Abstract. [Purpose] This study aimed to clarify whether the distribution range of the forward reach distance and the relationship between the forward reach distance and movement distance of the center of pressure differed depending on whether the controlled starting standing position during the functional reach test with an ankle joint strategy. [Participants and Methods] Sixteen healthy male volunteers participated in the study. The distribution range of the forward reach distance and the relationship between the forward reach distance and movement distance of the center of pressure in the controlled starting standing position and non-controlled starting standing position conditions were analyzed. [Results] The distribution range of the forward reach distance was significantly smaller in the controlled starting standing position than in the non-controlled starting standing position. In both groups, the forward reach distance was associated with the movement distance of the center of pressure. [Conclusion] The findings suggested that the use of an ankle joint strategy with a controlled starting standing position in the functional reach test may be a more accurate method to evaluate standing balance ability.

Key words: Functional reach test, Ankle joint strategy, Standing balance ability

INTRODUCTION

The functional reach test (FRT) is a simple method to measure standing balance ability (SBA), as reported by Duncan et al. In the FRT, Duncan et al. reported a moderate positive correlation between the forward reach distance (FoRD) and the sway trajectory length of the center of pressure (COP). In addition, the movement distance of the COP (MDCOP) has been reported to be associated with SBA, and the FRT has been used as a method to assess SBA. Conversely, Thomas et al. reported no significant difference in the FoRD between fallers and non-fallers. Jonsson et al. pointed out that the FRT is a poor measure of the limits of forward stability because the correlation between the FoRD and the forward movement range of
the COP is low. These studies suggest that there is no consensus on whether the FRT is an appropriate method for assessing SBA.

One of the reasons for this lack of agreement may be that the starting standing position of the whole body including the feet is not well defined in the FRT\(^9\). Dai et al.\(^9\) reported that, in a conventional FRT measurement method without a controlled starting standing position (CSSP), measurement errors in the FoRD are likely to occur because of unconscious body sway and accompanying finger position sway. Nishimura et al.\(^7\) reported that the distribution range of the FoRD (DRFoRD) was reduced by a CSSP in the FRT. These results suggest that a CSSP is an important factor for accurately calculating the FoRD in an FRT. Conversely, it has been reported that there is no correlation between the FoRD and the anteroposterior MDCOP in the forward reach with the hip joint strategy adopted by Duncan et al.\(^13\), regardless of whether the starting standing position was controlled\(^7\). The MDCOP is one of the indicators of the limits of stability in the standing position\(^8\) and has been reported to be related to the SBA\(^3\). In other words, to evaluate SBA using the FRT, in addition to the CSSP, a measuring method is required in which the FoRD reflects the anterior MDCOP. The FoRD and MDCOP are affected by movement strategies\(^9\), and a positive correlation between the FoRD and the center of gravity displacement distance in the ankle joint strategy has been reported\(^10\). Thus, it is speculated that the forward reach using the ankle joint strategy with a CSSP in the FRT may reflect the SBA, as the FoRD is related to the MDCOP. Accordingly, it is important to clarify the effectiveness of the FRT using the ankle joint strategy in a CSSP to examine the conventional FRT measurement method, which has been inconsistently reported in relation to SBA.

Therefore, the purpose of this study was to investigate whether the DRFoRD and the relationship between the FoRD and MDCOP differed depending on whether the starting position of the FRT was controlled with an ankle joint strategy. The hypotheses of this study are as follows: (1) The DRFoRD is smaller in the CSSP condition than in the non-CSSP condition; and (2) there is a stronger relationship between the FoRD and the MDCOP in the anteroposterior direction in the CSSP condition using the ankle joint strategy compared to the non-CSSP condition.

**PARTICIPANTS AND METHODS**

Sixteen healthy male volunteers participated in the study. The eligibility criteria were no orthopedic or neurological disease, and those with previous spine or lower extremity joint surgery were excluded. The mean and standard deviation of the participants’ age and height were 22.4 ± 3.1 years and 171.2 ± 4.6 cm, respectively. All participants gave consent to the experimental procedures approved by the Kanazawa University Medical Ethics Review Committee (Approval No.: 645-1).

