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ORIGINAL RESEARCH

Comparison of the Lower Extremity Kinematics and Center of Mass Variations in Sit-to-Stand and Stand-to-Sit Movements of Older Fallers and Nonfallers

Yi-Ting Lin, MS, Heng-Ju Lee, PhD

Department of Physical Education and Sport Sciences, National Taiwan Normal University, Taiwan

KEYWORDS
Accidental falls;
Aged;
Rehabilitation;
Sitting position;
Standing position

Abstract *Objective:* To compare the differences in sit-to-stand and stand-to-sit movements of older nonfalling males and older male fallers (also referred to herein as fallers) to contribute to the development of posture transfer—assisting devices or interventional therapies to prevent falls.
Design: Controlled study.
Setting: University research laboratory.
Participants: Ten older men (mean age, 75.9±5.4 years) who had fallen or been unstable at least once in the past year and 10 nonfalling older men (mean age, 70.0±5.0 years) participated in this study.
Interventions: Not applicable.
Main Outcome Measures: Movement duration; sagittal trunk, hip, knee, and ankle joint range of motion (ROM); anteroposterior and mediolateral (ML) center of mass (COM) total trajectory.
Results: During the sit-to-stand transition, fallers exhibited greater trunk joint ROM in the flexion and extension phase and smaller hip joint ROM in the extension phase as well as greater ML COM total trajectory. During stand-to-sit, older fallers exhibited greater trunk joint ROM in the flexion phase and smaller hip and knee joint ROM in the flexion phase as well as greater ML COM total trajectory. Older fallers took more time to perform the stand-to-sit and had greater ML COM total trajectory during the movement; additionally, they exhibited different proportional distributions of ROM for each joint compared with nonfaller.
Conclusion: Older fallers had more difficulty performing stand-to-sit than sit-to-stand; they exhibited more body sway in COM motion and, in particular, were unable to control ML motion y. Older fallers were more likely to adopt trunk, hip, and knee joint flexion strategies to maintain balance during sit-to-stand and stand-to-sit than nonfaller participants were.

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Statistics from the World Health Organization indicate that falls are the second leading cause of accidental injury death globally, with the highest incidence among people over the age of 65.[1] The occurrence of falls in older adults is related to various factors, such as impaired balance, unstable lower limbs, and restricted joint range of motion (ROM).[2-5] As humans get older, aging causes decline in the neuromuscular system, such as strength loss,[6,7] as well as change in adaptation strategies to compensate for this decline, such as altered muscle recruitment.[8-10] Furthermore, certain aspects of aging, including decline in neuromuscular ability and decrease in sensorimotor system function, can cause considerable functional consequences.

A study on the probability of older people falling during various activities determined that although walking was associated with the highest rate of falls, sit-to-stand and stand-to-sit entailed the second highest risk of falling. The sit-to-stand action accounted for 12% of falls[11] and stand-to-sit accounted for 6%,[11] suggesting that older people have difficulty standing up or sitting down and that performing these movements increases their risk of falling. Sit-to-stand and stand-to-sit movements require coordination between the trunk and lower limbs for balance and stability[12-14] and therefore require the collective action of the trunk, hip, knee, and ankle joints. Sit-to-stand movement involves 3 major challenges for older adults: (a) bringing the center of mass (COM) forward, (b) vertically raising the COM from the sitting to standing position, and (c) transitioning from a relatively large and stable base of support (BOS) when sitting to the considerably smaller BOS when standing.[15] A previous study has shown that older people had different strategies than young people when performing sit-to-stand.[16] Moreover, stability control during the terminal phases of the sit-to-stand are more difficult for older people than for younger adults.[15] On the other hand, although stand-to-sit initially appears to be a reverse movement of sit-to-stand, a previous study observed some kinematic differences between these 2 movements. During sit-to-stand, the initiation of trunk flexion occurs before knee extension; however, during stand-to-sit, timings of the trunk flexion and the knee flexion are almost simultaneous, requiring the control of the entire body's COM for both anterior-posterior and vertical displacement.[17] Other studies have shown the importance of the lumbar-hip complex flexion ROM as well as maintaining the COM beyond the BOS when performing stand-to-sit.[12,18] In addition, the sit-to-stand-to-sit test is often used as a clinical assessment of functional lower extremity strength in older adults,[19,20] which includes 30 seconds of sit-to-stand-to-sit completions or 5 rapid sit-to-stand-to-sit completions. However, the focus on speed is at the expense of the controlled stability of the stand-to-sit phase. Therefore, a controlled stand-to-sit testing method should be considered in the sit-to-stand-to-sit functional test or as a separate test.

