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Short communication

BTrackS limits of stability test is a reliable assessment of volitional dynamic postural control

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ABSTRACT

Background: Unconstrained limits of stability assessment reveals aspects of volitional postural sway control that are inaccessible by other means. Prior versions of this assessment include instructions to sway towards pre-defined targets, and may not capture the full capability of the individual.
Research question: This study sought to establish the test-retest reliability of a novel limits of stability protocol.
Methods: Volitional sway area was determined during unconstrained trials, where participants were instructed to explore their ability to sway towards the perimeter of their base of support. Visual feedback was provided via computer monitor. Forty healthy young adults (mean age = 20.2 ± 1.3, 15 males, 25 females) participated in this study. Trials were collected in three sessions, repeated at the same time of the same day, with one week between. Reliability was assessed using IntraClass Correlation Coefficients (ICC), considering the total area of sway as well as quadrant level area.
Results: Reliability was moderate between the first and second session (0.583), and much higher 0.921) between the second and third session. The quadrant level reliability was poor to excellent (0.183 − 0.791), with similar trends between the three sessions.
Significance: Ultimately, these results indicate that the novel limits of stability test is reliable. However, it is recommended that a practice trial be conducted prior to baseline establishment.

1. Introduction

Investigating postural sway (i.e. balance) has revealed context-dependent and goal-specific behavior [1–3], multi-sensory contributions [4] signatures of aging [5], and disordered neuromotor function [6]. Traditionally, assessments of standing have been “static” in nature, following the instruction to “stand as still as possible”. Data (Fig. 1A) is commonly analyzed to describe characteristics of the amount of sway (e.g. pathlength, ellipse area) [5,7] and descriptions of its spatio-temporal variations (e.g. sample entropy, recurrence quantification analysis) [8]. Despite its widespread usage, static posture analysis only explores aspects of non-volitional sway and fails to capture aspects of more dynamic, volitional behavior.

Given that most postural control errors occur during dynamic actions (e.g. transition to walking, turning) [9], it is necessary to also assess sway control during volitional action. By asking participants to move, rather than stand still, during a posture trial, new aspects of postural sway can be studied. This approach has been termed a “limits of stability” (LoS) task, wherein the instruction is some variation of “move around, by leaning, to explore your base of support” [10]. To date, and essentially unchanged since original implementation, LoS testing has only been employed in a quasi-dynamic, targeted volitional sway (TVS) task with a set of mechanical and anthropometric-based constraints instructing individuals to “lean to pre-specified targets” (Fig. 1B) [10–12]. The trajectory of sway from static center to the target location is then evaluated for speed and accuracy [11].

The TVS version of LoS is, therefore, limited by an inability to get people to their true/genuine boundaries of self-support, due largely to suboptimal target placement. Assessment metrics from this task also suffer from computational complexity [11]. These limitations leave the assessor with incomplete insight to the participant’s complete self-generated and self-limited sway tolerance. A new undirected volitional sway (UVS) task was recently introduced for the Balance Tracking System (BTrackS). The BTrackS LoS assesses the total area that a person explores of their own determination (Fig. 1C). Specifically, a behaviorally driven decision of boundary placement is made by persons swaying to their tolerance. As they achieve positions further than previously travelled, the area between that distal point and their origin is

