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Age-related reduction in sagittal plane center of mass motion during obstacle crossing

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Abstract

Accidental falls are a leading cause of injury and death in the growing elderly population. Traumatic falls are frequent, costly, and debilitating. Control of balance during locomotion is critical for safe ambulation, but relatively little is known about the natural effect of aging on dynamic balance control. Samples of healthy young ($n = 13$) and elderly ($n = 13$) subjects were compared in the interactive measures of center of mass (COM) and center of pressure (COP) during level walking and obstacle crossing conditions. Obstacle heights were normalized to individual body height (2.5%, 5%, 10%, and 15%). Temporal-distance (T-D) variables of gait were also compared. Statistical analyses were conducted using a two-way ANOVA for subject group and obstacle height. T-D parameters were not significantly different between groups; nor were frontal plane COM and COP parameters. Significant age differences did exist for antero-posterior (A/P) motion of the COM (decreased motion in the elderly), and its relationship with the COP (reduced separation between the two variables in the elderly). Anterior COM velocities were also significantly lower in the elderly group. The results confirm the ability of healthy elderly adults to maintain dynamic balance control in the frontal plane during locomotion. Reduced A/P distances between the COM and COP indicate a conservative reduction of the mechanical load on joints of the supporting limb. This conservative strategy may be related to a reduction in muscle strength as it occurs in the natural aging process.

Keywords: Healthy elderly; Balance control; Center of mass; Sagittal plane; Obstacle crossing

1. Introduction

Accidental falls are the leading cause of injury for persons over the age of 65 and the leading cause of death in persons over the age of 85 (Pocinki, 1990). Hip fractures resulting from falls can be costly, with an overall cost of each fracture estimated at $35,000. Of these elderly adults who suffer from a hip fracture, 25% make a full recovery, 40% require nursing home admission, and 50% of all hip fracture patients require a cane or walker for assisted ambulation (AAOS, 1998). Not as easily measured is the psychological impact of these falls and subsequent fractures. Tinetti and Speechley (1989) proposed that the psychological trauma of an injurious fall may induce a reduction in activity levels, followed by strength reduction, leading to ever-increasing risk of future falls. It is therefore evident that falls are frequent, costly, and potentially debilitating (both physically and psychologically) in the aging population.

Imbalance and tripping over obstacles during gait were reported as two of the most common causes of falls in the elderly (Overstall et al., 1977; Blake et al., 1988; Tinetti and Speechley, 1989; Campbell et al., 1990). Several gait studies were performed to study the effect of obstacle height on the joint kinematics and kinetics (McFadyen and Winter, 1991; Patla and Rietdyk, 1993; Chou and Draganich, 1997, 1998) of either the trailing (i.e., limb crossing the obstacle last) or leading (i.e., limb crossing the obstacle first) limb. It was demonstrated that greater joint motion of both lower limbs during swing and greater joint kinetic demands (forces and torques) of the trailing limb during stance are required in young adults when stepping over an obstacle. Healthy elderly adults were reported to adopt a more conservative strategy when crossing obstacles, with

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slower crossing speed, shorter step length, and smaller step width, than young adults and demonstrated an increased risk for obstacle contact (Chen et al., 1991, 1994). Recent studies further revealed that, compared to young adults, limited frontal plane pelvic motion, shorter stride length, kinetic accommodation in the sagittal plane, and non-optimal foot placement might be contributing factors to a greater risk of tripping in elderly adults (Begg and Sparrow, 2000; McFadyen and Prince, 2002). However, no information about age-related differences in balance maintenance while negotiating obstacles was reported. To better understand mechanisms underlying the increased incidence of tripping and falling in the elderly, it is necessary to monitor the whole body's response during obstacle crossing.

It may be that the natural processes of aging do not directly affect dynamic stability, but that age-associated pathologies (i.e., vestibular hypofunction, peripheral neuropathy, osteoarthritis, etc.) are more responsible for reductions in dynamic stability. Control of dynamic balance is challenged by the extrinsic risks encountered during locomotion. When balance is perturbed, the control system applies a series of reactive and feed-forward corrections via the musculoskeletal system to continuously maintain whole body center of mass (COM) trajectory within close range of the center of pressure (COP). A few studies reported the adequacy of the COM–COP interaction in demonstrating dynamic stability (balance control during locomotion), with a consistent COM trajectory passing between the alternating COP of each supporting foot (Jian et al., 1993; MacKinnon and Winter, 1993; Prince et al., 1994; Winter, 1995). Recent results showed that COM medio-lateral (M/L) displacement and peak M/L velocity during obstacle crossing could be used to better detect dynamic instability in elderly adults (Chou et al., 2001, 2003).