To prevent loss of balance during sit-to-stand and stand-to-sit, it is crucial to maintain the body's COM within the BOS throughout these tasks.[21] In particular, the forward and backward movement of the body's COM must be precisely controlled to successfully maintain anteroposterior stability. Factors such as the position of the feet affect the horizontal movement of the COM and may lower the control of stability.[15] Compared to younger adults, older people had longer duration in which the COM remained beyond the BOS, thereby resulting in a longer state of instability in older people.[18] Therefore, when older people perform this type of posture transfer movement, the coordination between the joints and the stability of the body determines whether such movement can be completed successfully.

Studies have identified differences in the movements performed by older and younger people, but few have focused on COM stability and how the mechanics of the trunk, hip, knee, and ankle joints are related to falls among older people. Thus, this study's objective was to compare sit-to-stand and stand-to-sit movements among healthy older people and older fallers (also referred to herein as fallers) by using anteroposterior (AP) and mediolateral (ML) COM total trajectory to assess stability as well as to improve understanding of the relationship among the trunk, hip, knee, and ankle joints during movement.

Methods

All participants were informed of the study protocol and provided their written informed consent. Subjects' demographic data were collected before the experiment. This study was approved by the Research Ethics Committee, National Taiwan Normal University (REC Number: 202012HM035).

Ten older men (mean age, 75.9±5.4 years; mean height, 167.4±6.0 cm; mean weight, 68.0±12.9 kg) who had fallen or been unstable, such as swaying of the body, unable to stand up or walk properly due to imbalance, or almost about to fall over at least once in the past year and 10 nonfalling men (mean age, 70.0±5.0 years; mean height, 166.6±5.8 cm; mean weight, 69.5±7.3 kg) volunteered to participate in this study. All participants were older than 65 and had the capacity to follow movement instructions. Older people with vestibular disease, visual disorder, chronic disease, or a history of spine or lower limb surgery were excluded. To determine whether the participants belonged to the low- or high-risk falling group, the Tinetti Performance-Oriented Mobility Assessment (POMA) scale was used to assess risk of falling.[22-24] The POMA scores for falling risk are divided as follows: low (POMA score≥25-28), medium (POMA score≥19-24), and high (POMA score<19). Older fallers had a mean POMA score of 17.7±2.2, whereas that of nonfallers was 26±1.7 (table 1). In this study, all fallers' POMA scores were <19, and all nonfallers' POMA scores were >25. Written consent was acquired from each participant after they were informed of this study's purpose, procedure, and experimental method.

Each participant was fitted with 37 reflective markers,[a] and 8 VICON cameras[b] were used to collect the coordinate data of the reflective markers for subsequent analysis. All reflective marker coordinates are in a global reference frame. The procedure included sit-to-stand and stand-to-sit movements. Before the experiment started, subjects had 5 minutes to practice the movements. The subjects performed the experiment formally after they became familiar with the movements. Each participant were randomly assigned performing 3 sit-to-stand and 3 stand-to-sit movement trials at their own speed. Participants were instructed verbally to sit on a knee-high box that was adjusted according to the distance from the foot to the knee joint line of each participant, ensuring the subject's knee joint angle was between 80° to 100°. They were also instructed to cross their arms over the chest, have both heels aligned, toes facing forward and feet placed on force plates. To complete each movement, participants had to finish in the standing or sitting position without falling and maintaining their balance for 3 seconds without moving.[25] For stand-to-sit, participants start by standing upright with their feet placed in the same position as sit-to-stand. They also required to cross their arms over the chest. To complete each movement, participants had to finish in the standing or sitting position without falling and maintaining their balance for 3 seconds without moving. Participants were given 10 seconds for preparation before carrying out the stand-to-sit and sit-to-stand movements.

The sit-to-stand movement is divided into 4 phases[26] (fig 1): The phase 1 flexion phase begins when the velocity of the shoulder marker becomes greater than or equal to 0.1 m/s (T0) and ends when the velocity of the greater trochanter marker is greater than or equal to 0.1 m/s (T1). The phase 2 momentum transfer phase begins from T1 and ends when the vertical ground reaction force reaches its maximum (T2). The phase 3 extension phase starts at T2 and ends when the velocity of the shoulder marker becomes smaller than or equal to 0.1 m/s (T3). The phase 4 stabilization phase starts at T3 and ends when the velocity of the greater trochanter marker is smaller than or equal to 0.1 m/s (T4). The stand-to-sit movement is also divided into 4 phases (see fig 1). The phase 1 initiation phase starts when the velocity of the greater trochanter marker is greater than or equal to 0.1 m/s (T0) and ends when the velocity of the shoulder marker is greater than or equal to 0.1 m/s (T1). The phase 2 flexion phase starts at T1 and ends when the vertical ground reaction force reaches its maximum (T2). The phase 3 momentum transfer phase starts at T2 and ends when the velocity of the greater trochanter marker is smaller than or equal to 0.1 m/s (T3). The phase 4 extension phase starts at T3 and ends when the velocity of the shoulder marker is smaller than or equal to 0.1 m/s (T4).

