Journal of Bodywork & Movement Therapies (2015) 19, 473—481

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/jbmt

EXPLORATORY STUDY

Effects of Alexander Technique training experience on gait behavior in older adults

Matthew M. O'Neill, M.S., C.S.C.S. [a], David I. Anderson, PhD [a], Diane D. Allen, PT, PhD [b], Christopher Ross, B.S. [a], Kate A. Hamel, PhD [a,*]

[a] *Department of Kinesiology, San Francisco State University, San Francisco, CA, USA*
[b] *Department of Physical Therapy, San Francisco State University, San Francisco, CA, USA*

Received 3 November 2014; received in revised form 18 December 2014; accepted 22 December 2014

KEYWORDS
Aging;
Fall prevention;
Walking;
Center of mass stability

Summary Heightened fall risk, potentially caused by aging-related changes in gait, is a serious health issue faced by older adults. The Alexander Technique is thought to improve balance and motor function; however, the technique's effect on gait has not been studied. The purpose of this study was to examine the effect of Alexander Technique training in older adults on the temporospatial characteristics of gait and medio-lateral center of mass displacement during fast and comfortably paced over-ground walking. Six licensed Alexander Technique teachers and seven controls between the ages of 60 and 75 years of age participated in the study. Alexander Technique teachers exhibited a reduction in medio-lateral center of mass displacement during fast paced walking compared to comfortably paced walking that was not present in controls. Due to this difference Alexander Technique teachers displayed a smaller medio-lateral Center of Mass displacement compared to controls during fast paced walking. Alexander Technique teachers also demonstrated significantly smaller stride width and lower gait timing variability compared to controls. These findings, which suggest superior control of dynamic stability during gait and potentially reduced fall risk in Alexander Technique teachers, warrant further study.

Introduction

The mortality risk associated with falling increases markedly with age and represents a significant health risk to older adults (US Census Bureau, 2012). Side falls pose a particular problem as they are one of the primary risk factors for hip fractures, accounting for approximately 90% of all incidents in older adults (Grennspan et al., 1998). Hip

* Corresponding author. Department of Kinesiology, San Francisco State University, 1600 Holloway Ave. Gym 101, San Francisco, CA 94132, USA. Tel.: +1 415 338 2186.
E-mail address: hamelk@sfsu.edu (K.A. Hamel).

http://dx.doi.org/10.1016/j.jbmt.2014.12.006
1360-8592/

fractures are an increasingly prevalent medical concern as the global population of older adults continues to grow (Marks, 2010) because they have serious consequences, with one study finding 20% estimated risk of mortality during the year following a hip fracture (Leibson et al., 2002). Most falls, including those resulting in hip fractures, occur while walking (Niino et al., 2000) which is the most common form of exercise ("Sports and Exercise BLS," 2008) and the key to independent mobility (Shumway-Cook and Woollacott, 2012). It is imperative not only to identify the causes and risk factors of such falls, but also to explore preventative therapies to reduce fall risk.

Maintaining dynamic stability is a key component of locomotion. Of particular importance is dynamic stability in the medio-lateral (M-L) direction which, when impaired, is a risk factor for falling in older adults (Chou et al., 2003). Aging has been shown to correspond with increased M-L displacement and movement velocity of the COM during locomotion (Schrager et al., 2008). This change in COM behavior may be related to a decrease in the ability to maintain dynamic stability of the body, particularly the trunk, in the M-L direction during walking, which has also been associated with aging (Kang and Dingwell, 2009). Aging-related differences in other temporospatial and kinematic characteristics of gait have also been found, including: decreased step length, increased step width, an increased double support phase, increased gait timing variability, decreased ankle plantar flexion and plantar flexion power, decreased hip extension, and increased anterior pelvic tilt (Winter et al., 1990; Kerrigan et al., 1998; Kerrigan et al., 2001; Schrager et al., 2008; Owings and Grabiner, 2004; Menz et al., 2003).

In addition to magnitude differences in kinematic variables of gait, increases in the variability of stride width and gait timing have also been observed in older adults and identified as risk factors for falls (Verghese et al., 2009). The aforementioned aging-related changes in gait characteristics may be attributable to musculoskeletal factors, such as hip flexor contractures (Kerrigan et al., 2001) or weakness in the hip abductors (Winter, 1995), or functional declines in sensory systems that accompany aging (e.g., visual, vestibular, or kinesthetic; Robbins et al., 1995; Zwergal et al., 2012). Some of these changes (e.g., shorter step length, increased step width) may reflect the adoption of a more conservative gait strategy by older adults, either in response to functional declines or decreased confidence. While intended to prevent falls, this strategy may actually lead to further loss of function due to reduced challenge to the motor control and musculoskeletal systems (Winter, 1995).

The Alexander Technique (AT) is an educational method that has been used to improve posture and movement via conscious control of habits that interfere with good coordination (Alexander, 1923, 1932). Alexander argued that learning to identify and then inhibit habitual reactions to the stimuli that trigger specific behaviors was the first step toward changing maladaptive postures and movements and releasing chronic patterns of tension. The next step involves what he referred to as "directing" — a procedure in which guiding orders (motor commands) that specify the newly-desired coordination among body parts (i.e., the "means-whereby" a given objective can be accomplished) are projected to the body, without any attempt to physically carry out the orders (Alexander, 1923).

The most important directions concern the "Primary Control," a term Alexander coined to describe the dynamic relationship between the head, neck, and back, that he thought biased tonic muscular activity throughout the rest of the body, like a master reflex (McDonald, 1989). The purpose of these primary directions is to prevent the spine and back from shortening and narrowing during a movement. Consequently, these directions encourage the person to allow the neck be free, to allow the head to go forward (move anteriorly) and up (away from the spine), and to allow the spine and back to lengthen and widen. Alexander believed that by initially inhibiting the habitual response to a stimulus and then by projecting specific directions that encourage a pattern of lengthening and widening through the spine and joints, one can increase movement efficiency, diminish unnecessary muscle activation, and reduce chronic stress to the musculoskeletal system (Alexander, 1923, 1932; Garlick, 1932).

