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Effects of different initial foot positions on kinematics, muscle activation patterns, and postural control during a sit-to-stand in younger and older adults

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ABSTRACT

Background: Performing a sit-to-stand (STS) can be a challenging task for older adults because of age-related declines in neuromuscular strength and coordination. We investigated the effects of different initial foot positions (IFPs) on kinematics, muscle activation patterns, and balance control during a STS in younger and older adults. *Methods:* Ten younger and ten older healthy adults participated in this study. Four symmetric IFPs were studied: (1) reference (REF), (2) toes-out with heels together (TOHT), (3) toes-out (TO), and (4) Wide. Lower-extremity muscle activation patterns and kinetic and kinematic data in the sagittal and frontal planes were measured. *Results:* The trunk forward-tilt angle and hip extension torque during uprising were smaller in TO and Wide for both age groups. Postural sway and center of pressure sway area were smallest in TO after completion of uprising with no difference between age groups. Adductor longus and gluteus medius activity was greater in TO than in the other IFPs, and older adults activated these muscles to a greater degree than younger adults. *Conclusion:* Smaller trunk flexion angles with greater activation of the hip abductor and adductor muscles in TO contributed to improving postural stability during the STS. *Significance:* STS training with a toes-out foot position could be an effective rehabilitation strategy for older adults to strengthen hip muscles that control medio-lateral balance required for balance during a STS.

1. Introduction

The ability to perform a sit-to-stand (STS) is a vital prerequisite to regaining mobility in many clinical and elderly populations. A STS requires sufficient lower limb strength to move the body forward and upward. Precise motor coordination is essential for maintenance of stability. Unfortunately, lower extremity muscle strength and coordination both decline after age 50 (Macaluso and De Vito, 2004). These deficits limit the ability to perform a STS efficiently and safely. For example, older adults with reduced muscle strength showed greater trunk flexion for uprising and more dynamic use of the trunk during a STS (van Lummel et al., 2018); this could lead to decreased dynamic or static balance during a STS. Thus, improving balance during a STS is a cornerstone goal for rehabilitation to prevent falls in older adults.

Finding the optimal initial foot position (IFP) is an important strategy for improving STS performance. A symmetric anterior IFP requires a large trunk flexion in a short time to move the CoM over the feet for uprising. This led to greater hip extension torque with increased perturbations during the STS. Whereas a symmetric posterior IFP required only a small trunk flexion for uprising, and this resulted in smaller hip extension torque with improved balance during the STS (Jeon et al., 2019).

An IFP with toes pointing slightly outward is commonly used in daily life in healthy adults, particularly when transitioning from standing to walking (Yiou et al., 2017). Previous studies, however, have not investigated the effects of IFPs with different foot angles and base of support (BoS) on muscle activation patterns, kinematics, and balance during and after a STS or have compared differences between younger and older adults. Thus, the purpose of this study was to investigate the relationship between various IFPs and changes in kinematics, lower extremity muscle activity, and balance control during a STS. In addition, neuromuscular control strategies and biomechanical parameters were compared between younger and older adults.

We hypothesized that the trunk flexion and muscle activity of the hip extensors during a STS would be lower in a toes-out IFP compared to a parallel IFP because toes-out IFP requires less hip

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extension torque (Turcot and Lachance, 2019). We also hypothesized that hip abductor activity would be greater in a toes-out IFP because external hip rotation by toes-out allows for easier hip abduction to control medial-lateral (M-L) balance (Suehiro et al., 2015). Lastly, we hypothesized that co-activation of the knee flexors and extensors would be greater in older adults.

2. Methods

2.1. Participants

Ten healthy younger (5 males, 5 females, 20 ± 1 years) and ten healthy older (5 males and 5 females, 77 ± 7 years) adults participated in this study. All procedures were approved by the University of Texas at Austin's Institutional Review Board and were in accord with the Helsinki Declaration of 1975.

2.2. Data collection

A Bagnoli EMG System (Delsys, Inc) was used for EMG signal acquisition. Adhesive pre-gelled Ag/AgCl surface EMG electrodes (Delsys, Inc) were placed bilaterally on lower limb muscles (Lovell et al. (2012)): tibialis anterior (TA), soleus (Sol), rectus femoris (RF), adductor longus (ADD), long head of biceps femoris (BF), gluteus maximus (Gmax), and gluteus medius (Gmed).