MATLAB[c] was used to calculate the duration of each movement phase, the total duration, and each phase's percentage of the total duration. Visual 3D[d] software was used to calculate the joint angle for the trunk, hip, knee, and ankle as well as the AP and ML COM total trajectory. The right leg was used to measure joint angles. The trunk angle was defined as the angle between the pelvis and the thorax; the hip angle was defined as the angle between the thigh segment and the pelvis; the knee angle was defined as the angle between the shank segment and the thigh segment; the ankle angle was defined as the angle between the foot segment and the shank segment. Joint ROM was defined as the maximum angle minus the minimum angle of each movement phase. In addition, the proportion of each joint ROM in each phase is presented in figure 2. An independent sample *t* test was used to compare the difference between the groups (nonfaller and faller). First, the mean of each participants' 3 trials were recorded. Then, a paired sample *t* test was used to compare the difference between the movements (sit-to-stand and stand-to-sit). A P value of $\leq .05$ indicated a statistically significant difference.

Results

No significant difference was identified in participants' height or mass (height, P=.856; mass, P=.112), but significant differences in age and POMA scale score (age, P=.020; POMA scale, P<.001) were identified.

The elapsed time for nonfallers during the stabilization phase of sit-to-stand movement was significantly longer than the initiation phase of stand-to-sit movement in both nonfaller and faller groups. Older fallers also exhibited a significant difference between sit-to-stand and stand-to-sit total duration as well as a significant difference between the extension phase of sit-to-stand and the flexion phase of stand-to-sit. The mean and standard deviation of elapsed time are provided in table 2.

The joint ROMs for trunk, hip, knee, and ankle joints in each phase (phases 1-4) of sit-to-stand and stand-to-sit movement in each group are presented in table 3, and each joint's ROM percentage in each movement and phase is shown in figure 2. During sit-to-stand (see figure 2A), older fallers' trunk joint ROM during the flexion and extension phases was significantly greater than nonfaller's joint ROM, and older fallers' hip joint ROM during the extension phase was significantly smaller than that of nonfallers. During stand-to-sit (see figure 2B), older fallers' trunk joint ROM during the flexion phase was significantly greater than nonfallers' joint ROM, and older fallers' joint ROMs for the hip and knee joints during the flexion phase were significantly smaller than those of nonfallers. Between the sit-to-stand and stand-to-sit movements in nonfallers (see figure 2C), the ROM of the trunk, hip, and ankle joints during the stabilization phase of sit-to-stand was significantly greater than that in the initiation phase of stand-to-sit. Hip joint ROM during the extension phase of sit-to-stand was significantly smaller than that in the extension phase of stand-to-sit, and ankle joint ROM during the extension phase of sit-to-stand was significantly greater than that during the extension phase of stand-to-sit. Knee joint ROM during the momentum transfer phase of sit-to-stand was significantly smaller than that during the momentum transfer phase of stand-to-sit, and ankle joint ROM during the momentum transfer phase of sit-to-stand was significantly greater than that during the momentum transfer phase of stand-to-sit. Furthermore, the ROM of the trunk, hip, and ankle joints during the stabilization phase of sit-to-stand was significantly greater than that during the initiation phase of stand-to-sit (see figure 2D). Knee joint ROM during the extension phase of sit-to-stand was significantly greater than that during the extension phase of stand-to-sit. Knee joint ROM during the momentum transfer phase of sit-to-stand was significantly smaller than that during the momentum transfer phase of stand-to-sit.

The COM AP and ML total trajectory during both sit-to-stand and stand-to sit are presented in table 4. ML motion among older fallers was significantly greater than that among nonfallers. Among nonfallers, ML motion during sit-to-stand was significantly less than that during stand-to-sit.

Discussion

The main objectives of this study were to study and compare the biomechanical parameters of older nonfallers and older fallers in sit-to-stand and stand-to-sit movements in terms of duration, joint ROM of the trunk and lower extremity joints, and COM AP and ML total trajectories. According to the result of participants' information, although older fallers were significantly older than the nonfallers, they also had significantly lower POMA scale scores, indicating that their risk of falling were higher. Previous studies also showed that as humans get older, aging causes a decline in the neuromuscular ability and sensorimotor system function.[6-10] Therefore, the risk of falling also increases.