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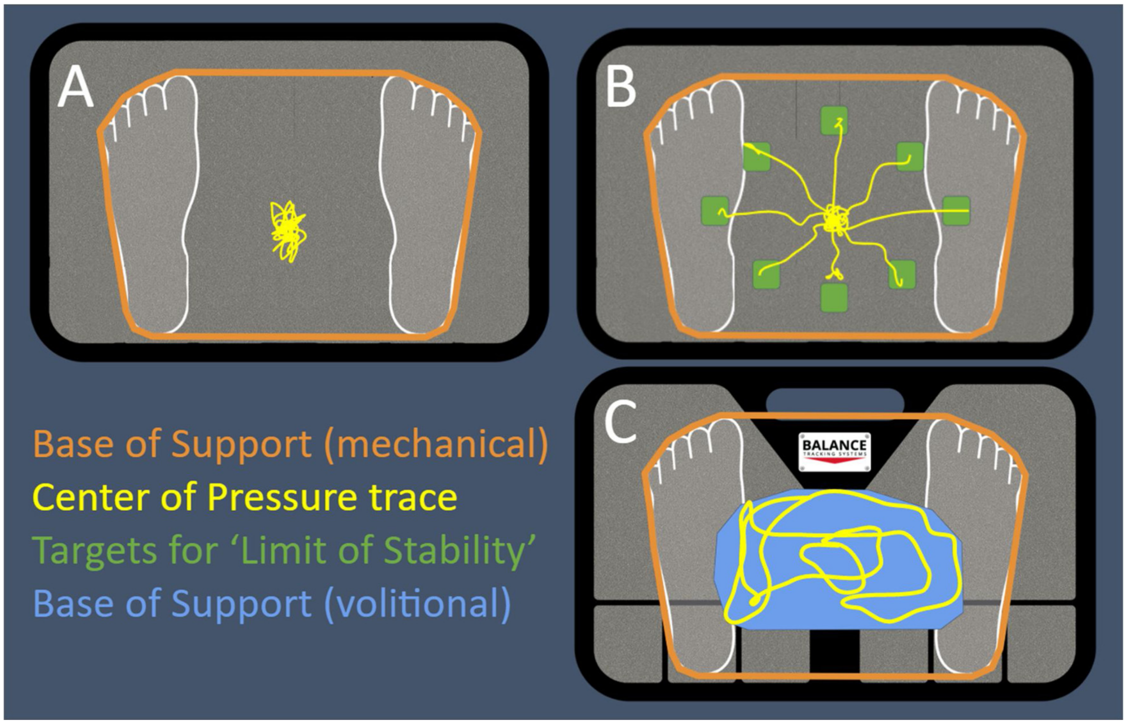

Fig. 1. Top-down views of the force plate during (A) traditional test of static posture, (B) traditional Limits of Stability, and (C) the novel BTrackS Limits of Stability. Mechanical base of support is defined as the perimeter around the set of contact points of the body with the ground, which in this case is the perimeter encompassing the two feet on the force plate. The volitional base of support is the area within which the person travels during intentional postural sway excursions.

