

The Test-Retest Reliability and Minimal Detectable Change of 3D Motion Analysis for Reactive Balance Assessment Among Older Adults

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ABSTRACT

Introduction: Older adults may have poor balance and postural control, leading to falls. Reactive balance is the ability to control balance in response to mechanical disturbances. A reactive balance assessment (RBA) should be performed using 3D motion analysis to evaluate fall-related capacity to back equivalence with accuracy data. Testing is required to ensure that this assessment is reliable. This study aimed to evaluate RBA's test-retest reliability and minimal detectable change (MDC) in older adults.

Methods: The study was conducted with 20 older adult women (Age mean±SD: 64.60±3.66). 3D motion analysis was applied to evaluate the reliability of RBA. The 29 reflective markers were placed on each participant's body in accordance with the Helen Hays marker set model, and one marker was attached to the rope by one rater. It was asked to conduct forward-direction compensatory stepping correction on two separate days within the span of one week. The center of mass (COM) displacement and reaction time were collected from the RBA. Intraclass correlation coefficient (ICC (3,1)), standard error of measurement (SEM), coefficient of stability (r), and MDC for COM displacement and reaction time were calculated between sessions.

Results: The ICC (3,1) values for COM displacement and reaction time were 0.79 and 0.83, respectively. They indicated good reliability for both variables (ICC (3,1) = 0.75-0.9). The MDC values for COM displacement and reaction time were 50.30 mm and 0.49 seconds, respectively. The coefficient of stability for COM displacement was 0.79, while for reaction time, it measured 0.84. These coefficient values indicated a strong correlation (r=0.70-0.89) within the respective datasets.

Conclusion: RBA had good test-retest reliability for both COM displacement and reaction time, with an acceptable MDC and a strong stability coefficient. Therefore, this technology's capability to deliver accurate assessments can lead to better monitoring of reactive balance impairments in older adults.

Keywords: Reliability; Reactive balance; 3D motion analysis; Older adults

Introduction

Aging involves biological and psychosocial changes over time in the individual development of living organisms [1, 2]. Tissue and organ atrophy, polymorphic amyloid degeneration, internal and external cell dehydration, increased fat, and decreased muscle tissue are common associated structural changes [2, 3]. The most common functional changes are abnormal adaptations on all body structure levels and

the weakness or failure of regulatory mechanisms, which leads to systemic imbalances [4, 5]. Degenerative changes in older adults can impact their daily lives and may contribute to falls and injuries [5].

Postural control depends on the interaction of the individual, task, and environment [6]. Three types of balance are necessary for functional tasks and activities: steady-state, reactive, and proactive [6, 7]. Steady-state balance is the ability to manage the center of mass

(COM) relative to the base of support under known and unchanging conditions [6, 7]. Proactive or anticipatory balance refers to activating muscles in the body for balance control before performing potentially destabilizing voluntary movements [6, 7]. Reactive balance control is the ability to return to a stable position following an unanticipated disruption [6, 7]. A fall can occur when the body cannot develop and use the necessary corrective muscular forces to recover equilibrium quickly enough. Thus, reactive balance assessment (RBA) is widely used to evaluate reactive balance control, measuring fall-related balance and the ability to restore equilibrium [6]. The test assesses the capacity of an individual to return to a stable position after an unanticipated disruption. Previous research has employed RBA in various settings [8, 9] and circumstances [10, 11], including athletes and older persons.

Each study of RBA has demonstrated moderate to excellent reliability [12–14], but this has not yet been researched in older adults using 3D motion analysis. 3D motion analysis measures movement in great detail and provides accurate outcomes [15], thus strengthening results. Therefore, the purpose of this study was to confirm the strength of RBA, using 3D motion analysis, by assessing the test-retest reliability and minimal detectable change (MDC) of RBA settings in older adults.

Methods

Research design

The study was a reliability study. The researcher screened older adult women before recruitment, and the study included all participants who met the screening requirements. Before data collection, all participants signed a consent form. The research related to human use has complied with all the relevant national regulations and institutional policies and has been approved by the Ethics Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University (COA 091/66).

