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Age and initial position affect movement biomechanics in sit to walk transitions: Whole body balance and trunk control

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ABSTRACT

Maintaining dynamic balance during transitional movements like sit-to-walk (STW) can be challenging for older adults. Age-related neuromuscular decline can alter movement in STW, such as rising with greater trunk flexion, narrowing the feet, or using arms to push off. Initial foot and arm position can affect subsequent movement biomechanics, with different ground reaction forces (GRFs) that stabilize and advance the body center of mass (COM). The purpose of this study was to quantify whole-body biomechanics and trunk control of STW transitions. Fifteen younger adults (18–35 years) and fifteen older adults (50–79 years) performed STW from four initial foot positions and two arm positions. Three-dimensional (3D) GRFs, 3D body COM displacement, and integrated electromyography values from the lumbar paraspinals and gluteus medius were evaluated. Younger adults generated greater mediolateral GRF ranges while rising, whereas older adults generated greater mediolateral GRF ranges when stepping forward suggesting different strategies to laterally control the body COM. Initial foot position affected the STW movement, with narrow foot positions having smaller body COM displacement than wide foot positions, associated with smaller medial GRFs to move the body COM toward the stance limb. Rising with arm support required less lumbar paraspinal excitation, which was further reduced when with a posteriorly offset foot. Gluteus medius activity was greater for older adults compared to younger adults in STW. Completing STW with arm support can reduce the muscle activity required to stabilize the torso when rising, which likely has implications for balance control and low back loading.

1. Introduction

Transitioning from standing up to walking, or sit-to-walk (STW), is a critical and frequent movement for independent living. Adults conduct rising transitions approximately 60 times daily (Dall and Kerr, 2010), which require maintaining balance while raising the center of mass (COM) and initiating gait (Millington, et al., 1992). Clinicians observe the duration and ability to perform STW to assess balance, frailty, and health in older adults, but may not consider biomechanics (Nnodim and Yung, 2015). There is a high frequency of injurious falls in older adults at first step contact of gait initiation (Rogers, et al., 2001). Biomechanics of STW can gain insight into potential fall mechanisms, which can help with fall prevention and improve clinical balance assessments.

STW is characterized by many whole-body movement strategies because it merges standing with gait in one continuous motion (Buckley, et al., 2009). The merging of tasks results in asymmetric vertical ground reaction forces (GRFs) because one limb must step forward immediately following seat-off (Magnan, et al., 1996). In the anterior/posterior direction, STW requires a propulsive impulse followed by a braking impulse during rising, and then subsequently requires propulsion to initiate gait (Magnan, et al., 1996). This chain of events is likely affected by initial position. For example, a posterior foot position during sit-to-stand (STS) has been shown to induce a dominant vertical rise strategy (Kawagoe, et al., 2000) indicated by small forward trunk flexion at seat off and primarily vertical body COM displacement with knee-hip extension (Scarborough, et al., 2007). The primarily vertical body COM displacement from greater vertical GRFs may result in smaller mediolateral COM displacement and GRFs during STS (Gilleard, et al., 2008). When rising with arm-supported push off in STS, a dominant vertical rise is also shown because torso flexion is counteracted by extension of the elbows (Burdett, et al., 1985). However, the effects of foot position and arm-supported push off on STW biomechanics, when

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Table 1
Participant anthropometric data (mean ± standard deviation). Pelvic width was calculated from the distance between right and left ASIS markers. Average leg length was the mean of the left and right leg lengths, measured as the distance between ipsilateral ASIS and lateral malleolus markers. Dominant foot length was measured using a tape measure from heel to toe.

	Younger Adults	Older Adults
Sex (M/F)	7M/8F	5M/10F
Age (years)	24.3 ± 4.4	62.2 ± 6.6
Weight (lbs)	159.4 ± 29.1	181.9 ± 50.2
Height (m)	1.73 ± 0.10	1.69 ± 0.11
Pelvic Width (m)	0.22 ± 0.04	0.27 ± 0.05 *
Average Leg Length (m)	0.94 ± 0.05	0.90 ± 0.06
Dominant Foot Length (m)	0.26 ± 0.02	0.26 ± 0.02

* indicates that older adults had significantly larger pelvic widths compared to younger adults using an unpaired *t*-test ($\alpha = 0.05$).

rising and gait initiation are merged, is unclear.

Little research has investigated how unrestricted initial foot placement and arm-supported rising affects body movement in STW. In an unrestricted setup, individuals who consistently used arm-supported rising strategies were mostly older men who had a higher fear of falling and reduced ankle range of motion, suggesting that arm use is related to the perception of stability (van der Kruk, et al., 2021). Moreover, adults with lower joint strength, compound muscle action potential amplitudes, hand grip strength, and longer nerve conduction latencies completed STW tasks with narrower foot positions (van der Kruk, et al., 2021). However, there is no systematic, within-participants, biomechanical comparison of initial foot position and arm support during STW across the lifespan.

The purpose of this study was to quantify the biomechanical effects of initial foot positions and arm-supported rising on the STW movement in younger and older adults. We examined three-dimensional whole-body COM, GRFs, as well as integrated electromyography (iEMG) values for lumbar paraspinals (LP) and gluteus medius (GMED) muscles given their importance in balance performance. We hypothesized that greater age and narrow foot positions would increase mediolateral GRF ranges and body COM displacement, and that posterior offset positions would decrease these outcome metrics. We also expected that LP and GMED activity would be smaller when rising with arm support. Results of this work can inform movement training and clinical assessment of older adults in movement transitions.