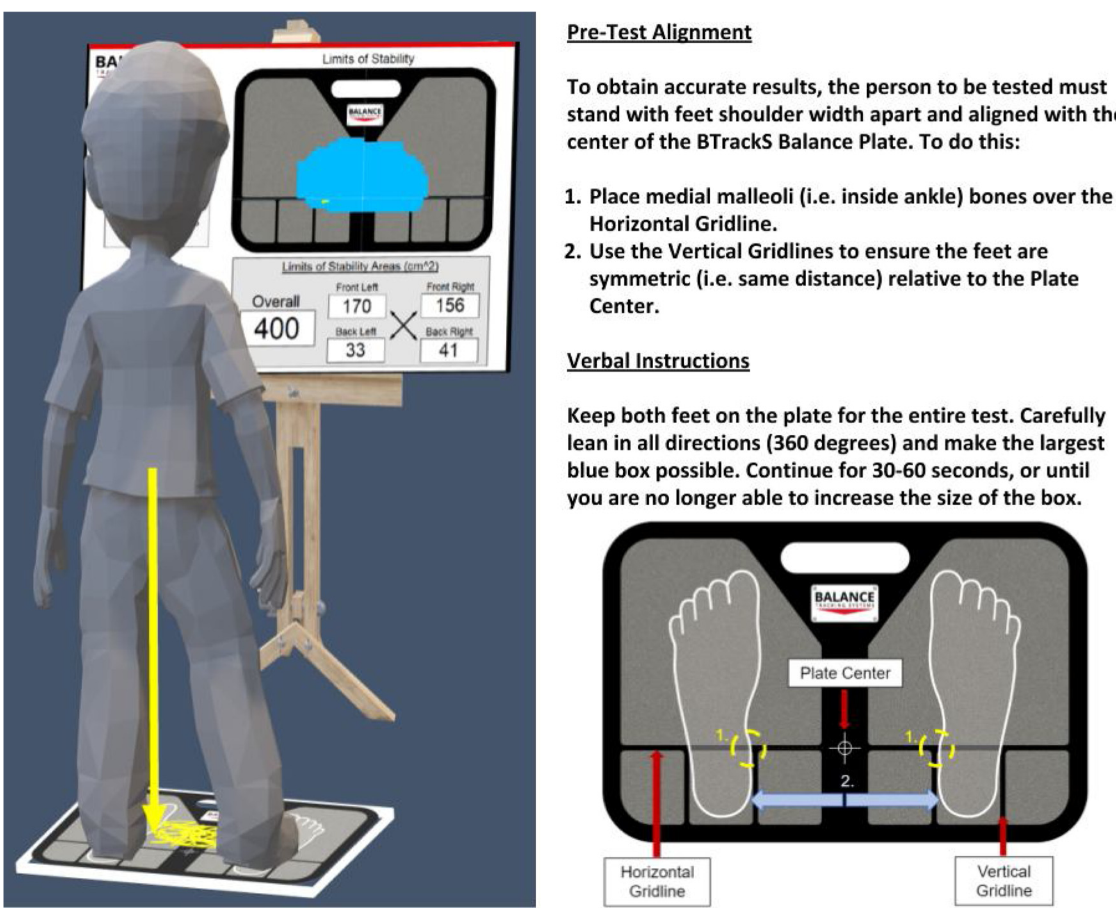

Fig. 2. Guidance for foot alignment and verbal instructions for participants for the limits of stability test (Adapted with permission from BTrackS Assess Balance, v5.5 Supporting Documentation).

