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Original Article

Effect of controlled start position on the reach distance distribution range in the functional reach test among community-dwelling older adults

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Abstract. [Purpose] This study investigated the effect of controlled start position (CSP) on the reach distance distribution range (RDDR) in the functional reach test (FRT) in community-dwelling older adults. [Participants and Methods] The participants were 34 community-dwelling older adults. We compared the RDDR in CSP and non-CSP and analyzed the relationship between the mean reach distance (MRD) and the length of movement of the center of pressure (LMCOP). [Results] The RDDR in CSP condition was significantly lower than non-CSP condition. A significant positive correlation was observed only for CSP condition. In the non-CSP condition, MRD was not reflected in the LMCOP. [Conclusion] The FRT in the CSP effectively reflects the standing balance ability of community-dwelling older adults.
Key words: Functional reach test, Controlled start position, Community-dwelling older adults

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INTRODUCTION

Older adults are at an increased risk of falling due to age-related declines in their standing balance ability (SBA)[1, 2]. Falls among older adults have a significant socioeconomic impact, such as increased medical costs and demand for nursing care[3, 4]. Therefore, accurately assessing SBA in older adults and preventing falls are essential socioeconomic issues.

In Japan, the functional reach test (FRT) has been used to evaluate SBA in older adults[5–7]. Mitani et al.[8] reported a positive correlation between the reach distance and the length of movement of the center of pressure (LMCOP), and the FRT is considered a valid tool for evaluating the stability limits[9]. Furthermore, the FRT is associated with reach distance and the risk of falling[10, 11], and a cutoff value of approximately 6 inches (15.2 cm) to identify individuals at high risk of falling in previous studies in Western populations[10]. These findings suggest that the FRT is useful as a method to assess SBA in older adults.

Despite the positive aspects mentioned above, some negative views on the relationship between reach distance measured by the FRT and SBA have been reported[12–14]. Maeoka et al.[12] reported no correlation between the reach distance and LMCOP. Wallmann et al.[13] reported similar reach distances for fallers and non-fallers and they emphasized that the reach distance in the FRT cannot serve as a reliable balance index[12, 13]. Omaña et al.[14] also reported that predicting falls in older

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adults undergoing the FRT is difficult. Consequently, results have been inconsistent regarding the relationship between reach distance and SBA in older adults. One reason for the lack of consistent results may be that the start position in the FRT is typically not well controlled[15–17]. Duncan et al.[18] reported that only the foot position was controlled as the start position in the FRT. Older adults tend to develop a thoracic kyphosis posture as they age[19–21], and this postural change has been reported to increase their center of gravity (COG) sway due to their inability to hold their COG in a fixed position while keeping a standing position[22, 23]. Furthermore, Nishimura et al.[17] reported that the start position differed from one execution to another because of body sway, resulting in an error in the reach distance measurement when only the feet were controlled. Therefore, in FRT assessments of older adults, the start position tends to fluctuate from one session to another, particularly in postural changes such as thoracic kyphosis. As a result, the measured reach distance fluctuates, making it difficult to calculate accurate reach distance measurements. Therefore, using conventional FRT cutoff values, SBA is difficult to assess in older adults.

In the FRT of young adults, it has been reported that the reach distance distribution range (RDDR) was reduced when the controlled area other than the foot was used as the start position[16, 17]. Therefore, even in the FRTs of older adults, controlling a position other than the foot as the start position may minimize the increase in COG sway associated with a thoracic kyphosis posture. Controlling the start position, in turn, would enable a more accurate measurement of the reach distance by reducing the RDDR. Therefore, the validity of the FRT must be analyzed with a controlled start position (CSP)[17] in older adults, especially considering the inconsistent results regarding conventional FRT measurement methods in relation to standing stability.

This study investigated the effects of CSP on RDDR during the FRT in older adults. The hypotheses of this study were as follows: (1) The CSP condition will show reduced RDDR compared to non-CSP condition in the FRT; (2) Under the CSP condition, FRT is associated with the mean reach distance (MRD) and LMCOP in the anterior-posterior direction; and (3) In the CSP condition, FRT is not related to the RDDR or degree of thoracic kyphosis, whereas non-CSP is.

