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Original Research

Reliability of the Instrumented Modified Clinical Test of Sensory Interaction on Balance Using a Virtual Balance Device

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ABSTRACT

International Journal of Exercise Science 17(1): 1183-1192, 2024. The purpose of this study was to evaluate the test-retest reliability of the instrumented version of the modified Clinical Test of Sensory Interaction on Balance (i-mCTSIB) using the VirtuSense VirtuBalance System™ (VSTBalance), a virtual balance device, in healthy young adults. Fifty-four subjects aged 20–27 years (Mean age 23.07, SD ± 1.6), participated in the study. A one-group design was utilized. Three trials of the i-mCTSIB were performed on two separate days to measure the mean sway velocity of the trunk under four conditions. Within-day reliability of trials 1–3 was estimated with intraclass correlation coefficients ($ICC_{3,1}$) and between-day reliability was estimated using the averages of trials 1–3 on day 1 and day 2 ($ICC_{3,3}$). Within-day reliability was moderate on day 1 (ICC = 0.511–0.672) and day 2 (ICC = 0.539 –0.677). Between-day reliability was moderate to good (ICC = 0.705–0.810). The lower bounds of the confidence intervals of within-day reliability estimates were 0.341–0.548, while the lower bounds of the confidence interval for the between-day reliability estimates were 0.390–0.671. Reliability of the VSTBalance for balance assessment using the i-mCTSIB test is moderate to good. Between-day reliability was higher than within-day reliability. When using the VSTBalance to assess balance with the i-mCTSIB, clinicians should provide practice of each condition contained in the test to improve reliability. The higher between-day reliability as compared to within-day reliability suggests that clinicians should use the averages of three trials when assessing balance performance change across time for each condition of the i-mCTSIB test when assessing balance using the VSTBalance.

KEY WORDS: Technology, 3D analysis, postural control

INTRODUCTION

Prevalence of falls in older individuals is increasing every year with a continued projected rise for the foreseeable future (14). Twenty-seven percent of older adults (aged 65 or older) have experienced a fall within the last 12 months (7). Healthcare costs due to these falls have been a financial burden on government programs such as Medicare and Medicaid with 50 billion dollars spent on fall related care in 2015 and a projected cost of 100 billion dollars by 2030 (7, 14). Causes of falls are well known, such as neuromuscular impairments (walking and balance), medication, poor fall risk education, and disease progression (14). Factors related to falling, such

as standing balance, should be addressed by an individual's multidisciplinary healthcare team to prevent the trend of fall injuries.

The maintenance of standing balance requires postural stability under static and dynamic conditions (5). The combination of sensory input from multiple systems including visual, vestibular, and somatosensory contributes to postural stability in the standing position. Changes in these systems related to normal aging may reduce postural stability of older individuals, increasing their susceptibility to falls (13). Balance disorders in older individuals can have a detrimental impact on both their physical and social abilities, which in turn will lead to a decrease in quality of life and loss of independence (16). Therefore, a comprehensive clinical assessment of balance to diagnose and treat deficits in older individuals should be performed.

The modified Clinical Test of Sensory Integration on Balance (mCTSIB) is a frequently performed clinical assessment of static and dynamic standing balance. The mCTSIB includes four testing conditions that create variations in sensory input while the individual is standing. The conditions include eyes open on a firm surface (condition 1), eyes closed on a firm surface (condition 2), eyes open on a foam surface (condition 3), and eyes closed on a foam surface (condition 4). The traditional method for administering the mCTSIB involves using a stopwatch to assess the time, over a 30-second period, in which balance is maintained in each of the four conditions. While the stopwatch method for administering the mCTSIB has high clinical applicability due to ease of use and minimal expense, it does not provide information related to postural control variables such as postural sway. Postural sway is important to measure as increased postural sway has been shown to distinguish older fallers from non-fallers (9).