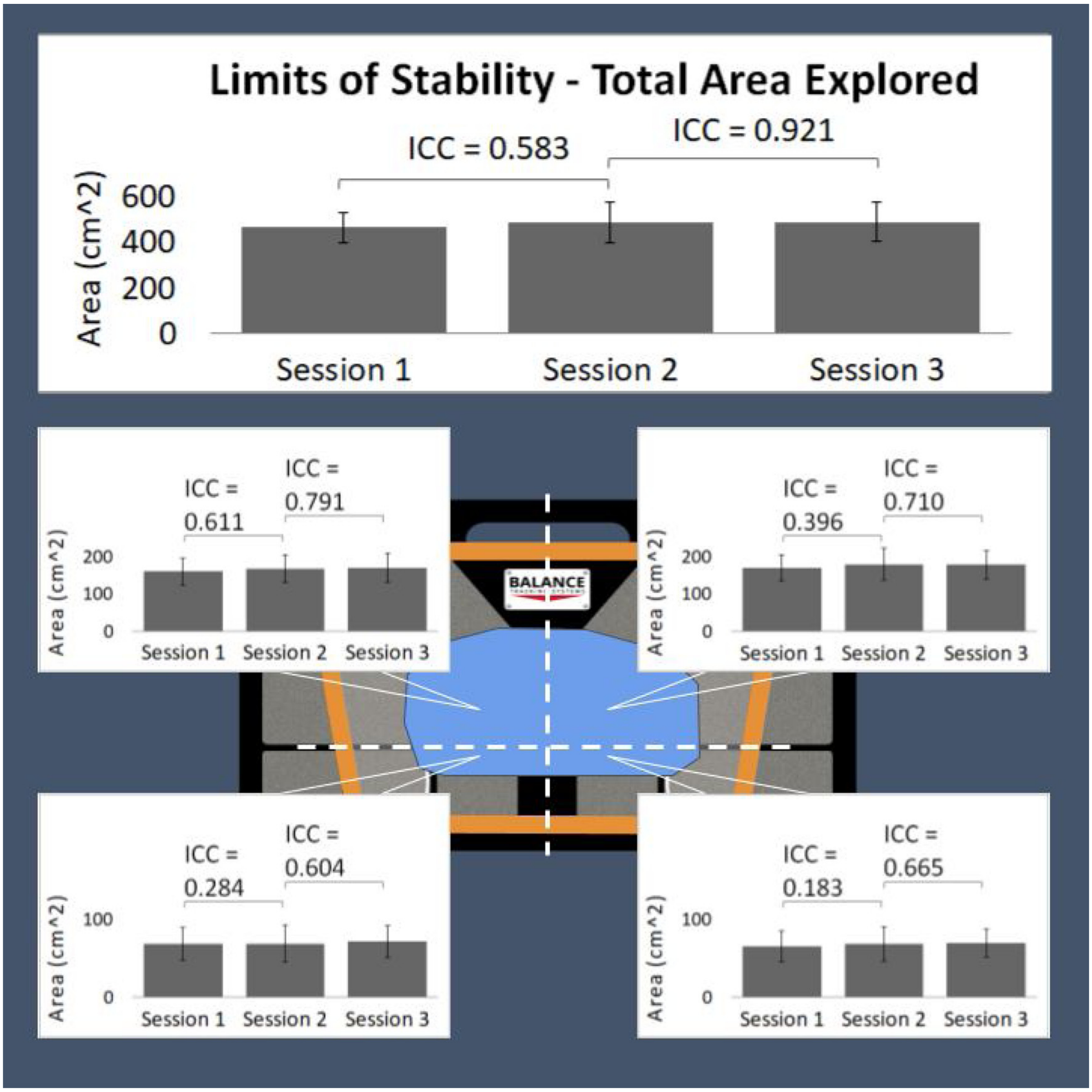

Fig. 3. Results of the Limits of Stability testing. The upper panel indicates the mean total area explored during each of the three sessions, as well as the ICC values. The lower four panels indicate the quadrant level areas. Error bars indicate standard deviation, with the y-axis units in area (cmˆ2).

labelled as travelled. The final test metric is the size of the accumulated area travelled at any point in the trial. This protocol likely provides greater insight into the impact of subjective personal factors revealed in sway dynamics.

The current study aimed to provide the first examination of the reliability of the BTrackS LoS protocol. Reliability is a key factor in determining the quality of a test; accomplished in this study by performing LoS testing at three time points, separated by one week in duration. We hypothesized that the BTrackS LoS would be at least as reliable (i.e. moderate/good) as pre-existing TVS-type LoS procedures [12]. These results would validate the use of BTrackS LoS as a reliable means of gaining more complete measure of volitional, dynamic postural ability.

2. Methods

2.1. Participants

Forty healthy young adults (age = 20.2 ± 1.3 years; 15 males, 25 females) participated, recruited by convenience. Participants were deemed healthy by answering “no” to all questions on the Physical Activity Readiness Questionnaire (Par-Q) [13]. All participants provided written consent and the study protocol was approved by a university institutional review board.

2.2. Protocol

Participants visited the lab three times, on the same day and time each week, where they performed a single LoS trial lasting up to 60 s. Weekly tests were chosen as they were thought to represent a typical use case in clinical environments.

LoS was performed on the BTrackS Balance Plate, connected to a laptop running BTrackS Assess Balance Advanced Software (version 5.5). As shown in Fig. 2, the participant used visual feedback from the monitor to maximize sway in all directions within 30–60 seconds. Instruction was given at the beginning of the trial to create the largest coverage area possible (displayed by an overlaid blue box), without lifting their feet off the plate. Performance on the BTrackS LoS Protocol was determined based on an algorithm built into the Assess Balance Advanced software. This algorithm calculates, in cmˆ2, the areas (Total and Quadrants - Front Left, Front Right, Back Left, and Back Right) in which a participant moves their center of pressure over the surface of the BTrackS Balance Plate. Area unfolds during the test as participants move further away from the center of the plate, which is defined as the midway point between the medial malleoli of the left and right feet. This area measurement assumes that all points between the center of the plate and the newly achieved location are achievable by the participant and shades the area accordingly. Final values of total and quadrant areas were provided by the software and recorded for further analysis.