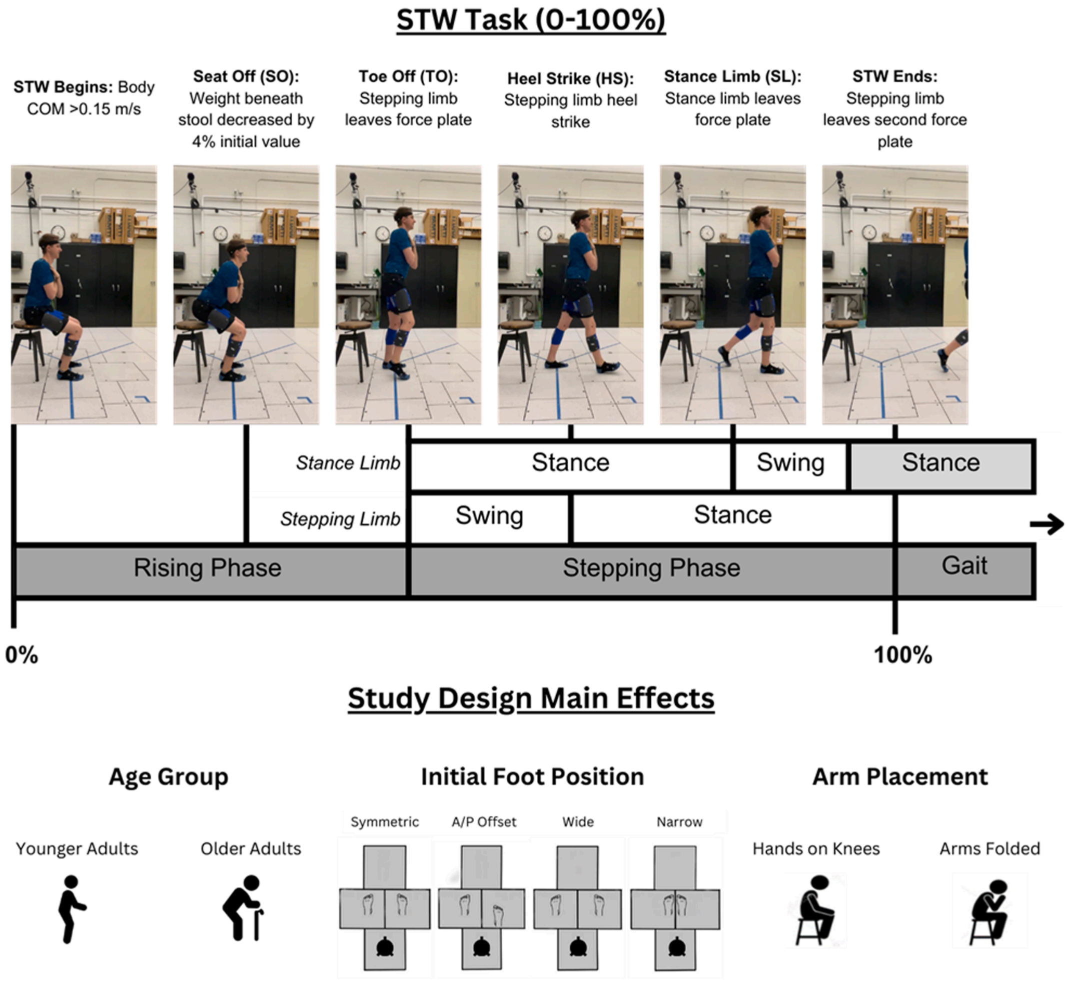

Fig. 1. STW transition phases and events (top). The beginning of the STW motion was defined as the instant the body forward COM velocity exceeded 0.15 m/s, adapted from Kerr et al. (2004). Seat off occurred when the weight beneath the stool decreased by 4% of its initial vertical GRF value (Kerr, et al., 2004; Kerr, et al., 2007). Toe-off was the instant when the participant's stepping limb no longer contacted the force plate. The stance limb event was defined as the instant the stance limb left its respective force plate (Kerr, et al., 2004). 3D GRF results were analyzed during the rising and stepping phases for both stance and stepping limbs. Body COM motion results were analyzed during the rising and stepping phases. iEMG results were analyzed for the full duration of the STW task. Schematic depiction of the study's main effects (bottom), including: age group (2 levels: younger and older adults), initial foot position (4 levels: symmetric, A/P offset, wide, narrow), and arm placement (2 levels: hands on knees and arms folded). Initial foot positions are defined for right foot dominance.

Table 2
Completion times (mean ± standard deviation) for the rising phase, stepping phase, and overall STW task.

	STW Completion Time (s)		
Main Effect	**Rising Phase**	**Stepping Phase**	**Overall STW Task**
Age Group	$p = 0.037$	$p = 0.038$	–
Younger Adults	1.30 ± 0.23	1.11 ± 0.11	2.41 ± 0.32
Older Adults	1.23 ± 0.26	1.14 ± 0.08	2.36 ± 0.30
Arm Placement	$p = 0.031$	–	–
Arms Folded	1.23 ± 0.26	1.13 ± 0.09	2.36 ± 0.30
Arm Support	1.30 ± 0.28	1.11 ± 0.10	2.41 ± 0.32
Foot Position	$p = 0.013$	–	–
A/P Offset	1.17 ± 0.23 *	1.14 ± 0.10	2.31 ± 0.27
Symmetric	1.28 ± 0.30	1.13 ± 0.09	2.41 ± 0.33
Wide	1.32 ± 0.27	1.12 ± 0.12	2.44 ± 0.34
Narrow	1.28 ± 0.26	1.10 ± 0.08	2.38 ± 0.30

p values are given for significant main effects ($p < 0.05$). The time values reported for each main effect of age, arm placement, and foot position have been averaged across the other remaining main effects. * indicates a significant pairwise post hoc comparison compared to the symmetric condition ($p < 0.05$).

Table 3
Main and interaction effects for STW completion time, 3D GRF peak and range values, body COM ranges, and iEMG values for LP and GMED ($\alpha = 0.05$).