Alternative methods have been developed for the clinical administration of the mCTSIB involving the use of computerized balance testing instruments to quantify the magnitude of postural sway occurring during each test condition. This version is termed the instrumented mCTSIB (i-mCTSIB). Examples of portable, computerized balance testing instruments providing the i-mCTSIB include the NeuroCom Very Simple Rehab (VSR) Sport (1, 23), the Balance Tracking System (BTrackS; 10-12), the Wii Balance Board (4, 21), the Biodex Balance System SD (BBS-SD; 2, 5, 19), and the Biodex BioSway™ (17). The BBS-SD assesses postural stability by measuring the degree of tilt of a dynamic circular platform, while the VSR Sport, the BTrackS, the Biodex BioSway, and the Wii Balance Board all use a stable platform force plate technology to calculate postural sway by computing center of pressure movement. Depending upon the testing system, postural stability during the i-mCTSIB is assessed individually for each of the conditions ((BBS-SD; 2, 5, 19), (VSR Sport; 1, 23), (Biodex BioSway; 17), Wii Balance Board; 4, 21)) or as a composite score across all four conditions ((VSR Sport; 1, 23), (BBS-SD; 2, 5, 19)). Previous research has found test-retest reliability of composite score measures of i-mCTSIB postural stability to be moderate for the BBS-SD (2, 5, 19) and good for the VSR-Sport (23). The test-retest reliability of i-mCTSIB for individual conditions is reported as moderate to good for the BTrackS (11) and the Wii Balance Board (21), good to excellent for the VSR Sport (23), poor to moderate for the Biodex BioSway (17), and poor for condition 1 (eyes open, firm surface) using the BBS-SD (5). While each of the aforementioned systems capable of conducting the i-mCTSIB are designed for clinic use, the ease of portability varies depending upon the size and weight of the

platform component. Recent technological developments have produced equipment that can be used for balance assessments and interventions without the necessity of computerized platforms to measure postural stability (6, 8).

The VirtuSense™ VirtuBalance™ System (VSTBalance) is a 3D motion analysis system that uses an infrared technology and a single camera to administer clinical gait and balance tests, such as the mCTSIB. The VSTBalance sensor is compact, with dimensions of 10.2 inches (wide) by 3.7 inches (deep) by 3.4 inches (high) and portable, weighing 2 pounds 12.8 ounces. Research related to the VSTBalance assessment of standing balance during the i-mCTSIB is limited to one study (6). Dodge et al. investigated standing balance in healthy adults, aged 18-65 years, by simultaneously collecting data with the VSTBalance and an AMTI™ force plate and found no difference in postural sway when comparing the measurements from these instruments (6). Reliability of VSTBalance postural sway measures during each condition of the i-mCTSIB was moderate, however, reliability was assessed using Pearson correlation coefficients and compared two trials of each condition performed in only one test session. More research is needed to establish the reliability of VSTBalance measures of postural sway during the i-mCTSIB and to define the associated psychometric properties. Therefore, the purpose of this study was to determine the within and between-day test-retest reliability and psychometric properties of the i-mCTSIB using the VSTBalance in healthy adults ages 18-29. It was hypothesized that postural stability measured by the VSTBalance would have good within and between-day test-retest reliability for the individual test conditions of the i-mCTSIB.

METHODS

Participants

Fifty-four participants (females: n = 36; males: n = 18) (Table 1), with a mean age of 23.07 years (± 1.6 SD), participated after being recruited at a local university via word of mouth, mass email, and advertisement flyers posted on campus after university institutional review board approval was obtained. Participants had a mean height of 1.7 ± 0.1 meters and mean weight of 75.7 ± 17.9 kilograms. Those who completed the study were given a $10 gift card funded through an internal university grant. Inclusion criteria comprised the following: between the ages of 18–29 years old, the ability to speak and read English, and passing screening questionnaires including the Physical Activity Readiness Questionnaire (PAR-Q; 15,22). Exclusion criteria included the following: pregnancy, medication use that might negatively impact balance, and any medical conditions that may impede balance. Subjects were instructed on the study protocol and provided informed consent before participating. Sample size was projected to be a minimum of 22 participants, at 80% statistical power, for an intraclass correlation coefficient (ICC) of 0.5 (3). To allow for attrition, a minimum of 38 participants were planned for the project. The Western Kentucky University Institutional Review Board approved the data collection methods and protocol of this study. This research was carried out fully in accordance to the ethical standards of the *International Journal of Exercise Science* (18).

