Comparison of the One-Arm and Two-Arm Functional Reach Test in Young Adults

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Abstract. [Purpose] We investigated which functional reach test was more highly correlated with center of pressure excursion, a one-arm reach or a two-arm reach, and explored the relationship between reach distance and trunk rotation in the case of one-arm reach. [Subjects] The subjects were 25 healthy young adults (14 males, 11 females; average age 21.2 years, range 19–30 years). [Methods] Three-dimensional coordinate data (of both acromions and the right index finger) and the movement of the center of pressure were recorded. [Results] In a comparison of measurements of one-arm reach and a two-arm reach, the correlation between the reach distance and the center of pressure excursion was significantly higher for the one-arm reach. In one-arm reach, there was no noticeable correlation between the reach distance and trunk rotation. With multiple regression analysis, trunk rotation was not a significant factor affecting reach distance. When using the heel as a reference, the correlation between reach distance and center of pressure excursion was the strongest. [Conclusion] To evaluate dynamic balance, the one-arm reach is more suitable for young adults. It is useful to measure the reach distance from a fixed point (e.g. heel), or to develop an adjustment technique that can reproduce the starting position.

Key words: Functional reach test, Balance, Three-dimensional analysis, Center of pressure excursion

INTRODUCTION

The functional reach test (FRT) developed by Duncan et al. in 1990 is a popular method of measuring the physical function of the elderly. Functional reach (FR) is measured as the maximum distance a subject can reach forward beyond arm length at shoulder height while maintaining a fixed base of support in the standing position1,2). The FRT was originally designed as a measure of the margin of stability, similar to center of pressure excursion (COPE), an indicator of dynamic balance, which is recorded on a force plate. Duncan et al. reported that FR was highly correlated with COPE (r = 0.71)3). Moreover, FR is inversely associated with recurrent falls, physical frailty, and physical changes2–4), as is COPE5,6).

Although the original method uses reaching forward with one arm, recently, reach distance using two arms has been used to examine dynamic balance7–14). This is because it is considered by some researchers that two-arm reach excludes the influence of trunk rotatory flexibility on reach distance, thereby indicating dynamic balance more effectively and accurately. Volkman et al. reported higher reproducibility of two-arm reach than one-arm reach14). Tsushima et al. reported a slightly smaller variation in two-arm reach7). However, to our knowledge, there are no reports which show the relationship between one-arm reach distance and
trunk rotation. Also, there is no evidence that the two-arm reach distance is more highly associated with dynamic balance than the one-arm reach distance.

The purpose of this study was to investigate which reach distance was more highly correlated with COPE. We also explored the relationship between reach distance and trunk rotation in the case of one-arm reach. Although the FRT is widely used for elderly populations, interpretation of the results may be difficult because of changes of posture, mental function decline, and unexpected aging factors. In this study, we recruited healthy young adults. The findings from young adults may provide basic information for future research.

SUBJECTS AND METHODS

Subjects

Twenty-five healthy subjects (14 males, 11 females; average age 21.2 years, range 18–30 years) participated in this study. The subjects had an average weight of 59.0 kg and an average height of 166.7 cm. They reported no diagnosed musculoskeletal diseases, and could reach forward without pain or discomfort. This study was approved by our institutional review board, and written informed consent was obtained from all of the subjects.

Methods

The subjects stood barefoot, comfortably, with their feet shoulder-width apart and their toes at a baseline marked on the force plate. Then they were instructed to raise their arms until they were parallel to the floor. The finger location at the starting position of the first trial was recorded and recreated in each trial. After the subjects took the starting position, they were instructed to begin a reaching movement on a cue from the examiner, to reach their maximal distance at their own speed, and return to the upright position. To keep the arms level with the acromion, the subjects reached forward while pushing a horizontal sliding bar with their fingers instead of their fist, because a marker was attached to the finger joint. The subjects performed the forward reaching movement under two conditions:

1. One-arm reach. Subjects took the starting position with their right arm horizontal and their left arm at their side. They were instructed to extend their right arm and reach as far forward as they could.

2. Two-arm reach. Subjects took the starting position with both of their arms horizontal. They were instructed to extend both arms and reach as far forward as they could.

If a subject took a step during testing, the trial was repeated. To minimize order effects, the order of the two conditions was randomized. Measurement was duplicated in each condition, and the trial which showed the longest reach in each condition was selected for statistical analysis.