PARTICIPANTS AND METHODS

The number of participants was set using G*Power (Heinrich Heine University, Düsseldorf, Germany, G*Power 3.1.9.2) with a power of 0.8, an effect size of 0.5, and a significance level of 0.05. Consequently, the minimum number of participants required was 34. The eligibility criteria were as follows: (1) participants aged 65 years or older who were able to walk independently and perform activities of daily living independently; (2) participants who did not have orthopedic or neurological diseases of the hip joint or lumbar region; (3) participants who could raise both upper limbs more than 90°; and (4) participants who scored 21 or higher on the Hasegawa's Dementia Scale-Revised (HDS-R)[24] and had no cognitive decline. Those who failed to meet any of the above criteria were excluded. Forty-seven individuals were willing to participate; however, as 13 did not meet the eligibility criteria, the final sample comprised 34 participants. The participants' age and height (mean ± standard deviation) were 72.0 ± 6.2 years and 158.0 ± 9.5 cm, respectively. This study was approved by the Kanazawa University Medical Ethics Review Committee (Approval No.: 111088-1).

The flow of this study was as follows: Measurement 1, followed by Measurement 2 on different days. Measurement 1 included the length of both upper limbs, angle of elbow extension, hip flexion, knee extension, and degree of thoracic kyphosis. The upper limb length was defined as the distance from the acromial process to the processus styloideus radii. In the supine position, elbow extension, hip flexion, and knee extension angles were measured using a goniometer (plastic angle meter, ÖSSUR, Japan G.K., Tokyo, Japan). The degree of the thoracic kyphosis angle was calculated using the Flexicurve index (FI) (Fig. 1)[19]. The participants were instructed to maintain a resting standing position as straight as possible to measure the degree of thoracic kyphosis. The examiner placed a free-form curve ruler (Shinwa Sokutei Co. Ltd., Niigata, Japan) between the seventh cervical vertebra, fifth lumbar vertebra, and first sacral vertebra and traced the curve. Thoracic kyphosis measurements were performed three times for each participant.

In Measurement 2, the FRT was performed under two conditions: CSP and non-CSP. Reflex markers were affixed to the participants' right acromial process (one marker in the resting standing position and another one at 90° flection of the upper limbs), great trochanter, processus styloideus ulnae, and third metacarpal head before the anterior reach measurement[17].

Measurement 2 was performed using a force plate (WA1001, WAMI, Tokyo, Japan) to measure the COP position (Fig. 2)[17]. A string with an attached weight was placed on the right lateral side of the participant as a vertical line through the malleolus lateralis. A laser projector (GT2i, TAJIMA, Tokyo, Japan) was placed behind the participant and a horizontal line was projected through the right acromial process during the upper limb drop in the resting upright posture to maintain constant elevation of the upper limb[17]. Two digital cameras (SP-100EE, OLYMPUS, Tokyo, Japan) were positioned 10 m to the right to capture the participant's acromial process, great trochanter, and third metacarpal head movements[17]. Camera A was positioned such that the participant's acromial process and great trochanter positions were captured at the top and bottom of the center of the screen, respectively, and the height of the camera was adjusted for each participant[17]. Camera A zoom function was set to 6.1 times. Camera B captured the participant in a reaching posture, and the lens height was set to the height at which the participant's right third metacarpal head appeared at the center of the screen[17]. Camera B-zoom function was set to 4.9 times.

The procedure for Measurement 2 was adapted from Nishimura et al[17]. The participants flexed both shoulder joints at 90° and held this posture for 5 s. The posture was photographed, and the position of the COP was measured[17]. In the CSP condition, the participants started the forward reach task while their right acromial process was aligned with the vertical line through the right malleolus lateralis (Fig. 3a). The participant reached forward and held the posture at maximum forward reach for 5 s. The posture was photographed, and the position of the COP was measured[17].