We determined that although stand-to-sit is simply the reverse movement of sit-to-stand, the stabilization phase of sit-to-stand takes longer than the initiation phase of stand-to-sit does. This may be because older fallers must control their forward and upward momentum during sit-to-stand but during the corresponding phase of stand-to-sit, they must only bend the trunk, hip, and knee joints. Previous study also presented that the timings of the trunk flexion and the knee flexion start at about the same time.[17] Because maintaining stability when experiencing both forward and upward momentum is more difficult, older adults require more time to complete the stabilization phase of sit-to-stand than for the corresponding phase in stand-to-sit. Additionally, older fallers exhibited greater differences between the movements, requiring more time to complete stand-to-sit than sit-to-stand. A previous study also found that the stand-to-sit task requires longer duration compared to the sit-to-stand task.[27] This is owing to the need to control the eccentric muscle contraction more carefully.[18,22] Moreover, the duration of the extension phase of sit-to-stand was longer than the flexion phase of stand-to-sit for fallers. The extension phase of sit-to-stand involves the trunk returning to the upright position and the extension of the hip and knee joints, which may require more upward momentum and the ability to control the body. This study's results accord with a previous study in which the velocity of the trunk's backward movement to regain an upright standing position during sit-to-stand was lower than the velocity during stand-to-sit.[17] Furthermore, the results demonstrated that older fallers may face different challenges when executing stand-to-sit and sit-to-stand movement.

When older fallers were in phases that require them to bend or straighten their trunk, such as during the flexion or extension phase, their trunks bent more than those of healthy older men. Therefore, the ROMs of the hip and knee joints in the same phase were reduced, which was particularly obvious in the flexion phase of stand-to-sit. Older adults often adopt an exaggerated trunk flexion chair rise strategy[17,28,29]; this strategy was observed during stand-to-sit in this study. Additionally, among people with lower back pain performing sit-to-stand and stand-to-sit, ROM in the lumbar spine and hip joints may be restricted during the movement.[30,31] This may also be the case with older fallers—their lower hip and knee joint ROM may be restricted, resulting in limited mobility compared with nonfallers. As a result, the coordination between different body joints or muscle groups is necessary in order to control the multijoint movement in a fluent manner.[22]

Multiple differences in joint ROM between sit-to-stand and stand-to-sit were evident among participants, whether they were healthy older adults or older fallers. As shown in figures 2C and 2D, the patterns of the 2 groups were similar, but the older fallers' trunk ROM accounted for a larger proportion of total ROM. Hence, the differences among hip, knee, and ankle ROM differed somewhat from those of healthy older men. During the momentum transfer phases of the 2 movements, the proportions of trunk and hip joint ROM in healthy older adults were almost equally large; however, the proportions of knee and ankle joint ROM differed somewhat, with sit-to-stand involving smaller knee joint ROM and greater ankle ROM. The ankle joint typically experiences more activity during the momentum transfer, extension, and stabilization phases of sit-to-stand than during stand-to-sit in the same phases, which is possibly because when standing up, older adults must first move their COM into a horizontal position and then upward and position their COM within the BOS to maintain dynamic stability.[21] This causes ankle joint dorsiflexion and greater joint ROM when the ankle joint returns to the normal position. Other differences between the 2 groups were also observed. During the extension phase of sit-to-stand, nonfallers had less hip joint ROM and more ankle joint ROM than they did in the flexion phase of stand-to-sit; however, older fallers' knee joints had more joint ROM during the extension phase of sit-to-stand. This may be because the trunk activity of older fallers contributes to a larger proportion of joint ROM, which reduces the proportions of joint ROM in the hip, knee, and ankle joints. A similar pattern was observed in the momentum transfer phase.

In this study, differences in COM ML motion were evident. In a previous study, the COM ML direction displacement fell within 1 cm in healthy older adults during the sit-to-stand movement.[32] Even the COM ML direction displacement of subjects with hip osteoarthritis fell within 2 cm during the sit to stand movement.[33] In this study, the sit-to-stand COM ML motion of older fallers is greater than previous studies, and the stand-to-sit COM ML motion is even greater than the sit-to-stand in this study. However, no significant difference in the ML total trajectory distance of older fallers was evident between sit-to-stand and stand-to-sit. The ML total trajectory distance of older fallers during sit-to-stand was 3.2 ± 0.7 cm, and that during stand-to-sit was 4.6 ± 1.1 cm. In the 2 movements, older fallers exhibited more motion on the frontal plane than nonfallers did (sit-to-stand: 1.9 ± 0.9 cm; stand-to-sit: 2.7 ± 0.9 cm), especially when sitting down.