Participants performed 3 maximal voluntary isometric contractions (MVIC) for each muscle for the normalization of EMG data. Thirty-nine reflective markers were placed on the body according to the Plug-In Gait Model. A 10-camera motion capture system (VICON Motion Systems Ltd, UK) was used to record kinematics.

At the start of the STS, the participants sat upright with their hands on their chest. They sat on an armless, backless height-adjustable bench with the back of the knees not touching the bench. Seat height was adjusted as the distance from the center of the knee joint to the floor. The feet were shoulder-width apart with each foot placed on a force plate (Bertec Corporation, Columbus, OH, USA). A pressure pad (Microgate, NY, USA) was on the seat to determine seat-off. Participants performed the STS at their preferred speed after the visual light cue was turned on. Three trials were performed for each of IFP (Fig. 1) in random order. Following STS completion, participants maintained standing for 5 s.

The 4 IFPs tested were: (1) reference (REF): participants sat with a knee angle of 105° flexion and were instructed to place their feet in a self-selected parallel foot position. The mean foot placement

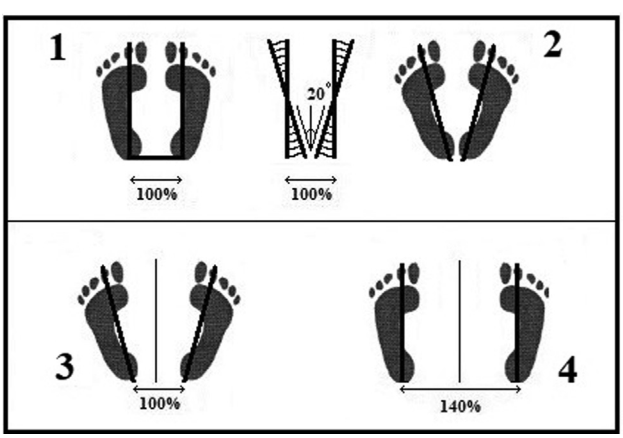

Fig. 1. The four different initial foot positions (IFPs) tested: (1) REF: reference; (2) TOHT: symmetric toes-out angle of 20° with small base of support; (3) TO: symmetric toes-out angle of 20° from reference; (4) Wide: each foot was shifted outwards 20% from reference, widening the stance to 140% REF).

angle was 2.50 ± 0.52° toes-out with no difference between age groups (2) toes out with heels together (TOHT): toes were turned out at an angle of 20°. The heels were positioned close together to have the same total BoS as REF (3) Toes-out (TO): toes turned laterally 20° from the REF (4) wide stance (Wide): each foot was shifted laterally 20% of shoulder-width.

2.3. Data processing

The average of 3 trials for each IFP was calculated for data analysis. EMG, force plate, and pressure pad data were sampled at 1200 Hz and kinematic data was sampled at 120 Hz. All data were analyzed in Matlab 9.3 (Matworks Inc., Natick, MA, USA).

2.4. Kinematics

The CoM trajectory, lower limb joint and trunk flexion angles, hip and knee joint moments, and the distance between the CoM and CoP in the sagittal plane before seat-off were calculated using Nexus 1.8.5 Software (Vicon, Oxford Metrics, UK). To calculate STS speed, the movement distance of the CoM in the sagittal plane (vertical and antero-posterior) was divided by the elapsed time from the onset of CoM movement to STS completion. The time of STS completion was defined as the instant when hip angular velocity on the sagittal plane first reached 0°/sec (Jeon et al., 2019). All joint moments were normalized to body mass.

2.5. Weight-bearing symmetry

Weight-bearing symmetry during the STS was calculated from the vertical GRFs at seat off for all IFPs as shown in the following equation (Talis et al. 2008):

$$\text{Symmetry}\ \ (\%) = 100 - \frac{|Dominant\ \ \max - Non\ \ dominant\ \ max| \cdot 100}{Dominant\ \ \max + Non\ \ dominant\ \ max} \quad (1)$$

2.6. EMG

Surface EMG was filtered with a 5–500 Hz band-pass filter. The EMG signals were normalized to the MVIC EMG for each muscle (Hsu et al., 2006). Muscle onset was determined as the time at which the EMG exceeded three standard deviations (SD) of the initial mean baseline (Di Fabio, 1987). Percent co-activation of RF and BF was calculated according to the equation below (Falconer and Winter, 1985).

$$\%\text{co} - \text{activation} = 2 \times \frac{\text{common area A\&B}}{\text{area A} + \text{area B}} \times 100\% \quad (2)$$

where area A, B, and common area are the areas below the EMG curves of muscle A, B, and common area between A and B, respectively.