The purpose of this study was to determine the age-related differences in dynamic stability between healthy young and elderly adults during level walking and obstacle crossing tasks. It was hypothesized that there would be age-related differences in the measures of whole body dynamic stability. Specifically, it was expected that the COM trajectory would be conservatively adjusted to remain closer to the COP in elderly adults, as compared to young adults.

2. Methods

Thirteen young adults (7 male/6 female; 25.7±3.6 years, 171.8±9.2 cm, 74.2±13.1 kg) and thirteen elderly adults (8 male/5 female; 72.8±6.0 years, 168.9±11.4 cm, 72.2±14.8 kg) were recruited for this study from the University of Oregon campus and surrounding community, within the guidelines of the Institutional Review Board. Elderly subjects were noted to be active community members, with many of them currently involved in recreational sporting activities. Informed consent was obtained from each subject before participation. All participants were self-reported to be free of neuromuscular and musculoskeletal pathologies. The mental status of each elderly subject was assessed using the Folstein Mini-Mental test for the potential of comparison with clinically involved elderly patients (Folstein et al., 1975). Additionally, a clinical measure of possible deficits in sensory function was made for each elderly subject using the Berg Balance test (Berg et al., 1992). Mini-Mental scores were high ($>28/30$), as were scores for the Berg Balance test ($>54/56$), indicating that our sample was within the range of a healthy normal population.

Subjects were asked to walk at a self-selected pace while barefoot, during level, and obstructed gait tasks along a 10-m walkway. Two upright standards and a light-weight crossbar presented a single obstacle at a height of 2.5%, 5%, 10%, and 15% body height (BH). The obstacle was a plastic pipe measuring 1.5 m long, with a diameter of 2.5 cm and was presented to the subjects prior to obstacle crossing trials. The obstacle was attached to the upright standards in such a way as to easily dislodge if contacted. Unobstructed walking trials were performed first, followed by obstacle-crossing trials. The obstacle height was randomly selected for each trial with three trials collected for each height. Subjects were allowed at least three complete steps before the obstacle-crossing stride to ensure that a comfortable, steady pace was achieved. Approach distances for all subjects ranged from 3.8 to 5.5 m. Only three of the elderly subjects had stride lengths small enough to allow the 3.8 m approach distance (11.5% of total subjects). The remainder used approach distances of greater than 4.7 m. For each subject, the same approach distance was used throughout all trials. The crossing stride was defined as the heel-strike of the trailing limb before the obstacle to the heel-strike of the same limb after clearing the obstacle. Due to this crossing stride definition, only trailing limb stride lengths and stride times were used in the analysis.

Whole-body motion data were collected using a six-camera ExpertVision system (Motion Analysis Corp., Santa Rosa, CA) with a set of 28 reflective markers, modified from Kadaba et al. (1989) and Jian et al. (1993), placed on bony landmarks of each subject. Specifically, for the lower extremity segments, markers were placed bilaterally over the dorsum of the foot (between second and third metatarsal heads), posterior aspect of the heel (at same level with foot marker), lateral malleoli, distal–lateral aspect of the shank, lateral femoral epicondyle, distal–lateral aspect of the thigh, anterior superior iliac spine (ASIS), and one sacral marker (midway between posterior superior iliac spines) for the posterior aspect of the pelvis. For the trunk and upper extremities; markers were placed over the superior aspects of the scapular acromion processes, lateral humeral epicondyles, and dorsal wrist lines (midway between radial and ulnar styloid). The head–neck segment was indicated by markers placed at the superior apex of the head, and bilaterally over the temple regions (in order to indicate the superior–inferior midpoint of the head–neck segment), estimating the frontal plane of this segment. Additionally, markers on the medial malleoli and medial femoral epicondyles were used in a static condition to estimate ankle and knee joint centers. Hip joint center positions were calculated using directional estimates as proportions of the distance between ASIS markers (Bell et al., 1989).

