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Original Article

Reliability of measurement using Image J for reach distance and movement angles in the functional reach test

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Abstract. [Purpose] The purpose of this study was to examine the test-retest reliability and minimal detectable change (MDC) of reach distance and movement angle analyses using Image J. [Participants and Methods] Thirty-eight healthy young males performed the functional reach test (FRT) twice, and their reach movements were recorded using a digital video camera. Image J was used to combine the digital photographs taken at the start position and maximum reach and to measure each movement. The measurements recorded were the movement distance of the third metacarpal bone (reach distance), anterior-superior iliac spine, and trochanter major, and the angles recorded were the acromion-malleolus lateralis, acromion-trochanter major, and trochanter major-malleolus lateralis. The reliability of all the measurements was analyzed using intraclass correlation coefficients (ICCs), Bland-Altman plots, and MDCs. [Results] The ICCs (1, 1) were >0.80 for all the outcomes. The Bland-Altman analysis revealed no systematic bias in any outcome. The MDC of reach distance was 18.3 mm. [Conclusion] Measurement using Image J for reach distance and movement angles in the FRT showed acceptable high test-retest reliability. Measurement of the FRT and the MDC calculated in this study could be used as a reference for further research.

Key words: Reliability, Image J, Functional reach test

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INTRODUCTION

Reach movement is necessary for activities of daily living (ADL), but has been shown to decrease in some patient and elderly groups[1–3)]. Improved reach movement is an important treatment target in the clinical setting and is assessed by the functional reach test (FRT)[4)] which measures the distance between the length of an outstretched arm in a maximal forward reach from a standing position, while maintaining a fixed base of support. The FRT is widely used clinically and in research as an outcome measure to assess postural balance for community-dwelling elderly[5, 6)], dementia[7, 8)], stroke[9, 10)], and Parkinson disease[11)] and other participants. In the FRT, not only reach distance but movement strategy is an important indicator of postural balance involving reaching forward[12)], it was reported that there were significant correlations among reach distance, center of mass displacement, and kinematic variables[13)]. Specifically, the ranges of the trunk and hip movements were correlated with reach distance[13, 14)], assessment and simultaneous adjustment of both will be beneficial to conduce effective improvement forward reach movement while standing. Therefore, measurement both reach distance and movement angles

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simultaneously in the FRT may be useful to assess movement strategy in forward reach movement.

Multi-dimensional motion analysis devices have been used to measure joint angles and movement alignment with great accuracy, however, the associated cost is often high for the clinical setting[15, 16]. On the other hand, it has been reported that usefulness of image analysis using various digital tools and applications about the advantages of excellent portability, easy installation and operation of equipment, and cost effectiveness, and ease of administration[15–19]. Among these portable measurements, two-dimensional motion analysis using digital photography and Image J software has been especially used reliably to measure joint angles and movement alignment simultaneously. Although there is a limitation that the result of two-dimensional motion analysis using Image J is affected by the motion of another dimension[14], the FRT is originally measured the reach distance on the two-dimensional sagittal plane. The previous studies of measurement using Image J for movement angles in sit-to-stand movements[16] and lower limb alignment in standing position[17] showed the high test-retest reliability, we hypothesized that two-dimensional motion analysis using Image J may be applied to measure distance and movement angles in the FRT. However, there are no studies to report reliability to measure reach distance and movement angles using Image J. Additionally, these previous studies[16, 19] examined the relative reliability of movement angle by intraclass correlation coefficients (ICCs), which provide information on the degree of agreement between multiple measured values not the absolute reliability of this information or the error variability. It is necessary for verification of absolute reliability to confirm the presence of fixed and proportional bias, the standard error of measurement (SEM), and minimal detectable change (MDC). The purpose of this study was to examine both of relative and absolute reliability in measurement using Image J for reach distance and movement angles in the FRT by healthy young males.

PARTICIPANTS AND METHODS

Participants in this study were 38 healthy young males (mean age 20.8 ± 1.0 years, mean height 171.5 ± 5.4 cm, mean weight 66.0 ± 10.1 kg) with no neurological or orthopedic diseases. The sample size was based on recommendations in the literature citing ≥21 participants as the minimum for reliability studies[20]. We also considered a previous study of a camera-based tool designed to track joint trajectories and measure movement angles which calculated the minimum sample size for reliability studies to be 25 participants[21]. We included 13 more participants in our final sample in order to increase the study's power. Written informed consent was obtained from each participant and ethics approval was obtained from the Institutional Review Board of Kyorin University (reference number: 26–29).

