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Trunk Sway during Walking among Older Adults: Norms and Correlation with Gait Velocity

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Abstract

The aim of this study was to establish quantitative norms for trunk sway during walking for older male and female ambulatory adults at different age groups (65–70, 71–75, 76–80, 81). We also assessed the relationship between dynamic trunk sway and gait velocity in older individuals with clinically normal or abnormal gaits. Trunk sway in medio-lateral (roll) and antero-posterior (pitch) planes was measured using a body-mounted gyroscope (SwayStar) during walking on a 4.5 meter long instrumented walkway. Of the 284 older adults (mean age 76.8, 54.6% women) in this sample, the mean $\pm$ SD value of roll and pitch angles were $6.0 \pm 2.0^\circ$ and $6.7 \pm 2.2^\circ$ respectively. Older women showed significantly greater trunk sway in both roll and pitch angles than older men ($p < 0.01$). In both men and women, there was no significant association of roll angle with age although gait velocity decreased with increasing age. The relationship between roll angle and gait velocity was U-shaped for the overall sample. Among the subgroup with clinically normal gait, increased roll angle was associated with increased gait velocity ($p < 0.001$). However, there was no significant relationship between roll angle and gait velocity among the subgroup with abnormal

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gait. Therefore, the relationship between medio-lateral trunk sway and gait velocity differs depending on whether gait is clinically normal.

We conclude that trunk sway during walking should be interpreted with consideration of both gait velocity and presence of gait abnormality in older adults.

Balance impairment is highly prevalent among older adults living in the community, with up to 30% of older men and 40% of older women reporting postural instability [1]. Impaired static balance is a main predictor of negative health outcomes in older adults including mobility disability [2], falls [3], hospitalization [4], and mortality [4]. In addition, impaired dynamic balance has been shown to be associated with social isolation [1] and poor quality of life in the elderly even after taking into account the presence of medical conditions and physical activity level [5].

Balance is often assessed by postural stability, the ability to return to equilibrium when the body is away from the center of mass. In previous studies, postural instability was measured during static state using force plates methods [3]. However, it is also important to examine the postural stability of older individuals in motion as most falls occur during walking [6]. The SwayStar system (Balance International Innovations GMBH, Switzerland), which measures trunk sway using a body-mounted gyroscope, has been reported to be a reliable measure of dynamic postural stability during walking in both healthy and diseased populations [7, 8]. This system measures the angular deviation of the trunk close to the center of mass (around the L3-L5 vertebral level) [9]. Although increased trunk sway is reported among those with specific diseases such as vestibular dysfunction, Parkinson's disease, and cerebellar ataxia [8, 10–12] or during normal aging [13], reliable normative data for trunk sway among the independently ambulatory older individuals are currently not available. Previous studies have primarily focused on the comparison of trunk sway between old versus younger individuals with relatively small sample sizes, which limits the use of the reported values for sway in these studies as 'norms' for other populations. Establishing norms by age and gender for trunk sway to quantify dynamic balance in an elderly population is critical as it can easily serve as a screening index for balance problems in both clinical and research settings.

Another aspect to consider in interpreting dynamic balance measures in aging populations is the influence of gait velocity on trunk sway [13, 14]. In both young and older individuals, trunk sway increases with faster walking velocity [13]. Walking slower than preferred velocity has been reported to show a trend toward reduced trunk sway in healthy older individuals [13]. Therefore, it is plausible that increased trunk sway may be associated with higher gait velocity among older adults with normal gait patterns. Both slow gait velocity [15] and increased trunk sway [9] are associated with increased risk of falls, therefore, individuals with the slowest gait velocity may have increased sway in spite of their slower walking speed. Based on these findings, we hypothesized that the relationship between trunk sway and gait velocity in older adults may be U-shaped rather than linear; with increased trunk sway present at extremes of gait velocity in the elderly. Among older individuals living in the community, approximately 35% of community dwelling older adults have been reported to have clinically abnormal gait [16]. Our previous studies have shown that clinical

gait abnormality is associated with slow gait velocity [17] and increased fall risk [15]. We, hence, hypothesized that trunk sway may increase with increasing gait velocity in older individuals with clinically normal gait. On the other hand, among those with clinically abnormal gait, trunk sway may increase with reduced gait velocity.