This explains older fallers' greater number of differences between stand-to-sit and sit-to-stand (ie, duration, joint ROM) compared with nonfallers and suggests that stand-to-sit is a relatively more difficult action for older people at risk of falling; this movement may entail a relatively high probability of falling. Additionally, stand-to-sit requires more vertical control of the COM motion compared with sit-to-stand.[34,35] In summary, when fall prevention training for older people is designed in the future, more attention should be paid to the stability of the frontal plane.

This study contributes to understanding of the factors that make sit-to-stand and stand-to-sit movements difficult for older adults on the basis of an in-depth exploration of how the joints coordinate to complete the sit-to-stand and stand-to-sit movements and the extent of COM motion. This study established the biomechanical parameters that distinguish older fallers from older nonfallers when performing sit-to-stand and stand-to-sit. Our main results also show that the difference in the COM motion in the ML directions and the seemingly opposite movement of sit-to-stand and stand-to-sit are still more unstable in older faller. The differences reported between older fallers and older nonfallers could be explained by a different motion strategy when performing sit-to-stand and stand-to-sit. This knowledge can give clinicians more parameters to study the strategic motion of older fallers.

Study Limitations

Our study only included healthy older men and older men who had fallen once in the past year as participants. The participant group lacked older female participants. The results may not be generalizable to this subset of older adults.

Conclusions

This study revealed many differences in the performance of sit-to-stand and stand-to-sit movements among healthy older adults and fallers, regardless of the elapsed time, joint ROM, and COM trajectory. The 2 movements cannot be defined as purely opposite movements. Older fallers exhibited more motion of the COM of the frontal plane during the sit-to-stand and stand-to-sit movements than did nonfallers. The strategy of flexing the trunk, hip, and knee joints more was used to compensate for the lack of muscle strength in the lower limbs to maintain the ideal posture control achieve of the action. Older fallers may find stand-to-sit movement more challenging. This knowledge can give clinicians more parameters to study the strategic motion of older faller.

Suppliers

a.
b. VICON camera.
c. MATLAB.
d. Visual 3D.

Corresponding author

Heng-Ju Lee, PhD, Department of Physical Education and Sport Sciences, National Taiwan Normal University, No. 88, Sec. 4, Tingchou Rd., Wunshan Dist., Taipei City 11677, Taiwan. *E-mail address:* hjlee@ntnu.edu.tw.

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List of abbreviations: AP, anteroposterior; BOS, base of support; COM, center of mass; ML, mediolateral; POMA, Tinetti Performance-Oriented Mobility Assessment; ROM, range of motion.
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Table 1 POMA score of older nonfallers and older fallers

	Nonfallers		Older Fallers	
POMA score	NF 1	26	OF 11	19
	NF 2	27	OF 12	14
	NF 3	27	OF 13	19
	NF 4	27	OF 14	18
	NF 5	25	OF 15	18
	NF 6	26	OF 16	15
	NF 7	26	OF 17	20
	NF 8	22	OF 18	15
	NF 9	28	OF 19	19
	NF 10	25	OF 20	20

Abbreviations: NF, nonfaller; OF, older faller.

