Gait & Posture 40 (2014) 676–681

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Trunk sway during walking among older adults: Norms and correlation with gait velocity

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ARTICLE INFO

Article history:
Received 4 November 2013
Received in revised form 17 July 2014
Accepted 28 July 2014

Keywords:
Balance
Trunk sway
Gait velocity
Older adults

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 m long instrumented walkway. Of the 284 older adults (mean age 76.8, 54.6% women) in this sample, the mean ± 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 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.

1. Introduction

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

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http://dx.doi.org/10.1016/j.gaitpost.2014.07.023
0966-6362/

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 $\geq$ 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.

2. Methods

2.1. 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 $\geq$ 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.

2.2. 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 (128 Hz) 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° flexion in sitting position.

2.3. 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 cm $\times$ 90.2 cm $\times$ 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 g) with an adjustable belt that mounts securely near the center of mass on the lower back (L3–L5 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.