Three-dimensional marker trajectory data were collected at 60 Hz and low-pass filtered using a fourth-order Butterworth's filter with the cutoff frequency set at 8 Hz. Virtual marker positions were estimated using EVa software (Version 6.0, Motion Analysis Corp., Santa Rosa, CA) to represent internal segment endpoints from the external markers, and the relative positions of the segmental COMs. Both external markers and estimated joint centers (of both distal and proximal ends) were used to calculate the three-dimensional motion for individual body segments and locations of segmental COM. Anthropometric reference data were adapted from the initial work of Dempster (Winter, 1990) for both age groups and genders. Whole-body COM position data was calculated as the weighted sum of each body segment, with 13 segments representing the whole body (the head–neck, trunk, pelvis, upper and lower arms, upper and lower legs, feet). The validity of this COM estimation technique has been demonstrated previously (Chou et al., 2001). Furthermore, the magnitude and pattern of COM trajectories from this technique are in agreement with the values reported previously (Jian et al., 1993; MacKinnon and Winter, 1993; Prince et al., 1994; Winter, 1995).

Velocities and accelerations of the COM were estimated using the generalized cross-validated spline algorithm (Woltring, 1986). The COP position was calculated from the ground reaction forces/moments collected from two force platforms (AMTI, Watertown, MA), and the horizontal distance between COM and COP position was calculated for each frame of data. At the time instances of maximum COM–COP separation, antero-posterior (A/P) and M/L COM velocities were also recorded. The following temporal-distance (T-D) measures of gait were collected during the crossing stride: gait velocity (defined as the average forward speed of the sacral marker during the crossing stride), stride length (of the trailing limb), stride time, and step width (defined as the distance between ankle joint centers).

Initial statistical assessment required screening of outliers using inter-quartile range. If a case was found to be at a distance of more than three times the inter-quartile range away from the median, that case was removed from further analysis. The following dependent variables were analyzed for the effects of age group and obstacle height using a two-factor ANOVA with repeated measures of obstacle height: A/P, M/L and vertical range of motion (ROM), and peak A/P, M/L, upward and downward velocities of the COM during the crossing stride; peak posterior, anterior, and M/L COM–COP distances, and instantaneous COM velocities at those peak distances. T-D gait parameters (gait velocity, stride time, stride length, step width) were tested as well. As there were no significant differences in anthropometrics between the two subject groups (two-sample t-test: height $p = 0.484$; weight $p = 0.725$), the above-mentioned parameters were not normalized to body dimensions. A significance level was set at $\alpha = 0.05$ for all statistical tests. For those dependent variables showing significant differences for obstacle height, a polynomial test was performed to determine the trend (linear, quadratic, cubic). All statistical analyses were conducted with SYSTAT (Version 9, SPSS Inc., Chicago, IL).

3. Results

Initial screening indicated that 19 individual data points were outside reasonable variability (± 3 inter-quartile ranges). Of the 6630 total data points in the analysis (17 variables × 26 subjects × 5 conditions × 3 trials), the outlying data accounted for only 0.3% of the total data collected. Removal of these data from the analysis was therefore justified.

All subjects were able to complete the condition trials with no incidents of tripping. No significant age group differences were found for any of the T-D parameters (Table 1). As obstacle height increased so did stride time ($p < 0.001$, linearly), stride length ($p = 0.005$, quadratically), and step width ($p = 0.033$, linearly). Gait velocity was found to decrease linearly with increased obstacle height ($p < 0.001$).

When young and elderly adults were compared across the unobstructed walking condition, significant differences were detected for A/P ROM of the COM ($p = 0.046$; Table 2). When stepping over obstacles of different heights, significant age group differences were detected in A/P ROM of the COM ($p = 0.014$). No significant age group differences were detected for either M/L or vertical ROM of the COM. Nor were there significant age group differences in peak A/P (forward), M/L, upward, or downward velocities of the COM during the crossing stride. Increasing obstacle height resulted in linear increases ($p < 0.003$) of the following variables; A/P and vertical ROM, and peak M/L, upward and downward velocities of the COM. There

Table 1
Gait temporal-distance measurements for both groups during the crossing stride: group means (SD)