Sample size

The sample size was calculated based on the mathematics of Walter et al. [16]. The expected effect size was 0.50. A reliability study conducted of two experimental trials ($n = 2$), a null hypothesis of 0.7, and an alternative hypothesis of 0.9, based on an alpha of 0.05 and a beta of 0.20, would require at least 18 participants (k). The study finally included 20 participants.

Participants

The data collection began in July 2023 and ended in September 2023. An advertisement was used to recruit 20 participants from the Bangkok metropolitan region. All participants were informed of the testing and

training processes and gave their informed consent before participation. They were included according to the criteria: (1) a woman aged 60 to 70 years [17], (2) the ability to walk without assistance aids [17], (3) the ability to step forward in the lean and release test [18], and (4) a normal mental state as measured by the Thai Geriatric Depression Scale [17]. Potential participants were excluded if they met at least one of the following conditions: (1) body mass index (BMI) greater than 30 kg/m² [19], (2) leg length difference [20], (3) history of lower extremity fracture or surgery [17], (4) diagnosis of gout, diabetic neuropathy, rheumatoid arthritis, tumor, cancer, systemic lupus erythematosus, or infectious disease [17], or (5) history of treated lower extremity joint inflammation [17].

Research protocol

The assessment was conducted at The Motor Control and Motion Analysis Research Laboratory, Department of Physical Therapy, Faculty of Allied Health Science, Chulalongkorn University. All participants who passed the screening test were instructed to prepare for data collection by eating a meal two hours before, not drinking alcohol or coffee for 24 hours, sleeping at least six hours the night before, and not putting lotion or oil on their skin on the day of data collection. All participants disclosed the medicines used at the time of data collection.

Throughout the examination, participants wore a harness with a safety suspension system wrapped around their bodies to keep them from falling completely. To assess reactive balance, using 3D analysis, each subject had 29 reflective markers attached to anatomical landmarks, following the Helen Hayes marker set [21], and one marker on the harness rope. After the marker attachment, each participant was asked to walk around the room 2–3 times to become familiar with the markers. The study evaluated RBA in the forward direction (anteroposterior). The 3.3-meter rope was connected at the level of the lower corner of the scapula, near the medial body line, to a digital force gauge [22]. The external loading was measured using a digital force gauge (SMAT SENSOR, aostorer-1542650011, China).

For the assessment, each participant was instructed to stand bipedally erect, arms aligned with the torso, knees straight, feet apart and aligned with the shoulders, with eyes open throughout the assessment. They slowly leaned forward until the load was totally suspended at 10% of body weight [22, 23]. At 10% body weight leaning, the researcher suddenly cut the rope behind its marker. When the loading sling was released, the participant had to take a step to prevent a fall and return to stability. Only one repetition was performed, avoiding the effects of fatigue while minimizing the impacts of anticipatory reflexes and learning. The assessment was conducted twice, with a one-week interval between sessions, to mitigate sources of

variability that could potentially influence measurement reliability, such as memory and habituation. Figure 1 depicts the RBA setting.

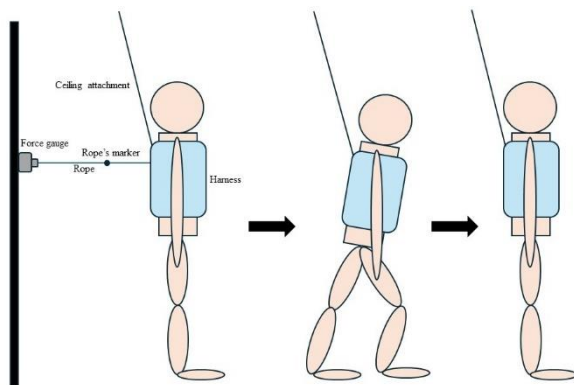


Figure 1 RBA setting

Reactive balance assessment

The study used 3D motion analysis (Motion Analysis Corp., Santa Rosa, CA, USA) to evaluate reactive balance response. The system featured eight cameras with a flash rate of 120 Hz. Cortex software version 8.1 was used to collect data. This has three main functions: calibrating the capture volume, tracking and recognizing marker locations in calibrated 3D space, and processing data for other packages. Analog signals were smoothed with a 6th-order, low-pass Butterworth filter at 5 Hz and 50 Hz. The study used 30 reflective markers (29 on the individual and one on the rope). The COM displacement and reaction time were derived from the raw motion analysis data (KIN and TRC) using a custom Python script, processed in Visual Studio Code (version 1.85).