The experiment consisted of two measurements, each on a different day. The first measurement (measurement 1) was performed to analyze and define the CSSP of the FRT for each participant. The right acromion position, right greater trochanter position, and trunk tilt angle in the anteroposterior direction in the sagittal plane were measured when the right upper extremity was held in a 90° elevated posture from the quiet standing position. The environment for measurement 1 is shown in Fig. 1. The first measurement was performed on a force plate (WA1001, WAMI, Tokyo, Japan). A laser light projector (EXA-YR21, STS Inc., Nagoya, Japan) was installed on the floor at the right side of the participant, and a perpendicular and vertical line passing through the right lateral malleolus was projected onto the participant. In addition, a laser light projector (GT2i, TAJIMA, Tokyo, Japan) was installed diagonally behind the participant, and a horizontal line passing through the right acromion during the right upper extremity drooping in a quiet standing position was projected to maintain a constant height of right upper extremity elevation. A digital camera (SP-100EE, Olympus, Tokyo, Japan) was placed 15 m to the right side of the participant (camera A). The zoom function of camera A was set to 18.1 times, and the lens height was adjusted for each participant, with the right acromion position, right greater trochanter position, and trunk tilt angle in the measurement start position for each participant measured in measurement 1 were reproduced. The participant’s body was matched to these average positions. In addition, a digital camera (GT2i, TAJIMA, Tokyo, Japan) was set up directly above camera A at a position 15 m to the right of the participant (camera B). The zoom function was set at 14.5, and the lens height was set to the height at which the right head of the third metacarpal of the participant was captured in the center of the screen. A right upper extremity contact device (touch sensor) was placed in front of the participant to reduce body sway due to the light touch effect of less than 1 N\(^11\) (controlling device 2 in Fig. 2a).
Fig. 1. Environment for measurement 1.
Laser light projector 1: Projector illuminating a horizontal line passing through the right acromion (in a quiet standing position).
Laser light projector 2: Projector illuminating a vertical line passing through the right lateral malleolus.

Fig. 2. Environment for CSSP condition (a) and non-CSSP condition (b) during measurement 2.
Laser light projector 1: Projector illuminating a horizontal line passing through the right acromion (in a quiet standing position).
Laser light projector 2: Projector illuminating a vertical line passing through the right lateral malleolus.
Laser light projector 3: Projector to illuminate trunk tilt angle.
Controlling device 1: Controlling device to reproduce the starting position.
Controlling device 2: Touch sensor.
CSSP: Controlled starting standing position.
The touch sensor consisted of a metal plate mounted on a stand (Fig. 3). Strain gauges were attached to the metal plate, and the load was quantified as a voltage value through a strain amplifier (NEC, AS1603, Itami, Japan). The examiner monitored this value to ensure that the participant was always in contact with less than 1 N. During this forward reaching motion, the touch sensor rotates forward around its base axis, so that it does not interfere with the movement of the upper extremity during the reaching motion (Fig. 3). In the non-CSSP condition, only camera B was added to the environment of measurement 1 (Fig. 2b).

The procedures for measurement 2 were as follows. The participant first held a standing position with the right shoulder joint elevated 90°, and then the COP was measured and photographs of the standing position were taken. In the CSSP condition, the participant started reaching with the right acromion and right greater trochanter positions, and the trunk tilt angle was reproduced, with the right palmar side of the wrist joint in contact with the touch sensor. In the non-CSSP condition, the right ulnar styloid process was only aligned with the projected horizontal line to maintain the height of the right upper extremity elevation constant. In both conditions, the participants reached as far forward as possible using the ankle joint strategy in reference to the method of Liao et al.10) and held the posture at the maximum forward reach for 3 s. The COP at the maximum forward reach was measured and photographed. Three sets of three trials each (a total of nine trials) were performed for each condition with a 30-s rest between sets in the sitting position. The order of each condition was randomized for each participant. In addition, a 5-min rest in a sitting position was taken between each condition to eliminate the effects of participant fatigue. In addition, the participants practiced forward reaching movements with the ankle joint strategy and contact practice of less than 1 N sufficiently as exercise strategy practice before starting measurement 2. In all measurements, the participants were asked to wear a white tank top and white leggings. Reflex markers were placed on the right acromion (one in the quiet standing position and one in the right upper extremity 90° elevation position), the right greater trochanter, the spinous process of the seventh cervical vertebra, the right ulnar styloid process, and the right head of the third metacarpal. As for the order of measurement, measurement 2 was performed on different days after measurement 1.

All photographs were analyzed using ImageJ12). In this study, as a preliminary experiment, to confirm the accuracy of ImageJ, we photographed a 30-cm long ruler placed at the center and the edge of the lens, and confirmed that the length of the ruler photographed at the edge of the lens increased or decreased in relation to the length of the ruler photographed at the center of the lens. Using the length of the ruler taken at the center of the lens analyzed by ImageJ as a reference, the ruler taken at the edge of the lens was 29.5 cm, confirming an error of 0.5 cm. For this reason, we minimized the error by adjusting the camera position so that the part to be photographed was reflected in the center of the lens when taking photographs.