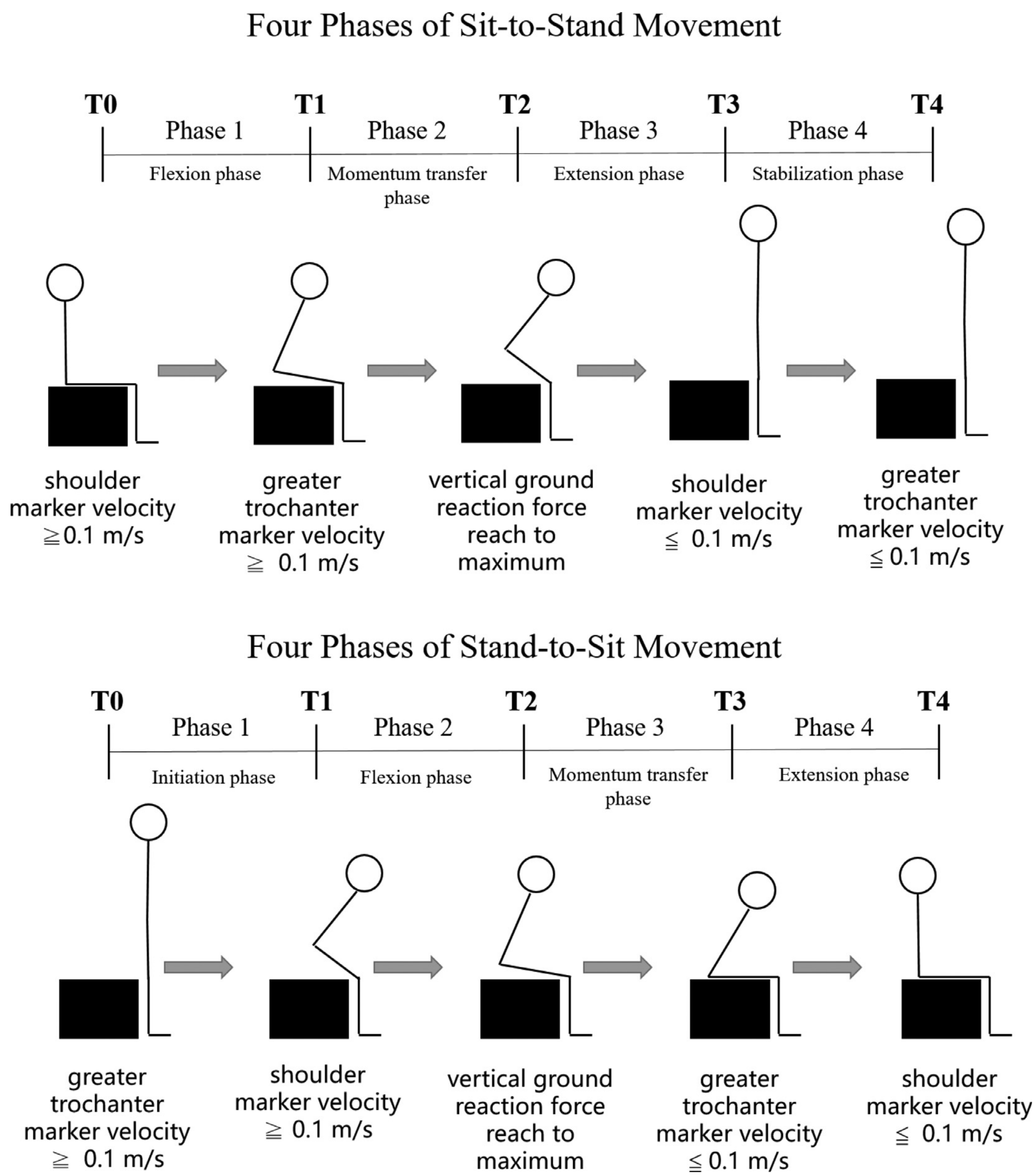

Fig 1 Sit-to-stand and stand-to-sit movement phases.