2.7. Kinetics

CoP and GRF were recorded from the two force plates. GRF was normalized to body mass (kg). Measures of the SD of the CoM acceleration (SDCoMaccel), and the CoP sway area on the anterior-posterior (A-P) and M-L axes were used to quantify postural sway during the stabilization phase. To measure the sway area, the 95% confidence ellipse area enclosed by the points of the CoP path was calculated (Oliveira et al., 1996), and normalized to the time interval of the stabilization phase (mm^2/sec). The stabilization phase was defined as the time between STS completion and the beginning of the quiet standing (Jeon et al., 2019).

2.8. Statistical analysis

A one-way ANOVA was used to examine whether there were differences between the variance of the three trials within each IFP and the variance between the four IFPs. A mixed- ANOVA (IFPs × Groups) was used to determine the main effect and interactions for the kinematics (STS speed, distance between CoM and CoP before seat off, anterior displacement of the CoM, trunk flexion angle), kinetics (GRFs, hip and knee extension torque), EMG (EMG peak amplitude, coactivation between RF and BF), and body sway (SD of the CoM acceleration, normalized CoP sway area). A one-way repeated measures ANOVA was used to determine the sequence of EMG onset of all muscles within each IFP. A Tukey's test was used for post hoc analysis. An independent samples *t*-test was used to compare baseline knee extension torque. SPSS (Chicago, IL) was used for all statistical analysis with an alpha level of 0.05 set a-priori.

3. Results

All data are presented as mean ± standard deviation (SD) in the text and table. For all parameters, the average of the variance of the 3 trials for each IFP was smaller than the average of the variance between the IFPs ($p < 0.01$).

3.1. Kinematics and kinetics

There was no difference in normalized maximum knee extension torque between age groups (younger: 152.76 ± 47.76 Nm; older: 126.99 ± 40.21 Nm).

3.2. Sit-to-stand speed

There were main effects of IFPs and age groups on STS speed. The STS speed was greater for TO (597.40 ± 152.33 mm/sec) than REF (575.25 ± 115.19) and TOHT (541.20 ± 138.96 mm/sec, $p < 0.01$). STS speed for Wide (442.71 ± 147.22 mm/sec) was slower than all other IFPs ($p < 0.01$). Younger adults had greater STS speed (612.26 ± 114.62 mm/sec) than older adults (446.02 ± 144.26 mm/sec) across all IFPs ($p < 0.01$). No interactions were detected for STS speed.

3.3. Kinematics before Seat-Off

There was a main effect for IFP, but not age, on the distance between CoM and CoP, anterior displacement of the CoM, and trunk flexion. The toes-out foot positions caused the CoP to move posteriorly before seat-off compared to REF and this shortened the distance between the CoM and CoP (Fig. 2). The initial distance between the CoM and CoP was greater for REF than TOHT ($p < 0.01$) and TO ($p < 0.01$). The anterior displacement of the CoM and the trunk flexion angle from the vertical axis were also greater in REF and smaller in TO ($p = 0.03$) and Wide ($p < 0.01$).

3.4. Ground reaction force

There was a main effect of IFPs, but not age on GRFs. The vertical GRF in REF was greater than in TO ($p = 0.01$). Weight-bearing symmetry of the vertical GRF was higher in TO (98.85 ± 1.01%) than REF (98.19 ± 1.27%, $p = 0.03$) and TOHT (97.22 ± 2.30%, $p < 0.01$). However, there was no difference between TO and Wide (98.17 ± 1.56%) and no difference between the two groups. The A-P GRF in TO was smaller than in REF and TOHT (both $p < 0.01$), whereas the M-L GRF were greater in Wide than in all the other IFPs ($p < 0.01$, Table 1).

