cm) in the tile and anti-slipping mat conditions

	Tile			Anti-slipping mat		
	Med.–Lat.	Ant.–Post.	Vertical	Med.–Lat.	Ant.–Post.	Vertical
Young	34.97 (5.69)	9.53 (3.33)	7.91 (1.76)	34.46 (5.85)	8.31 (3.50)	9.02 (4.00)
Elderly	32.73 (4.43)	9.85 (3.13)	8.87 (2.23)	32.93 (5.88)	9.66 (2.31)	10.54 (5.52)

participants' movement performance in this task. This finding did not support our hypothesis. A previous study of healthy elderly participants using a sensory organization test found that the postural sway and balance strategy in the standing posture are not significantly different in the conditions of a force plate and a selected commercial-grade carpet (Dickinson et al. 2002). This implies that the static balance of the healthy elderly is not affected by a carpeted surface. However, Fong et al. (2008) reported that greater toe grip and a gentler heel-strike was used to accommodate a slippery surface during walking in their healthy young subjects. The differences in the previous investigations along with our current findings suggest that the surface effect on the postural control may depend on the task.

Although the anti-slipping mat has higher friction intended to lower the likelihood of slipping, its effect on the temporospatial parameters was minimal in our participants. A previous study found that both young and old subjects adopt a slip avoidance strategy when walking on different surfaces (Lockhart et al. 2007). Putting on shorts is a more static task than walking, so the shear force may not have reached the maximum static friction on the anti-slipping mat during the dressing task. This may be one reason why the anti-slipping material had little effect on the movement performance of the participants. In addition, subjects in our study were asked to execute the task in the way they usually did in the bathroom, but in a laboratory setting. These subjects might have known the requirement of the task and thus executed it with a conservative strategy in the laboratory setting in order to be sure that the execution of task was correct and safe.

A study investigating the risk factors of falling demonstrated that an improper environment is the major cause for falls (Masud and Morris 2001). In a meta-analysis of institution-dwelling and community-dwelling old people, 31% of the total falls compiled from 12 studies resulted from environment-related accidents (Oakley et al. 1996). Although the participants in our study did not present significantly different motion patterns between anti-slipping mat and tile conditions, a dry bathroom is still strongly recommended to avoid slipping. In addition, most participants reported that they were more confident when performing the task on the anti-slipping mat, but it was not necessarily easier. Based on the findings of this study, psychological confidence may not be reflected in the motion pattern.

Several limitations need to be acknowledged. The weight and texture of the plastic transparent shorts may have been different from the regular shorts subjects wear. These specially made shorts, however, provided a way to avoid concealment of marker and to comprehensively monitor the lower extremity motion patterns. In addition, subjects performed the task in a laboratory setting, and this may not reflect their real performance.

Clinical application

Muscle strengthening of the lower extremities, especially the hip muscles, and stepping practice in various directions should be suggested as part of regular exercise. Environmental modification in the bathroom should be considered for the elderly. A grab-bar installed on the wall, bright illumination, and a bathing chair may be provided as additional support for the older population. Anti-slipping mats may enhance fall prevention, but their effect was not evident from the current findings. Longitudinal observation on anti-slipping mat use and risk of fall may shed light on how effective these mats are in fall prevention. A material that provides friction should be considered in the bathroom.

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