Journal of Mechanics in Medicine and Biology
Vol. 16, No. 8 (2016) 1640027 (10 pages)

DOI: 10.1142/S0219519416400273

AGE–GENDER DIFFERENCE IN THE BIOMECHANICAL FEATURES OF SIT-TO-STAND MOVEMENT

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Received 1 February 2016
Revised 25 February 2016
Accepted 20 April 2016
Published 22 September 2016

The purpose of this study was to investigate the effects of age and gender on the biomechanical features of sit-to-stand (STS) movement. Twenty young subjects and 20 elderly subjects participated in this study. Nine events during STS movement were defined where joint angles and joint moments were extracted for further analyses. Two-way repeated measures ANOVA was performed for joint angles and joint moments with age and gender as independent factors. Major gender differences were shown in joint angles. Women used a sliding forward strategy more than men (more flexion of ankle and knee joint) during mid-phases of STS movement ($p < 0.01$) and men used an exaggerated trunk flexion strategy more than women (more hip flexion) in later phases of STS movement ($p < 0.01$). Age differences were shown in joint moments. Elderly subjects showed smaller knee extension moment (normalized by body weight) but greater ankle plantar flexion moment than young subjects in mid-to-late phases of STS movement ($p < 0.001$). More anterior positioning of center of mass (COM) in the elderly might be the reason for the strategy difference. That is, the shorter distance of COM from the knee joint would require less knee extension moment, and likewise, the more forward

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displacement of COM with respect to the ankle joint would need more plantar flexion moment. More anterior positioning of COM in the elderly, compared to the young was reflected on center of pressure (COP), and the forward displacement of COP was correlated well with the higher body mass index (BMI) and shorter thigh length ($r = 0.359 - 0.66; p < 0.01$).

Keywords: Age; gender; sit-to-stand; kinematic; kinetic features.

1. Introduction

Chair rising involves the transition from a stable seated position to a relatively unstable upright stance, and requires coordinated contractions of the muscles of the lower extremities and trunk.[1] The sit-to-stand (STS) movement is performed every day and is an important prerequisite to the achievement of many functional goals.[2] Therefore, it is important and necessary for the elderly to maintain an independent life.[3]

However, the elderly may experience difficulty during STS movement[4] and this difficulty is deeply associated with falling.[5] The elderly were reported to have a high occurrence of falls during STS movement.[6] Among the elderly, falls occur more in women than in men showing 6–10% higher fall rates of women.[7] Therefore, it is valuable to investigate both effects of age and gender on the biomechanical features of STS movement.

However, major subjects in STS movement research were confined to specific disease groups and age groups, such as patients with hemiplegia,[8,9] knee arthroplasty,[10,11] Parkinson's disease,[5] obesity,[12] normal healthy young males[13] and normal children.[14]

Only a few studies investigated normal populations.[4] Normalized ground reaction force (GRF) was smaller in elderly females than in the young females in all phases of STS movement.[15] Elderly people exert significantly less force by the legs during the rising phase than young people ($p < 0.001$).[4] However, these studies failed to investigate gender effects on STS movement and joint moments (causal factors of movement) were not analyzed, i.e. their analyses were limited to GRF of post seat-off (SO) phases.

Kinematic and kinetic analysis of the movement before SO is important, because hip joint contact pressure before SO during STS movement is higher than other movements such as walking, jogging or jumping[16] and the peak joint moments are generated mainly before SO.[17] Therefore, the purpose of this study was to investigate both effects of age and gender on the kinematic and kinetic features of STS movement and also to analyze total phases of STS movement (both before and after SO).

2. Method

2.1. *Subjects and STS task*

Twenty healthy young subjects (10 men and 10 women) and 20 healthy elderly subjects who were 65 years old and over (10 men and 10 women) without any

Table 1. Characteristics of participant.