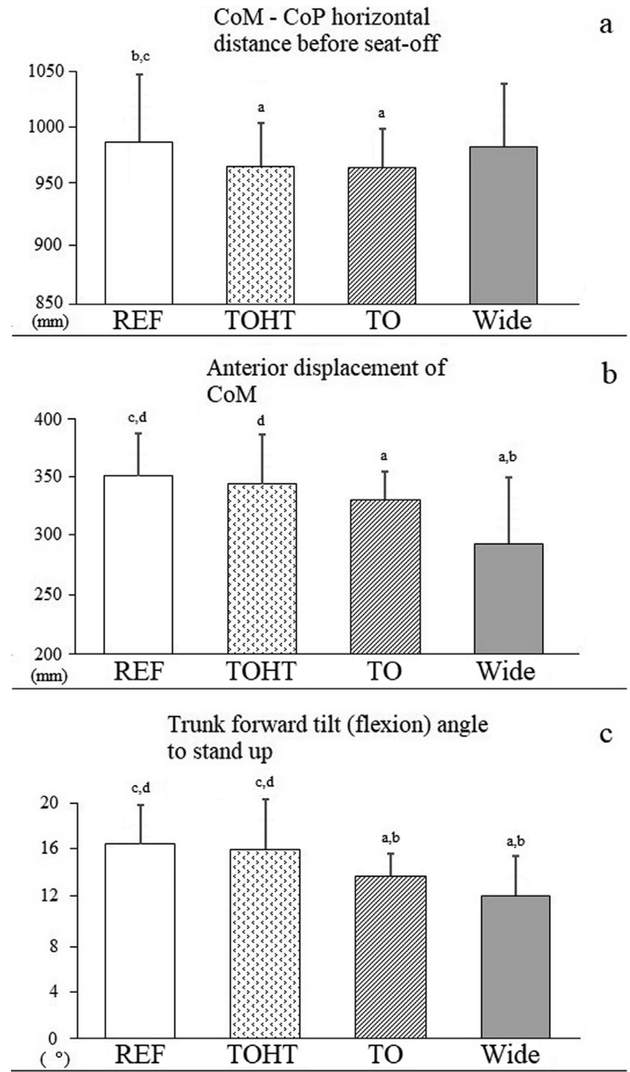

Fig. 2. (a) Initial horizontal distance between the body's CoM and CoP before seat-off (b) anterior displacement of the body's CoM (c) trunk forward-tilt angle before leg extension. a,b,c,d represent a statistically significant difference ($p < 0.05$) from REF, TOHT, TO, Wide, respectively. Error bars display the standard deviations.

3.5. Hip and knee extension torque

There was a main effect of IFPs on hip extension torque, but not knee extension torque. The hip extension torque in REF was greater than in all the other IFPs (all $p < 0.01$). However, there was no difference in knee extension torque across all IFPs. There were no main effects for age on hip or knee extension torques (Table 1).

3.6. Balance during the stabilization phase

3.6.1. Standard deviation of the CoM acceleration

There were main effects of both IFP and age for SDCoMaccel. It was smaller in TO than REF (A-P axis: $p < 0.01$, M-L axis: $p = 0.02$) and was greater in older adults (A-P axis: $p < 0.01$, M-L axis: $p = 0.04$) than in younger adults (Table 1).

3.6.2. CoP sway area

There were main effects of IFPs and age on CoP sway area. It was largest in TOHT and smallest in TO and Wide (both $p < 0.01$). Older adults showed greater CoP sway area than younger adults ($p < 0.01$). There was an interaction between IFP and age for the

Table 1
GRF and maximum joint torque during sit-to-stand and balance in the stabilization phase.