Three-dimensional kinematic data and COPE data were synchronously acquired during each trial. The Peak 3D motion analysis system (VICON Motion Systems Inc., CO, USA) was used for collecting three-dimensional kinematic data during the forward reach. Five infrared reflective markers were placed on both acromions, both anterior superior iliac spine (ASIS) points, and the proximal interphalangeal joint of the right index finger. The finger marker simulated the front end of the forward reaching fist used in the original method. The motion of each marker was captured with six cameras placed around the subject, and the locations of the markers were derived from the most posterior point of the heel, which served as the origin. An AMTI force plate (Advanced Mechanical Technology Inc., Waterton, MA, USA) was used to record the ground reaction force. Kinematic data and ground reaction force were sampled by a computer at a frequency of 60 Hz for 15 seconds. Peak Motus software ver.7.0 (VICON Motion Systems, Inc., CO, USA) was used to calculate the 3D coordinates of each marker and COP. Values of marker displacement and COPE were rounded to the nearest 0.1 cm.

Body height was measured to the nearest 0.1 cm using a height measuring stadiometer (NJ-0330-02, ASONE Corporation, Osaka, Japan). Foot lengths (distance between the most posterior point of the heel and the tip of the frontmost toe) were measured to the nearest 0.1 cm using an anthropometer (Lafayette Instrument Company Model 01291, IN, USA) while the subject was standing.

Before the reach trials, shoulder location at the starting position was measured as the horizontal distance from the most posterior point of the heel to the right acromion. The reach distance was obtained in three ways: (1) finger-to-finger, using the marker location on the finger at the starting position as a
reference point; (2) heel-to-finger, using the most posterior point of the heel as a reference point; and (3) finger forward distance, using the heel-to-finger distance minus the arm length. A: Lateral view at the start position (gray line) and at maximal reach (black line). Three definitions of reach distances (cm) were used: (1) finger-to-finger, reach distance from the finger location at the start position; (2) heel-to-finger, reach distance from the most posterior point of the heel; and (3) finger forward distance, i.e. heel-to-finger distance minus arm length. a: shoulder location; horizontal distance from most posterior point of heel to right acromion at the start position. b: arm length.

B: Overhead view at maximal reach when reaching with one arm. c: trunk rotation angle (degree) is formed by a line connecting the right and left acromions and the frontal plane. d: shoulder protraction is the anteroposterior distance between the right and left acromions.

The trunk rotation angle and shoulder protraction at the maximal reach in one-arm reach was also calculated (Fig. 1-B). The trunk rotation angle was determined as the angle formed by a line connecting the right and left acromions and the frontal plane, and the shoulder protraction was determined as the anteroposterior distance between the right and left acromions.

The paired t-test was used for comparison of the reach distances, COPE, and ASIS displacement between one-arm reach and two-arm reach. The relationship between reach distance and COPE was examined with Pearson’s correlation. The difference of correlation coefficients between one-arm reach and two-arm reach was examined using the z test. The association of reach distance with trunk rotation angle and shoulder protraction in one-arm reach was also examined with Pearson’s correlation. A multivariate regression analysis with forced entry was performed with the one-arm reach distance as a dependent variable control for COPE, and trunk rotation angle. The possible confounders included in the model were sex, age, and height, as in previous reports. SPSS version 12.0J for Windows (SPSS Institute Japan, Tokyo, Japan) was used for the analysis, and variables are represented as mean ± standard deviation. Statistical significance was defined as p<0.05.

RESULTS

Shoulder locations at the starting positions were measured using the 3D kinematic system. The right acromions were located between 0.2 cm and 15.4 cm (mean ± SD, 8.71 ± 3.7 cm) from the heel point. The midpoints of the bilateral acromions were located within the range of 3.4 to 12.4 cm (7.7 ± 2.5 cm) in the one-arm reach, and within the range of 2.0 to 13.2 cm (8.6 ± 3.0 cm) in the two-arm reach.

The reach distance and COPE are shown in Table 1. The one-arm reach distance was significantly longer than the two-arm reach distance (mean difference, 8.0 ± 5.2 cm, p<0.001). There was no significant difference in COPE between the one-arm reach and the two-arm reach (p≥0.05). In the one-arm reach, the right ASIS moved 4.1 cm forward, and the left ASIS 5.1 cm backward, but the midpoints of the bilateral points hardly moved (0.4 cm backward). On the other hand, the midpoints of both ASISs in the two-arm reach moved backward (3.3 cm).