The objectives of this study were twofold: 1) to establish quantitative norms for dynamic trunk sway during walking by age and gender among community dwelling older adults (age 65); 2) to assess the relationship between gait velocity and trunk sway during walking in the overall sample, as well as in both clinically normal and abnormal gait subgroups.

Methods

Study Population and Design

Participants of this cross-sectional study were cross-enrolled from a cohort of older adults enrolled in a longitudinal research study entitled “Central Control of Mobility in Aging (CCMA)” [18, 19]. The primary aims of the CCMA study were to determine cognitive and brain control processes related to mobility and mobility disability in aging. Potential participants (age 65 and older) were identified from a population list of the city of Yonkers, New York, and were first contacted with a letter and then by telephone. A structured telephone screening interview was administered to potential participants to assess eligibility (65 years of age and older, residing in lower Westchester county, speaking English). Participants were screened using the AD 8 Dementia Screening Interview (cutoff score 2 [20]) and the Memory Impairment Screen (MIS; cutoff score < 5 [21]) to exclude dementia. Exclusion criteria included inability to independently ambulate, significant loss of vision (acuity worse than 20/100) and/or hearing (acuity worse than 40 dB HL at 2000 Hz), current or history of neurological or psychiatric disorders, recent or anticipated medical procedures that would affect mobility, reliance on dialysis, residing in nursing home, and participation in interventional trials. After completing the structured telephone interview, eligible individuals were scheduled for in-person visits at our research center. During the visits, the participants received neurological, cognitive, and mobility assessments. Cognitive status was confirmed using clinical case conference using procedures as previously described [22].

Clinical gait evaluations were performed by trained study clinicians as part of the neurological examination. Participants were asked to walk in a well-lit hallway wearing comfortable footwear at their preferred pace. Participants who used assistive devices (e.g. cane) were included if they were able to walk unassisted for the protocol. Gait was rated as normal or abnormal (neurological and non-neurological subtypes) following visual inspection based on our well-established rating scale [17, 23] with high inter-rater reliability (kappa 0.8) [17]. The neurological subtypes include ataxic, frontal, parkinsonian, neuropathic, hemiparetic, unsteady or spastic (video link of these gait subtypes is available at <http://www.nejm.org/doi/full/10.1056/NEJMoa020441>). Non-neurological subtypes include gait limitations due to shortness of breath from cardiopulmonary diseases and orthopedic conditions (e.g. osteoarthritis of the knee) [23]. All participants provided written informed consent and the local institutional review board.

Medical Evaluation

Research assistants elicited a history of medical illness using structured questionnaires. Dichotomous rating (present or absent) of hypertension, diabetes, heart failure, angina, myocardial infarction, strokes, Parkinson's disease, chronic obstructive lung disease, depression, and arthritis was used to calculate a summary illness index score (range, 0–10), as previously described [22]. Visual acuity was measured using Snellen chart and score was converted to a decimal point scale. Sensory loss of the lower limb was measured at the big toe using tuning fork (128Hz) by the study clinician, and rated as normal or impaired. Knee extension strength was measured on the right side with a custom-mounted dynamometer [24] with hips and knees at 90 degrees flexion in sitting position.

Measurement of Trunk Sway and Gait Velocity during Walking

Trunk sway and gait velocity was simultaneously measured for all participants. Gait velocity was measured on an instrumented walkway (dimension of $457.2 \times 90.2 \times 0.64$ cm, GAITRite, Havertown, PA) with excellent reliability and validity [15]. Participants were asked to walk on the GAITRite walkway at their preferred pace in a quiet well-lit room for one trial. Start and stop points were marked by white lines on the floor and included 3 feet from the edge of the recording surface to account for initial acceleration and terminal deceleration [25].