Characteristics	Young men	Young women	Old men	Old women	Age difference	Gender difference	Interaction
Age (years)	22.6 (2.3)	21.3 (2.2)	75.6 (3.8)	78.9 (4.0)	**	0.133	0.038
Height (cm)	172.5 (4.8)	159.4 (3.4)	164.1 (5.4)	148.8 (3.2)	**	**	0.612
Weight (kg)	64.2 (6.0)	52.8 (7.3)	68.2 (11.1)	54.0 (6.8)	0.426	**	0.394
BMI (kg/m^2)	21.3 (2.1)	20.8 (3.2)	38 (1.7)	38.0 (1.7)	**	0.355	0.134
Trunk (mm)	522.5 (18.0)	464.6 (16.7)	528.8 (28.0)	472.8 (31.1)	0.351	**	0.907
Thigh (mm)	434.8 (23.8)	390.3 (15.6)	378.5 (21.8)	331.8 (25.6)	**	**	0.875

Note: ** $p < 0.001$.

musculoskeletal injury participated in this study (Table 1). This study was approved by the institutional review board and written informed consents were received from all subjects.

2.2. *Experiment and analysis*

The chair height was adjusted to be 80% of the height of knee joint marker.[18] Initial sitting posture was standardized in the way that the sitting depth on the chair would be 70% of thigh length and the feet distance would be equal to each subject's shoulder width. Subjects were instructed to rise from the chair at a self-paced comfortable speed and to flex their arms in front of the chest (Fig. 1).

Four force plates (one Accusway dual top and two OR6-7, AMTI Inc., MA) were used to measure the reaction forces from the chair and the ground. Chair reaction

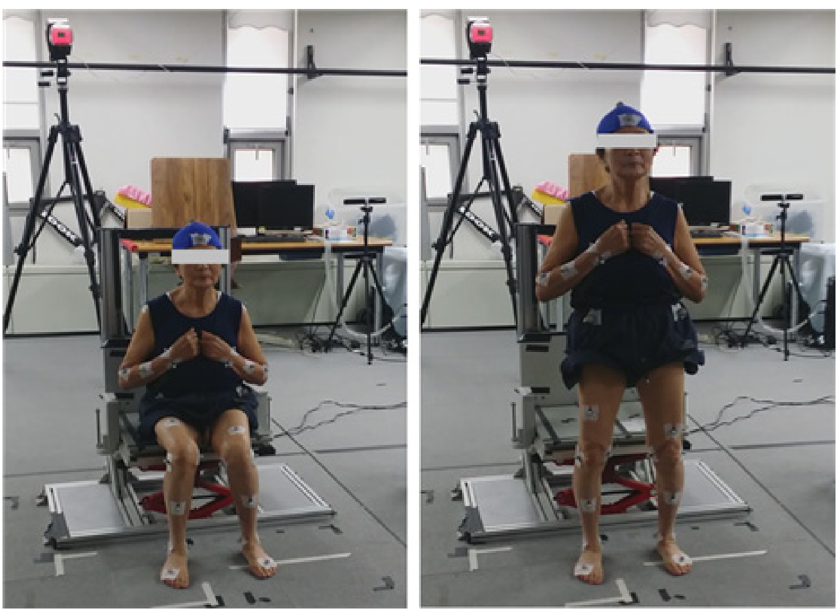


Fig. 1. STS movement (initial and final postures).

force (CRF) and GRF were low-pass filtered to exclude high frequency noise with a fourth-order Butterworth zero-lag filter, with a cutoff frequency of 10 Hz.[8,9,12] Three-dimensional coordinates of 33 reflective markers were measured during STS movement by a 3D motion capture system with six infrared cameras (Eagle, Motion analysis Inc., CA). Kinematic data and CRF/GRF were collected at 120 samples per second.

Joint moments were calculated by using Software for Interactive Musculoskeletal Modeling (SIMM, Musculo Graphics Inc., CA), specifically, by feeding the measured reaction forces and marker data into the inverse solution model of 'Full body Dynamic Flexible' built in SIMM.