Because Alexander also believed that the demands of adapting to a rapidly changing civilization had dulled kinesthetic awareness and thus rendered kinesthetic feedback less reliable (Alexander, 1923), the AT is taught by an experienced teacher who uses manual guidance to help the student connect the aforementioned verbal directions to a new kinesthetic experience. In a typical lesson, a teacher might work on an every—day activity like transitioning from standing to sitting or from sitting to standing. The teacher might initially invite the student to sit, i.e., provide a stimulus that would typically trigger sitting, but simultaneously ask the student to inhibit her habitual response to the stimulus. While the student inhibited the desire to sit, the teacher would provide the verbal directions to let the neck be free, to allow the head to move forward and up, to allow the back to lengthen and widen, and then subtly manipulate the head-neck-back relationship so that the student experienced the appropriate kinesthetic feedback connected to the directions while being guided into sitting. With sufficient practice receiving the directions, but refraining from attempting to enact the directions in a habitual way, and connecting the directions to the new kinesthetic experience provided by the teacher's manipulation, the student would be expected to develop a more reliable kinesthetic appreciation and to ultimately be capable of consciously directing movements more effectively on her own.

Preliminary scientific research into the AT revealed distinct postural changes during quiet stance as a result of AT training, namely decreased forward protrusion of the head and flexion of the cervical spine, reduced curvature of the thoracic spine, and a slight forward shift of the COM relative to the base of support (Garlick, 1932). The changes in the head-neck-back relationship are likely related to a subsequent finding of decreased activation of the sternocleidomastoid muscle during guided movements common to AT sessions (Jones et al., 1961). More recent studies have shown AT to be beneficial for treatment of musculoskeletal (low back pain; Cacciatore et al., 2005; Little et al., 2008) and neurological pathologies (Parkinson's disease; Stallibrass et al., 2002). The AT has also been shown to improve functional reach in older adults (Dennis, 1999), increase ability to dynamically regulate postural tone (Cacciatore et al., 2011a; Cacciatore et al., 2014), and improve performance during training in the execution of laparoscopic surgical techniques (Reddy et al., 2011). Additionally, individuals with extensive training in the AT have been shown to employ a fundamentally different strategy in sit-to-stand movements (Cacciatore et al., 2011b). These differences are theorized to be related to a change in central set, a preparatory state within the central nervous system associated with conscious movement control and anticipatory postural adjustments (Horak et al., 1989; Brooks, 1986; Cacciatore et al., 2011a). Central set is thought to be a requisite for effectively adapting and refining complex movement strategies such as those used when recovering one's balance. If the AT is an effective method of improving motor function and changing central set, it may be a valuable preventive or restorative therapy for aging related deteriorations in gait and dynamic stability, and it may be an effective method for decreasing fall risk.

In this study we explored the effects of the AT on the temporospatial characteristics and COM displacement of gait during over-ground walking in older adults. To gauge the effects of long-term exposure to the AT (>3 years) we compared American Society for the Alexander Technique (AmSAT) licensed AT teachers between the ages of 60 and 75 to a matched Control group of healthy older adults. Although no studies have examined the relationship between AT training and gait, based on the available research on the AT and the impact of aging on gait, we expected AT practitioners (i) to demonstrate superior M-L stability illustrated by a decrease in M-L movement of the COM compared to the controls (ii) to show decreased evidence of the stereotypical aging-related changes to gait, resulting in: a decreased step width; greater velocity; increased step length; and a decreased double limb support phase, compared to controls and (iii) to exhibit reduced variability in step width and gait timing compared to controls during over-ground walking.

Methods

Participants

This project was approved by the San Francisco State University Institutional Review Board (H14-01) in accordance with the Federal Policy for the Protection of Human Subjects. All participants received written and oral instructions regarding the procedure of the study and gave their written informed consent prior to participating. Exclusion criteria for the study included history of a stroke, Parkinson's disease, current visual or vestibular disorder, Meniere's disease, recent injuries or surgeries of the legs or feet, use of medications known to impair balance, or recent falls resulting in medical treatment or hospitalization.

Alexander Technique (AT) group

Six licensed AT practitioners ($N = 6$; female $= 4$; male $= 2$; mean age $= 65.8 \pm 5.2$ years; age range $= 63-75$ years; mean height $= 175.1 \pm 5.8$ cm; mean weight $= 74.8 \pm 7.8$ kg) were recruited through fliers posted at the Alexander Educational Center in Berkeley. All participants in the AT group had completed an AmSAT approved Teacher Training Course that consisted of 1600 h of hands-on training over a three year period, and had been practicing as an Alexander Technique teacher for an average of 29 years (sd $= 15.68$ years).

Control group

7 healthy older adult controls ($N = 7$; female $= 3$; male $= 4$; mean age $= 66.6 \pm 4.2$ years; age range $= 60-71$ years; mean height $= 173.3 \pm 7.5$ cm; mean weight $= 73.7 \pm 11.9$ kg) were recruited through the newsletter of the San Francisco State University Osher Lifelong Learning Institute and physical postings at the Institute. No significant differences in age, height or weight were found between the AT and Control groups ($p_{age} = 0.765$; $p_{height} = 0.659$; $p_{weight} = 0.845$).