All participants performed the FRT[4] twice on the same day. Between the first and second measurements, participants rested for 5 minutes on sitting position to exclude the effect of fatigue. The time of interval between measurements was referred to the COSMIN checklist recommendations for reliability studies[22]. The COSMIN checklist manual recommended that appropriate time of interval between measurements depends on the construct to be measured and the target population and should be short enough to ensure that patients have not been changed on the construct to be measured[23].

All participants wore tight-fitting elasticated long sleeves and leggings, and were attached custom-made reflective markers were attached on the head of the third metacarpal bone, acromion, anterior superior iliac spine (ASIS), trochanter major, and malleolus lateralis on the right side of participants. They were given the following verbal instructions "You are measured by the maximum distance you can reach forward. Reach as far as possible" immediately before starting the reach movement without pre-training. The starting position of the FRT was standing adjusted by foot width combined with shoulder width, 90°flexion position of the shoulder joint, fully-extended position of the elbow joint, and intermediate position of the forearm between pronation and supination.

The reach movements from start to finish during the FRT were captured using a digital video camera (Sony, HDR-PJ630V, total number of pixels: 5.43 million, effective pixels for video: 5.02 million). According to the previous studies of measurement using Image J[16, 19], a standard ruler was attached to the wall as criterion for distance, and a tripod-mounted digital camera was positioned 4 m away from the ruler and participant. The height of camera lens was set to the height of trochanter major of each participant for showing a participant in the center of the camera monitor screen. Based on the video record, digital photography at the start position and at maximum reach were tracked; then, a combination of the images and measurement of each movement were performed using Image J software (Fig. 1). All measurements were carried out by one same rater. The rater practiced the operation of Image J and trained to use the application before this study.

The measurements recorded were the movement distance of the third metacarpal bone (reach distance), the ASIS (ASIS distance), the trochanter major (TM distance), and the movement angles recorded were between the acromion and malleolus lateralis (A-M angle), the acromion and trochanter major (A-T angle), and the trochanter major and malleolus lateralis (T-M angle). The movement distances were measured as the distance of the horizontal straight lines connecting each marker between the starting position and the maximum reaching position. The movement angles were measured the angle formed by the line connecting the two points of the starting position and the maximum reaching position. ASIS distance, TM distance, and T-M angle were measured to assess backward displacement of the hip because it is known that forward trunk movement in forward reach movement was accompanied by movement of the hip joint in the opposite direction[12, 13]. A-T angle was measured to evaluate forward trunk movement against hip as an associated factor for reach distance in the FRT[14]. A-M angle was measured to assess the whole-body alignment against base of support in the FRT[24]. Distances and movement angles in the FRT were expressed as plus (+) for the forward movement and minus (−) for the backward movement.

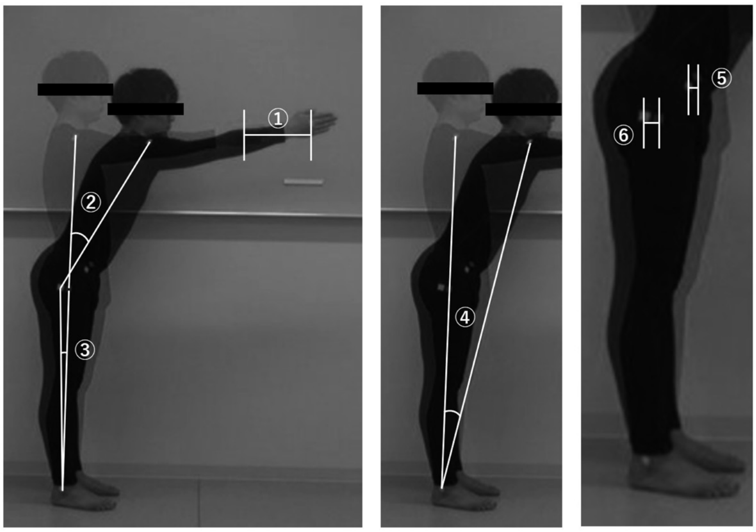

Fig. 1. A combination of the images and measurement of each movement using Image J.
1. reach distance; 2. acromion-trochanter major angle (A-T angle); 3. trochanter major-malleolus lateralis angle (T-M angle); 4. acromion-malleolus lateralis angle (A-M angle); 5. anterior superior iliac spine distance (ASIS distance); 6. Trochanter major distance (TM distance).