Outcome Metric	Age	Foot	Arms	Interaction
STW Completion Time				
Rising Phase	0.037	0.013	0.031	–
Stepping Phase	0.038	–	–	–
Overall	–	–	–	–
GRFs				
Stepping Limb				
Rising Phase				
A/P Peak	<0.001	<0.001	–	–
M/L Range	0.014	<0.001	–	–
Vertical Peak	<0.001	–	–	Foot x Age (0.010)
Stepping Phase				
A/P Peak	–	–	–	–
M/L Range	0.037	<0.001	–	–
Vertical Peak	–	–	–	–
Stance Limb				
A/P Peak	–	–	–	–
M/L Range	<0.001	<0.001	–	–
Vertical Peak	–	–	–	–
COM Range				
Rising Phase				
A/P	–	–	–	–
M/L	–	<0.001	–	–
Vertical	–	–	0.015	–
Stepping Phase				
A/P	–	–	–	–
M/L	<0.001	<0.001	–	–
Vertical	–	–	–	Foot x Arm ($p < 0.001$) Arm x Age ($p < 0.001$)
LP iEMG				
Stepping Limb	–	–	0.036	–
Stance Limb	–	–	0.005	–
GMED iEMG				
Stepping Limb	<0.001	–	–	–
Stance Limb	<0.001	–	0.034	Foot x Age (0.042)

2. Methods

2.1. Participants

Fifteen younger and fifteen older adults (Table 1) provided their informed consent to participate in the protocol approved by the Colorado Multiple Institutional Review Board. Participants were free from neurological disorders and musculoskeletal injury in the last six months by self-report and were between 18–35 years (younger group) or 50–79 years (older group). Exclusion criteria included taking medications that could cause dizziness or affect balance, significant vision problems, or impaired verbal communication.

2.2. Experimental instrumentation and protocol

GRFs were collected using four in-ground force plates (AMTI, Watertown, MA, 2000 Hz) alongside 3D motion capture data from a seven-camera system (Qualisys, Götenborg, Sweden, 200 Hz) tracking 74 retroreflective markers. Markers were placed bilaterally on the temple, back of head, acromion, upper arm, medial and lateral elbow, radial wrist, ulnar wrist, iliac crest, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), four-marker thigh cluster, four-marker shank cluster, 5th metatarsal head, 1st metatarsal head, 2nd phalange, dorsal foot surface, and heel. Torso markers included the C7, clavicle, right back, and marker triads on T9-T10 as well as L4-L5. Surface electromyography (EMG) sensors (Delsys, Boston, MA; 99.9% contact Ag; 5x1 mm; inter-electrode distance, 10 mm; 2000 Hz) were placed bilaterally on the LP and GMED (Konrad, 2005; Perotto, 2011).

Participants completed the Lateral Preference Survey (Coren, 1993) and all were right foot and hand dominant. We performed a static standing calibration trial and functional movements including the modified Star Excursion Balance Test (SEBT), self-selected walking, a body weight squat, and the five times sit-to-stand test. Then, participants began the STW trials without shoes, with socks, and seated on a backless stool, with their feet arranged in one of four initial foot positions: symmetric, offset, wide, and narrow (Fig. 1). In the symmetric position, feet were placed hips width apart, and initial hip and knee angles of 90° flexion were confirmed by a manual goniometer. In the anterior/posterior (A/P) offset position the dominant limb was shifted backward 2/3 the dominant foot length (Table 1). The wide position shifted each limb laterally the width of the foot from the symmetric position. In the narrow position the medial borders of the feet were in contact, with each foot on its own force plate. Each foot position was tested with two arm conditions: arms folded across the chest, and arms supported with hands on the top of the knees. The sit-to-walk conditions were randomized and participants completed three repeated trials of each condition, for a total of 24 self-paced STW trials.

2.3. Data analysis

Marker trajectories and GRF data were processed with a bidirectional 4th order low pass Butterworth filter (f_C=6 Hz). EMG data were digitally band-pass filtered with a 4th order Butterworth filter (20–500 Hz), full wave rectified, and low pass filtered (f_C=6 Hz) (De Luca, 2010). Kinematic, kinetic and EMG signals were analyzed during STW from the initiation of torso movement to second toe-off of the stepping limb and STW was comprised of rising and stepping phases (Fig. 1). LP and GMED signals were normalized in magnitude by dividing the filtered STW EMG signal by the average maximum EMG value of a similarly processed signal (Sousa and Tavares, 2012) on the stance limb from three repeated posterolateral SEBT reach trials. Normalized EMG signals were integrated over the STW movement time time duration to compute integrated EMG (iEMG) for each trial.

A dynamic, 12-segment model for each participant included a lumped head-torso, pelvis, thighs, shanks, feet, upper arms, and forearms with six degree-of-freedom joints (Visual3D, C-Motion, Inc., Kingston, ON). Segments were defined as cylinders (trunk and pelvis), and cone frusta (other segments) using marker positions (Dempster and Aitkens, 1995, Hanavan, 1964) to calculate the whole-body COM. Mass distribution was the same for older and younger adults. 3D body COM position was defined relative to the initial seated position. 3D GRFs were normalized to body weight.

2.4. Statistical analysis

A three-factor mixed model ANOVA ($\alpha = 0.05$) was used to examine the main and interaction effects of age (younger vs older adults), initial