Experimental measures

Prior to the test date, participants completed The Balance Efficacy Scale (BES) and a Health/Activity Information questionnaire (Rose, 2010). The BES consisted of 18 questions related to activities of daily living assessed on an 11-point scale (0–10) with 10 representing "absolutely confident." All questions were worded in the following manner: "How confident are you that you can ... without losing your balance." Tasks of daily living that were assessed in the BES included: stair climbing/descent; sit-to-stand; rising from a bed; use of a shower/bath tub; reaching tasks; walking on uneven ground; and single leg balance. The health and activity questionnaire provided a record of medical issues and current activity levels.

Temporospatial and center of pressure data were collected using a 0.61 m wide $\times$ 7.92 m long Zeno Walkway (Protokinetics; Peekskill, NY) operating the PKMAS v.507C7C software package. The Zeno walkway contains a 16-level pressure sensing pad and the entirety of its area is filled with 1 cm square pressure sensors that sample data at 120 Hz (Protokinetics, 2014). The temporospatial variables recorded included: stride width; stride length; velocity; percentage of the gait cycle spent in single and double limb support; Center of Pressure (COP) displacement; and estimated Center of Mass (COMe) displacement. All data were normalized by height for statistical comparison, but the normalization process did not impact the significance of any findings so only absolute values are reported.

Motion capture data from nine rigid marker clusters secured to the pelvis, upper arms, forearms, thighs, and shanks, and markers attached to participants' shoes and head band, along with individual markers affixed to the C7 vertebrae, the acromion on each shoulder, the suprasternal notch, and three markers on each hand were collected by a 10-camera VICON 3D motion capture system. The kinematic data collected in this study will be analyzed and discussed in a future paper.

Study design

All participants completed walking trials under four different conditions: Comfortably Paced walking without

Knowledge of Testing (CP w/o KOT); Fast Paced walking without Knowledge of Testing (FP w/o KOT); Comfortably Paced walking with Knowledge of Testing (CP w/KOT); Fast Paced walking with Knowledge of Testing (FP w/KOT).

Walking pace

Participants were asked to walk at two distinct walking paces: Comfortable Pace (CP) and Fast Pace (FP). During the CP walking trials participants were asked to walk at their "normal comfortable walking pace," while during the FP walking trials participants were asked to walk "as fast as possible without experiencing discomfort."

Knowledge of Testing (KOT)

Participants were recorded under two different KOT conditions: with (w/) and without (w/o) KOT. During the w/o KOT condition, participants were told that they were performing a warm-up that exactly replicated the procedure of the "actual" walking trials to be performed later in order to become accustomed to the procedure and the lab setting. During this time participants were also told that none of their walking trials were being recorded and researchers participated in decoy filing and computer set-up activities to mask the recording process. Following the w/o KOT trials, a high-definition camcorder was set up and participants were informed that the remainder of the trials would be recorded. Immediately following the completion of all walking trials, the participants were informed of the deception and were given the opportunity to withdraw from the study.

Protocol

Each participant performed a total of 24 walking trials under each of the four testing conditions. Each walking trial consisted of the participant beginning in a standing position at one end of the Zeno walkway, walking the length of the walkway, and coming to a complete stop at the opposite end. Participants were instructed to repeatedly walk the length of the walkway in both directions, coming to a complete stop at each end of the walkway, until 6 trials had been recorded under each condition.

Following the walking trials, participants' balance was assessed using a modified 12-item version of the Fullerton Advanced Balance Scale (Rose, 2010). The modifications included the performance of the single leg balance test on each leg, the addition of 'eyes open' variations of the stable ground and foam pad standing tests, and the removal of the standing broad jump due to safety concerns. Each item of the scale was assigned a score between zero and four for a maximum total score of 48. Data collection concluded with three trials of a modified version of the Timed Up and Go (TUG; Podsiadlo and Richardson, 1991). For the modified-TUG, two identical benches were placed 3 m apart directly opposite one another in the center of the lab area. The participants began in a seated position on one bench facing the other. Participants were instructed to stand, walk to the opposite bench, turn around, and sit down as quickly as possible. Total time required for the completion of this sequence of movements was recorded for each trial.

Data analysis model

A four-factor repeated measures General Linear Model ANOVA (fixed factors: group, pace, KOT; random factor: participant) was used to analyze differences within and between groups for each experimental measure. The within participant means and standard deviations of all temporospatial and COMe measures of the six walking trials performed under each testing condition were calculated in order to obtain the between trial coefficients of variation. The data were split by KOT and Pace and one-way ANOVAs were run to examine the between group differences for each testing condition. A significance level of $\alpha = 0.05$ was used for all statistical tests and due to the exploratory nature of this study no corrections were applied. Statistical tests were performed using MINITAB 16 (Minitab Inc., State College, PA).

Results

Questionnaires

Balance efficacy scale (BES)

No significant difference in BES score was detected between the AT (mean = 98.8%; SD = 1.2%) and Control (mean = 96.3%; SD = 5.7%; $p = 0.311$) groups.

Health/activity questionnaire

No significant difference in estimated days per week participants engage in strenuous physical activity was found between the AT (mean = 4.7 days SD = 2.7 days) and Control (mean = 5.7 days; SD = 0.4 days; $p = 0.36$) groups. The types of physical activity listed by participants included walking, running, cycling, swimming, golf, resistance training, dancing and stair climbing.

Knowledge of testing

A significant main effect was found for KOT on velocity (Table 1; $p < 0.001$). Both groups showed an increase in velocity w/KOT at both CP ($p_{AT}<0.001$; $p_C < 0.001$) and FP ($p_{AT} = 0.001$; $Pc < 0.001$). This increase in velocity created differences in all velocity-dependent gait variables including stride length and double support percentage. Due to these differences all further statistical analyses for each state of KOT were conducted separately.