Trunk sway was measured using the SwayStar system (Balance International Innovations GMBH, Switzerland); which consisted of two angular-velocity transducers. The SwayStar device was light weight device (750 gram) with an adjustable belt that mounts securely near the center of mass on the lower back (L3-5 vertebral body) of the participant [7]. The SwayStar transducers measure angular velocity deviations in the medio-lateral (roll) and anterior-posterior (pitch) planes with a sampling frequency of 100 Hz. Angular displacement is then calculated on-line using trapezoid integration of the angular velocity samples. Peak-to-peak measures of angle and angular velocity in the two planes were used as analysis measures [7]. Participants were not required to be tethered with cables since wireless communication was employed between the base measuring system at the computer and the SwayStar unit. The test-retest reliability for trunk sway measured at baseline and two weeks later was good ($r = 0.69$ for roll angle and $r = 0.81$ for pitch angle) in our sample. The correlation of the gait velocities measured while walking with and without SwayStar in the first 205 individuals in our sample was excellent (Intra-class correlation coefficient; $ICC = 0.82$); confirming the minimal impact of the sway recording equipment on gait characteristics of participants.

Statistical Analysis

The mean ($\pm$ standard deviation) values of the roll (medio-lateral) and pitch (antero-posterior) angles and angle velocities were tabulated per 5 year age stratum for each gender. (see Table 2) Descriptive statistics were used to compare the values of gait velocity, roll and pitch angles and angular velocity between male and female participants (Wilcoxon Rank Sum test) as well as among different age groups for each gender (Kruskal Wallis test).

The possible U-shaped relationship between the gait velocity and trunk sway (roll and pitch angle) was examined by regression analysis including quadratic term for gait velocity to account for non-linear trends.

Gait velocity served as the predictor, and roll or pitch angle was the outcome variable in separate multivariate linear regression analysis. These analyses were further stratified by the presence of absence of clinical gait abnormalities. As the values of the roll and pitch angles were skewed, they were log transformed. Variables of p value of < 0.1 in bivariate regression analysis or of clinical significance were included in the final regression model. The final model utilized stepwise backward selection. Variables in the final model included age, gender, visual acuity, sensory loss in lower limbs, and gait velocity. All analyses were performed using Stata version 12 (StataCorp LP, College Station, TX).

Results

Study Population and Clinical Characteristics

The demographic and clinical characteristics of the study participants are summarized in Table 1.

Among the 334 CCMA participants seen between June 2011 to March 2013, 284 (85%) had trunk sway measurements. Reasons for missing trunk sway assessments included unavailability of the device ($n=43$) and refusals ($n = 7$). The mean age ($\pm$ standard deviation) of the participants was 76.8 ± 6.8 years (54.6% women). The illness index summary score was 1.16 ± 1.0 indicating that our study population was relatively healthy. The proportion of participants with visual impairment and sensory loss of the lower limb was 59.7% and 29.1% respectively. One hundred thirty two participants (48%) had clinically abnormal gaits diagnosed by the study clinician (28.8% neurological, 54.5% non-neurological, 16.7% combined), which is higher than our previous report [16].

Trunk sway during walking by age group and gender

The mean (median) values of roll and pitch angles in the overall study sample were $6.0 \pm 2.0^\circ$ (5.6) and $6.7 \pm 2.2^\circ$ (6.2) respectively. The mean ($\pm$ SD) gait velocity was $98.7 (\pm 22.9)$ cm/s. Table 2 shows the mean values for trunk sway angles and gait velocity by gender and age groups. Older women demonstrated significantly greater trunk sway in both planes compared to older men [mean $\pm$ SD, $6.5 \pm 2.2^\circ$ versus $5.4 \pm 1.7^\circ$ in roll angle, $p<0.01$ and $7.0 \pm 2.2^\circ$ versus $6.3 \pm 2.2^\circ$ in pitch angle, $p< 0.01$ respectively]. There was no significant difference between men and women in angle velocity in both planes.

There was no significant difference in roll angle among the age groups ($p=0.375$ for men, $p=0.157$ for women). Pitch angle in women was not significantly different across age groups ($p=0.602$). The pitch angle of the oldest male age group was significantly greater than the rest of the age groups ($p=0.032$). With increasing age, the roll angle velocity was significantly decreased in female ($p < 0.01$). There was no trend of increase or decrease in roll and pitch angle velocity with age in men.