IFP		Sit to stand Phase			Stabilization phase				
		GRF (%BW, Fz)	GRF (%BW, Fx)	GRF (%BW, Fy)	Hip extension torque (Nm/Kg)	Knee extension torque (Nm/Kg)	SD of CoM Acceleration (mm/s^2, Fx/m)	SD of CoM Acceleration (mm/s^2, Fy/m)	Normalized CoP Sway Area (mm^2/s)
REF	Young	104.66 ± 2.95	11.33 ± 3.54	8.98 ± 2.53	0.80 ± 0.15	0.78 ± 0.14	56.86 ± 11.61	47.62 ± 8.76	23.84 ± 8.60
	Older	105.17 ± 5.13	10.47 ± 3.30	9.07 ± 3.04	0.72 ± 0.12	0.70 ± 0.13	87.12 ± 19.22[*]	63.71 ± 16.25[*]	41.05 ± 14.09[*]
	Pooled	104.91 ± 4.08[c]	10.89 ± 3.36[c]	9.02 ± 2.72[c,d]	0.76 ± 0.14[b,c,d]	0.74 ± 0.14	71.99 ± 21.90[c,d]	55.67 ± 15.15[c]	32.44 ± 14.39[b,c,d]
TOHT	Young	104.95 ± 2.49	10.54 ± 3.03	10.11 ± 3.74	0.74 ± 0.16	0.77 ± 0.17	56.38 ± 13.76	59.79 ± 14.51	29.24 ± 12.02
	Older	110.21 ± 15.49	11.30 ± 3.92	10.39 ± 3.99	0.65 ± 0.10	0.66 ± 0.12	90.95 ± 27.18	78.65 ± 30.20	50.75 ± 16.60[*]
	Pooled	107.57 ± 11.13	10.92 ± 3.43[c]	10.25 ± 3.77[d]	0.70 ± 0.14[a]	0.74 ± 0.14	73.67 ± 27.46	69.22 ± 25.01[c,d]	39.99 ± 17.91[a,c,d]
TO	Young	102.89 ± 1.83	8.95 ± 3.03	11.81 ± 3.13	0.71 ± 0.14	0.78 ± 0.14	44.85 ± 14.05	45.12 ± 11.99	18.28 ± 11.00
	Older	101.04 ± 1.55	7.68 ± 2.18	10.84 ± 2.42	0.65 ± 0.12	0.69 ± 0.14	58.95 ± 20.08	50.05 ± 13.93	27.77 ± 10.39
	Pooled	101.96 ± 1.90[a]	8.32 ± 2.65[a,b]	11.33 ± 2.77[a,d]	0.68 ± 0.13[a]	0.74 ± 0.15	51.90 ± 18.35[a]	47.59 ± 12.90[a,b]	23.03 ± 11.49[a,b]
Wide	Young	100.04 ± 8.01	10.52 ± 3.86	16.74 ± 5.11	0.73 ± 0.15	0.77 ± 0.11	53.61 ± 22.21	47.30 ± 13.68	22.14 ± 7.03
	Older	100.87 ± 8.12	10.80 ± 3.59	16.12 ± 3.58	0.64 ± 0.12	0.65 ± 0.13	64.65 ± 14.33	49.88 ± 14.77	25.27 ± 9.42
	Pooled	100.45 ± 7.86	10.66 ± 3.63	16.43 ± 4.31[a,b,c]	0.68 ± 0.14[a]	0.71 ± 0.13	59.13 ± 19.07[a]	48.59 ± 13.92[b]	23.70 ± 8.25[a,b]

GRF (ground reaction force). Fz (vertical GRF), Fx (anterior-posterior GRF), Fy (medio-lateral GRF). %BW (percent of body weight). SD (standard deviation). m (mass), CoM (center of mass), CoP (center of pressure).
[a] Significantly different than REF ($p < 0.05$).
[b] Significantly different than TOHT ($p < 0.05$).
[c] Significantly different than TO ($p < 0.05$).
[d] Significantly different than Wide ($p < 0.05$).
[*] Significantly different than younger adults ($p < 0.05$).

CoP sway area; older adults had greater sway area in REF than younger adults (younger: 23.84 ± 8.60 mm^2/s, older: 41.05 ± 14.09 mm^2/s, p < 0.01), and TOHT (younger: 29.24 ± 12.02 mm^2/s, older: 50.75 ± 16.60 mm^2/s, p < 0.01).

3.7. EMG activity

3.7.1. Muscle onset

There was a main effect for IFP, but not age, for muscle onset. The TA and ADD activated earlier in REF than in all the other IFPs (all p < 0.01).

The sequence of EMG muscle onset in TOHT, TO, and Wide showed the same pattern (Fig. 3): the TA activated first, prior to seat-off, followed by the RF and BF, and then the ADD and Gmax, and then the Gmed. The Sol activated last with a relatively small EMG amplitude (21–25% EMG max). In REF, the ADD activated earlier than RF (p = 0.01) with its onset before seat-off.

3.7.2. EMG peak amplitude

All EMG peak amplitude data for all IFPs for both age groups are shown in Fig. 4-5.