Pace

A significant main effect of Pace on velocity was found for both groups under each condition of KOT (Table 1; $p < 0.001$ for all). As expected, participants walked significantly faster during FP trials than CP trials. This increase in velocity led to statistically significant differences between the two Paces in all velocity-dependent gait variables including: cadence; stride length; single and double limb support percentage ($p < 0.001$ for all). No significant difference in stride width was present between CP and FP trials in either group and under any KOT condition.

Table 1 Gait variables measured in Alexander Teachers (AT) and Controls; * significant between groups difference $p < 0.05$; ** marginally significant between groups difference $p < 0.08$, † significant within group difference $p < 0.05$.

Temporospatial data										
Measure	Group	CP w/o KOT		FP w/o KOT		CP w/KOT		FP w/KOT		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Stride Velocity (cm/s)	*AT*	*114.42*	*12.6*	*160.94***	*17.62*	*128.09*	*12.21*	*176.46***	*18.85*	
	control	**108.01**	**15.92**	**177.11****	**16.33**	**128.23**	**11.73**	**196.23****	**14.11**	
Cadence (steps/min)	*AT*	*99.4*	*7.98*	*120.56*	*5.42*	*106.97*	*6.34*	*127.39*	*6.3*	
	control	**99.32**	**10.69**	**129.38**	**12.70**	**107.74**	**8.48**	**137.13**	**16.14**	
Stride Length (cm)	*AT*	*136.51*	*6.68*	*158.39*	*15.41*	*142.38*	*9.84*	*164.88*	*18.26*	
	control	**128.76**	**8.85**	**163.14**	**16.49**	**141.80**	**10.39**	**170.76**	**16.19**	
Stride Width (cm)	*AT*	*8.52*	*2.14*	*7.24**	*2.43*	*7.91*	*2.23*	*8.26*	*2.28*	
	control	**10.18**	**4.19**	**10.02***	**2.13**	**9.8**	**2.06**	**10.07**	**2.49**	
Single Support %	*AT*	*35.28*	*0.97*	*37.84*	*1.27*	*36.03*	*0.74*	*38.36*	*1.18*	
	control	**34.96**	**1.47**	**38.55**	**1.36**	**36.28**	**0.78**	**39.19**	**1.65**	
Double Support %	*AT*	*29.32*	*1.92*	*23.95*	*2.74*	*27.79*	*1.55*	*22.89*	*4.49*	
	control	**29.95**	**2.98**	**22.56**	**2.67**	**27.31**	**1.60**	**21.05**	**3.15**	

Group differences

Velocity

A significant 2-way interaction between Group and Pace was present for Velocity both with and without KOT (Table 1; $p_{w/o} < 0.001$; $p_{w/}<0.001$). The Control group tended to walk faster than the AT group in both the FP w/KOT and FP w/o KOT conditions than in the CP conditions. Post-hoc analyses revealed no significant differences in velocity between groups for any of the four conditions. However, the higher velocity of the Control group approached statistical significance in the FP w/o KOT ($p = 0.077$) and FP w/KOT conditions ($p = 0.051$).

Stride length

A significant 2-way interaction between Group and Pace was revealed for stride length under both KOT conditions (Table 1; $p_{w/o} < 0.001$; $p_{w/} = 0.005$). The Control group tended to walk with longer strides than the AT group in the FP trials than in the CP trials. However, post-hoc analyses revealed that there was no significant difference in stride length between groups under either Condition.

Stride width

AT teachers demonstrated a reduced stride width during FP w/o KOT trials (Table 1; $p = 0.04$) compared to Controls. This trend persisted across all other conditions as well but did not reach statistical significance (p-values between 0.102 and 0.163).

Single limb support %

A 2-way interaction between Group and Pace was present for single support % both with and without KOT (Table 1; $p_{w/o} = 0.002$; $p_{w/} = 0.027$). The Control group tended to have a greater single support percentage than the AT group in the FP trials than in the CP trials. However, post-hoc analyses revealed that there was no significant difference in single support % between groups under either Condition.

Double limb support %

A 2-way interaction between Group and Pace was present for double support % both with and without KOT (Table 1; $p_{w/o} = 0.003$; $p_{w/} = 0.009$). The Control group tended to have a lower double support percentage than the AT group in the FP trials than in the CP trials. However, post-hoc analyses revealed that there was no significant difference in double support % between groups under either Condition.

Cadence

A 2-way interaction between Group and Pace was present for cadence both with and without KOT (Table 1; $p_{w/o} < 0.001$; $p_{w/}<0.001$). The Control group tended to have a higher cadence than the AT group in the FP trials than in the CP trials. However, post-hoc analyses revealed that there was no significant difference in cadence between groups under either Condition.

Medio-lateral center of mass estimate (COMe)

Due to differences between participants in the number of steps taken to traverse the walkway, and the methodology used to obtain COMe values, only one stride contained data for all participants. Therefore all statistical analyses are based on stride #3, which is defined as heel strike of the fourth foot fall until heel strike of the sixth.

A significant interaction between Group and Pace was present for COMe displacement in the M-L direction under both KOT conditions (Table 2; $p_{w/o} = 0.001$; $p_{w/} = 0.004$), with M-L displacement decreasing at FP for the AT group but not for the Control group (Fig. 1a and b). Post-hoc analysis revealed that the AT group showed a significant decrease in M-L COMe displacement from CP w/o KOT to FP w/o KOT ($p < 0.001$) and from CP w/KOT to FP w/KOT ($p < 0.001$), while the Control group exhibited no significant changes across conditions. Additionally, under both KOT conditions the AT and Control groups' M-L COMe displacement at CP was not significantly different ($p_{w/o} = 0.467$; $p_{w/} = 0.509$), while the difference in

Table 2 Gait variables measured in Alexander Teachers (AT) and Controls; * significant between groups difference $p < 0.05$; ** marginally significant between groups difference $p < 0.08$, † significant within group difference $p < 0.05$.