2.3. Statistical design

To test for practice/learning effects, separate one-way repeated measures ANOVA (session number 1–3) were performed. Test-retest reliability was calculated using intraclass correlation coefficients [ICCs (2,1)] to confirm stability of results. Interpretations of ICC values were based on guidelines provided by Ciccetti and Sparrow (1981). Values below 0.40 indicated poor reliability, $0.40 - 0.59$ indicated fair reliability, $0.6 - 0.74$ indicated good reliability, and above 0.75 is excellent [14].

3. Results

Fig. 3 depicts the mean and standard deviations of the total and quadrant areas for each of the sessions, as well as the ICC values. LoS performance did not significantly differ across testing days for total area ($F_{2,123} = 0.73$, $P = 0.48$) or any of the four quadrant areas (cmˆ2) - front left ($F_{2,123} = 0.97$, $P = 0.58$). front right ($F_{2,123} = 0.6$, $P = 0.54$), back left ($F_{2,123} = 0.16$, $P = 0.85$), or back right ($F_{2,123} = 0.44$, $P = 0.64$). Despite this, ICC results for the Total area had fair reliability from the first to second testing session (ICC = 0.583), that improved to excellent reliability in subsequent sessions (ICC = 0.921). Quadrant level analysis indicates reliabilities from 0.183 to 0.611 (poor to good) for the first pair of trials, and $0.604 - 0.791$ (good to excellent) between subsequent sessions.

4. Discussion

The current investigation sought to establish the test-retest reliability of the BTrackS LoS protocol. Reliability improved for all measures when comparing the second to third trial versus the first to second trial ICCs. Second to third trial ICCs were all in the good to excellent range, supporting the recommendation that a practice trial is collected and discarded for optimum test-retest confidence.

The primary novelty of the BTrackS LoS is that it uniquely and reliably indicates volitional sway dynamics during unconstrained postural sway exploration. Quadrant level results indicate relatively large discrepancy between front and back sway areas, in both amount and reliability. One possible explanation is in the computational nature of ICCs, whereby a limited range of results due to smaller values reduces ICC. In this case, it is perhaps not surprising that the small aft sway of the BL/BR quadrants have less reliability, especially in the first trial. It is also possible that a genuine biomechanical (anthropometrics of the foot) or behavioral (inexperience with maximal rearward postural excursion) explanation is available. Further studies investigating lateral imbalances associated with various clinical conditions (e.g. vestibular dysfunction or joint pain) are planned.

It is possible that the LoS area is constrained by top-down factors (e.g. learning or pain state). Postural sway area was consistently reliable in the current UVS task, which reflects the same as during traditional static tasks [15]. Though without significant differences between trials, improved ICC reliability after the first trial indicates malleability of LoS. Further investigation is warranted to explore the degree of malleability due to interventions (e.g. stretching, strengthening) or mood (e.g. pain, motivation). The BTrackS LoS test, in isolation or combined with static sway area, may afford new insights into context-dependent and goal-specific effectors of postural sway regulation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

DG receives royalties from a pending patent (OMB 0651-0032) related to the balance technology in this study. In addition, he has an equity stake (i.e. stock options) and performs contract work for Balance Tracking Systems Inc., the parent company of the BTrackS Balance Plate and BTrackS Assess Balance software. This conflict is mitigated by a management plan put in place by his academic institution (i.e. Oakland University) to ensure the integrity of his research. The other authors of this work (JH, BK) have no conflicts of interest to declare.

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