Table 1. Participant demographics.

	Overall (*n* = 54) Mean ± SD	Male (*n* = 18) Mean ± SD	Female (*n* = 36) Mean ± SD
Age (yrs)	23.1 ± 1.6	23.5 ± 1.9	22.9 ± 1.4
Height (m)	1.7 ± 0.1	1.8 ± 0.1	1.7 ± 0.1
Weight (kg)	75.7 ± 17.9	90.2 ± 18.9	68.4 ± 12.1

SD = standard deviation; yrs = years; m = meters; kg= kilograms; *n* = number.

Protocol

The VSTBalance (VirtuSense Technologies, VirtuSense™ VirtuBalance™ System, Model number: M1011) was used to perform the i-mCTSIB test. VSTBalance is an instrumented system consisting of a single sensor that utilizes infra-red light to detect and capture body position and movement. Data collected and processed using special software designed by VirtuSense Technologies, results in measures of postural stability using the descriptors of sway and shift with only sway analyzed. Sway movement is measured by the VSTBalance software as the total distance traveled by the center of the body segment expressed in inches per unit of time (inches/second but converted to inches/cm) for the trial. Shift movement (mean displacement) is measured as the average distance traveled from the subject's center point of the body over the course of each trial, expressed in inches (converted to cm).

All testing was conducted in a university research lab over two testing sessions with a minimum of 24 hours between sessions (mean 9.9 days, ± 10). Prior to each test session, the system was calibrated as per manufacturer specifications. The sensor was positioned on a tripod set at 1.27 meters (m) from the surface. Each participant stood facing the sensor, standing on a white sheet to avoid shadows, in a designated area at a distance of 2.74 m from the sensor (Figure 1). Participants wore gait belts and were guarded by an investigator to prevent falls during the balance testing. All testing was performed with participants standing barefoot. The i-mCTSIB was conducted in standard order of the conditions as follows: condition 1: eyes open, firm surface; condition 2: eyes closed, firm surface; condition 3: eyes open, foam surface; condition 4: eyes closed, foam surface. An Airex® brand foam pad (dimensions 50 x 41 x 6 cm) was used for conditions 2 and 4. During each test condition, participants were provided scripted instructions by an investigator. A trial consisted of the participant going through the 4 test conditions in order (condition 1 – condition 4) with each condition lasting 30 seconds each. The participants completed 3 total trials and were offered an optional rest break between trials. The second test session occurred a minimum of 24 hours (Mean 9.9 ± 10 days), with no maximum time set, after the first session and utilized the same testing procedures. For each trial of a sensory condition, VSTBalance software measured total body sway in inches/second, but then converted to inches/cm, over the total duration of the trial, and body shift movement, defined as the average distance traveled from the subject's center point of the body over the course of each trial, was measured in inches but then also converted to cm. Although both shift and sway were measured, only sway was used for analysis. Each participant's data was de-identified and stored in the system's software, then exported for data analysis.

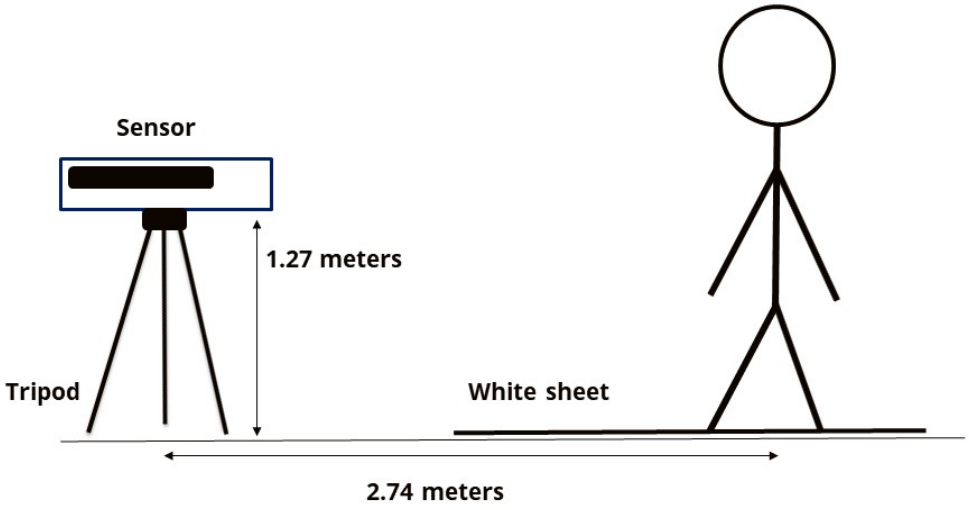

Figure 1. Equipment set-up and subject placement.