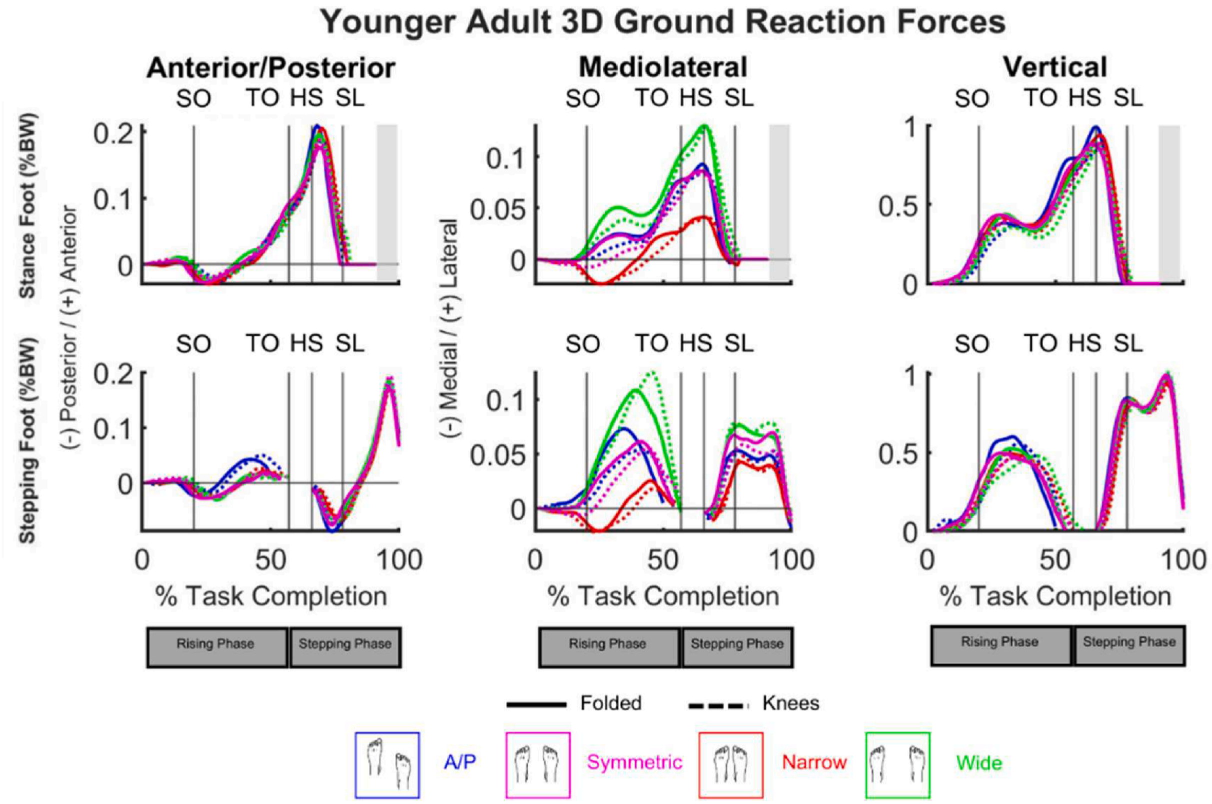

Fig. 2. Average normalized stance and stepping limb ground reaction forces for younger adults in STW for four initial foot positions and two arm placements. Anterior, medial, and superior directions were defined positively. Vertical lines indicate STW (0–100%) events seat off (SO), toe-off (TO), heel strike (HS), and stance limb toe-off (SL). See Fig. 1 for full definitions of each STW event. The grey shaded region represents time when the stance limb was in contact with the ground beyond the force plate, so no data were collected. Significant main, interaction, and pairwise post hoc differences are detailed in the text and numerical values are provided in Supplementary Table S.1, S.2, and S3.

foot position (symmetric, A/P offset, wide,narrow) and arm placement (hands on knees vs. arms folded) on multiple outcome metrics (Rstudio v.4.2.2, Posit, Boston, MA). Time to completion was compared for the rising phase, stepping phase, and full STW task duration. A/P GRF peaks, M/L GRF range, and vertical GRF peaks were evaluated for each foot contact on the stance (one foot contact) and stepping (two foot contacts, one in the rising phase and one in the stepping phase) limbs (see Fig. 1). 3D body COM position range (i.e., displacement) in the rising and stepping phases was evaluated. LP iEMG, and GMED iEMG were compared for the full STW task duration. When significant main or interaction effects were found, post hoc pairwise comparisons were completed using paired or unpaired t-tests with a Tukey adjustment for multiple comparisons ($\alpha = 0.05$). Significant initial foot placement pairwise results are reported compared to the symmetric position.

3. Results

There were no significant main or interaction effects for time to complete the STW task (Table 2). However, there were significant main effects of foot position ($p = 0.013$), arm placement ($p = 0.031$), and age ($p = 0.037$) on the time to complete the rising phase of the STW task (Table 2), and no significant interaction effects. These results indicate that the A/P offset condition had faster rise times compared to the symmetric condition, older adults rose faster than younger adults, and faster rise times were observed with arms folded compared to pushing off from the knees. Rise times from the narrow and wide positions were not different from symmetric. During the stepping phase, there was a significant main effect of age ($p = 0.038$), indicating younger adults completed the swing and stance phases faster than older adults.

3.1. *Rising phase GRFs (stepping limb)*

For A/P peak GRFs, there were significant main effects of foot condition ($p < 0.001$) and age ($p < 0.001$) for the stepping limb. The stepping limb in the A/P offset condition had a 28.4% greater peak propulsive GRFs compared to the symmetric position ($p < 0.001$) and older adults had 17.8% less propulsive GRFs compared to younger adults. The peak A/P GRF when rising from narrow and wide positions was not different from symmetric. For the mediolateral GRF range on the stepping limb, there were significant foot position ($p < 0.001$) and age ($p = 0.014$) main effects. The narrow position generated 32.1% smaller range ($p < 0.001$) and the wide position generated 50.8% greater range compared to the symmetric position ($p < 0.001$). The mediolateral GRF range between the A/P offset and symmetric positions was not different. In addition, older adults had a 9.1% smaller range in mediolateral GRFs values compared to younger adults. During the rising phase, there was a significant main effect of foot position on the stepping limb's vertical GRF ($p < 0.001$, Table 3), with the A/P offset condition generating 19.9% greater average vertical peak GRF compared to the symmetric position ($p < 0.001$, Figs. 2 and 3). The peak vertical GRF generated when rising from the narrow and wide positions was not different from the symmetric.

There was a significant foot position and age interaction effect on peak rising phase vertical GRF, with older adults in the A/P offset position having 23.1% greater peak vertical GRFs on the stepping limb compared to the symmetric position ($p < 0.001$), whereas younger adults only had 16.8% greater peak vertical GRF ($p < 0.001$). An age pairwise comparison of vertical GRFs yielded nonsignificant results ($p = 0.127$) due to the Tukey correction.