Correlations between reach distance and COPE are shown in Table 2. The one-arm reach distances were significantly correlated with COPE for all of the three definitions of reach distance (r = 0.40–
However, correlations of COPE with the two-arm reach distance were not significant, with the exception of the heel-to-finger distance (r = 0.46, p < 0.05). Correlations with COPE were higher in one-arm reach than in two-arm reach with the heel-to-finger definition (p<0.05). Correlations with COPE were higher with the heel point as a reference than with the starting finger position, regardless of whether one-arm reach or two-arm reach was performed.

The correlations between trunk rotation angle or shoulder protraction and reach distance in the case of the one-arm reach are shown in Table 3. There were no significant correlations, except for the heel-to-finger reach distance, which showed weak correlation with shoulder protraction (r = 0.41, p< 0.05).

Multivariate regression analyses revealed that COPE was a significant determining factor of the one-arm reach distance (p<0.001 for heel-to-finger and heel-to-finger minus arm length, respectively), but trunk rotation angles showed no significant association with the one-arm reach distance (Table 4). Using shoulder protraction in the model instead of trunk rotation angle did not produce a significant association either. The goodness of fit of the model in the finger-to-finger case was not significant (coefficient of determination = 0.262, p≥0.05). The average variance inflating factors (VIFs) of all variables were lower than 2.6, and the correlation coefficients between each of the variables were lower than 0.69. Therefore, the problem of multicolinearity was considered to be avoided.

**DISCUSSION**

The original FRT involving one-arm reach, developed by Duncan et al.\(^1\), is a popular method for assessing dynamic balance, but recently, two-arm reach has been put to wide use with the aim of eliminating the effect of trunk rotation and shoulder protraction\(^7\)–\(^14\). However, to our knowledge, there are no reports which show a relationship between one-arm reach distance and trunk rotation. Also, there is no evidence that the two-arm reach distance is more highly associated with dynamic balance than the one-arm reach distance.

In the present research, the correlation between

### Table 1. Reach distance, COPE, and ASIS displacement at maximum reach (mean ± standard deviation)

<table>
<thead>
<tr>
<th>Reach distance (cm)</th>
<th>One-arm reach</th>
<th>Two-arm reach</th>
<th>Difference*</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) finger to finger</td>
<td>43.1 ± 5.1</td>
<td>35.1 ± 7.2</td>
<td>8.0 ± 5.2</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>(2) heel to finger</td>
<td>118.4 ± 5.7</td>
<td>110.4 ± 7.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) (2) - arm length</td>
<td>51.4 ± 3.9</td>
<td>43.4 ± 6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COPE (cm)</td>
<td>21.9 ± 2.1</td>
<td>22.0 ± 1.8</td>
<td>-0.2 ± 1.7</td>
<td>≥ 0.05</td>
</tr>
<tr>
<td>Displacement of ASIS** (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>4.1 ± 4.2</td>
<td>-3.4 ± 4.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>-5.1 ± 3.1</td>
<td>-4.0 ± 3.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Midpoint of right and left</td>
<td>-0.4 ± 3.2</td>
<td>-3.3 ± 4.0</td>
<td>2.8 ± 2.4</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

*Difference represents one-arm reach variables minus two-arm reach variables.

**Displacement of ASIS: antero-posterior moving distance of ASIS from the starting position. Minus means posterior movement.

COPE: center of pressure excursion, ASIS: anterior superior iliac spine.

### Table 2. Correlation coefficients between reach distance and COPE

<table>
<thead>
<tr>
<th></th>
<th>One-arm reach</th>
<th>Two-arm reach</th>
<th>Comparison between two methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>p</td>
<td>Coefficient</td>
</tr>
<tr>
<td>(1) finger-to-finger</td>
<td>0.4</td>
<td>&lt; 0.05</td>
<td>0.17</td>
</tr>
<tr>
<td>(2) heel-to-finger</td>
<td>0.78</td>
<td>&lt; 0.001</td>
<td>0.46</td>
</tr>
<tr>
<td>(3) (2) - arm length</td>
<td>0.7</td>
<td>&lt; 0.001</td>
<td>0.36</td>
</tr>
</tbody>
</table>