Statistical Analysis

The Statistical Package for Social Sciences (SPSS), version 26, and Microsoft® Excel® Version 2203 were used to analyze the data. Descriptive statistics for participant demographic data were calculated using mean and standard deviation for age, height, and weight, and frequency count for sex. Boxplots were constructed for body sway measures during each trial of an i-mCTSIB condition and inspected for outliers which were defined as data values more than 3 box-lengths. Individual outlier scores for a condition during a trial, if identified, were removed from the statistical analyses rather than removing the entire subject's data. Intra-class correlation coefficients (ICC) with 95% confidence intervals were determined by using a two-way mixed effects model to calculate the test-retest reliability of the i-mCTSIB. Within-day test-retest reliability of body sway across trials 1-3 was computed for each i-mCTSIB sensory condition during both session 1 and session 2 ($ICC_{3,1}$). Between session test-retest reliability was computed by using the average of trials 1-3 for each sensory condition during session 1 and session 2 ($ICC_{3,3}$). ICC values were interpreted as: excellent: ICC > 0.90; good: ICC > 0.75-0.90; moderate: ICC 0.50–0.75; poor: ICC < 0.50 (19). The alpha level of 0.05 was set for all statistical analyses for this study. In addition, the psychometric properties of the VSTBalance i-mCTSIB were determined by using the standard error of measurement (SEM) and minimal detectable change (MDC). The SEM was determined by using the formula: SEM = $sd \sqrt{}$ (1-ICC), with *sd* being the standard deviation of postural stability measures across three trials in each test session and *r* being the test-retest reliability coefficient (ICC). MDC at the 90% confidence level was calculated by using the formula MDC_{90} = SEM x 1.65 x $\sqrt{2}$ (20).

RESULTS

In the fifty-four subjects, there were 8 outlier scores (0.62%) in the body sway data, as assessed by inspection of boxplots, that were removed before further data analysis.

Table 2 provides a summary of the results of the within-day test-retest reliability of the four i-mCTSIB sensory conditions assessed with the VSTBalance system, including SEM and MDC values. The calculated ICC (3,1) values of body sway postural stability measures ranged from 0.511–0.672 in session one and from 0.539–0.677 in session two, which can be interpreted as moderate within-day reliability in both test sessions. The SEM and MDC_{90} ranged from 3.732–13.299 and 10.343–36.863, respectively, for conditions 1–3. Condition 4 (eyes closed foam) yielded higher SEM (12.510–14.724) and MDC (34.677–40.814) results.

Table 2. Summary of body sway (centimeters/second) during the instrumented modified Clinical Test for Sensory Interaction of Balance within-day reliability results.

Condition	Session	Trial 1 Mean (SD)	Trial 2 Mean (SD)	Trial 3 Mean (SD)	ICC (3,1)	SEM	MDC
1-Eyes Open Firm	1	12.97 (4.48)	11.37 (3.05)	11.27 (3.04)	0.511 (0.341, 0.663)	4.973	13.785
1-Eyes Open Firm	2	12.33 (3.41)	11.78 (3.81)	12.02 (4.30)	0.539 (0.383, 0.680)	7.416	20.555
2-Eyes Closed Firm	1	16.10 (4.29)	14.93 (4.72)	14.87 (4.86)	0.592 (0.444, 0.721)	3.732	10.343
2-Eyes Closed Firm	2	15.95 (5.47)	14.70 (4.07)	14.88 (4.88)	0.646 (0.509, 0.762)	5.894	16.337
3-Eyes Open Foam	1	19.51 (5.35)	18.97 (5.04)	18.62 (4.75)	0.629 (0.485, 0.751)	10.520	29.161
3-Eyes Open Foam	2	20.02 (6.23)	19.89 (5.66)	20.02 (5.50)	0.646 (0.508, 0.763)	13.299	36.863
4-Eyes Closed Foam	1	46.36 (13.64)	41.28 (10.96)	38.67 (10.94)	0.672 (0.462, 0.805)	12.510	34.677
4-Eyes Closed Foam	2	38.76 (9.31)	36.91 (9.20)	36.34 (8.76)	0.677 (0.548, 0.784)	14.724	40.814