There were main effects for IFP and age on EMG peak amplitude of the TA, Gmax, ADD, Gmed, and BF. EMG amplitude of the TA and Gmax was greater for REF than for the other IFPs (TA: TOHT (p = 0.02), TO (p = 0.01), Wide (p < 0.01), Gmax: TOHT (p = 0.04), TO (p < 0.01), Wide (p < 0.01)) whereas the ADD and Gmed was greater in TO (ADD: REF (p < 0.01), Wide (p < 0.01), Gmed: REF (p < 0.01), Wide (p = 0.02)). While there was no difference in EMG activity of the RF across all IFPs, the BF activated greater in REF than TO (p < 0.01) and Wide (p = 0.01). There was no difference in the Sol between the two age groups or across IFPs.

EMG amplitude of the TA, RF, ADD, Gmed, and BF was greater for older adults than for younger adults (TA (p = 0.01), RF (p = 0.01), ADD (p = 0.01), Gmed (p = 0.01), BF (p = 0.01)).

There was an interaction between IFP and age for the EMG amplitude in ADD. Older adults activated the ADD to a greater degree in TO than younger adults (younger: 35.43 ± 7.97% EMG max, older: 25.36 ± 4.30% EMG max, p < 0.01).

3.7.3. Rectus femoris: biceps femoris co-activation

There was a main effect of age, but not for IFP on RF:BF co-activation. Greater co-activation was observed in older adults across all IFPs (older adults: 39.09 ± 10.47%; younger adults: 33.37 ± 8.54%, p < 0.01).

4. Discussion

The choice of IFP is an essential movement strategy for older and clinical populations to improve STS performance. We investigated the effect of various IFPs on lower limb neuromuscular control and biomechanical parameters during and after a STS to assess age-related differences in response to IFP.

4.1. Kinematics

Balance is maintained by continuously moving the CoP with respect to the relative position of the CoM within BoS (Winter, 1995). In order to maintain stability during the STS extension, the CoM moves forward and the CoP under the foot moves posteriorly prior to seat-off. Compared to REF, the initial CoP on the A-P axis moved more posteriorly in TO. This allowed the CoP to quickly approach the CoM before uprising. Thus, less trunk flexion was required in TO than in REF to move the CoM closer to the CoP.

Despite the smaller CoM - CoP distance in TOHT compared to REF, TOHT required greater trunk flexion than TO and Wide. This is likely due to the narrow margin of stability (MoS) from the heels to midfoot in TOHT. Larger MoS provides better dynamic balance control (Buurke et al., 2019). Therefore, greater trunk flexion in TOHT was required to move the CoM over the relatively wider BoS in order to maintain balance during the STS.

Less trunk flexion was observed in Wide compared to REF and TOHT. Given that a wider stance increases knee valgus angle (Yamaguchi et al., 2009), the initial hip adduction by Wide may have limited the trunk flexion before seat-off.

4.2. Muscle activation patterns

4.2.1. Tibialis anterior and soleus

The TA was the first muscle activated during the STS for all IFPs. TA activation shifts the CoP posteriorly toward the ankle, reducing the distance between the CoM and CoP before uprising (Brunt et al., 2002). Compared to the other IFPs, earlier onset with higher activation of the TA was observed in REF. This is likely due to a