The data were analyzed using statistical analysis software R2.8.1. and Excel 2013 for Windows. The level of significance was predetermined to be $p<0.05$ for all statistical analyses. One sample t-test was carried out to compare the reach distance in this study with the reference value of reach distance reported by the previous study that measured the FRT using three-dimensional motion analysis in healthy young adults[13]. Relative reliability was calculated with the ICCs of each measurement outcome. The ICCs (1, 1) were calculated using one-way, random, absolute agreement on single measure model with a 95% confidence interval (CI). We interpreted the results of ICCs value based on the literature that the ICCs values<0.5 are indicative of "poor" reliability, values between 0.5 and 0.75 indicate "moderate", values between 0.75 and 0.9 indicate "good", and values greater than 0.90 indicate "excellent"[25]. To confirm the absolute reliability of each measurement outcome, Bland-Altman analysis was conducted and the standard error of measurement (SEM), and the MDC were calculated with a 95% CI.

The SEM and MDC were calculated using the following equation[26]:

$$\mathrm{SEM}=\mathrm{SD}\sqrt{(1-ICC)}$$

where standard deviation (SD) is the SD of all participant measurements.

$$\mathrm{MDC}_{95}=\mathrm{SEM}\ \times 1.96\ \times\sqrt{2}$$

RESULTS

The result of one sample t-test showed no significant differences between the reference value of reach distance (332.0 mm) reported in the previous study and the value of reach distance for first trial (333.1 ± 51.0 mm) or second trial (336.3 ± 51.2 mm) in this study (first trial: $p=0.891$, second trial: $p=0.608$).

The ICCs for each measurement outcome showed that the ICCs (1, 1) were 0.84 to 0.91, and the ICCs (1, 2) were 0.92 to 0.95 (Table 1).

As a result of the Bland-Altman analysis, no fixed bias was observed because the upper and lower limits of the 95% CI of the difference between the 2 measurements in all the measurement outcomes were all values that included 0 (Fig. 2, Table 1). As a result of testing the significance of the correlation between the difference of the 2 measurements and the average in all the measurement outcomes, proportional bias was not observed because the correlation was not significant (Fig. 2, Table 1).

The MDC_{95} of each measurement outcomes was reach distance=18.3 mm (SEM=6.6 mm), ASIS distance=21.1 mm (SEM=7.6 mm), TM distance=17.2 mm (SEM=6.2 mm), A-M angle=1.3° (SEM=0.5°), A-T angle=2.6° (SEM=0.9°), and T-M angle=1.2° (SEM=0.4°) (Table 1).

Table 1. Reliability of measurement using Image J for reach distance and movement angles

Outcome	FRT1	FRT2	ICC (1, 1) (95%CI)	ICC (1, 2) (95%CI)	95%CI of difference between two measurements	Fixed bias	Significance of correlation between difference of two measurements		Proportional bias	SEM	MDC_{95}
							r	p			
Reach distance (mm)	333.1 ± 51.0	336.3 ± 51.2	0.91 (0.83 to 0.95)	0.95 (0.91 to 0.97)	−10.37 to 4.07	(−)	−0.01	0.939	(−)	6.6	18.3
A-T angle (deg)	39.6 ± 7.2	40.2 ± 7.7	0.91 (0.84 to 0.95)	0.95 (0.91 to 0.98)	−1.66 to 0.36	(−)	−0.18	0.277	(−)	0.9	2.6
T-M angle (deg)	−3.3 ± 2.7	−3.4 ± 3.0	0.89 (0.80 to 0.94)	0.94 (0.89 to 0.97)	−0.27 to 0.61	(−)	−0.26	0.113	(−)	0.4	1.2
A-M angle (deg)	16.2 ± 2.3	16.5 ± 2.4	0.86 (0.75 to 0.93)	0.93 (0.86 to 0.96)	−0.70 to 0.10	(−)	−0.11	0.496	(−)	0.5	1.3
ASIS distance (mm)	−27.6 ± 32.3	−28.6 ± 34.9	0.84 (0.72 to 0.92)	0.92 (0.84 to 0.96)	−5.26 to 7.22	(−)	−0.14	0.386	(−)	7.6	21.1
TM distance (mm)	−41.0 ± 33.4	−42.9 ± 38.0	0.88 (0.78 to 0.93)	0.93 (0.87 to 0.97)	−4.00 to 7.80	(−)	−0.26	0.113	(−)	6.2	17.2

FRT1: First functional reach test; FRT2: Second functional reach test; ICC: intraclass correlation coefficient; CI: confidence interval; SEM: standard error of measurement; MDC: minimal detectable change; A-T angle: acromion-trochanter major angle; T-M angle: trochanter major-malleolus lateralis angle; A-M angle: acromion-malleolus lateralis angle; ASIS: Anterior Superior Iliac Spine; TM distance: Trochanter major distance
FRT1 and FRT2 were represented in average ± standard deviation.