Relationship between trunk sway and gait velocity in total study population

The relationship between the gait velocity and roll angle showed a U-shaped relationship with sway being the smallest in the midrange of the gait velocity and larger at the lower as well as higher gait velocity ranges (test for U-shape, $p=0.020$). A similar relationship was evident for the pitch angle which did not reach statistical significance (test for U-shape, $p=0.120$). Figure 1 depicts a U-shaped relationship between the gait velocity (quartiles) and trunk sway in the total study population.

A linear relationship was observed between roll angle velocity and gait velocity (increasing roll angle velocity with increasing gait velocity, $p=0.050$). No significant relationship was noted between pitch angle velocity and gait velocity.

Relationship between trunk sway and gait velocity in subgroups of normal vs. abnormal gait

Trunk sway angles (both roll and pitch) were significantly greater in older adults with abnormal clinical gait compared to those with normal gait (mean $\pm$ SD; $6.2^\circ \pm 2.0$ versus $5.7^\circ \pm 2.0$ for roll, $p=0.034$, $7.2^\circ \pm 2.3$ versus $6.2^\circ \pm 2.0$ for pitch angle, $p<0.001$). Roll sway angle velocity was decreased (55.9 ± 21.9 °/sec versus 62.4 ± 25.3 °/sec, $p=0.012$) and gait velocity was slower in those with abnormal gait compared to those with normal gait (88.8 cm/s $\pm$ 21.2 versus 108.4 cm/s $\pm$ 20.2, $p<0.001$).

Table 3 describes the results of the multivariate linear regression analysis for the association between gait velocity and roll angle in the groups with and without clinical gait abnormalities. Increasing gait velocity was significantly associated with larger roll angle (medio-lateral sway) among those with normal gait. As a post hoc analysis, we estimated the amount of increase in mediolateral trunk sway associated with 10 cm/sec increase in gait velocity in the subgroup with normal gait. There was 0.31 degree increase in mediolateral sway with each 10 cm/sec increase in gait velocity. For those with clinical gait abnormalities, gait velocity did not show significant association with roll angle. For both subgroups, female gender showed significant association with increased roll angle compared to male.

Figure 2 illustrates the relationship between gait velocity (quartiles) and roll angle among individuals with or without gait abnormalities. Among those without gait abnormalities, the roll angle increases with increasing gait velocity (Figure 2a), however, this relationship is not shown among those with gait abnormalities (Figure 2b).

There was no association between gait velocity and pitch angle in either group. In those with clinical gait abnormalities, only impaired lower limb sensory loss was associated with larger pitch angle.

Discussion

In this study, we report normative values of dynamic trunk sway angles and angle velocity during walking by age and gender in a relatively large non-disabled community dwelling sample of adults age 65 years and older. On average, trunk sway was 5 to 6 degrees in the

mediolateral and 6 to 7 degrees in anteroposterior plane; these values are comparable to those reported in previous smaller studies [13, 26]. The median value of the roll and pitch angles during walking at a preferred velocity was 4.5 ± 1.4 degrees and 8.4 ± 1.3 degrees in 59 healthy elderly [26]. Goutier et al. reported roll and pitch angles of approximately 5° at preferred speed of 1.2 m/s in 20 healthy older adults [13].

Mediolateral sway during walking was not substantially different in our age groups of 65 years and older in men and women. There is a common belief that aging is associated with worsening of balance, including trunk sway as previously described in the comparison of young and elderly by Goutier et al [13]. Although this may be true for static balance, our results suggest that trunk sway during walking at preferred gait velocity may not necessarily increase with age. We are currently conducting a longitudinal study to further verify these cross-sectional findings.

Older women demonstrated larger sway across all age groups in both mediolateral and anteroposterior planes. The association between the female gender and roll angle remained robust even after accounting for several factors such as gait velocity and age. It has been reported that women, particularly older women, tend to have larger pelvic motion in coronal plane (pelvic obliquity) compared to men [27]. This increased pelvic motion in coronal plane (pelvic obliquity) is thought to be a mechanism to reduce the vertical displacement of center of mass (COM) and conserve energy during walking [28]. Although increased mediolateral sway may be beneficial with respect to biomechanical energy considerations, greater pelvic obliquity may be maladaptive with respect to falls and lumbosacral spine. Increased lateral trunk sway is associated with increased risk of falls [3], which may in part explain the increased fall related injury rates among older women, approximately 1.5 to 2 times higher than men [29].