COP/COMe data									
Measure	Group	CP w/o KOT		FP w/o KOT		CP w/KOT		FP w/KOT	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
COP ML (cm)	*AT*	*15.12*	*2.67*	*13.66*	*2.50*	*14.04*	*2.59*	*13.85*	*3.14*
	control	**17.71**	**4.32**	**16.11**	**4.28**	**16.50**	**3.75**	**15.92**	**4.20**
COMe ML (cm)	*AT*	$5.61^{\dagger}$	*2.28*	$3.36^{\dagger}$	*1.67*	$4.36^{\dagger}$	*1.81*	$3.33^{*\dagger}$	*1.98*
	control	**5.96**	**2.90**	**5.20**	**3.44**	**5.60**	**2.90**	**5.53***	**3.03**

displacement between groups was significant during the FP w/KOT trials ($p = 0.007$).

Between trial variability

There was no significant difference between the AT and Control groups in the between trial Coefficient of Variation (CV) for stride width under any of the testing conditions (Table 3). In the w/KOT conditions a significant Group by Pace interaction was found for the CV of double support % ($p = 0.044$), with the AT group exhibiting a lower CV during FP w/KOT but not CP w/KOT. Post-hoc analysis revealed that this difference approached significance ($p = 0.063$). A similar Group by Pace interaction for the CV of single support % was marginally significant ($p = 0.056$). Post-hoc analysis showed the difference in CV of single support % between the AT and Control groups during FP w/KOT to be statistically non-significant ($p = 0.123$).

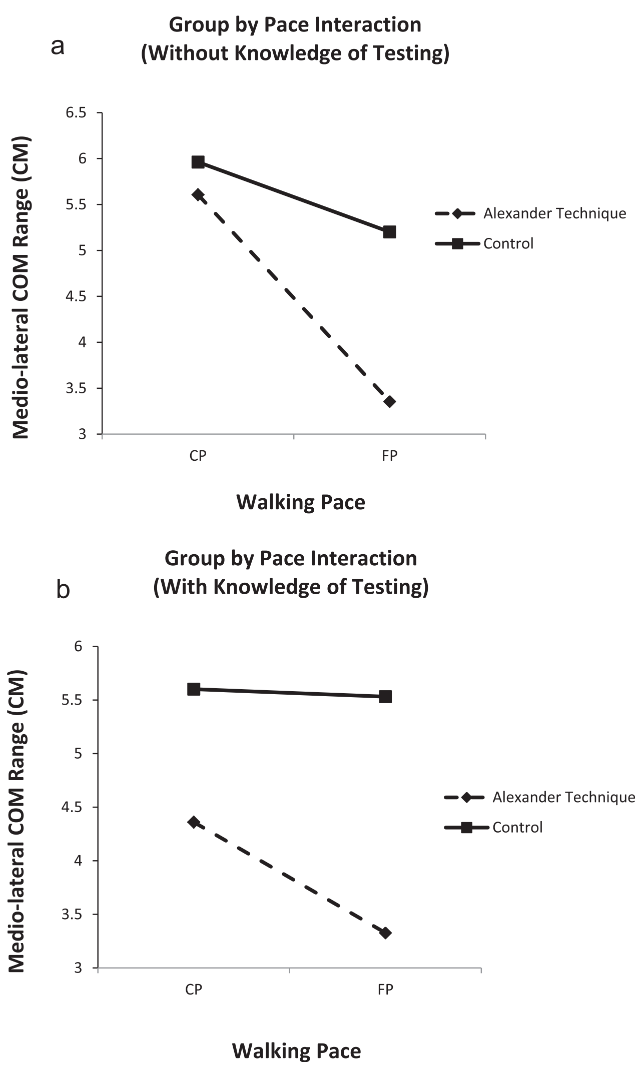

Figure 1 a. Group by Pace interaction for COM M-L displacement, without Knowledge of Testing. b. Group by Pace interaction for COM M-L displacement, with Knowledge of Testing.

Fullerton advanced balance scale

There was no significant difference in total score on the FABS between the AT (mean = 45.0; SD = 1.549) and Control groups (mean = 42.29; SD = 3.64; $p = 0.119$).

Timed Up-and-Go (TUG)

There was no significant differences in time scores on the TUG between the AT (mean = 4.21; SD = 1.17) and Control groups (mean = 4.72; SD = 1.40; $p = 0.491$).

Discussion

Initial observation of the temporospatial data revealed significant Group by Pace interactions in most of the targeted variables including: velocity; cadence; stride length; and single and double support percentages. Further analysis suggests that these interactions may all stem from the faster velocity of the Control group as compared to the AT group during the fast paced walking trials. The remaining interactions reflect changes that are expected with an increase in walking speed e.g., increased stride length, increased cadence, and a reduced double support phase (Orendurff et al., 2004). The difference in velocity is contrary to hypothesis (ii) and may be indicative of superior walking performance in the Control group. However, the lack of enhanced performance on the Timed Up-and-Go by the Control group suggests that these differences may just be an artifact of the subjective nature of the directions given regarding walking speed. In other words, the AT group may have simply chosen not to walk as fast in the FP trials. Additionally, there were no significant differences between the groups during comfortable paced waking, when participants were prompted to walk at their "normal, comfortable walking pace," which may be a more accurate representation of natural gait behavior.

Table 3 Gait variables measured in Alexander Teachers (AT) and Controls; * significant between groups difference $p < 0.05$; ** marginally significant between groups difference $p < 0.08$, † significant within group difference $p < 0.05$.