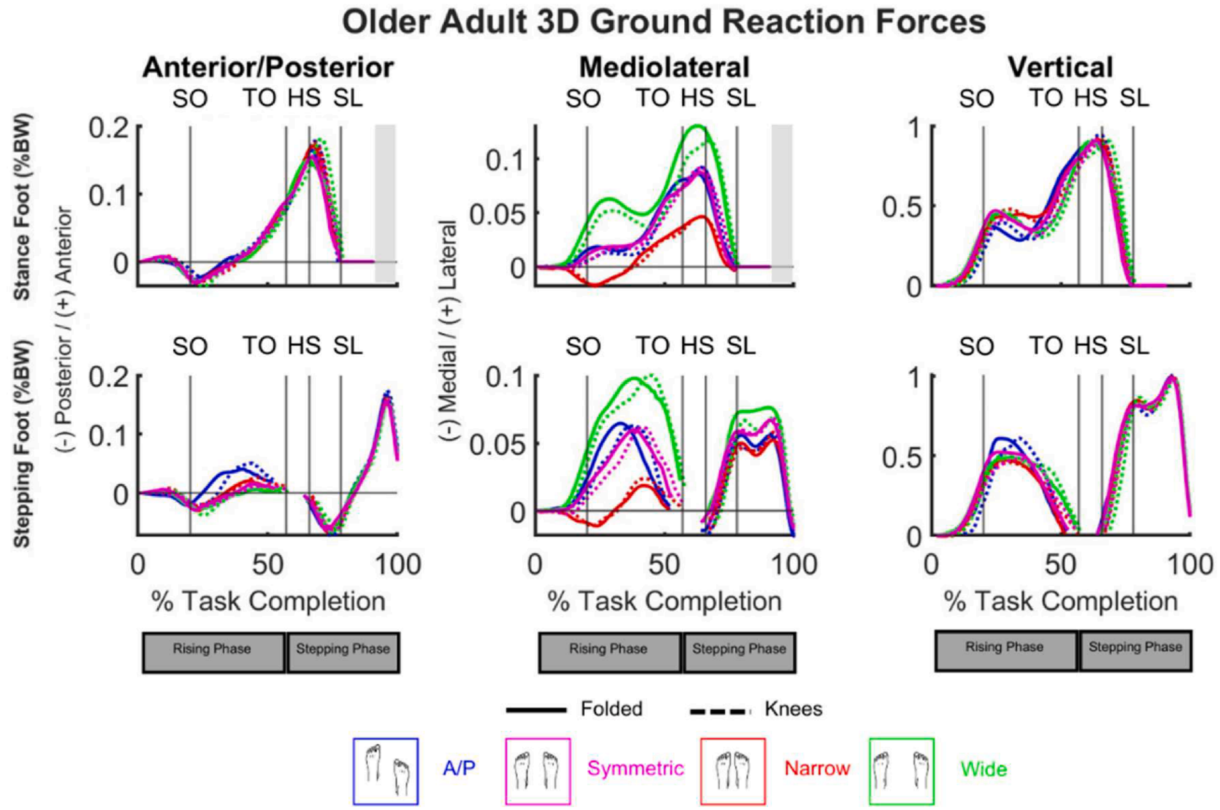

Fig. 3. Average normalized stance and stepping limb ground reaction forces for older adults in STW for four initial foot positions and two arm placements. Anterior, medial, and superior directions were defined positively. Vertical lines indicate STW (0–100%) events seat off (SO), toe-off (TO), heel strike (HS), and stance limb toe-off (SL). See Fig. 1 for full definitions of each STW event. The grey shaded region represents time when the stance limb was in contact with the ground beyond the force plate, so no data were collected. Significant main, interaction, and pairwise post hoc differences are detailed in the text and numerical values are provided in Supplementary Table S.1, S.2, and S3.

3.2. Stepping phase GRFs (stepping limb and stance limb)

During the stepping phase, there were no significant main effects for peak A/P GRFs on either limb. However, there were significant main effects of foot condition ($p < 0.001$) and age ($p = 0.037$) for the range of mediolateral GRF on the stepping limb (Table 3). The wide position had a 10.3% greater range in mediolateral GRF compared to the symmetric position ($p < 0.001$) and the narrow position had a 24.7% smaller range in mediolateral GRFs compared to the symmetric position ($p < 0.001$, Figs. 2 and 3). The range in mediolateral GRFs between the A/P offset and symmetric positions were not different. Older adults had a 5.4% greater range in mediolateral GRFs values compared to younger adults. On the stance limb, there were significant main effects of foot condition ($p < 0.001$) and age ($p < 0.001$) also. The wide position produced 31.5% greater range in mediolateral GRFs ($p < 0.001$), and the narrow position generated 25.1% smaller range in mediolateral GRFs ($p < 0.001$) over the duration of ground contact (including portions of both rising and stepping phases) compared to the symmetric position. The range in mediolateral GRFs between the A/P offset and symmetric positions were not different. Consistent with the stepping limb, older adults produced a 7.2% greater range in mediolateral GRF compared to younger adults. Lastly, there were no significant main effects for peak vertical GRFs during the stepping phase.

3.3. Body COM motion

There were no significant main effects for A/P movement of the body COM position. There was a significant main effect of foot condition for range of mediolateral body COM position during the rising ($p < 0.001$) and stepping phases ($p < 0.001$) (Table 3). The narrow position had 65.0% smaller range when rising ($p = 0.004$) and 37.3% smaller range when stepping ($p < 0.001$) compared to the symmetric position, which did not support our hypothesis that the wide position would have the smallest range (Fig. 4). Mediolateral body COM range when rising from A/P offset and wide positions was not significantly different from symmetric. Our hypothesis that older adults have greater mediolateral body COM range was supported by a significant age effect during the stepping phase ($p < 0.001$), where older adults had 7.3% larger range than younger adults across all foot and arm placements. Lastly, there was a significant arm effect during rising ($p = 0.015$), where arm-supported push off increased the vertical displacement of the body COM by 5.2% compared to arms folded.

3.4. Muscle iEMG

There was a significant arm effect on LP iEMG for the stance ($p = 0.005$) and stepping ($p = 0.036$) sides, and on GMED iEMG for the stance limb ($p = 0.034$), which supported our hypothesis (Table 3). Rising with arm support had 15.4% smaller LP iEMG for the stance side and 15.9% smaller LP iEMG for the stepping side (Figs. 5 and 6). For GMED, rising with arm support had 9.9% smaller stance limb GMED iEMG compared to the arms folded condition. There was also a significant age effect on GMED iEMG for both limbs ($p < 0.001$), supporting our hypothesis. Older adults had 69.0% larger stance limb GMED iEMG and 40.2% larger stepping limb GMED iEMG compared to younger adults. In addition, there was a significant interaction between age and foot placement for stance limb GMED iEMG ($p = 0.042$), where older adults rising from the A/P offset condition had 33.4% lower iEMG compared to the symmetric position ($p = 0.018$).