2.3. *Event definitions*

In the analysis of STS movement, it is typical to focus on specific time events rather than on continuous time trajectories.[1,8,9,11,14] We defined nine events on which age–gender comparison of feature variables were performed.

ONSET is the starting point of STS movement and was defined as the time when the CRF started to rise from the steady value at the initial sitting posture. Max chair reaction force (MCRF) was defined as the instant when CRF peaks; that is, when maximum push-off effort or force is applied on a chair by the chair-contacting region of body. Transition (TR) is the central phase of body weight transfer from chair to ground and was defined as the instant that total GRF is equal to total CRF. Both maximum hip flexion angle (MHfA) and maximum ankle dorsiflexion angle (MAdfA) were defined as the instants when the mean angle of bilateral joints becomes the maximum. SO is the instant when the hip is getting off the chair and was defined as the instant when total CRF (sum of bilateral CRFs) becomes lower than 20 N (about 2 Kg). The maximum and minimum of total reaction force (TRFMax and TRFMin) were detected from the sum of bilateral CRF and bilateral GRF. Finally, END is the termination of STS movement and was set to be the instant the hip joint angle is stabilized at the later phase of STS. All the events will be described in the abbreviated forms in this paper as follows: ONSET, MCRF, TR, MHfA, SO, TRFMax, MAdfA, TRFMin and END.

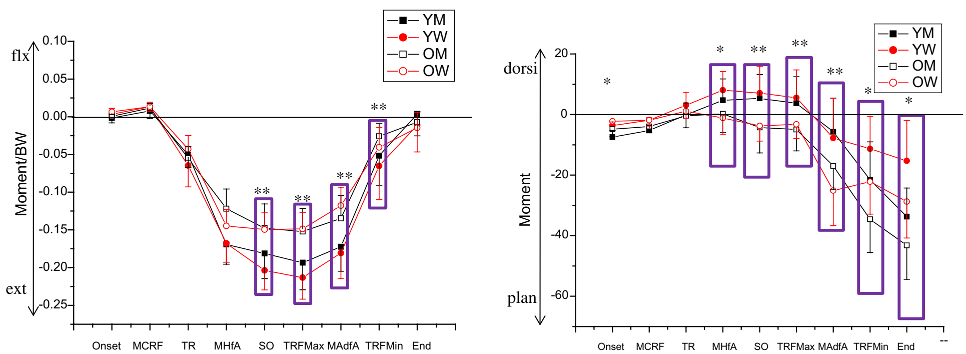
2.4. *Statistics*

Analysis variables were joint angles and moments of hip, knee and ankle at the nine events. Hip and knee joint moments were normalized by body mass because they were significantly correlated with body mass ($r = 0.813^{**}$ and 0.644^{**}, respectively). On the other hand, ankle moment was used as itself without normalization, because of insignificant correlation with body mass ($r = 0.007$). Two-way repeated measures ANOVA was performed for each variable with two factors of age and gender. The level of significance was set to $p < 0.01$ considering multiple comparisons.

3. Results

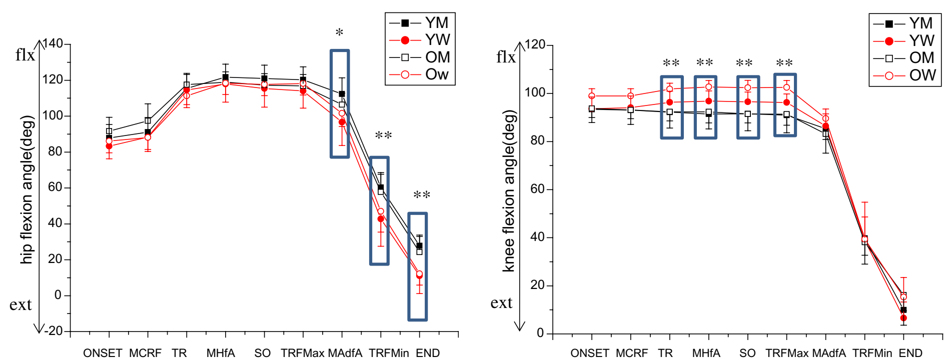
Age differences were shown in knee and ankle joint moments (Fig. 2). Elderly subjects showed smaller knee extension moment compared to young subjects at mid-to-late phases of STS movement ($p < 0.001$), although it is normalized by body weight (Fig. 2(a)). In contrast, elderly subjects generated greater ankle plantar flexion moment than young subjects in mid-to-late phases of STS movement (Fig. 2(b), $p < 0.01$). Interestingly, the elderly generated plantar flexion moment in mid-phases (MHfA–TRFMax), while the young generated dorsiflexion moment (Fig. 2(b)).