To our knowledge, the U-shaped association between gait velocity and trunk sway in community living older adults has not been reported. Trunk sway appears to be the smallest for the mid range of gait velocity and increases with either higher or lower gait velocity than mid range. This implies that trunk sway needs to be interpreted differently depending on the associated gait velocity. The right arm of the U relationship can be explained by those with normal gait showing increased roll angle with increased gait velocity. It suggests that the increased trunk sway with faster gait velocity may not necessarily be pathological. We anticipated that the left arm of the U shape relationship might be explained by the subgroup with abnormal gait. The subgroup with clinically abnormal gait is heterogeneous population with various neurological or non-neurological pathologies. We hypothesize that lack of clear linear relationship (left arm of the U shape) may be attributed to this heterogeneity in quality and severity. Individuals with mild clinical gait abnormality may still be able to compensate by slowing gait velocity to reduce the sway. However, for the individuals with moderate to severe gait abnormality, this compensatory mechanism may fail to work. The latter may represent the left arm of the U shape relationship of overall sample. Further investigation will be needed to clarify this hypothesis.

The influence of clinical gait abnormalities on sway has not been well-studied. Older adults in our study with abnormal clinical gait showed significantly higher roll and pitch angles

despite having slower gait velocity. Previous studies reported that trunk sway increases with faster gait velocity within an individual [13, 26]. Our results reveal that mediolateral trunk sway also increases as the value of preferred gait velocity increases among this study sample without clinical gait abnormalities. This association between mediolateral trunk sway and the gait velocity was significant even after taking into account the factors that can affect trunk sway such as age, gender, sensory loss and visual impairment. The lack of significant differences in the raw values of trunk sway in the age groups studied (except the increase pitch angle in the oldest men) may be explained in part by the simultaneous decrease in gait velocity with increasing age.

For participants diagnosed with clinical gait abnormalities, there was no positive linear relationship between the gait velocity and the trunk sway of roll or pitch.

We found that roll angle velocity and gait velocity were both decreased among individuals with abnormal clinical gaits compared to those with normal gait patterns. Similar to our findings, Goutier [13] and Van Iersel et al [26] reported reduced angle velocity with decreased gait speed suggesting reduced sway velocity as a mechanism to increase a person's stability with decreasing gait velocity. The report by Allum et al [12] described reduced pitch angle velocity during the get up phase of the get-up-and-go test as a predictor of falls. However, the findings of angle velocity in relationship for fall risk have not been consistent [11, 12, 30]. In contrast to the above studies, larger oscillation of angle velocity was described in stoppers (individuals who stops during walking while talking- those considered at higher risk of falling) compared to non-stoppers [30].

Study Strengths and Limitations

This study has a number of strengths including use of a relatively large sample, standardized and validated clinical gait evaluations, and simultaneous measurement of gait velocity and trunk sway using reliable methods. There are some limitations of the study. To improve the reliability of our measures and safety of participants, we did not include individuals with disability or dementia. Therefore, our sample is relatively healthier and the result may not apply to individuals with dementia or disability.

CONCLUSIONS

Our findings suggest that dynamic trunk sway during walking is not affected by age, which may be explained by the simultaneous decrease in gait velocity with aging. Larger mediolateral trunk sway is associated with increased gait velocity in those with clinically normal gait but no such relationship was shown in those with abnormal gait patterns. Dynamic trunk sway needs to be interpreted in light of the associated gait velocity and clinical gait pattern in older individuals.

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Truncal sway was measured during walking in community dwelling older adults.

Trunk sway was significantly increased in older women than older men.

There was no significant association of roll angle with age in older adults.

The relationship between roll angle and gait velocity was U-shaped.

1(a)

1(b)

Figure 1.