Obstacle height	None		2.5%		5%		10%		15%		*p*-Values*
	Young	Elderly	Young	Elderly	Young	Elderly	Young	Elderly	Young	Elderly	
Gait velocity (m/s)	1.363	1.295	1.331	1.268	1.317	1.237	1.253	1.169	1.195	1.120	$p_{\mathrm{h}} < 0.001$
	(0.169)	(0.097)	(0.161)	(0.148)	(0.147)	(0.141)	(0.155)	(0.183)	(0.140)	(0.219)	$p_{\mathrm{g}} = 0.182$
Stride time (s)	1.032	1.008	1.098	1.071	1.118	1.097	1.185	1.140	1.244	1.200	$p_{\mathrm{h}} < 0.001$
	(0.072)	(0.118)	(0.086)	(0.163)	(0.082)	(0.166)	(0.117)	(0.196)	(0.121)	(0.221)	$p_{\mathrm{g}} = 0.544$
Stride length (cm)	140.0	135.4	145.4	139.8	146.6	139.4	147.4	140.0	147.7	139.5	$p_{\mathrm{h}} = 0.005$
	(13.84)	(11.69)	(14.49)	(14.62)	(13.84)	(13.32)	(14.72)	(20.68)	(13.84)	(22.82)	$p_{\mathrm{g}} = 0.265$
Step width (cm)	10.71	10.28	11.01	10.80	11.92	10.68	11.89	10.93	11.96	12.04	$p_{\mathrm{h}} = 0.033$
	(2.46)	(1.96)	(2.69)	(2.61)	(3.21)	(2.62)	(2.89)	(2.51)	(2.93)	(2.26)	$p_{\mathrm{g}} = 0.530$

*p_{h} represents height effect. p_{g} represents group effect.

Table 2
COM displacements and peak velocities: group means (SD)

Obstacle height	None		2.5%		5%		10%		15%		*p*-Values*
	Young	Elderly	Young	Elderly	Young	Elderly	Young	Elderly	Young	Elderly	
A/P ROM (m)	1.408	1.314	1.472	1.361	1.480	1.365	1.514	1.361	1.522	1.360	$p_{\mathrm{h}} < 0.001$
	(0.136)	(0.081)	(0.138)	(0.127)	(0.138)	(0.103)	(0.151)	(0.135)	(0.141)	(0.155)	$p_{\mathrm{g}} = 0.014$
M/L ROM (m)	0.037	0.042	0.036	0.041	0.040	0.053	0.047	0.041	0.040	0.049	$p_{\mathrm{h}} = 0.046$
	(0.007)	(0.010)	(0.008)	(0.013)	(0.012)	(0.006)	(0.016)	(0.014)	(0.012)	(0.019)	$p_{\mathrm{g}} = 0.170$
Vertical ROM (m)	0.039	0.037	0.054	0.053	0.059	0.058	0.071	0.069	0.084	0.079	$p_{\mathrm{h}} < 0.001$
	(0.009)	(0.006)	(0.010)	(0.006)	(0.011)	(0.008)	(0.011)	(0.009)	(0.011)	(0.009)	$p_{\mathrm{g}} = 0.468$
Peak anterior velocity (m/s)	1.513	1.402	1.529	1.418	1.535	1.401	1.518	1.369	1.521	1.341	$p_{\mathrm{h}} = 0.438$
	(0.182)	(0.112)	(0.174)	(0.185)	(0.162)	(0.161)	(0.171)	(0.192)	(0.173)	(0.242)	$p_{\mathrm{g}} = 0.058$
Peak M/L velocity (m/s)	0.138	0.142	0.150	0.145	0.155	0.159	0.161	0.146	0.163	0.168	$p_{\mathrm{h}} = 0.001$
	(0.024)	(0.029)	(0.036)	(0.033)	(0.038)	(0.037)	(0.039)	(0.027)	(0.041)	(0.030)	$p_{\mathrm{g}} = 0.869$
Peak upward velocity (m/s)	0.224	0.203	0.285	0.263	0.307	0.282	0.350	0.319	0.394	0.355	$p_{\mathrm{h}} < 0.001$
	(0.058)	(0.042)	(0.064)	(0.038)	(0.063)	(0.042)	(0.072)	(0.037)	(0.071)	(0.043)	$p_{\mathrm{g}} = 0.161$
Peak downward velocity (m/s)	0.226	0.217	0.283	0.271	0.297	0.281	0.327	0.316	0.366	0.339	$p_{\mathrm{h}} < 0.001$
	(0.059)	(0.048)	(0.062)	(0.042)	(0.059)	(0.048)	(0.061)	(0.043)	(0.051)	(0.057)	$p_{\mathrm{g}} = 0.427$

*p_{h} represents height effect. p_{g} represents group effect.

were no significant interactions between the main effects of age group and obstacle height.