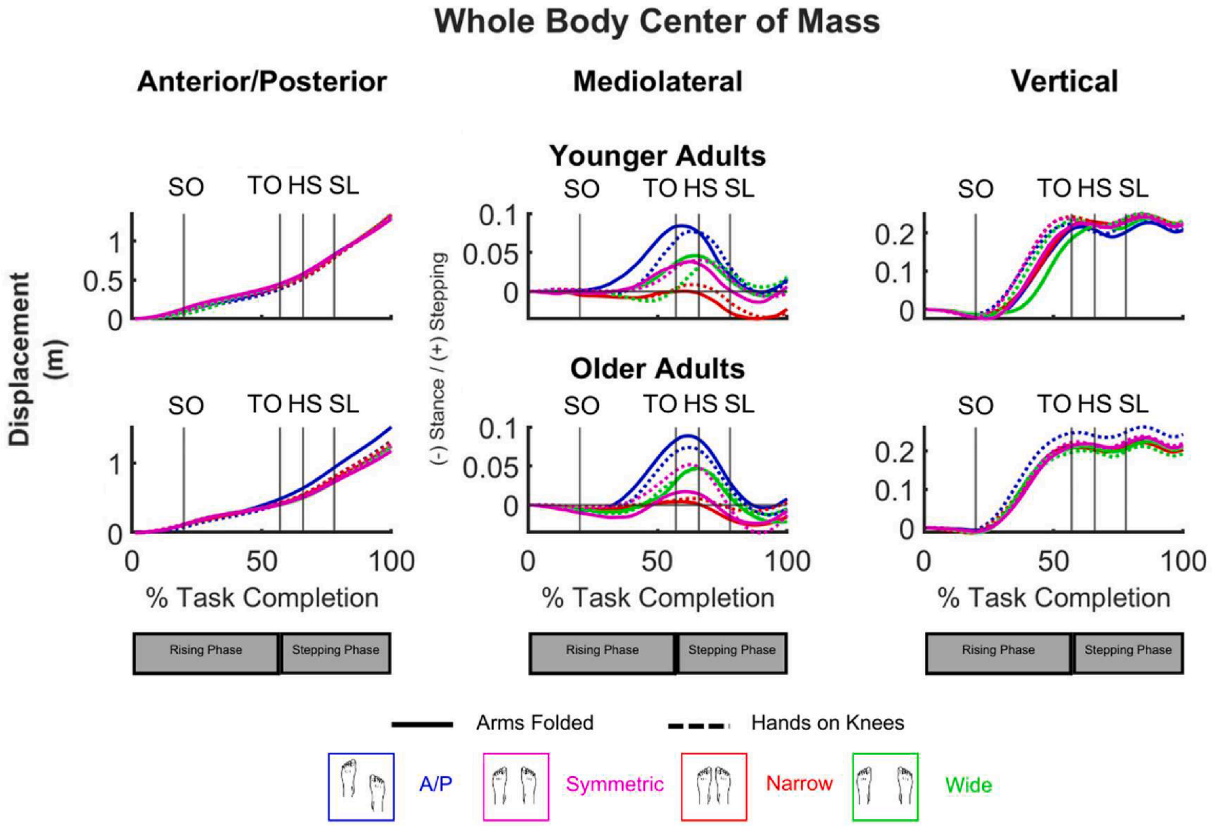

Fig. 4. Average normalized whole-body COM position for younger and older adults for four initial foot positions and two arm placements. In the mediolateral direction, a positive value is toward the stepping limb and a negative value is toward the stance limb. In the vertical direction, a positive value is upward from the initial seated position. Vertical lines indicate STW (0–100%) events seat off (SO), toe-off (TO), heel strike (HS), and stance limb toe-off (SL). See Fig. 1 for full definitions of each STW event. Significant main, interaction, and pairwise post hoc differences are detailed in the text and numerical values are provided in Supplementary Table S.4 and S5.

4. Discussion

In this study, we quantified the biomechanical effects of initial foot positions and arm-supported rising on the STW movement in younger and older adults. Differences in the range of mediolateral GRFs and body COM position across age groups and arm placements are a result of the initial foot positions. The narrow initial foot position generated the smallest average range in mediolateral GRFs and body COM, and the wide foot position generated the largest. This result did not support our hypothesis that the narrow position would have the greatest range. During the rising phase, the wide stance necessitated larger medial GRFs to move the body COM toward the stance limb for the first step. Although the wide initial foot position has a greater base of support initially, there is greater demand to control the body in the mediolateral direction to maintain balance during the transition to a single limb stance and stepping forward from a wide position. This result supports the idea that initial foot placement when rising will affect dynamic balance in the initial step.