For processing the outcomes, the COM displacement of RBA was defined as the average distance between the onset of weight release and the participants' return to a stable upright position on two feet [24]. Similarly, reaction time was defined as the duration between the onset of weight release and the participants' return to a stable upright position on two feet [25]. The period of release beginning was noted when the rope marker began to move at 0.8 mm after cutting the rope. The time to return to a stable upright position on two feet was then indicated at the normal pelvic and standing positions before testing, with the rope marker moving less than 0.8 mm for five frames.

Statistical analysis

IBM SPSS Statistics version 22.0 (IBM Corp., Armonk, NY, USA) was used for the quantitative data analysis. The numerical demographic data of the participants in both groups were presented as the mean and standard deviation. The test-retest reliability was calculated using the intraclass correlation coefficient (ICC) with a two-way mixed effect, consistency, and single-rater model (ICC (3,1)). Based on the 95% confidence intervals of the ICC estimates, values less

than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 indicate poor, moderate, good, and excellent reliability, respectively [26]. The standard error of measurement (SEM) also provides a measure of variability but was primarily used for calculating the MDC. SEM values were calculated as follows: $SEM = SD \times \sqrt{1 - ICC}$, with SD representing the standard deviation of the measure. MDC values, which reflect the magnitude of change necessary to provide confidence that a change is not the result of random variation or measurement error, were calculated as follows: $MDC = z\text{-score (95\% CI)} \times SEM \times \sqrt{2}$ [27, 28]. To assess the coefficient of stability, the Pearson product-moment correlation coefficient (r) was used [29, 30]. The interpretations of the correlation values were as follows: 0.00–0.10: negligible correlation, 0.10–0.39: weak correlation, 0.40–0.69: moderate correlation, 0.70–0.89: strong correlation, and 0.90–1.00: very strong correlation [30].

Results

A total of 20 older women participated in the study with a mean age of 64.60 years, average weight was 56.49 kg, average height was 151.42 cm, and average BMI was 22.57 (Table 1).

Table 1 Clinical characteristics of the participants

Characteristic	Mean±SD
Age (years)	64.60±3.66
Weight (kg)	56.49±9.53
Height (cm)	151.42±5.44
BMI (kg/m ²)	22.57±2.91

SD = standard deviation; BMI=body mass index

The test-retest reliability was determined with a one-week interval by one rater. The mean of the first trial of COM displacement was 495.55±41.84 mm, and the second trial mean was 495.78±38.87 mm. The mean of the first reaction time was 2.14±0.48 seconds, and the second was 2.13±0.39 seconds. The ICC (3,1) for COM displacement was 0.79 (0.55–0.91). The ICC (3,1) for reaction time was 0.83 (0.62–0.93), which indicated good reliability in both variables (ICC (3,1) =0.75–0.9). The MDC for COM displacement was 50.30 mm, and the reaction time MDC was 0.49 seconds (Table 2).

Table 2 Reliability outcome measures overview

Outcome	ICC	95% CI	SEM	MDC
COM displacement (mm)	0.79	0.55–0.91	18.15	50.30
Reaction time (s)	0.83	0.62–0.93	0.18	0.49

CI=confidence interval; SEM=standard error of the mean; MDC=minimal detectable change

The Pearson product-moment correlation coefficient (r) for COM displacement was 0.79, and for reaction time, it was 0.84. These r values indicate a strong correlation within the data.

Discussion

Technological advancements have enabled measurement accuracy data for the device used in this study, but reliability data is sometimes absent. This study aimed to determine the test-retest reliability and MDC values for RBA in older adults. Based on the interpretation of the ICC (3,1), values between 0.75 and 0.9 indicate good reliability [26]. Thus, the results of this study show good test-retest reliability in both COM displacement and reaction time. Moreover, this demonstrates acceptable measurement errors.