COPE: center of pressure excursion.
reach distance and COPE were compared for one-arm reach and two-arm reach, and the correlation coefficient was significantly higher for one-arm reach. There is a report that the reach distance less reflects COPE when using the hip strategy \(^{17}\). In our research, the midpoint of the bilateral ASISs moved backward in two-arm reach more than in one-arm reach. This means that two-arm reach took the hip strategy into account more than one-arm reach. It doesn’t contradict the previous report. One-arm reach was found to reflect COPE better than two-arm reach. Moreover, no significant correlation between the maximum reach distance and trunk rotation angle or shoulder protraction was observed for one-arm reach, except for a weak correlation between reach distance and shoulder protraction in the heel-to-finger case. It appears that trunk rotation has little impact on one-arm reach distance. Also according to multivariate regression analysis, trunk rotation angle was not a factor determining reach distance. These findings suggest that one-arm reach, which better reflects COPE, is more suitable for evaluating dynamic balance in young adults.

We showed that the starting positions of the acromion varied among the subjects. The finger position at the start can deviate forward or backward along with flexion and tilting of the trunk. This inter-individual variation of the starting acromion position can affect the measured reach distance in the finger-to-finger setting. When the reach distance was measured using the heel as a reference point, the correlation between reach distance and COPE was higher, which means that the reach distance is less affected by the starting position.

Currently, there are some FRT studies suggesting that FRT is useful as a predictor of the risk of falling and a decline in function of elderly people \(^{18-24}\), but others contest this \(^{2,25-31}\). These inconsistent results may be partially derived from the inter-individual variation of the starting position. In order to increase the accuracy of FRT, the reach distance should be measured from a fixed point (e.g. heel), or an adjustment technique that can reproduce the starting position should be developed.

This research had some limitations. The results obtained from the young participants are not directly applicable to elderly people. It will be necessary to carry out the same research with elderly people in the future. In addition, the sample size of this study was small. It will also be necessary to evaluate other measurement variations, for example, spacing of the feet, and heel movement and loading during the reaching movement.

### Table 3. Correlation coefficients between trunk rotation angle or shoulder protraction and reach distance in one-arm reach

<table>
<thead>
<tr>
<th></th>
<th>Rotation angle (47.6 ± 10.4 degree)</th>
<th>Shoulder protraction (22.5 ± 4.9 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient p</td>
<td>Coefficient p</td>
</tr>
<tr>
<td>(1) finger to finger</td>
<td>0.01 ≥ 0.05</td>
<td>−0.15 ≥ 0.05</td>
</tr>
<tr>
<td>(2) heel to finger</td>
<td>0.19 ≥ 0.05</td>
<td>0.41 &lt; 0.05</td>
</tr>
<tr>
<td>(3) (2) - arm length</td>
<td>0.05 ≥ 0.05</td>
<td>0.18 ≥ 0.05</td>
</tr>
</tbody>
</table>

### Table 4. Multivariate regression analysis of one-arm reach distance

<table>
<thead>
<tr>
<th></th>
<th>(1) finger-to-finger</th>
<th>(2) heel-to-finger</th>
<th>(3) (2) – arm length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( R^2 = 0.262, p ≥ 0.05 )</td>
<td>( R^2 = 0.747, p &lt; 0.001 )</td>
<td>( R^2 = 0.690, p &lt; 0.001 )</td>
</tr>
<tr>
<td>( \beta )</td>
<td>( \beta )</td>
<td>( \beta )</td>
<td>( \beta )</td>
</tr>
<tr>
<td>COPE (cm)</td>
<td>0.539 2.264 &lt; 0.05</td>
<td>0.604 4.332 &lt; 0.001</td>
<td>0.606 3.927 &lt; 0.001</td>
</tr>
<tr>
<td>Trunk rotation angle (degree)</td>
<td>−0.038 −0.182 ≥ 0.05</td>
<td>0.113 0.936 ≥ 0.05</td>
<td>−0.059 −0.436 ≥ 0.05</td>
</tr>
</tbody>
</table>

\( \beta \): standardized partial regression coefficients, \( R^2 \): coefficient of determination.

Standardized coefficients were adjusted for sex, age, height, COPE, and trunk rotation.

COPE: center of pressure excursion.
REFERENCES