We hypothesized that older adults would produce greater ranges of mediolateral GRFs and body COM displacement than younger adults, which was partially supported. Younger adults generated larger mediolateral GRFs while rising, but older adults generated larger mediolateral GRFs and body COM ranges during the stepping phase. These differences suggest differing movement strategies to laterally control the body COM in STW. Differences between age groups suggest anticipatory movement control and merging of tasks in younger adults compared to older adults who may have a reactive strategy (Kanekar and Aruin, 2014; Laudani, et al., 2021). Greater mediolateral GRFs from younger adults may better direct the body COM toward the stance limb during rising to initiate gait, and older adults may instead rise more quickly and symmetrically, and then redirect their body COM to initiate gait. This interpretation is further supported by older adults completing the rising phase faster, but the stepping phase slower, than younger adults. The greater mediolateral movement of older adults during STW indicates an altered balance control strategy, which is affected by initial foot placement. Individuals with lower muscle strength and reduced nerve conduction velocities, characteristics associated with age-related decline, tend to have narrower foot positions when standing up (van der Kruk et al., 2022). This positioning may be chosen to reduce the mediolateral movement of the center of mass (COM) compared to a wider stance. Our hypothesis that the A/P offset foot position would have the lowest range in mediolateral GRFs and body COM displacement was not supported. During the rising phase, the A/P offset position produced the largest vertical and propulsive GRFs on the stepping limb and mediolateral GRFs that were comparable to the symmetric position. The propulsive forces from the posteriorly offset stepping limb accelerate the body forward, preparing for transitioning into gait and reducing the lateral shift during the first step of gait initiation. Smaller LP excitation when rising with arm support is likely related to altered trunk movement. To confirm that smaller LP activity when rising with arm support corresponded with less trunk flexion, a post hoc analysis was conducted to compare the peak global torso segment angle between arm conditions, occurring just after seat off. A paired *t*-test between arm conditions revealed that rising with arm support reduced the peak global torso segment flexion angle by 11.2% compared to arms folded ($p = 0.015$) (Fig. 7). The arms on the knees support the trunk, which stabilizes the COM. In addition, proprioceptive feedback when using arm support may help modulate balance control. However, less forward

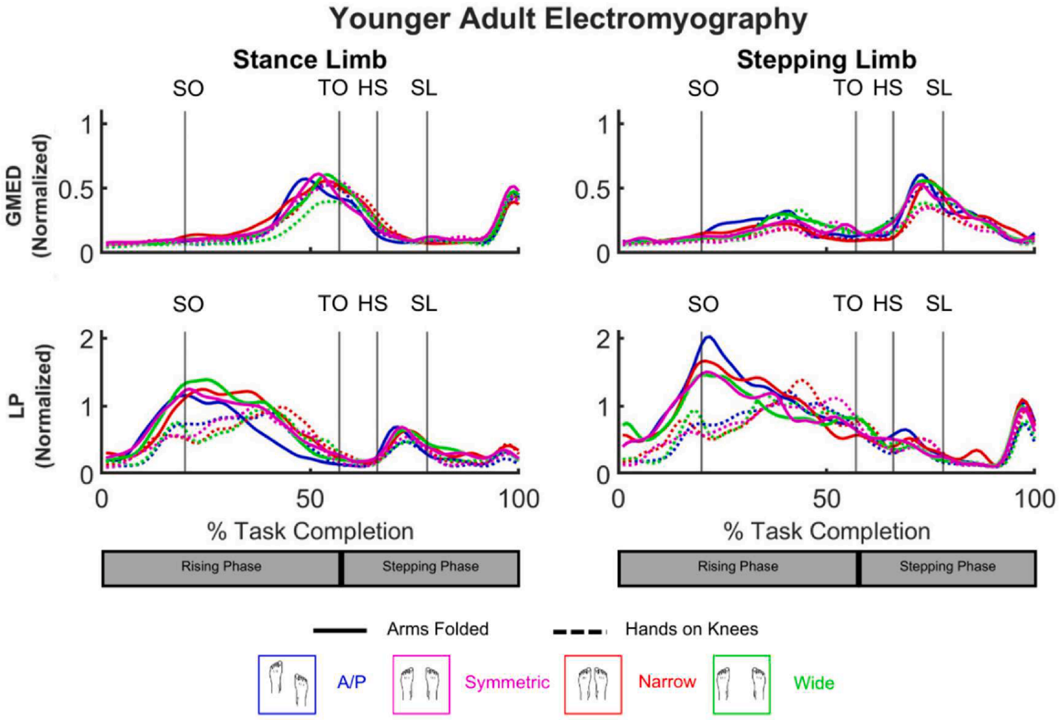

Fig. 5. Average processed lumbar paraspinals (LP) and gluteus medius (GMED) excitation for younger adults in STW for four initial foot positions and two arm placements. Vertical lines indicate STW (0–100%) events seat off (SO), toe-off (TO), heel strike (HS), and stance limb toe-off (SL). See Fig. 1 for full definitions of each STW event. Significant main, interaction, and pairwise post hoc differences are detailed in the text and numerical values are provided in Supplementary Table S.6 and S.7.

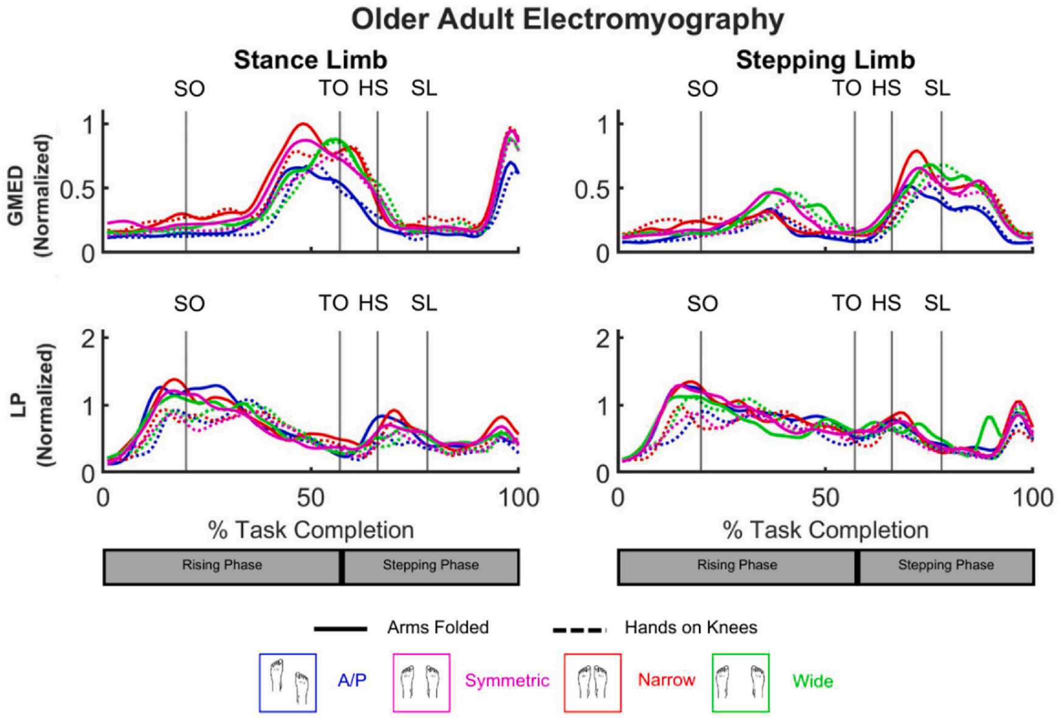

Fig. 6. Average normalized lumbar paraspinals (LP) and gluteus medius (GMED) excitation for older adults in STW for four initial foot positions and two arm placements. STW (0–100%) events seat off (SO), toe-off (TO), heel strike (HS), and stance limb toe-off (SL). Full definitions of each STW event are detailed in Fig. 1. Significant main, interaction, and pairwise post hoc differences are detailed in the text and numerical values are provided in Supplementary Table S.6 and S.7.