The position of the right acromion and greater trochanter in the anteroposterior direction in measurement 1 was calculated as the distance from the perpendicular line passing through the right lateral malleolus. The trunk tilt angle was defined as the angle between the line connecting the spinous process of the seventh cervical vertebra and the right greater trochanter in the sagittal plane and the vertical line. The COP in the anteroposterior direction was expressed relative to the most posterior point of the heel in relation to the foot length (%FL).

The distribution range of the right acromion position (DRAP), distribution range of the right greater trochanter position (DRGTP), distribution range of the COP (DRCOP) in the anteroposterior direction in the starting position, and DRFoRD in the CSSP and non-CSSP conditions of measurement 2 was defined as the difference between the most anterior and the most posterior position in the individual’s nine trials6). The distribution range for each value was calculated for each participant.

Fig. 3. Touch sensor diagram.
1: Metal plate; 2: Strain gauge; 3: Stand.
The FoRD was defined as the difference between the distance from the perpendicular line through the right lateral malleolus to the right head of the third metacarpal of the maximum anterior reach position and the distance from the perpendicular line through the right lateral malleolus to the right head of the third metacarpal at the starting position. The MDCOP in the anteroposterior direction during forward reach was defined as the difference between the position of the COP at the maximum forward reach position and the COP at the starting position. The DRAP, DRGTP, DRFoRD, and mean FoRD (MFoRD) were normalized by height. The mean values of the FoRD and the MDCOP in the anteroposterior direction for nine trials were calculated for each participant in each condition.

EZR (Easy R, Saitama Medical Center, Jichi Medical University, Saitama, Japan) was used for statistical analysis. The normality of all measurements was confirmed by the Shapiro-Wilk test. Paired t-tests were used to compare the DRAP, DRGTP, DRCOP in the anteroposterior direction in the starting position, DRFoRD, and MFoRD in the CSSP and non-CSSP conditions. Pearson’s correlation coefficient was used to analyze the correlation between the normalized MFoRD (%) and the MDCOP in the anteroposterior direction in the CSSP and non-CSSP conditions. The correlation coefficients r for both conditions were Z-transformed using Microsoft Excel (Microsoft, Redmond, WA) to compare the results between the conditions. The significance level was set at 5%.

**RESULTS**

The DRAP, DRGTP, DRCOP in the anteroposterior direction in the starting position, DRFoRD and MFoRD in the CSSP and non-CSSP conditions are shown in Table 1. The DRAP, DRGTP, DRCOP in the anteroposterior direction in the starting position, DRFoRD, and MFoRD were significantly smaller in the CSSP condition than in the non-CSSP condition (p<0.05). The mean FoRD was not significantly different between the conditions (p>0.05).

The correlation between the MFoRD and the MDCOP in the anteroposterior direction in both conditions and the comparison of the correlation coefficients in the two groups are shown in Table 2. In both conditions, there was a significant correlation between the normalized FoRD and the MDCOP in the anteroposterior direction (CSSP condition, r=0.76, p<0.05; non-CSSP condition, r=0.50, p<0.05). The correlation coefficients were not significantly different between the conditions.

![Table 1](image1)

| CSSP condition | Non-CSSP condition |
|---------------|-------------------|
| DRAP (cm)     | 1.1 ± 0.6*        | 3.2 ± 1.0 |
| DRAP (%)      | 0.7 ± 0.3*        | 1.9 ± 0.6 |
| DRGTP (cm)    | 0.9 ± 0.4*        | 3.5 ± 0.9 |
| DRGTP (%)     | 0.5 ± 0.2*        | 2.1 ± 0.5 |
| DRCOP (%FL)   | 4.5 ± 1.8*        | 9.0 ± 2.9 |
| DRFoRD (cm)   | 3.7 ± 1.4*        | 5.1 ± 1.7 |
| DRFoRD (%)    | 2.0 ± 0.8*        | 3.0 ± 1.0 |
| MFoRD (cm)    | 18.0 ± 4.4        | 16.5 ± 4.2 |
| MFoRD (%)     | 10.5 ± 2.5        | 9.6 ± 2.3 |

Values are expressed as mean ± standard deviation.