SD = standard deviation; ICC = intraclass correlation coefficient; SEM = standard error of measurement; MDC_{90} = minimal detectable change. ICC values reported with 95% confidence interval.

Table 3 provides a summary of the results of the between-day test-retest reliability of the four i-mCTSIB sensory conditions assessed with the VSTBalance system, including SEM and MDC values. The calculated ICC (3,3) values ranged from 0.7050.810, which can be interpreted as moderate to good between-day test-retest reliability (with good test-retest reliability noted for conditions 1-3 (ICC = 0.773–0.810) and moderate for condition 4 (ICC = 0.705)). The SEM and MDC_{90} results ranged from 4.558–9.438 and 12.635–26.160, respectively, for conditions 1–3. Condition 4 (eyes closed foam) yielded higher SEM (13.566) and MDC (37.602) results.

Table 3. Summary of body sway (centimeters/second) during the instrumented modified Clinical Test for Sensory Interaction of Balance between-day reliability results.

Condition	Session 1 Mean (SD)	Session 2 Mean (SD)	ICC (3,1)	SEM	MDC
1-Eyes Open Firm	12.07 (3.10)	12.189 (3.32)	0.773 (0.608, 0.868)	4.558	12.635
2-Eyes Closed Firm	15.48 (4.14)	14.439 (4.63)	0.810 (0.671, 0.890)	4.613	12.787
3-Eyes Open Foam	19.29 (4.42)	20.267 (5.45)	0.793 (0.644, 0.879)	9.438	26.160
4-Eyes Closed Foam	42.24 (10.79)	37.335 (8.08)	0.705 (0.390, 0.846)	13.566	37.602

SD = standard deviation; ICC = intraclass correlation coefficient; SEM = standard error of measurement; MDC_{90} = minimal detectable change. ICC values reported with 95% confidence interval

DISCUSSION

VSTBalance was intended for clinical use due to the systems portability, easy implementation, and relative convenience of implementation across a broad spectrum of clinical environments. The purpose of this study was to determine the within and between-day test-retest reliability and psychometric properties of the i-mCTSIB using the VSTBalance in healthy adults ages 18–29. It was hypothesized that postural stability measured by the VSTBalance would have good within and between-day test-retest reliability for each test condition of the i-mCTSIB. The results of the study demonstrated only moderate test-retest reliability for within-day trials on both Day 1 and Day 2. However, the between-day analysis showed good test-retest reliability on all conditions except for condition 4 (eyes closed, foam surface) which was moderate. This finding agrees with Scaglioni-Solano et al. who found moderate to good reliability (ICC = 0.64–0.85) while measuring postural sway by center of pressure movement utilizing the Wii Balance Board for three, 30 second trials of the i-mCTSIB over 2 testing days (21). Likewise, the findings are also congruent with a study by Dodge et al. who also found moderate reliability of the VSTBalance in measuring postural sway through the i-mCTSIB in a within-day analysis but with two trials and by using Pearson correlations coefficients rather than ICC (6). This data shows that the VSTBalance may be used as a tool to objectively measure sway on the mCTSIB. The present study, to our knowledge, is the first to establish the psychometric properties for the VSTBalance for the i-mCTSIB. Scaglioni-Solano et al. previously established the MDC and SEM for the i-mCTSIB on force plates and on the Wii Balance Board™ (21).