trunk flexion can result in greater demand from knee extensors and larger GRFs, and as a result, probable larger knee joint contact loading (Shia et al. 2018).

We hypothesized that rising with arm support would reduce LP and GMED iEMG. This hypothesis was supported bilaterally for the LP, and for stance limb GMED (Figs. 6 and 7). Rising with arm support can

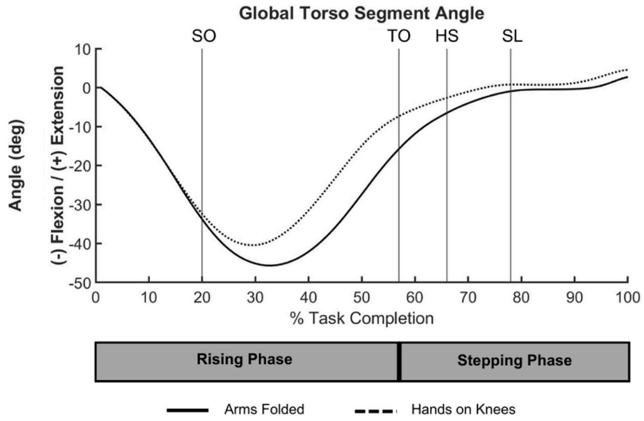

Fig. 7. Average global torso segment angle for the two arm placements. Curves are averaged across all foot positions as well as the older and younger adult groups. The torso segment angle was defined relative to the initial, seated global angle. STW (0–100%) events seat off (SO), toe-off (TO), heel strike (HS), and stance limb toe-off (SL) are indicated with vertical lines.

reduce GMED excitation by lessening the demand for torso vertical and lateral stability from a hip abduction torque (Jang, and Yoo, 2015). Therefore, rising with hands on knees reduces LP and GMED excitation and may be recommended for adults that experience low back pain when rising. There was greater GMED iEMG for older adults over the duration of the STW task compared to younger adults. GMED action compensates for lateral instability when preparing for and recovering from a loss of balance while initiating gait (Maki, et al., 1994; Mille, et al., 2005). In addition, aging disproportionately reduces ankle plantarflexor strength, resulting in a proximal redistribution of joint work from the ankle to the hip in older adults during several tasks such as walking (Buddhadev and Martin, 2016; McGibbon and Krebs, 1999), static postural control (Amiridis, et al., 2003; Horak, 2006), and dynamic functional tasks like whole-body reaching (Saito, et al., 2014). Therefore, our results are in line with prior work on walking and rising studies in showing higher muscle output in hip extension and abduction, like from the gluteus medius.

Potential limitations of this study include the inclusion and exclusion criteria. Muscle atrophy, joint replacements, anthropometry, and activity level, which can vary greatly across individuals, may influence the generalizability of the results. We included both males and females in our younger and older adult age groups, but groups were not perfectly matched. Participant selection affects generalizability, and potential differences between males and females is an important area of future investigation. In addition, the LP and GMED EMG signals were normalized to muscle activity of the stance limb during the posterolateral reach of a Star Excursion Balance Test, which can vary depending on individual effort during the task. However, level of effort can affect all maximum and functional tasks used for EMG normalization. We chose to normalize EMG signals by the SEBT because it is a functional, maximal reach task as well as a clinical assessment for balance performance, which elicited strong excitations for both GMED and LP. The arm effect for LP was not affected by EMG magnitude normalization, as the arm comparison was within-participants. Differences in GMED excitation between older and young adults have potential to be affected by EMG magnitude normalization, but we found our age effect to remain when normalized by other functional tasks in the study such as a body weight squat and the five times sit-to-stand test. Thus, we do not believe differing levels of effort in the SEBT affected the results. Older study participants were healthy, had an average age of 62.2 years, and did not have a recent history of falls. Thus, future work aims to apply this analysis to people with balance deficits. A standardized protocol with prescribed initial conditions has limitations for assessing the compensation strategies used in daily living; however, our experimental protocol was designed to enable the comparison between participant groups and quantify the systematic, biomechanical relationships between each condition and its resulting biomechanics.

5. Conclusion

This study quantified the biomechanical effects of initial foot position and arm-supported rising in STW in younger and older adults. Younger adults generated larger mediolateral GRF ranges during rising while older adults generated larger mediolateral GRF ranges and body COM displacement while taking their first step. Older adults completed the rising phase faster but the stepping phase slower than younger adults. This age effect may originate from differences in anticipatory and reactive movement behaviors between younger and older adults. Ranges in mediolateral GRFs and body COM position were greatest when rising from a wide position and smallest from a narrow position, which suggests a narrow foot position may lessen the mediolateral control demands required to move from double to single limb stance. The results highlight the importance of initial foot positions in promoting lateral balance control into the stepping phase. Older adults had greater GMED excitation throughout STW compared to younger adults, suggesting reliance on hip muscles for trunk control in STW. Arm-supported rising from the knees lowered LP, which likely reduces low back loads when rising.

CRediT authorship contribution statement

Michael F. Miller: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Eline van der Kruk:** Writing – review & editing, Supervision, Conceptualization. **Anne K. Silverman:** Writing – review & editing, Visualization, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

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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Appendix A. supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbiomech.2024.112256.

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