Figure 3 shows the gender effect on joint angles and hip moment. Men flexed hip joint more than women at terminal phases (MAfA–END) (Fig. 3(a), $p < 0.01$) and generated greater hip extension moment than women in terminal phases (Fig. 3(d),



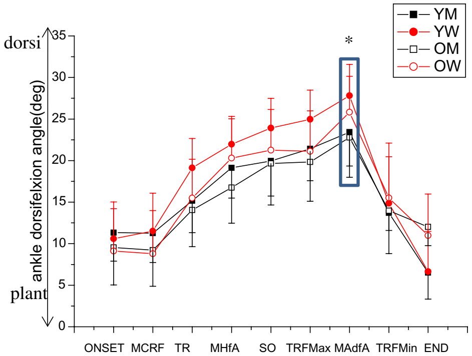
(a) (b)

Fig. 2. Age effect on joint moments (*: $p < 0.01$, **: $p < 0.001$). (a) Knee moment (b) Ankle moment.

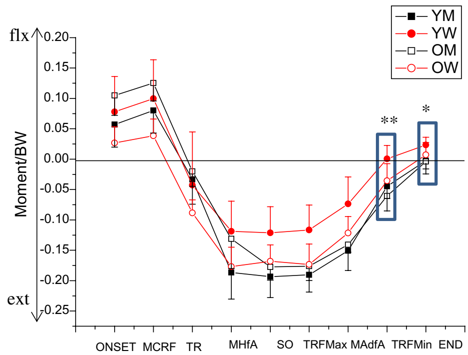


(a) (b)

Fig. 3. Gender effect on joint angles and moment (*: $p < 0.01$, **: $p < 0.001$). (a) Hip angle (b) Knee angle (c) Ankle angle (d) Hip moment.



(c)



(d)

Fig. 3. (*Continued*)

$p < 0.01$). In contrast, women had greater knee flexion angle at mid-phases (TR–TRFMax) and greater peak dorsiflexion angle than men (Figs. 3(b) and 3(c), $p < 0.01$).

4. Discussion

4.1. *Age effect*

Knee joint moment: Normalized knee extension moment was smaller in the elderly than in the young (Fig. 2(a)). More anterior positioning of center of mass (COM) in the elderly might be the reason for the altered STS strategy, supposing COM can be approximated by COP. The shorter distance of COM with respect to the knee joint in the elderly (Fig. 5(a)) would require less knee extension moment after SO (Fig. 2 (a)). This is supported by the result that the COP of the elderly was closer to knee joint than that of the young in the later phases (Fig. 4(a), $p < 0.01$).

More anterior positioning of COM (or COP) in the elderly may be related to the altered anthropometry, as the joint angle was not different between age groups. Aging is known to be associated with many anthropometric changes such as increase in body mass index (BMI)[19], shortening of height.[20] In this study, the elderly showed higher BMI and shorter thigh length than the young (Table 1). Again, BMI and thigh length were significantly correlated with the COP displacement at most events after SO (Table 2, $p < 0.001$). That is, the COP positioned more at front with higher BMI and shorter thigh length. In this respect, it is highly feasible that the higher BMI and shorter thigh length in the elderly may have positioned COM closer to the knee joint (body mass tends to concentrate on the upper body in high BMI subjects and shorter thigh result in upper body position closer to the knee joint), and this would require less knee extension moment as in Fig. 2(a).