The present study examined within-day reliability of the i-mCTSIB on the VSTBalance using three, 30 second individual trials over 2 days (at least 24 hours apart) for an 18–29-year-old population. Watson and Trudelle-Jackson also examined within-day reliability of the VSR-Sport in quantifying each condition of the i-mCTSIB and found good-to-excellent reliability in a healthy older population (23). Their study, however, examined within-day reliability using the average of three, 10 second trials in each condition performed with a 10-minute break before performing the 4 conditions a second time. The VSR-Sport also measures sway velocity in degrees per second whereas the VSTBalance used in the present study measures total body sway in inches per second. Goble et al. also administered the i-mCTSIB on the BTrackS to 18–29-year-olds but utilized 1–20 second trial for each condition over 2 days which were either a day, a

week, or a month apart (11). Their study measured test-retest reliability and found moderate to good reliability (ICC = 0.63–0.79) for all conditions except condition 3 (eyes open on foam) which had poor reliability (ICC = 0.47) for day-to-day comparison and poor to moderate reliability (ICC = 0.47–0.67) for week-to-week (11). The current study also had moderate to good reliability (but on all conditions) between-days with a protocol that stated the 2 testing days were at least 24 hours apart, however, the mean was 9.9 ± 10 days which may mean the week-to-week comparison for Goble et al. is more applicable. Also, they utilized total center of pressure path length to measure sway (11) which is different than the current study which used sway velocity. Miner et al. determined the reliability of the i-mCTSIB using the Biodex BioSway and utilized 30 second trials but only utilized the first 20 seconds of data over 2 test days which were 7-10 days apart (17). They found poor reliability (ICC = 0.00–0.47) with C1-C3 and moderate reliability (ICC = 0.62) with C4 for a healthy adult population (17). The mCTSIB has been used as a screening tool to determine strengths and deficits in multiple systems including vision, proprioception, and vestibular. When the i-mCTSIB is used with the VSTBalance, objective measures can be made on amount of sway which can transform the i-mCTSIB from a screening tool to an objective measure that can be used to document improvements in an individual's balance throughout the episode of care. Additionally, the established SEM and MDC values can be utilized for clinical use.

Limitations were noted in the present study. First, while there was a minimum of 24 hours between sessions for all participants, which met the protocol requirements, there was a high amount of variability of time between the sessions as there was a mean of 9.9 ± 10 days (Range 1–44 days) with 39% of participants (n = 21) exceeding 7 days. This variability was due to scheduling availability on the part of participants and researchers. It is possible that this variability could have influenced the results. Next, a learning effect could have impacted the results. While each participant was read a script and performed the same protocol on the device, the multiple trials over two days may have familiarized them to the test and improved performance over trials and sessions. Finally, there could have been variability of foot placement on the foam pad which could have impacted the results. The participants were told to stand in the center of the foam pad; however, this center was not marked so inconsistent placement could have occurred.

Future research should be completed to determine reliability of the i-mCTSIB using VSTBalance on an older adult population. As the older adult population could have a higher fall risk and more postural instability, this data could be useful for clinical applications. Additionally, the test-retest reliability of the i-mCTSIB on the VSTBalance in populations with different neurologic conditions such as multiple sclerosis, frontotemporal dementia, or Parkinson's disease could be analyzed. Finally, future research of within-day reliability with the VSTBalance is needed.

The current study findings suggest that the VSTBalance device could be used to assess body sway postural stability, which is a component of balance, using the i-mCTSIB test due to good to moderate test-retest reliability findings. The VSTBalance may be a feasible option for clinicians to administer initial balance assessments or assess interventional changes in balance. Reliability improved from Day 1 to Day 2 across single trials indicating that familiarization with

the protocol or device may have been impactful, however, this improvement did not result in changing the magnitude of reliability (for example from moderate to good reliability). Between-day reliability was higher than within-day reliability for this device which implies that clinicians should use the averages of multiple trials when assessing balance performance change across time for each condition of the i-mCTSIB test using the VSTBalance. Specifically, since Watson and Trudelle-Jackson found good to excellent within-day reliability with the average of 3 trials (23), performing 3 trials may be recommended to improve within-day reliability of the VSTBalance. Given that performing the average of 3 trials of each i-mCTSIB condition may not be feasible in the clinic, clinicians may need to defer to the psychometric properties (SEM and MDC) reported in this study for single trials.

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