The greatest A/P COM–COP separation occurred at either the initial (posterior COM–COP distance) or final (anterior COM–COP distance) moment of the single support phase. A schematic representation is shown in Fig. 1 to illustrate the COM–COP relationship in both sagittal and frontal planes. In the same figure, representative patterns are also shown of the A/P and M/L COM–COP distances when stepping over an obstacle of 15% body height. During an unobstructed walking, a significant age effect was only detected for maximum anterior COM–COP distance ($p = 0.022$). Similarly, significant age group differences were found in the maximum anterior COM–COP distance across the obstacle conditions ($p = 0.007$), with the elderly adults allowing up to 0.26 m (±0.05 m) of separation when crossing an obstacle of 15% BH, while the young adults allowed 0.32 m (±0.05 m) of separation (Fig. 2). No group differences were detected for maximum posterior COM–COP distance (range: 21.5–26.1 cm in the young, 24.2–28.4 cm in the elderly; across all conditions). Increasing obstacle height resulted in a significantly linear increase ($p < 0.003$) of both the maximum posterior and anterior COM–COP separation distances. There were no significant age group differences in the maximum M/L COM–COP separation distance (range: 7.3–7.7 cm in the young, 8.1–10.0 cm in the elderly; across all conditions).

The instantaneous forward velocities of the COM at the times of maximum anterior and posterior COM–COP separations were also significantly different between young and elderly adults across the obstacle crossing conditions ($p = 0.043$ and 0.038, respectively; Figs. 3 and 4). However, during unobstructed walking instantaneous forward velocity did not show an age effect. The instantaneous A/P COM velocity at the time of greatest anterior COM–COP separation decreased linearly ($p < 0.001$) as obstacle height increased. No age effect was detected for the instantaneous M/L velocity at

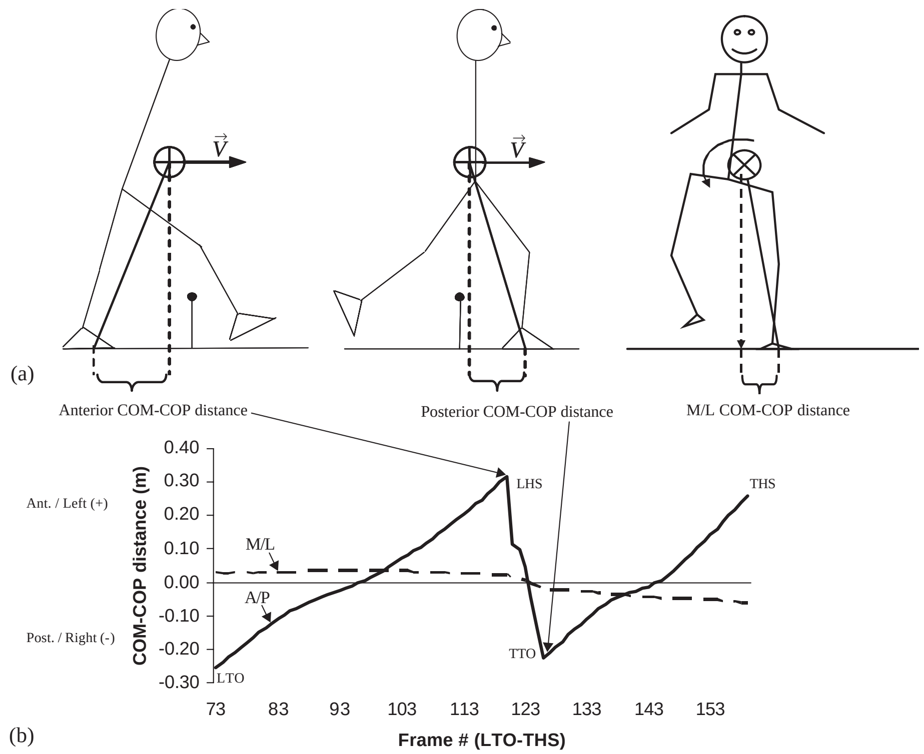

Fig. 1. (a) A sketch demonstrating the A/P and M/L COM–COP separation during the obstacle crossing stride. (b) Representative plots of A/P and M/L COM–COP separation distance over the time, from LTO to THS (LTO: leading limb toe-off; LHS: leading limb heel-strike; TTO: trailing limb toe-off; THS: trailing limb heel-strike). The left limb is the leading limb in this trial. Negative values indicate a COM position posterior (rightward for M/L) to the COP and positive values indicate anterior (or leftward) COM position.