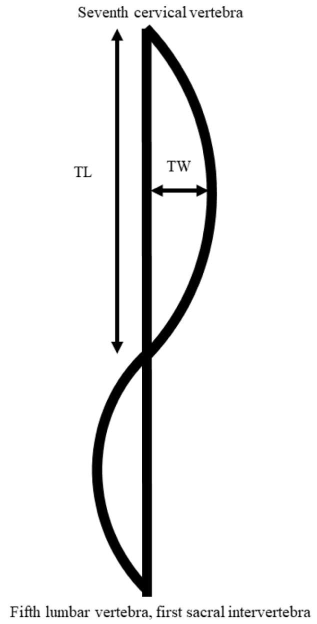

Fig. 1. Flexicurve index calculation methods.
TW: thoracic width (distance from the straight line connecting the seventh cervical vertebra to the fifth lumbar vertebra and the first sacral vertebra to the most distended position of the thoracic vertebra); TL: thoracic length (distance to the point where the traced curve intersects the straight line connecting the seventh cervical vertebra with the fifth lumbar and first sacral vertebrae). Flexicurve index (FI): TW/TL×100.

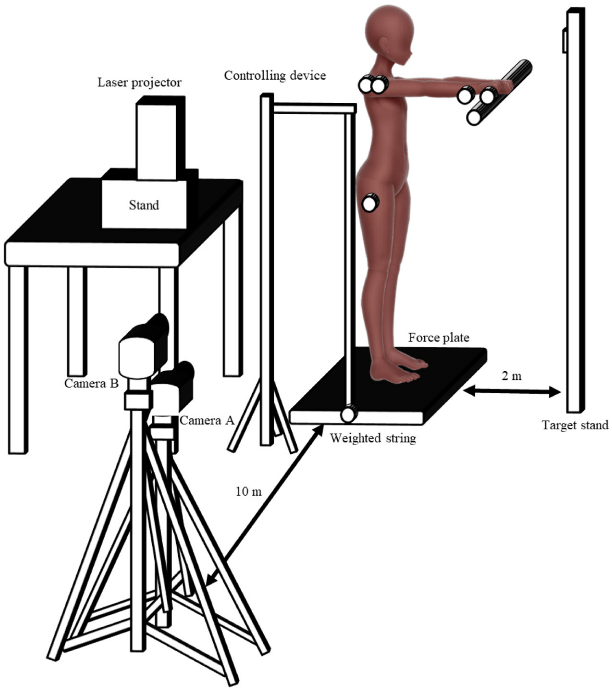

Fig. 2. Measurement environment.
Laser projector: The projector illuminates a horizontal line through the right acromial process (in a resting standing position). Plumb-line: Vertical line through the right malleolus lateralis.

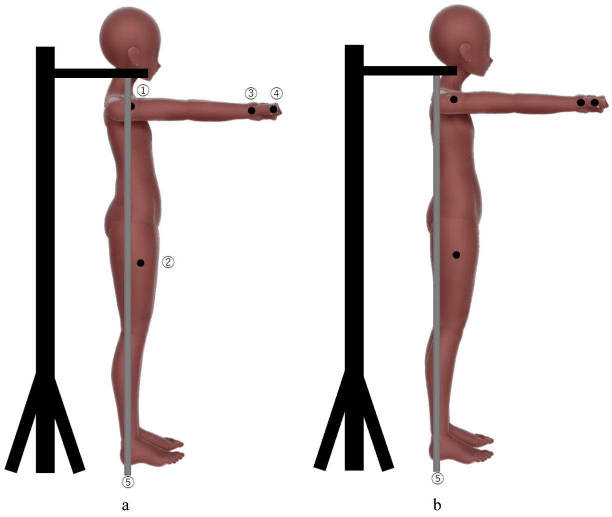

Fig. 3. Method for controlling the start position.
a: Controlled start position (the right acromial process position is controlled on a vertical line through the right malleolus lateralis); b: Non-controlled start position (the right acromial process position was not controlled).
1. Right acromial process position at 90° flection of the right upper limb; 2. Right great trochanter position; 3. Right processus styloideus ulnae; 4. Right third metacarpal head; 5. Vertical line through the right malleolus lateralis.