Between trial Variation of temporospatial and COP/COMe data

Measure	Group	CP w/o KOT		FP w/o KOT		CP w/KOT		FP w/KOT	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
CV Stride Width	*AT*	*11.97*	*7.06*	*15.10*	*10.32*	*13.58*	*8.54*	*9.59*	*5.12*
	control	**27.7**	**40.1**	**11.8**	**5.77**	**12.26**	**6.77**	**15.63**	**6.93**
CV Single Support %	*AT*	*1.71*	*0.76*	*1.52*	*0.64*	*1.11*	*0.38*	*1.16*	*0.39*
	control	**1.22**	**0.54**	**1.96**	**0.74**	**1.02**	**0.44**	**1.56**	**0.46**
CV Double Support %	*AT*	*3.71*	*1.80*	*4.65*	*2.04*	*2.91*	*0.84*	*3.28***	*1.42*
	control	**2.81**	**1.21**	**6.73**	**3.21**	**2.45**	**0.77**	**5.58****	**2.38**
CV COP Y	*AT*	*11.58*	*5.21*	*13.83*	*4.54*	*16.38*	*8.26*	*11.71*	*5.13*
	control	**9.01**	**4.65**	**18.2**	**6.33**	**13.3**	**5.8**	**17.28**	**6.87**
CV COMe Y	*AT*	*24.58*	*11.67*	*38.74*	*14.85*	*32.84*	*13.76*	*55.96*	*16.52*
	control	**30.14**	**15.01**	**43.15**	**11.4**	**33.34**	**10.46**	**51.28**	**17.94**
CV COMe Y/COP	*AT*	*19.54*	*6.61*	*39.69*	*16.52*	*23.12*	*6.87*	*52.18*	*17.77*
	control	**25.43**	**14.44**	**43.41**	**21.07**	**25.33**	**10.23**	**54.20**	**27.10**

Data for one temporospatial variable did not follow the trend expected with an increase in walking speed: stride width. Previous gait studies have found an inverse relationship between walking speed and stride width (Orendurff et al., 2004). However, during FP w/o KOT trials the AT group exhibited a significantly smaller stride width while walking at a slightly lower velocity as compared to the Control group (the difference in velocity approached statistical significance). The inverse relationship between walking speed and stride width suggests that any significant group differences in stride width should have been due to a decreased width in the Control group, just the opposite of what was found. In addition to the significant difference in stride width observed in the FP w/o KOT condition, non-significant differences that followed this trend were present in the remaining three testing conditions. An increase in stride width is a change associated with aging and is theorized to be a compensation strategy for the decrease in M-L dynamic stability associated with aging (Winter et al., 1990; Kang and Dingwell, 2009). By increasing stride width one is able to widen the base of support, one of the primary components of M-L stability (Bauby and Kuo, 2000; MacKinnon and Winter, 1993). The apparent lack of this compensation mechanism in the AT group suggests a superior control of M-L dynamic stability.

The conclusion that the greater stride width displayed by the Control group is a compensation for reduced M-L dynamic stability is further supported by the findings regarding M-L COMe displacement. AT participants displayed a clear decrease in M-L displacement of the COMe during fast paced walking as compared to comfortable paced walking. This trend is consistent with the decrease in COM displacement that accompanies an increase in walking pace in healthy young adults (Orendurff et al., 2004). The Control group did not exhibit this trend, which may be an indication of a reduction in their M-L stability at faster walking velocities. Additionally, in agreement with hypothesis (i), the AT group exhibited a smaller M-L displacement during fast paced walking than the Control group (only the 'with Knowledge of Testing condition' was statistically significant). This difference during fast paced walking between the AT and Control groups may indicate a prevention or reversal of the previously documented age-related increase in M-L COM displacement (Schrager et al., 2008).

The findings regarding M-L displacement of the COMe in the AT group may be explained by the teachings of the AT. Alexander believed movement efficiency was desirable as it would reduce stress to the body by minimizing requisite muscle activity (Alexander, 1923, 1932; Garlick, 1932), and minimal M-L displacement of the COM during walking is thought to be an indication of efficiency (Orendurff et al., 2004). One interpretation of the AT teaches that shifting the body laterally over the support leg during walking is unnecessary and that this shift can be avoided in a well-coordinated individual who directs the head to go forward and up and the back to lengthen and widen (Carrington, 1994). The smaller M-L COMe displacement observed in the AT group as compared to Controls during the fast paced walking trials (only the 'with Knowledge of Testing' condition was statistically significant) represents this teaching.

The reduced M-L displacement of the COMe in the AT group could be related to the previous findings regarding enhanced dynamic regulation of postural tone in AT practitioners. Cacciatore found reduced stiffness in the trunk during rotational movements (Cacciatore et al., 2011a) and in the hip extensors during the hip flexion portion of the sit-to-stand movement that occurs immediately prior to seat off (Cacciatore et al., 2014). This reduction in stiffness and improved dynamic regulation of postural tone could account for the differences in movement characteristics and the more efficient carriage of the COMe observed in AT teachers as compared to Controls. For example, if the reduction in hip stiffness exists in hip extension as well as hip flexion it could lead to increased hip extension range of motion during walking, which is a measure Kerrigan found to decline due to aging (Kerrigan et al., 2001). Kerrigan noted several apparent compensations due to decreased hip range of motion including decreased stride length and increased anterior tilt of the pelvis. An increase in M-L COM displacement during walking could be another product of reduced hip range of motion, and thus the reduced stiffness observed in AT practitioners could counteract this increase. However, kinematic measures derived from motion capture data must be analyzed to determine if a difference in hip extension ROM exists between groups.

Regardless of its root cause, the difference in M-L COMe displacement is a possible indication of improved walking efficiency and superior frontal plane dynamic stability as a result of the AT. The direction of this difference may result in a decreased risk of experiencing a side fall in those possessing training in the AT (Chou et al., 2003; Orendurff et al., 2004) and suggests that further studies should be undertaken to determine whether the AT warrants inclusion in fall-prevention protocols. Whether this is due to the AT group utilizing a different movement strategy, as with sit-to-stand (Cacciatore et al., 2011b), or a musculoskeletal difference such as increased abductor function (Winter, 1995) remains uncertain based on the data collected.