DR (Distribution range): Difference between the most anterior and most posterior positions; GTP: Greater trochanter position; COP: Center of pressure; MFoRD: Mean forward reach distance; DRAP: Distribution range of the right acromion position; DRGTP: Distribution range of the right greater trochanter position; DRCOP: Distribution range of the center of pressure; DRFoRD: Distribution range of the forward reach distance; CSSP: Controlled starting standing position; DRAP, DRGTP, DRFoRD, and MFoRD: Relative distance in relation to body height; COP (%FL): Relative distance from the hindmost point of the heel in relation to foot length (FL).

*: Significant difference compared to the non-CSSP condition (p<0.05).

![Table 2](image2)

| MFeoRD in the CSSP condition (%) | Relative MDCOP in the anteroposterior direction (%FL) |
|---------------------------------|------------------------------------------------------|
| MFeoRD in the non-CSSP condition (%) | r=0.76* |
| MFeoRD in the non-CSSP condition (%) | r=0.50* |

MFeoRD: Mean forward reach distance; MFeoRD (%): Relative distance in relation to body height; COP: Center of pressure; COP (%FL): Relative distance from the hindmost point of the heel in relation to foot length (FL).

*: There was a significant correlation between the FRD and the MDCOP in the anteroposterior direction in both conditions (p<0.05). No significant difference in correlation coefficients for both conditions (p>0.05).

MDCOP: Movement distance of the center of the pressure; CSSP: Controlled starting standing position.
DISCUSSION

The purpose of this study was to investigate whether the DRFoRD and the relationship between the FoRD and the MDCOP differ depending on a CSSP in an FRT with the ankle joint strategy. The results of this study support hypothesis 1 but not hypothesis 2.

Hoshi et al.\(^{14}\) reported that immobilization of the ankle and knee joints reduced body sway in a quiet standing position. In this study, the right acromion position and right greater trochanter position at the starting position were controlled using a laser light and a controlling device at the starting position, without fixing any body part except for the foot position. As a result, it is thought that the range of distribution of the starting position for each trial could be reduced even in situations where each body part other than the foot was not fixed. In addition, it has been reported that light touch while holding a standing position decreases body sway\(^{11,15}\). This suggests that the effect of light touch further reduced the body sway in the starting position, and the DRFoRD was significantly smaller in the CSSP condition than in the non-CSSP condition. Dai et al.\(^{16}\) reported that the reproducibility of the conventional FRT method is reduced by unconscious body swaying and inconsistency in the starting position. In other words, the results of this study suggest that a CSSP in the FRT is important for accurately discriminating the risk of falling because it reduces measurement error.

There was a significant correlation between the FRD and the MDCOP in the anteroposterior direction, regardless of whether the starting position was controlled, but there was no significant difference between conditions. The ankle joint strategy is a method of maintaining the center of gravity at the center of the supporting base plane by moving the posture back and forth using only the ankle joint plantar dorsiflexion movements\(^ {16}\). Liao et al.\(^ {10}\) reported a positive correlation between the FoRD and the center of gravity displacement distance using an ankle joint strategy. Therefore, it is considered that the ankle joint strategy involves forward movement of the COP along with forward reach, resulting in a positive correlation between the FoRD and the MDCOP in the anteroposterior direction, regardless of whether the starting position is controlled. The results of this study suggest that, to evaluate SBA using an FRT, it is recommended to control the starting position and to use the ankle joint strategy as a movement strategy.

One limitation of this study is that in the present study, a light-touch-only condition was not performed in a CSSP for the FRT. In the future, we believe it is necessary to compare the DRFoRD in three conditions: the light-touch-only condition, the CSSP condition in this study, and the non-CSSP condition in this study. Also, only healthy adult males were included in the study. In the future, it will be necessary to study how to apply this method to elderly people and develop a more valid FRT. In addition, Mitani et al.\(^{17}\) reported that forward reaching with bilateral upper extremities in an FRT reflects better the ability to move the COP compared to that with a unilateral reach. Therefore, it will be interesting to compare FRT with unilateral and bilateral upper extremities in the CSSP condition to investigate the measurement error of the FoRD and the relationship between the FoRD and the MDCOP in the anteroposterior direction.

In conclusion, the present study tested whether the DRFoRD and the relationship between the MFoRD and the MDCOP differed depending on whether the starting position was controlled in the FRT using the ankle joint strategy. The results showed that the DRFoRD became smaller with a CSSP, and there was a significant correlation between the MFoRD and the MDCOP in the future, it will be necessary to verify the DRFoRD and the relationship between the MFoRD and the MDCOP in the anteroposterior direction by using FRT with an ankle joint strategy in the elderly depending on the CSSP.

Conflict of interest
None.

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