In a pilot study, we examined which of three CSP conditions (controlled acromial process, controlled great trochanter, and controlled acromial process and great trochanter) could be performed correctly in five community-dwelling older adults. The results revealed that all participants had difficulties in the controlled great trochanter position (solely) and the controlled acromial process and great trochanter positions. In this preliminary test, all participants could control the start position of their acromial process. Therefore, in this study, a controlled acromial process was adopted, in addition to the foot position as the starting position. There was no restriction on the initial position of the acromial process in the non-CSP condition (Fig. 3b). The participant reached forward and held the posture at maximum forward reach for 5 s. The posture was photographed, and the position of the COP was measured[17]. This series of movements was considered one trial, and six trials were conducted, with three trials per condition. No motor strategy for forward reaching was instructed, and the participants were instructed to reach as far forward as possible. The order of the two conditions was random for each participant.

All photographs were analyzed using ImageJ[25] image analysis software. Before the start of this study, a 30-cm ruler was placed horizontally at the center and edge of the camera lens to verify the accuracy of ImageJ, and the ruler's length was verified. When analyzed in Image J, the length of the horizontal ruler at the edge of the camera lens was 29.5 cm, based on a 30 cm ruler at the center of the camera lens. Consequently, care was taken to ensure that the target area was in the center of the camera lens to minimize errors.

The positions of the right acromial process and the great trochanter at the start position were calculated using the distance between the vertical line through the right malleolus lateralis and the target location (Fig. 4)[17]. The start position and anteroposterior COP position at maximum forward reach were monitored using a digital storage scope (DS-8607, IWATSU ELECTRIC Co., Ltd., Tokyo, Japan) and averaged over a 5-s period. COP position was defined relative to the heel point (%FL)[17]. Meanwhile, the reach distance was defined as the distance difference between the vertical line through the right malleolus lateralis and the third metacarpal head at the maximum forward position and at the start position of the FRT (Fig. 4)[17].

In both conditions, the right acromial process distribution range (ADR), great trochanter distribution range (GTDR), COP position distribution range (COPDR) in the start position, and RDDR were defined as the differences between the most anterior and posterior positions in the individual's three trials[16, 17].

The LMCOP was calculated by subtracting the COP position at the start of the FRT in the standing position from the COP position at the point of maximum reach. Additionally, ADR, GTDR, and reach distance were normalized according to the length of the right upper limb. The MRD and mean LMCOP for the three trials under each condition were calculated.

The FI was calculated by dividing the thoracic width (distance from the straight line connecting the seventh cervical vertebra to the fifth lumbar vertebra and the first sacral vertebra to the most distended position of the thoracic vertebra position) by the thoracic length (distance to the point where the curve traced intersects the straight line connecting the seventh cervical vertebra with the fifth lumbar vertebra and the first sacral vertebra). The results were then multiplied by 100[19]. The FI values were measured three times for each participant, and the average of the three measurements was used as the representative value.

Statistical analyses were performed using EZR (Easy R, Saitama Medical Center, Jichi Medical University, Saitama, Japan)[26]. The ADR, GTDR, and COPDR in the start position were compared between conditions using paired t-tests, and to compare the RDDR, MRD, and LMCOP in both conditions. The relationships between the upper limb length and height, normalized MRD and LMCOP, and RDDR and FI were analyzed using Pearson's correlation coefficients for each condition. The significance level was set at 5%.

RESULTS

Participants' general characteristics are presented in Table 1. No significant differences in length were observed between the right and left upper limbs. Furthermore, there were no significant limitations in the range of motion of the hip or knee joints. The correlation coefficient between the right upper limb length and height was 0.92, indicating a significant positive correlation.