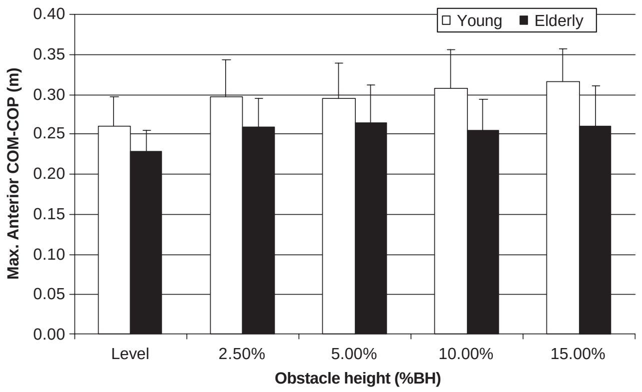

Fig. 2. Maximum anterior COM–COP separation values (means, SD bars) for both age groups during level and obstacle crossing conditions. Greater distances were allowed by the young group, increasing with obstacle height.

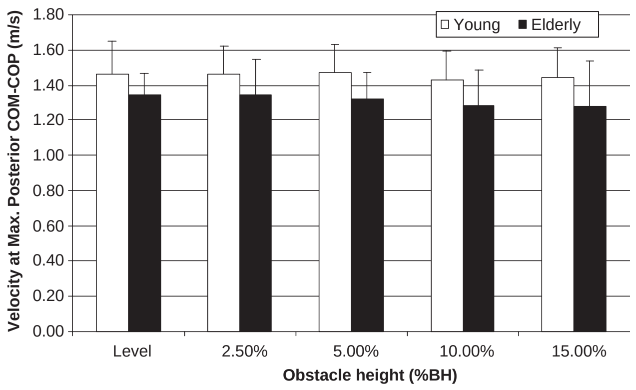

Fig. 3. Anterior COM velocity values (means, SD bars) at the maximum Posterior COM–COP distance for both age groups. Young adults demonstrated greater velocities across all conditions.

maximum COM–COP separation in either unobstructed or obstacle crossing conditions. Significant interactions between main effects were not detected.

4. Discussion

As age-related declines occur in the balance control system, it is reasonable to expect that a reduced ability to maintain dynamic stability would be evident in altered patterns of COM motion and its coordination with the COP. Results from this study revealed that there are age-dependent decreases in A/P ROM of the COM, maximum anterior COM–COP distance allowed, and the instantaneous anterior COM velocity at the timing of maximum anterior or posterior COM–COP separation. These significant age-related differences indicate that a conservative strategy is adopted by the

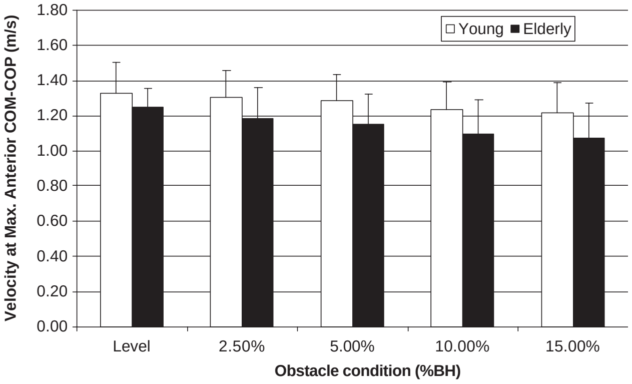

Fig. 4. Anterior COM velocity values (means, SD bars) at the maximum Anterior COM–COP distance for both age groups. Young adults demonstrated greater velocities across the conditions, and anterior velocities decreased as obstacle height increased.

elderly to reduce the instantaneous COM forward velocity and distance between the COM and COP. As obstacle height increased, this indication was confirmed by a decrease in the forward velocity when the COM–COP separation distance was greatest.

Elderly individuals with balance control disabilities were previously reported to demonstrate a significantly greater and faster M/L COM motion than their age-matched controls during obstructed gait, with an average increase of 3 cm in M/L COM displacement and 7 cm/s in peak M/L COM velocity (Chou et al., 2003). Present results indicate that healthy elderly adults were able to adequately maintain frontal plane dynamic stability during obstructed walking when compared to healthy young adults. In general, elderly adults did allow greater M/L COM motion, but these differences were less than 1 cm in magnitude. Additionally, there were no detectable differences in the peak M/L velocity allowed. These findings confirmed that elderly adults recruited for this study were free of balance problems during locomotion.