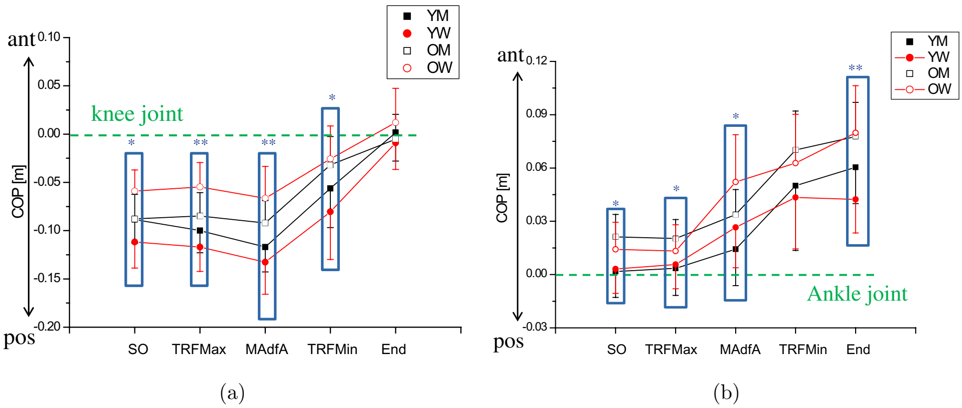


Fig. 4. COP at the latter phase (age effect, *: $p < 0.01$, **: $p < 0.001$). (a) Center of pressure (COP) from knee joint (b) COP from ankle joint.

Ankle joint moment: Around the SO, the elderly generated plantar flexion moment, while the young generated dorsiflexion moment (Fig. 2(b)). Similar to the knee moment, this age difference may be due to more anterior positioning of COM in the elderly (Fig. 5(b)). For example, COP of the elderly was positioned about 2 cm in front of the ankle joint right after SO (TRFMax) while that of the young was close to ankle joint (Fig. 4(b)). More anterior positioning of COM (or COP) in the elderly would have required plantar flexion moment for balancing at the ankle, while positioning of COM (or COP) close to the ankle joint would have demanded dorsiflexion moment to make forward and upward momentum for standing up. Again, the anterior positioning of COM would be associated with the anthropometric difference.

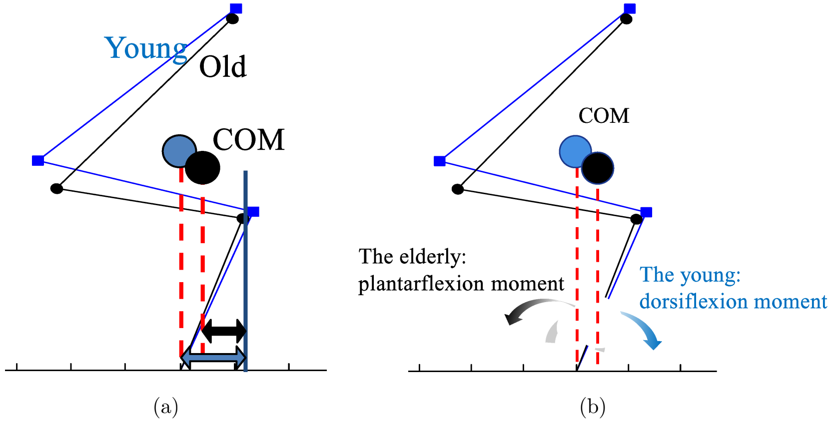


Fig. 5. (Color online) Stick diagram for the age effect at TRFMax (blue: the young, black: the elderly). (a) knee moment (b) ankle moment.

Table 2. Correlations between COP and anthropometric data at the later phases.