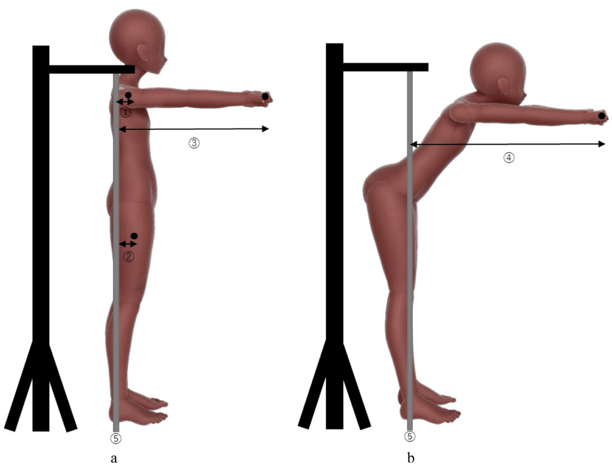

Fig. 4. Calculation of the right acromial process and great trochanter positions for the start position and forward reach distance.
a: Start position; b: Maximum forward reach. The maximum forward reach distance was obtained by 4 − 3.
1. Distance between the vertical line through the malleolus lateralis in the start position and the right acromial process position at 90°flection of the right upper limb; 2. Distance between the vertical line through the malleolus lateralis in the start position and the great trochanter position at 90° flection of the right upper limb; 3. Distance between the vertical line through the malleolus lateralis in the start position and the right third metacarpal head position at 90° flection of the right upper limb; 4. Distance between the vertical line through the malleolus lateralis in the start position and the right third metacarpal head position at maximum forward reach; 5. Vertical line through the malleolus lateralis.

Table 1. General characteristics of the participants

Evaluation item	Value
Age (years)	72.0 ± 6.2
Height (cm)	158.0 ± 9.5
Weight (kg)	62.0 ± 10.8
Gender (Male n/ Female n)	12 / 22
Right upper limb length (cm)	50.0 ± 3.1
Left upper limb length (cm)	50.0 ± 3.1
Right elbow extension angle (°)	0 ± 0
Left elbow extension angle (°)	0 ± 0
Right hip flexion angle (°)	107.6 ± 9.0
Left hip flexion angle (°)	107.8 ± 8.9
Right knee extension angle (°)	0 ± 0
Left knee extension angle (°)	0 ± 0
FI	9.9 ± 3.1

Values are expressed as mean ± standard deviations.
Upper limb length: distance from the acromial process to the processus styloideus radii; FI: flexicurve index (Fig. 1).

Table 2 presents the ADR, GTDR, and COPDR for the start position under both conditions as well as the RDDR, MRD, and LMCOP. The ADR, COPDR, and RDDR were significantly lower in the CSP condition than in the non-CSP condition (non-normalized values for ADR: t=7.2, p<0.05; normalized values for ADR: t=7.2, p<0.05; COPDR: t=3.1, p<0.05; non-normalized values for RDDR: t=8.7, p<0.05; normalized values for RDDR: t=8.7, p<0.05). Conversely, the LMCOP in the CSP condition was significantly greater than in the non-CSP condition (t=−3.5, p<0.05). Notably, the GTDR and MRD values did not significantly differ between the conditions (non-normalized value for GTDR: t=−1.1, p>0.05, normalized value for GTDR: t=−0.8, p>0.05; non-normalized value for MRD: t=−1.2, p>0.05, normalized value for MRD: t=−1.2, p>0.05).

The correlations between the normalized MRD and the LMCOP under both conditions are listed in Table 3. The correlation between normalized MRD and LMCOP in FRT showed a significant positive correlation in the CSP condition (r=0.51, p<0.05). However, no correlation was observed between normalized MRD and LMCOP in the non-CSP condition (r=0.27, p>0.05).

The correlations between the normalized RDDR and the FI under both conditions are presented in Table 4. In the CSP condition, there was no significant correlation between RDDR and FI (r=0.21, p>0.05). RDDR and FI were positively correlated in the non-CSP condition (r=0.42, p<0.05).

Table 2. Comparison of the ADR, GTDR, COPDR, RDDR, MRD, and LMCOP under the CSP and non-CSP conditions

	CSP condition	Non-CSP condition
ADR (cm)	1.0 ± 0.7*	3.4 ± 2.0
ADR (%)	2.0 ± 1.3*	6.9 ± 4.0
GTDR (cm)	1.7 ± 1.0	1.5 ± 0.6
GTDR (%)	3.3 ± 2.0	3.0 ± 1.2
COPDR (%FL)	3.3 ± 2.8*	6.1 ± 4.2
RDDR (cm)	1.1 ± 0.6*	5.3 ± 2.9
RDDR (%)	2.2 ± 1.2*	10.6 ± 5.8
MRD (cm)	25.6 ± 5.0	24.8 ± 6.2
MRD (%)	51.4 ± 10.2	49.8 ± 12.9
LMCOP (%FL)	19.9 ± 14.4*	12.9 ± 10.2