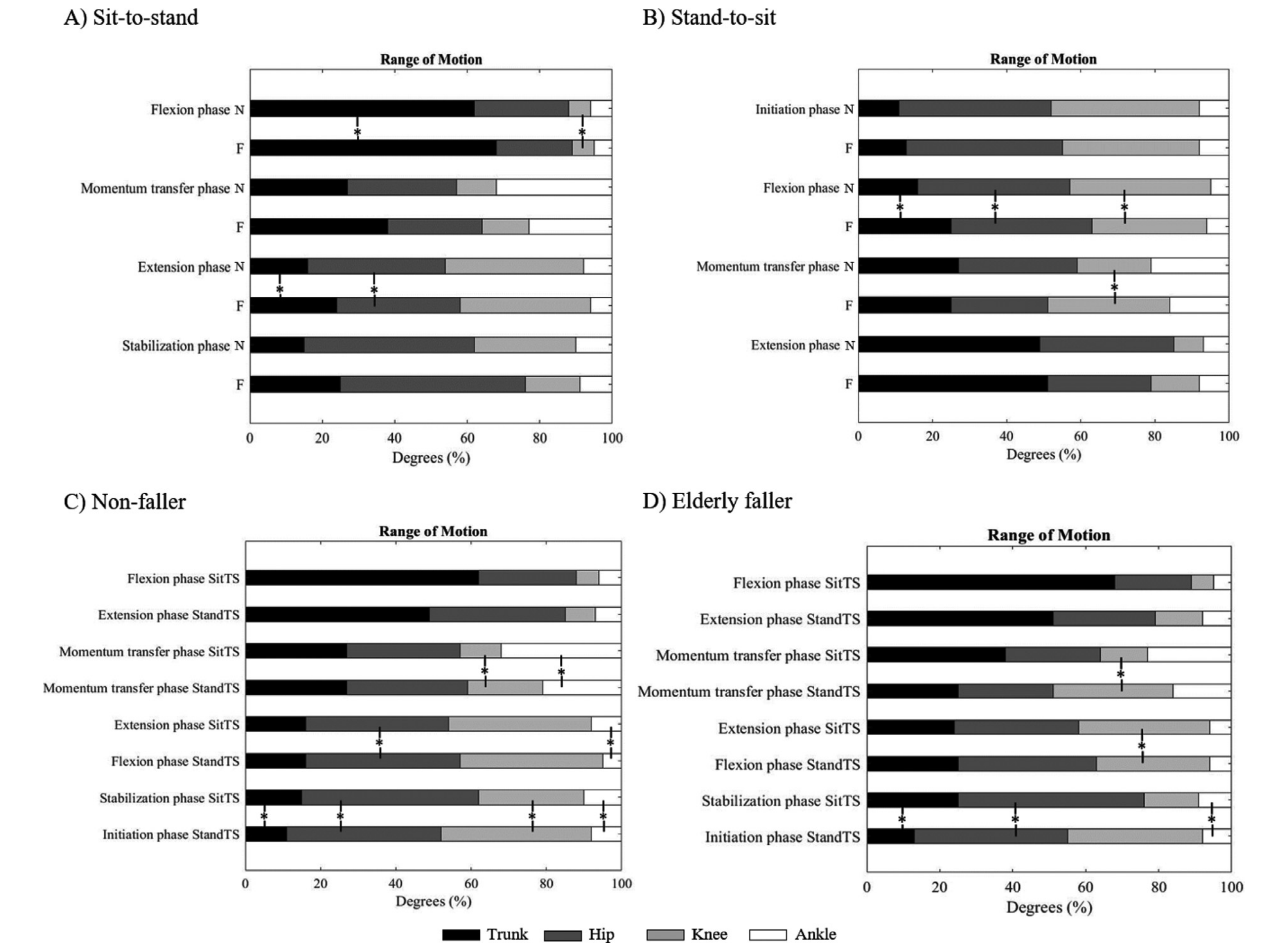

Fig 2 Percentages of each joints' ROM in the 4 phases of sit-to-stand and stand-to-sit movements, classified as **(A)** nonfallers and older fallers during sit-to-stand, **(B)** nonfallers and older fallers during stand-to-sit, **(C)** sit-to-stand and stand-to-sit in nonfallers, and **(D)** sit-to-stand and stand-to-sit in older fallers. F, older faller; N, nonfaller; SitTS, sit-to-stand; StandTS, stand-to-sit. *Statistically significant difference in joint ROM (*P*<.05).

Table 2 Duration of sit-to-stand and stand-to-sit movements in older nonfallers and older fallers

		Mean ± SD			
		Sit-to-Stand		Stand-to-Sit	*P*
Nonfallers (n=10)	Duration time (s)	1.7±0.3		2.0±0.5	.139
	Flexion phase (%)	19±4.0	Extension phase	27±16.4	.169
	Momentum transfer phase	22±4.2	Momentum transfer phase	27±9.1	.106
	Extension phase	50±6.4	Flexion phase	44±10.0	.059
	Stabilization phase	9±2.8	Initiation phase	3±1.7	<.001*
Older fallers (n=10)	Duration (s)	1.9±0.4		2.4±0.7	.030*
	Flexion phase (%)	19±1.1	Extension phase	29±16.0	.100
	Momentum transfer phase	22±7.1	Momentum transfer phase	33±13.7	.080
	Extension phase	48±8.2	Flexion phase	36±7.7	.010*
	Stabilization phase	11±3.8	Initiation phase	3±2.1	<.001*

NOTES. Data are mean±SD.
* Statistically significant difference (*P*<.05).

Table 3 Trunk, hip, knee, and ankle ROM in each phase during sit-to-stand and stand-to-sit movements in older nonfallers and older fallers