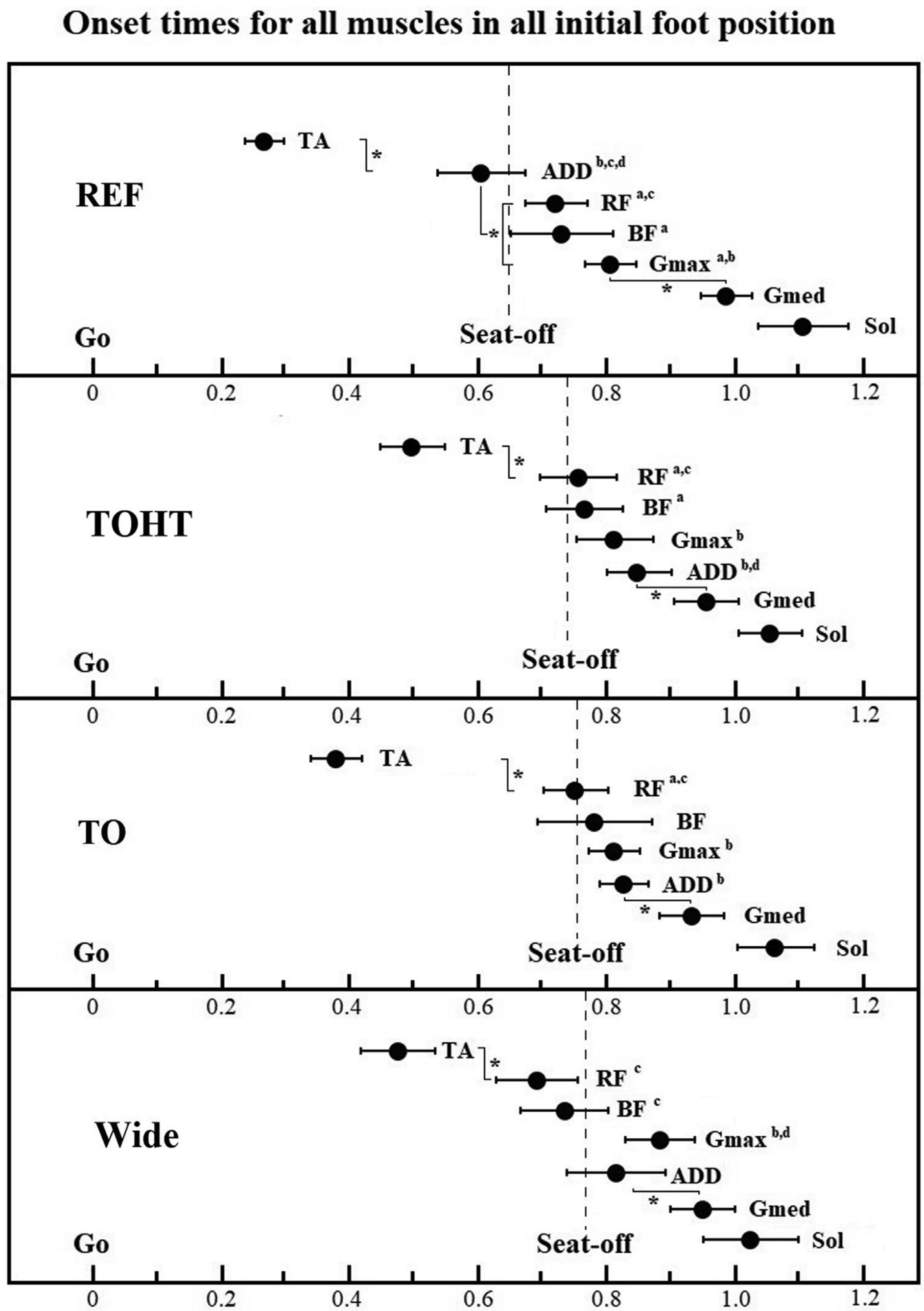

Fig. 3. Onset times for all muscles across all initial foot positions. Asterisks represent a statistically significant difference ($p < 0.05$) between EMG onset times. a,b,c,d represent a statistically significant difference ($p < 0.05$) from adductor (ADD), rectus femoris (RF), gluteus maximus (Gmax), biceps femoris (BF), respectively. The left and right error bars represent the standard deviations.

longer posterior movement of CoP in REF that requires faster and greater ankle dorsiflexion. This finding indicates that the onset time and activation level of the TA to control the posterior movement of the CoP changes according to the magnitude of forward displacement of the CoM, which is determined by the initial CoM – CoP distance difference.

The onset of the Sol was later than knee and hip extension and it remained activated throughout the stabilization phase for balance control. This observation is in agreement with previous findings that the Sol helps to maintain standing balance in coordination with the TA by modulating ankle plantar flexion (Mochizuki et al., 2006).

4.2.2. Rectus femoris and biceps femoris

Co-contraction of the RF and BF occurred in the extension phase of the STS for all IFPs. Older adults showed greater activation of the RF and BF across all IFPs. Both the RF and the long head of the BF are biarticular and reinforce each other to maintain standing postural stability through efficient control of GRF direction with double joint actuation (Hof, 2001). RF and BF coordination between the hip and knee joints contribute to standing balance recovery following postural perturbations (Junius et al., 2017; Schumacher et al., 2019; Sharbafi et al., 2016).