Values are expressed as mean ± standard deviations.
Distribution range (DR): Difference between the most anterior and posterior positions; COP: center of pressure; MRD: mean reach distance; LMCOP: length of movement of the center of pressure; ADR: acromial process distribution range; GTDR: great trochanter distribution range; COPDR: center of pressure distribution range; RDDR: reach distance distribution range; CSP: controlled start position; APDR, GTDR, RDDR, and MRD (%): Relative distance in relation to right upper limb length; COP (%FL): Relative distance from the hindmost point of the heel in relation to foot length (FL).
*Significant difference compared to the non-CSP condition (p<0.05).

Table 3. Correlation between the MRD and LMCOP in the CSP and non-CSP conditions

	LMCOP in the anteroposterior direction (%FL)
MRD in the CSP condition (%)	r=0.51*
MRD in the non-CSP condition (%)	r=0.27

MRD: mean reach distance; MRD (%): Relative distance in relation to right upper limb length; CSP: controlled start position; COP: center of pressure; LMCOP: length of movement of the center of pressure; COP (%FL): Relative distance from the hindmost point of the heel in relation to foot length (FL).
*Significant correlation was observed between MRD and LMCOP in the CSP condition (p<0.05).

Table 4. Correlation between RDDR and FI in the CSP and non-CSP conditions

	FI
RDDR in the CSP condition (%)	r=0.21
RDDR in the non-CSP condition (%)	r=0.42*

RDDR: reach distance distribution range; RDDR (%): relative distance in relation to the right upper limb length; CSP: controlled start position; FI: flexicurve index.
*Significant correlation was observed between RDDR and FI in the non-CSP condition (p<0.05).

DISCUSSION

This study aimed to investigate the effect of a CSP on the RDDR in the FRT in older adults. The results of this study supported all three initial hypotheses. The hypotheses of this study were as follows: (1) The CSP condition will show reduced RDDR compared to non-CSP condition in the FRT; (2) Under the CSP condition, FRT is associated with the MRD and LMCOP in the anterior-posterior direction; and (3) In the CSP condition, FRT is not related to the RDDR or degree of thoracic kyphosis, whereas non-CSP is.

In this study, RDDR was reduced compared to the conventional FRT method by controlling the initial position of the right acromial process in the CSP of the FRT. When maintaining a standing posture, the body sway in the sagittal plane is greater than that in the frontal plane[27], and the standing posture control in older adults tends to have hip strategy dominance compared to younger adults[28]. Therefore, the COG position could be maintained at a constant level in older adults by performing postural control centered on the hip motion, even when the position of the great trochanter, which is located close to the hip joint, is not controlled. On the other hand, in the acromial process position, segmental movements of the upper thoracic vertebrae have been reported to be associated with the control of body movements in the sagittal plane in the upright posture[29]. In older adults, the range of COG displacement during standing is increased due to postural changes to a thoracic kyphosis posture[22, 23]. Thus, the segmental control of the upper thoracic vertebrae in the upright posture becomes difficult in older adults owing to increased thoracic kyphosis, leading to difficulty in controlling COG sway. We believe that the present study, which controlled the starting position as the acromial process positioned close to the upper thoracic vertebra, made it easier to maintain a consistent COG position even with limited segmental movement of the upper thoracic vertebra. This regulation led to a reduction in the distribution range, similar in magnitude to the findings reported in a previous study[16] that controlled the acromial process and great trochanter positions. Consequently, the start position for each forward reach movement was kept constant, and the RDDR was considered to have decreased. These results indicated that the measurement error of the reach distance was reduced when controlling the shoulder position with respect to the malleolus lateralis in the FRT, resulting in a smaller distribution range of the start position.