ROM (°)			Group/Movements (Mean±SD)						
			Nonfallers (n=10)		Paired Sample *t* Test	Older Fallers (n=10)		Paired Sample *t* Test	Independent Sample *t* Test
			Sit-to-Stand	Stand-to-Sit	*P*	Sit-to-Stand	Stand-to-Sit	*P*	*P*
Trunk	P1 flexion phase	(sit-to-stand)	9.8±3.9	8.8±3.3	.455	15.6±6.8	15.2±9.5	.906	.033*
	P4 extension phase	(stand-to-sit)							.071
	P2 momentum transfer phase	(sit-to-stand)	9.2±4.8	9.6±4.1	.823	14.3±6.4	13.8±6.1	.873	.057
	P3 momentum transfer phase	(stand-to-sit)							.085
	P3 extension phase	(sit-to-stand)	30.5±6.9	29.4±3.6	.409	43.4±9.4	43.0±9.7	.887	.003*
	P2 flexion phase	(stand-to-sit)							.001†
	P4 stabilization phase	(sit-to-stand)	1.6±0.7	0.5±0.3	.002‡	2.9±2.5	0.5±0.4	.009§	.146
	P1 initiation phase	(stand-to-sit)							.888
Hip	P1 flexion phase	(sit-to-stand)	4.1±1.9	6.5±3.2	.081	4.6±2.4	8.1±5.7	.102	.597
	P4 extension phase	(stand-to-sit)							.454
	P2 momentum transfer phase	(sit-to-stand)	10.1±7.5	11.4±4.8	.566	9.7±6.0	14.3±8.9	.183	.881
	P3 momentum transfer phase	(stand-to-sit)							.368
	P3 extension phase	(sit-to-stand)	72.6±11	76.3±11	.008‡	62.1±7.1	65.3±9.7	.460	.020*
	P2 flexion phase	(stand-to-sit)							.032†
	P4 stabilization phase	(sit-to-stand)	5.3±3.1	1.8±1.5	.018‡	6.0±3.7	1.6±1.6	.008§	.670
	P1 initiation phase	(stand-to-sit)							.817
Knee	P1 flexion phase	(sit-to-stand)	1.0±0.3	1.5±1.1	.180	1.4±0.5	3.9±5.1	.152	.015*
	P4 extension phase	(stand-to-sit)							.164
	P2 momentum transfer phase	(sit-to-stand)	3.7±1.1	7.3±2.5	.002‡	4.7±1.9	4.7±1.9	.006§	.147
	P3 momentum transfer phase	(stand-to-sit)							.010†
	P3 extension phase	(sit-to-stand)	71.8±9.1	71±8	.483	66±9.9	53.6±6.3	.021§	.184
	P2 flexion phase	(stand-to-sit)							>.001†
	P4 stabilization phase	(sit-to-stand)	3.2±1.4	3.2±1.4	.031‡	1.8±1.7	1.4±1.6	.696	.056
	P1 initiation phase	(stand-to-sit)							.678
Ankle	P1 flexion phase	(sit-to-stand)	0.9±0.3	1.3±0.6	.174	1.2±0.8	2.4±2.2	.161	.317
	P4 extension phase	(stand-to-sit)							.147
	P2 momentum transfer phase	(sit-to-stand)	11±4.9	7.4±2.0	.017‡	8.6±2.4	9.3±5.5	.682	.182
	P3 momentum transfer phase	(stand-to-sit)							.313
	P3 extension phase	(sit-to-stand)	15±6.1	10.4±3.6	.010‡	12±3.7	10.1±3.2	.125	.212
	P2 flexion phase	(stand-to-sit)							.825
	P4 stabilization phase	(sit-to-stand)	1.1±0.6	0.4±0.3	.014‡	1.0±0.7	0.3±0.3	.037§	.708
	P1 initiation phase	(stand-to-sit)							.831

NOTE. P1, P2, P3, P4 represent phases 1, 2, 3, and 4.

* Significant difference between nonfallers and older fallers during sit-to-stand (*P*<.05).

† Significant difference between nonfallers and older fallers during stand-to-sit (*P*<.05).

‡ Significant difference between nonfallers' sit-to-stand and stand-to-sit (*P*<.05).

§ Significant difference between older fallers' sit-to-stand and stand-to-sit (*P*<.05).

Table 4 COM trajectory of sit-to-stand and stand-to-sit movements in older nonfallers and older fallers

COM trajectory (cm)	Group/Movements (Mean±SD)						
	Nonfallers (n=10)		Paired Sample *t* Test	Older Fallers (n=10)		Paired Sample *t* Test	Independent Sample *t* Test
	Sit-to-Stand	Stand-to-Sit	*P*	Sit-to-Stand	Stand-to-Sit	*P*	*P*
ML direction total motion distance	1.9±0.9	2.7±0.9	.006[‡]	3.2±0.7	4.6±1.1	.061	.003[*] .012[†]
AP direction total motion distance	30.4±5	30.8±5.5	.860	33.3±2.5	31.3±6.1	.193	.104 .819

[*] Significant difference between nonfallers and older fallers during sit-to-stand ($P<.05$).
[†] Significant difference between nonfallers and older fallers during stand-to-sit ($P<.05$).
[‡] Significant difference between nonfallers' sit-to-stand and stand-to-sit ($P<.05$).