Contrary to what was hypothesized, no significant difference in the variability of stride width existed in any of the four testing conditions. Analyses did indicate decreased variability in single and double support percentages for the AT group during fast paced walking under the 'with Knowledge of Testing' condition (the Group by Pace interaction for double support percentage approached significance). These interactions follow the pattern of those for M-L COM displacement and velocity and may be related to one or both aforementioned findings. It is reasonable to posit that the reduction in variability of the phases of the stride cycle, and therefore more consistent gait behavior of the AT teachers at higher velocities, is indicative of enhanced M-L dynamic stability and a decreased fall risk (Verghese et al., 2009).

Perhaps the most intriguing and unexpected finding pertains to the effect of Knowledge of Testing on the walking speed of participants. Both the AT and Control groups walked significantly faster in the trials when they believed testing was occurring. The idea that gait behavior can change due to the awareness of a testing or recording situation has been demonstrated in treadmill running (Morin et al., 2009). In the speed-controlled environment of a treadmill, knowledge of testing resulted in changes in the running patterns of participants rather than velocity as observed in this study. This finding has major implications for the design of future gait analyses, as it suggests gait behavior recorded in contexts where participants have knowledge that testing is occurring may not accurately represent natural movement patterns.

In conclusion, the results discussed above indicate significant differences in M-L COMe displacement, stride width, and the variability of single and double support phases between older adults possessing extensive training in the AT and untrained matched controls. The directions of these trends may indicate an attenuation of some aging-related changes in gait and improved frontal plane dynamic stability as a result of AT training. These are both positive indications for further study of the efficacy of AT as a tool in fall-prevention protocols for older adults. Additionally, knowledge of being recorded for the purposes of testing was found to alter gait behavior in the form of increased velocity, which has important implications for the future study of human gait.

Limitations

The primary limitation to this study is the small sample size ($N_{total} = 13$). As such, many of the trends observed do not reach the threshold for statistical significance. Additionally, the lack of objective control of walking speed was associated with a significant 2-way interaction between Group and Pace for walking velocity, making it difficult to compare velocity-dependent gait characteristics.

Future directions

This study was intended to be exploratory in nature and, despite the limitations listed above, has provided indications for future research. The trends observed merit more extensive research into the effects of the AT on M-L dynamic stability during gait. A randomized, controlled trial based on an AT intervention would provide a more powerful comparison and examine the transferability of AT principles to untrained older adults. Additionally, the analysis of the kinematic data gathered in this study may support the current findings and provide insight into the biomechanical mechanisms responsible for the differences observed in temporospatial measures and COMe displacement.

Acknowledgements

The authors would like to thank Giora Pinkas and John Baron of the Alexander Educational Center in Berkeley California as well as the San Francisco State University Osher Lifelong Learning Institute for their help in the recruitment of participants for this study. This study was funded in part by an Office of Research and Sponsored Programs grant from San Francisco State University.

References

Alexander, F.M., 1923. Constructive Conscious Control of the Individual. E.P. Dutton & Company, New York, NY.

Alexander, F.M., 1932. The Use of the Self. Methuen & Co. Ltd, London.

Bauby, C.E., Kuo, A.D., 2000. Active control of lateral balance in human walking. J. Biomech. 33 (11), 1433–1440.

Brooks, V.B., 1986. The Neural Basis of Motor Control. Oxford University Press, New York, pp. 290–315.

Cacciatore, T.W., Horak, F.B., Henry, S.M., 2005. Improvement in automatic postural coordination following Alexander technique lessons in a person with low back pain. Phys. Ther. 85 (6), 565–578.

Cacciatore, T.W., Gurfinkel, V.S., Horak, F.B., Cordo, P.J., Ames, K.E., 2011a. Increased dynamic regulation of postural tone through Alexander Technique training. Hum. Mov. Sci. 30 (1), 74–89.

Cacciatore, T.W., Gurfinkel, V.S., Horak, F.B., Day, B.L., 2011b. Prolonged weight-shift and altered spinal coordination during sit-to-stand in practitioners of the Alexander Technique. Gait Posture 34 (4), 496–501.

Cacciatore, T.W., Mian, O.S., Peters, A., Day, B.L., 2014. Neuromechanical interference of posture on movement: evidence from Alexander technique teachers rising from a chair. J. Neurophysiol. 112 (3), 719–729.

Carrington, W., 1994. Thinking Aloud: Talks on Teaching the Alexander Technique. Mornum Time Press, Berkeley, CA.

Chou, L.S., Kaufman, K.R., Hahn, M.E., Brey, R.H., 2003. Medio-lateral motion of the center of mass during obstacle crossing distinguishes elderly individuals with imbalance. Gait Posture 18 (3), 125—133.

Dennis, R.J., 1999. Functional reach improvement in normal older women after Alexander Technique instruction. J. Gerontol. Ser. A: Biol. Sci. Med. Sci. 54 (1), M8—M11.

Garlick, D., 1932. The Lost Sixth Sense: a Medical Scientist Looks at the Alexander Technique. Laboratory for Musculoskeletal and Postural Research, School of Physiology and Pharmacology, the University of New South Wales.

Greenspan, S.L., Myers, E.R., Kiel, D.P., Parker, R.A., Hayes, W.C., Resnick, N.M., 1998. Fall direction, bone mineral density, and function: risk factors for hip fracture in frail nursing home elderly. Am. J. Med. 104 (6), 539—545.

Horak, F.B., Diener, H.C., Nashner, L.M., 1989. Influence of central set on human postural responses. J. Neurophysiol. 62 (4), 841—853.