Although there was no significant difference in the MRD between the conditions, the RDDR in the CSP was significantly smaller than that in the non-CSP. The results of this study showed a difference of approximately 4 cm in RDDR between the two conditions, and since previous studies have also reported an RDDR of approximately 2.5 cm in FRT with only foot position control[15], the RDDR is likely to be larger in conventional FRT. Thus, relying solely on the MRD value may lead to a misinterpretation of the cutoff value for discriminating fall risk in older adults. Consequently, it appears that a more rational approach for assessing fall risk would involve controlling the start position in the FRT, using the acromial position in addition to the foot position, and considering the MRD under conditions where the RDDR is smaller.

No correlation was found between the MRD and LMCOP in the non-CSP condition. Older adults possess more hip strategy-dominant postural control than that exhibited by younger adults[28]. Additionally, studies have shown that there is no significant correlation between reach distance when using a hip strategy and the extent of COG shift[30]. Moreover, when employing a hip-dominant strategy for forward reach movements, the distance of forward COG displacement decreases, whereas the reach distance increases[31]. Therefore, the FRT in the non-CSP condition was likely performed with little anterior movement of the COP during the forward reach due to backward movement of the buttocks and hip flexion.

In contrast to the abovementioned results of previous studies, a significant positive correlation was found between the MRD and LMCOP under the CSP condition. Hip strategies in the FRT in older adults include reaching movements with small hip flexion movements and large hip flexion movements[9]. Reaching movements with small hip flexion movements have been reported to show a positive correlation between the MRD and LMCOP[9]. The results of this study showed that the COPDR in the CSP condition was significantly smaller and the LMCOP in the CSP condition was significantly greater than those in the non-CSP condition. Because the distance of voluntary forward COG movement in the standing position is considered to be more strongly related to ankle joint movement than it is to hip joint movement[30], the CSP condition might have been able to hold the start position in a constant position. This, in turn, might have facilitated forward COG movement with the ankle joint as the axis and enabled reaching with minimal hip flexion, which is a characteristic of the hip strategy. Hence, the CSP was assumed to be positively correlated with the MRD and LMCOP. However, this study did not conduct a motion analysis of movement strategy. Therefore, the characteristics of movement strategies under both conditions are unknown. Consequently, the characteristics of movement strategy during forward reach in both CSP and non-CSP conditions must be examined in the future.

FI, an index of the degree of thoracic kyphosis, exhibited a significant positive correlation with RDDR in the non-CSP condition. Changes in the spine, such as thoracic kyphosis in older adults, have been reported to increase COG sway while maintaining a standing position[22, 23]. In this study, the ADR and COPDR were significantly higher in the non-CSP condition than in the CSP condition. Therefore, in the non-CSP condition, the start position might have differed for each forward reach owing to changes in the spine of older adults, leading to an increase in RDDR. However, no correlation was found between the FI and RDDR in the CSP condition. This suggests that the degree of thoracic kyphosis does not affect the RDDR when the start position is controlled. Therefore, it can be assumed that the method used in this study to control the start position reduced the RDDR, regardless of the degree of thoracic kyphosis. Consequently, the results of this study suggest that it is necessary to control the start position when assessing SBA using the FRT in older adults.

This study has two limitations. First, the participants were mainly those whose spinal columns were not deformed by thoracic kyphosis. The definition of thoracic kyphosis is defined as an FI of 13 or more[19]; moreover, individuals with thoracic kyphosis reportedly have a higher risk of falling than that observed in individuals without thoracic kyphosis[32]. In this study, most participants had an FI of 9.9 ± 3.1 and no spinal deformities (Table 1). Therefore, it is necessary to verify whether the RDDR can be reduced by controlling the start position in patients with thoracic kyphosis who are at a high risk of falling. Second, this study did not examine movement strategies during forward reaching. Therefore, the movement strategies must be compared in both conditions to clarify the distinctive features of these strategies in different contexts.

In conclusion, this study examined the effects of CSP on RDDR during the FRT in community-dwelling older adults. CSP effectively decreased the RDDR, and the MRD significantly correlated with the LMCOP. In the future, the influence of CSPs on RDDRs and whether movement strategies differ between CSP and non-CSP conditions in older adults with thoracic kyphosis should be examined.

Conflict of interest

None.

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