Significant reductions observed in the sagittal plane COM motion indicate a conservative approach to management of the mechanical challenge imposed during level locomotion and obstacle crossing. By maintaining a slower instantaneous COM velocity and a shorter distance between the COM and COP at the beginning and end of single support phase elderly adults would be able to reduce mechanical challenge of locomotion. A greater distance between the COM and COP is expected to result in larger moment arms for the body weight about joints of the supporting limb and require greater muscular efforts for the counterbalance. Healthy elderly adults are known to have decreased muscular strength (Grimby and Saltin, 1983; Fiatarone and Evans, 1993), indicating that exposure to the same challenge poses a greater threat to elderly adults. In addition to having significantly reduced lower extremity isometric joint torques, elderly adults were found to use significantly greater proportions of their muscular capacity than younger adults when performing activities of daily living (Hortobagyi et al., 2003). As obstacle height increased, elderly subjects used 38–50% of their lower extremity muscular capacity, compared to 25–36% in younger subjects (Hahn et al., 2003). These findings support the notion that a conservative obstacle crossing strategy, which could be the magnification of an already existing conservative behavior, is adopted in the elderly population due to reduced strength in the lower extremities.

Typical gait T-D parameters revealed no significant group differences. This finding is somewhat unexpected, as gait velocity, stride length, and step width were reported to decrease significantly in older adults during obstacle crossing (Chen et al., 1991; McFadyen and Prince, 2002). However, it should be noted that walking speeds and stride lengths of our young adults were in agreement with those reported by Chen et al. (1991), and data of our elderly adults also compared favorably with those reported by McFadyen and Prince (2002). This reflects possible inter-laboratory variations in the gait T-D parameters. An alternative explanation might be the vigorous activity level of our elderly subjects. Their gait velocities were not significantly lower than the younger sample, indicating that they may be more able-bodied than the broader elderly population.

One interesting phenomenon within our obstacle results is that reduction in A/P ROM and A/P COM–COP distance was achieved without a significant decrease in the gait velocity or stride length. One possible explanation is that elderly adults made postural adjustments in the form of anterior trunk lean prior to beginning the crossing stride, and subsequently straightened the trunk into a vertical attitude towards the end of the crossing stride. A further examination of our data indicated that elderly adults demonstrated a greater range of trunk sway in the sagittal plane than young adults when stepping over the highest obstacle (the elderly: $9.4 \pm 2.02^\circ$; the young: $7.2 \pm 2.62^\circ$). This might also explain the relatively greater discrepancy between the A/P ROM of the COM and stride length in elderly adults during unobstructed walking. Furthermore, a greater range of variation (or adjustment) of the instantaneous COM velocity during a gait cycle in elderly adults might explain why only significant age-related differences were detected for the instantaneous forward COM velocity at maximum COM–COP separation, but not for the average gait velocity. These findings imply that more frequent postural adjustments of the trunk are needed in the elderly to maintain proper coordination between the COM and COP (i.e., maintain dynamic balance).

It has been reported previously that both the instantaneous velocity and position (with respect to the stance foot) of the COM are required to determine a feasible stability region for safe movement termination (Pai and Patton, 1997). The instantaneous forward COM velocity observed in the present study immediately following trailing limb toe-off (maximum posterior COM position) was found to sufficiently maintain a forward progression of the whole body. At the instant just prior to leading limb heel-strike (maximum anterior COM position) our elderly subjects reduced the separation between COM and COP while also decreasing their instantaneous anterior velocity, effectively maintaining the COM trajectory within a feasible range of the base of support, thereby reducing the risk of imbalance.

In conclusion, findings of this study revealed significant age-related differences in sagittal plane COM and COP interaction, however there were no indications of frontal plane dynamic instability in the elderly when compared to healthy young adults. Elderly adults demonstrated a conservative strategy for reducing the mechanical load placed on joints of the supporting limb, while adequately maintaining forward progression. A reduction in COM–COP separation coincided with lower instantaneous anterior COM velocities at either end of the single support phase of obstacle crossing. This conservative strategy may be related to a reduction in muscle strength as it occurs in the natural aging process. Application of these results could be used in the prevention of falls by designing interventions to target increased strength in the lower extremities.

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