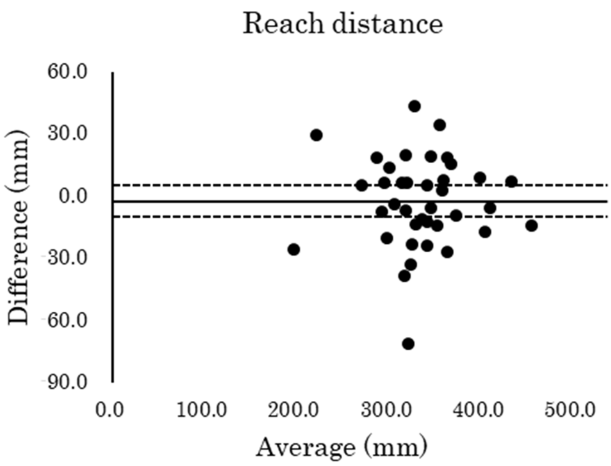

Fig. 2. Bland-Altman plot of reach distance.
The solid line represents the mean difference between two measurements.
The dashed lines represent the 95% limits of agreement.

DISCUSSION

This present study provided information about the accuracy of a measurement using Image J for reach distance and movement angles in the FRT. The results revealed that the measurement using Image J for the FRT can measured with acceptable reliability and measurement error. To the best of our knowledge, this is the first study to report the reliability for the measurement using Image J for the FRT.

One sample t-test showed no significant differences between the reach distance in this study and the representative value of reach distance reported in the previous study[13], and the reach distance measured using Image J was almost the same level as the external reference. General characteristics such as age and height are known to be factors associated with the FRT[4, 27]. Since the characteristics of participants in this study (mean age 20.8 ± 1.0 years, mean height 171.5 ± 5.4 cm, mean weight 66.0 ± 10.1 kg) was similar to those of the participants in the previous study (mean age 22.0 ± 2.0 years, mean height 167.4 ± 9.7 cm, mean weight 62.5 ± 13.2 kg)[13], it was assumed that the FRT between studies had similar results.

This study examined reliability of measurement using Image J for reach distance and movement angles in the FRT. The ICCs (1, 1) were above 0.80, and the ICCs (1, 2) were above 0.90 for all outcomes, respectively. The relative reliability of all outcomes in this study were "excellent" or "good". Furthermore, not only the outcomes of distance but also the outcomes of movement angles were confirmed to have high test-retest reliability. These results were similar to previous studies on the reliability of a method for analyzing two-dimensional motion to measure movement angles[16] and lower limb alignment[19] using Image J. Additionally, Bland-Altman analysis revealed neither fixed bias nor proportional bias in any outcomes. Therefore, Image J could measure movement angles in the FRT and reach distance simultaneously with high reproducibility. It was suggested that Image J can be used as a useful tool for analyzing movement distance and movement angle with high accuracy, but without high cost and special equipment. In this study, possible reasons for high reproducibility and the minor errors in distance and movement angle measurements were as follows: 1) participants were healthy young people without neurological and orthopedic diseases, 2) the FRT was a simple task with as easily-understood purpose of action, and 3) the reach movement was an automated movement that was often used in daily living.

The MDC_{95} of each measurement outcome were as follows: reach distance=18.3 mm, ASIS distance=21.1 mm, TM distance=17.2 mm, A-M angle=1.3°, A-T angle=2.6°, and T-M angle=1.2°. The MDC can be used as a reference value to determine the meaningful change that exceeds the measurement error. Based on the current results, it seems that the measurement using Image J is not only a reliable method to measure each distance but also it is a useful tool to determine different angles in the FRT. However, the MDCs may generally differ depending on characteristics of subjects, and be best be understood when interpreted in light of participant characteristics.

The limitation of this study is that the measurement was performed on healthy young males. Therefore, in order to generalize the measurement method in this study, it is necessary to examine the reliability and clarify the MDC for other populations, such as the elderly and patients with the various diseases. Additionally, the inter-rater reliability has not been confirmed in this study. Despite these study limitations, using Image J to measure reach distances and movement angles in the FRT showed high reliability, and measurement of the FRT and the MDC calculated in this study could be used as references to interpret other measurements made using Image J. Further studies are needed to examine the intervention effect to improve forward reach movement utilizing the measurement verified in this study.

Conflict of interest

There is no conflict of interest.

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