Co-contraction of the quadriceps and hamstrings muscles provides dynamic stability in the frontal and sagittal planes, control-

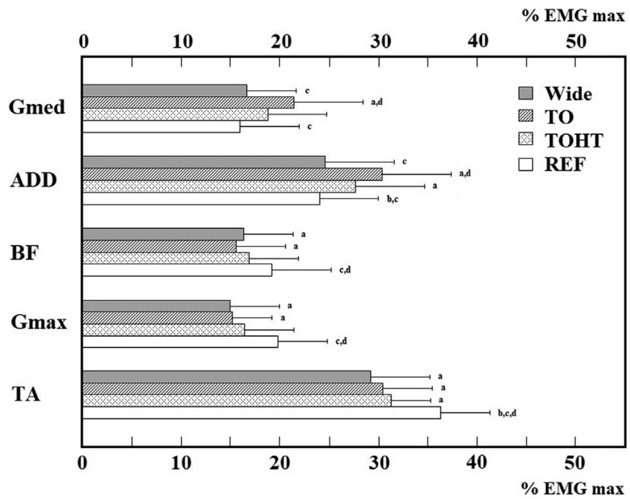

Fig. 4. Highest peak (% MVIC EMG) during a sit-to-stand. a,b,c,d represent a statistically significant difference (p < 0.05) from reference (REF), toes-out with small base of support (TOHT), toes-out (TO), and wide initial foot position, respectively (the upper plot). Asterisks represent a statistically significant difference (p < 0.05) between age groups (the lower plot). The error bars represent the standard deviations.

ling the varus and valgus moments and anterior/posterior knee shear forces (Baratta et al., 1988; Lloyd and Buchanan, 2001). Increased hamstrings/quadriceps co-activation in older adults is likely an age-related neuromuscular strategy to control A-P and M-L postural sway at the knee joint. Although greater co-activation can reduce knee and hip range of motion to increase joint stiffness, it is not a major contributor to slower STS speed in older adults (Bouchouras et al., 2015). It should also be noted that although co-activation is used during STS execution in older adults, it can increase joint pressure and be harmful to the joint (Butler et al., 2003).

4.2.3. Adductors, and gluteus medius

ADD and Gmed were activated to a greater degree in TO than REF and Wide. Previous studies support this finding and have shown greater activation of the hip adductors and abductors during a squat with external hip rotation and a wide stance (McCaw and Melrose, 1999; Pereira et al., 2010). Considering both muscles originate from the pelvis and insert at the femur (Marieb and Hoehn, 2018), external hip rotation during TO may increase initial tension in these muscles and enhance the stretch reflex response to contribute to greater muscle activation (Cavagna et al., 1968).

Older adults activated the ADD and Gmed muscles to a greater degree than younger adults in TO. Considering the age-related decline in lower extremity muscle strength (Reid et al., 2014), the greater ADD and Gmed activation in older adults could be a neuromuscular control strategy to create power for STS balance on the M-L axis (MacKinnon and Winter, 1993). Aging causes a redistribution of extension torque from the knee joint to the hip joint to create greater vertical GRF (DeVita and Hortobagyi, 2000). Thus, the greater ADD activity could also enhance hip extension torque development to compensate for reduced knee extensor strength in the older adults.

4.3. Balance in stabilization phase

The TO IFP provided the smallest M-L postural sway. Greater muscle activation of the hip abductors and adductors (which was not observed in Wide) might have contributed to additional postural stability on the M-L axis. There is reduced hip abduction torque and increased M-L sway during dynamic balance recovery with age (Johnson et al., 2004; Rogers et al., 2001) and older adults depend more on hip joint proprioception to maintain standing balance than younger adults (Chen and Qu, 2019). Thus, a TO IFP could be used as an intervention for rehabilitation exercises for older adults who have decreased flexibility and weakened muscles. In older adults, greater postural sway on the A-P axis in REF may have been due to greater hip extension torque.

5. Conclusions

The TO IFP required a smaller trunk flexion with greater hip abductor and adductor activity during the STS and less postural sway after STS completion. A TO IFP could help compensate for decreased muscle strength and balance control with age and may be a self-selected strategy because of greater activation of ADD and Gmed to compensate reduced knee extensor strength. The findings of this study are important for designing STS exercise interventions for older and clinical populations to improve dynamic stability control during and after STS. For example, a toes-out IFP during a chair squat could contribute to strengthening the hip adductors and abductors as well as improving dynamic balance in older adults.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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