The test-retest reliability of RBA has been employed in prior studies in various settings [12–14] differing from this study. This is the first study to use 3D motion analysis to determine the reliability of COM displacement and reaction time for assessing reactive response in older adults. The COM position is an important variable representing postural control [31]. The COM displacement in this study represents the response distance after falling to stability. This can illustrate how older persons use neuromuscular control to prevent falls [32]. Furthermore, the reaction time represents the latency of postural responses to balance perturbations [33]. Individuals must possess adaptability in postural control to enhance visuomotor reaction time on the behavioral level, which is defined as the time required to select and execute the appropriate motor response in a changing environment [33]. This study demonstrates the capability of employing COM displacement and reaction time to represent the reaction response with good reliability in older adults.

The MDC is the minimal change that falls outside the measurement error in the score of an instrument used to measure a condition [34]. This study shows the first MDC value of COM displacement and reaction time of RBA in older adults. These numbers can be used to guide future studies using this method to analyze RBA as the cutoff measurement error of COM displacement and reaction time.

When evaluating the coefficient of stability, as defined by the interpretation of the Pearson product-moment correlation coefficient (r), values falling between 0.70 and 0.89 indicate a strong correlation [30]. In the context of this study, the results demonstrated a strong correlation between the data points in both COM displacement and reaction time measurements. This implies that the measurements were reliably consistent over time, showing minimal variation due to external factors or measurement errors [30]. In addition, a coefficient of stability within this range suggests that the observed measurements are reliably consistent, reinforcing the reliability of the data collected for COM

displacement and reaction time and supporting the validity of the conclusions drawn from the study.

The study focused solely on older women; caution is needed when applying these findings to older men. Furthermore, the study's age range was set at 60–70 years, which may limit using the results for older persons above 70 years. Additionally, the exclusion of older adults with certain conditions—such as leg length discrepancy, inability to walk without assistance, BMI greater than 30 kg/m², a history of lower extremity fracture or surgery, and diagnoses of gout, diabetic neuropathy, rheumatoid arthritis, tumor, cancer, systemic lupus erythematosus, infectious diseases, or a history of treated lower extremity joint inflammation—also restricts the generalizability of the study's findings.

The clinical implications of using 3D motion analysis for measuring reactive balance in older adults are significant and multifaceted. Primarily, the good reliability of 3D motion analysis ensures that clinicians can depend on its measurements for consistent and accurate assessments of an individual's balance capabilities. This accuracy is crucial for diagnosing balance impairments, particularly those subtle issues that might not be detectable with traditional methods. Consequently, clinicians can design more targeted and effective rehabilitation programs tailored to each patient's specific needs, potentially enhancing recovery outcomes and overall quality of life. Moreover, the detailed data from 3D motion analysis, including COM displacement and reaction time, offers a comprehensive view of the biomechanics involved in balance. This information allows for a more nuanced understanding of the underlying factors contributing to balance issues, which can be vital for creating personalized intervention strategies. For instance, if the analysis reveals a particular weakness in a patient's ability to stabilize their center of mass, therapists can focus on specific exercises and therapies that strengthen that aspect.

Conclusion

The RBA setting in this study shows good reliability in assessing reactive balance, which can be applied in future studies. The study highlights the potential of 3D motion analysis in reliably assessing and providing accurate evaluations of reactive balance among older adults. Further study on 3D motion analysis for measuring reactive balance in older adults should focus on assessing its responsiveness to detect meaningful changes over time and establishing the Minimal Clinically Important Difference (MCID), which represents the smallest change indicating significant improvement or decline in a patient's condition. Longitudinal studies tracking balance metrics in response to therapies and correlating these with patient-reported outcomes and clinical assessments are essential. Additionally, comparing 3D motion analysis with traditional balance tools will provide insights into its advantages and limitations, enhancing its clinical

utility for optimizing care and fall prevention in older adults.

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