Event	SO	TRFMax	MAdfA	TRFMin
BMI	0.436**	0.519**	0.568**	0.432**
Thigh length	−0.522**	−0.676**	−0.610**	−0.359*

Notes: *: $p < 0.01$, **: $p < 0.001$.

4.2. *Gender effect*

Knee and ankle joint angles: Women had greater knee flexion angle at mid-phases (TR–TRFMax) and greater peak dorsiflexion angle than men (Figs. 3(b) and 3(c), $p < 0.01$). Figure 6(b) shows the displacement of hip joint center from ONSET to MAdfA averaged for men and women. Women's hip joint moved (10, 4) cm and men's hip joint moved (9, 8) cm in (forward, upward) directions. This indicates that women's hip joint moved more forward than upward, as in the sliding forward strategy, reported to make STS movement easier[21] and to be used by community dwelling older women.[22] Excessive forward sliding in women resulted in greater knee flexion and ankle dorsiflexion than men (Figs. 3(b) and 3(c), $p < 0.01$).

Hip joint angle and moment: Men flexed hip joint more than women at terminal phases (MAfA–END) (Fig. 3(a), $p < 0.01$) and generated greater hip extension moment than women at terminal phases (Fig. 3(d), $p < 0.01$). This result indicates that men used "exaggerated trunk flexion strategy" which flexes the trunk to place the COM over the feet.[23] Greater hip extension moment in men may be required to maintain posture against gravity at terminal phases.

Strategy difference between genders: Achilles tendon which was reported to be more compliant thus provide more dorsiflexion range of motion (ROM) in women,[24] and this may be the reason why women used sliding forward strategy more than men

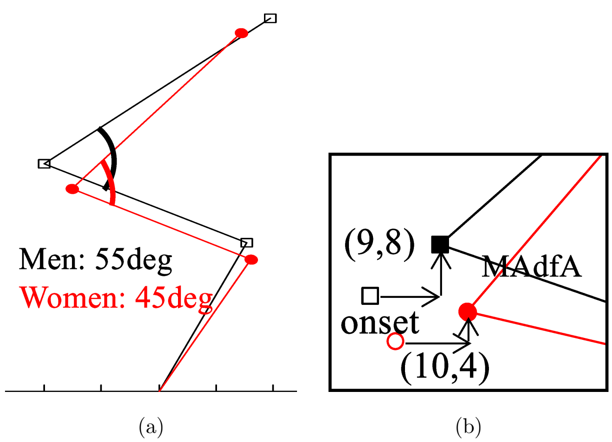


Fig. 6. (Color online) Gender effect at MAdfA (black: men, red: women). (a) Stick diagram (b) Hip joint displacement from onset.

in the result of this study. In contrast, exaggerated trunk flexion strategy in men may be a compensation of relatively posteriorly positioned body mass due to smaller ankle dorsiflexion. That is, pulling the upper body mass more forward by excessive hip flexion may make the anterior displacement of total body COM similar to that of women. This is supported by the result that COP displacement was not different between genders (not shown in the result).

4.3. *Contributions*

This study analyzed joint moments as well as joint angles during STS movement and compared them among different age groups and genders, which is original to this study. The main finding about gender difference was that women used excessive "sliding forward strategy" and men used "exaggerated trunk flexion strategy", which is original to this study. This strategy difference was discussed to come from the difference in ROM of ankle. Age differences were found in knee and ankle joint moments, which is a new finding. The different moment strategies were shown to be correlated with the COP placement, which is again associated with the anthropometric features (BMI and thigh length).

5. Conclusion

This study investigated the effects of age and gender on the biomechanical features of STS movement. We suggested that men and women use different STS strategies by results of joint angle. The age difference in knee and ankle moment is likely to occur because the anthropometric features such as BMI and thigh length change with age. The findings of this study may serve as important basic data which can help profound understanding of STS movement and its age–gender differences.

Acknowledgment

This work was supported by Konkuk University in 2013.

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