Jones, F.P., Hanson, J.A., Gary, F.E., 1961. Head balance and sitting posture II; role of the sternomastoid muscle. J. Psychol. 52, 363—367.

Kang, H.G., Dingwell, J.B., 2009. Dynamic stability of superior vs. inferior segments during walking in young and older adults. Gait Posture 30 (2), 260—263.

Kerrigan, D.C., Todd, M.K., Della Croce, U., Lipsitz, L.A., Collins, J.J., 1998. Biomechanical gait alterations independent of speed in the healthy elderly: evidence for specific limiting impairments. Arch. Phys. Med. Rehabil. 79 (3), 317—322.

Kerrigan, D.C., Lee, L.W., Collins, J.J., Riley, P.O., Lipsitz, L.A., 2001. Reduced hip extension during walking: healthy elderly and fallers versus young adults. Arch. Phys. Med. Rehabil. 82 (1), 26—30.

Leibson, C.L., Tosteson, A.N., Gabriel, S.E., Ransom, J.E., Melton, L.J., 2002. Mortality, disability, and nursing home use for persons with and without hip fracture: a population-based study. J. Am. Geriatrics Soc. 50 (10), 1644—1650.

Little, P., Lewith, G., Webley, F., Evans, M., Beattie, A., Middleton, K., Sharp, D., 2008. Randomised controlled trial of Alexander technique lessons, exercise, and massage (ATEAM) for chronic and recurrent back pain. BMJ 337, 965—968.

MacKinnon, C.D., Winter, D.A., 1993. Control of whole body balance in the frontal plane during human walking. J. Biomech. 26 (6), 633—644.

Macdonald, P., 1989. The Alexander Technique: as I see it. The Alpha Press, Portland, OR.

Marks, R., 2010. Hip fracture epidemiological trends, outcomes, and risk factors, 1970—2009. Int. J. General Med. 3, 1—17.

Menz, H.B., Lord, S.R., Fitzpatrick, R.C., 2003. Age-related differences in walking stability. Age Ageing 32 (2), 137—142.

Morin, J.B., Samozino, P., Peyrot, N., 2009. Running pattern changes depending on the level of subjects' awareness of the measurements performed: a "sampling effect" in human locomotion experiments? Gait Posture 30 (4), 507—510.

Niino, N., Tsuzuku, S., Ando, F., Shimokata, H., 2000. Frequencies and circumstances of falls in the national institute for longevity sciences, longitudinal study of aging (NILS-LSA). J. Epidemiol. 10 (1 Suppl.), S90—S94.

Orendurff, M.S., Segal, A.D., Klute, G.K., Berge, J.S., Rohr, E.S., Kadel, N.J., 2004. The effect of walking speed on center of mass displacement. J. Rehabil. Res. Dev. 41 (6A), 829—834.

Owings, T.M., Grabiner, M.D., 2004. Variability of step kinematics in young and older adults. Gait Posture 20 (1), 26—29.

Podsiadlo, D., Richardson, S., 1991. The timed "up & go": a test of basic functional mobility for frail elderly persons. J. Am. Geriatrics Soc. 39 (2), 142—148.

Protokinetics, 2014. PKMAS Measurements & Definitions Guide. Retrieved from: http://www.protokinetics.com/images/PKMAS_M_D.pdf.

Reddy, P.P., Reddy, T.P., Roig-Francoli, J., Cone, L., Sivan, B., DeFoor, W.R., Noh, P.H., 2011. The impact of the Alexander Technique on improving posture and surgical ergonomics during minimally invasive surgery: pilot study. J. Urol. 186 (4), 1658—1662.

Robbins, S., Waked, E., McClaran, J., 1995. Proprioception and stability: foot position awareness as a function of age and footware. Age Ageing 24 (1), 67—72.

Rose, D.J., 2010. Fallproof!: a Comprehensive Balance and Mobility Training Program. Human Kinetics, Champaign, IL.

Schrager, M.A., Kelly, V.E., Price, R., Ferrucci, L., Shumway-Cook, A., 2008. The effects of age on medio-lateral stability during normal and narrow base walking. Gait Posture 28 (3), 466—471.

Shumway-Cook, A., Woollacott, M., 2012. Motor Control: Translating Research into Clinical Practice, fourth ed. Lippincott Williams & Wilkinson, Baltimore, MD.

Sports and Exercise BLS Spotlight on Statistics, 2008. U.S. Bureau of Labor Statistics. Online document at: http://www.bls.gov/spotlight/2008/sports/pdf/sports_bls_spotlight.pdf (accessed 21.11.13.).

Stallibrass, C., Sissons, P., Chalmers, C., 2002. Randomized controlled trial of the Alexander technique for idiopathic Parkinson's disease. Clin. Rehabil. 16 (7), 695—708.

United States Census Bureau, 2012. Births, deaths, marriages, & divorces: deaths. 2012 Statistical Abstract. Retrieved from http://www.census.gov/compendia/statab/cats/births_deaths_marriages_divorces/deaths.html.

Verghese, J., Holtzer, R., Lipton, R.B., Wang, C., 2009. Quantitative gait markers and incident fall risk in older adults. J. Gerontol. Ser. A: Biol. Sci. Med. Sci. 64 (8), 896—901.

Winter, D.A., Patla, A.E., Frank, J.S., Walt, S.E., 1990. Biomechanical walking pattern changes in the fit and healthy elderly. Phys. Ther. 70 (6), 340—347.

Winter, D.A., 1995. Human balance and posture control during standing and walking. Gait Posture 3 (4), 193—214.

Zwergal, A., Linn, J., Xiong, G., Brandt, T., Strupp, M., Jahn, K., 2012. Aging of human supraspinal locomotor and postural control in fMRI. Neurobiol. Aging 33 (6), 1073—1084.