Roll (1a) and pitch (1b) angle by quartiles of gait velocity in overall sample

Q1: 42–82.6 cm/s, Q2: 83.2–99.4 cm/s, Q3: 99.6–114.2 cm/s, Q4: 114.3–166.7 cm/s

2(a)

2(b)

Figure 2.

Roll angle in subgroups with normal (2a) versus abnormal clinical gait (2b) by quartiles of gait velocity

Figure 2a Q1: 54.1–95.1 cm/s, Q2: 96.4–107.5 cm/s, Q3: 107.7–119.7 cm/s, Q4: 120.5–166.7 cm/s

Figure 2b Q1: 42–74.6 cm/s, Q2: 74.8–87.4 cm/s, Q3: 87.9–103.3 cm/s, Q4: 103.9–144.1 cm/s

Table 1

Demographic and clinical characteristics of study population

Characteristics	Total (n=284)
Age (years)	76.8 ± 6.8
Female (%)	155 (54.6)
Ethnicity, White (%)	247 (87.0)
Illness index summary score (range 0–10)	1.16 ± 1.0
Geriatric depression scale (0–30)	4.8 ± 4.0
Impaired Vision (%)	169 (59.7)
Knee extensor strength (kg)	31.8 ± 13.2
Sensory loss of lower limb (%)	78 (29.1)
Clinical gait abnormality (%)	132 (48)
Gait velocity (cm/s)	98.7 ± 22.9

Values are presented as mean ± SD (continuous variables), n (%).

Table 2

Trunk sway angle and gait velocity in normal walking based on age and gender

Male (n=129)				Female (n =155)			
Age	Roll (degrees)	Pitch (degrees)	Gait Velocity (cm/sec)	Age	Roll (degrees)	Pitch (degrees)	Gait Velocity (cm/sec)
65-70 (n=21)	5.8 ± 1.8 (5.5)	6.2 ± 2.4 (5.8)	102.1 ± 20.8 (104.5)	65-70 (n=40)	7.1 ± 2.5 (6.6)	6.9 ± 2.1 (6.1)	110.1 ± 24.8 (112.7)
71-75 (n=39)	5.4 ± 1.6 (5.1)	6.0 ± 2.1 (5.7)	108.3 ± 19.7 (107.8)	71-75 (n=36)	6.4 ± 1.7 (6.2)	7.0 ± 1.9 (6.9)	102.9 ± 21.5 (107.0)
76-80 (n=28)	5.4 ± 1.8 (4.6)	5.8 ± 1.9 (5.6)	100.1 ± 21.0 (95.1)	76-80 (n=36)	5.8 ± 2.1 (5.6)	6.5 ± 1.8 (6.4)	90.9 ± 21.9 (94.9)
81 (n=41)	5.1 ± 1.5 (4.8)	7.1 ± 2.4 (6.4)	94.5 ± 19.9 (89.4)	81 (n=43)	6.5 (6.0)	7.4 ± 2.0 ± 2.6 (6.7)	84.0 ± 21.1 (80.3)
Total (n=129)	5.4 ± 1.7 (5.1)	6.3 ± 2.2 (5.9)	101.1 ± 20.7 (100.2)	Total (n=155)	6.5 ± 2.2 (6.1)	7.0 ± 2.2 (6.6)	96.7 ± 24.5 (98.9)

NOTE. Values are mean ± SD (median)

Table 3

Multivariate linear regression analysis with roll angle as the dependent variable

Variable	No Gait Abnormalities (n=152)		Gait Abnormalities (n=132)	
	Beta (95% CI)	P	Beta (95% CI)	P
Gait velocity	0.0046 (0.0018–0.0073)	0.001	0.0017 (–0.0011–0.0046)	0.230
Age	–0.0059 (–0.0153–0.0035)	0.216	–0.0002 (–0.0089–0.0085)	0.968
Female gender	0.136 (0.0262–0.2457)	0.016	0.2313 (0.1116–0.3511)	0.000
Visual acuity	–0.0262 (–0.1362–0.0837)	0.637	0.0530 (–0.0638–0.1697)	0.371
Vibration loss	0.0553 (–0.0652–0.1760)	0.366	–0.0198 (–0.1458–0.1063)	0.757

The value of roll angle is log transformed.