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Test-retest reliability of a balance testing protocol with external perturbations in young healthy adults

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ABSTRACT

External perturbations are utilized to challenge balance and mimic realistic balance threats in patient populations. The reliability of such protocols has not been established. The purpose was to examine test-retest reliability of balance testing with external perturbations. Healthy adults (n = 34; mean age 23 years) underwent balance testing over two visits. Participants completed ten balance conditions in which the following parameters were combined: perturbation or non-perturbation, single or double leg, and eyes open or closed. Three trials were collected for each condition. Data were collected on a force plate and external perturbations were applied by translating the plate. Force plate center of pressure (CoP) data were summarized using 13 different CoP measures. Test-retest reliability was examined using intraclass correlation coefficients (ICC) and Bland-Altman plots. CoP measures of total speed and excursion in both anterior-posterior and medial-lateral directions generally had acceptable ICC values for perturbation conditions (ICC = 0.46 to 0.87); however, many other CoP measures (e.g. range, area of ellipse) had unacceptable test-retest reliability (ICC < 0.70). Improved CoP measures were present on the second visit indicating a potential learning effect. Non-perturbation conditions generally produced more reliable CoP measures than perturbation conditions during double leg standing, but not single leg standing. Therefore, changes to balance testing protocols that include external perturbations should be made to improve test-retest reliability and diminish learning including more extensive participant training and increasing the number of trials. CoP measures that consider all data points (e.g. total speed) are more reliable than those that only consider a few data points.

1. Introduction

Balance is frequently assessed in both research and clinical contexts in a variety of populations, and many different tools exist to quantify balance [1–3]. Balance deficits likely play a role in diminished physical function and place individuals at a greater fall risk [4]. Stable and reliable measures are needed if changes in balance are to be assessed in response to treatment, changes in disease status, or aging.

Force plates are frequently used to quantify balance. They measure center of pressure (CoP) and numerous methods exist to reduce complex CoP patterns to more manageable, discrete measures (e.g. standard deviation of CoP) [3,5]. Additionally, different protocols exist with varying conditions including leg position (e.g. double or single leg stance), eyes open or closed, and surface type [6]. Reliability of CoP measures has been examined in static situations when patients are expected to remain motionless. Studies found that CoP measures demonstrate moderate to good test-retest reliability over different balance conditions [7–9]. Other studies have found poor to fair test-retest reliability [10,11]. Discrepancies are likely due to differences in CoP measures, balance testing conditions, data processing, and study samples. However, there is sufficient evidence that force plate measures of balance provide acceptable reliability in various populations [7,8,12,13].

Balance can be further challenged by inducing either an internal or external perturbation. These balance threats should be considered because they occur within a range of daily activities such as standing on a moving bus. Force plates placed on translating platforms provide an opportunity to examine balance recovery following perturbations in a controlled and standardized manner. For instance, patients after anterior cruciate ligament reconstruction and patients with knee

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Table 1
A description of the center of pressure (CoP) measures.

CoP Measure	Description
$Range_{AP}$	Difference between maximum and minimum CoP position in the anterior-posterior direction [3]
$Range_{ML}$	Difference between maximum and minimum CoP position in the medial-lateral direction [3]
$Excursion_{AP}$	Absolute length of the CoP path movements (i.e. sum of distance between consecutive data points) in the anterior-posterior direction [3]
$Excursion_{ML}$	Absolute length of the CoP path movements (i.e. sum of distance between consecutive data points) in the medial-lateral direction [3]
Mean $Excursion_{AP}$	The mean of the absolute distances between the average CoP position and instantaneous CoP position in the anterior-posterior direction [5]
Mean $Excursion_{ML}$	The mean of the absolute distances between the average CoP position and instantaneous CoP position in the medial-lateral direction [5]
SD_{AP}	Standard deviation of the CoP position in the anterior-posterior direction [5]
SD_{ML}	Standard deviation of the CoP position in the medial-lateral direction [5]
Area	The area of an ellipse that captures 95% of the data points [3]
Max $Speed_{AP}$	The maximum of the absolute speed between adjacent CoP points in the anterior-posterior direction [5]
Max $Speed_{ML}$	The maximum of the absolute speed between adjacent CoP points in the medial-lateral direction [5]
Total $Speed_{AP}$	$Excursion_{AP}$ divided by collection time [3]
Total $Speed_{ML}$	$Excursion_{ML}$ divided by collection time [3]

osteoarthritis have demonstrated impairments in balance responses to external perturbations compared to healthy controls [14,15]. Muscle responses to these perturbations have also been investigated in healthy and patient populations [16,17]. External perturbations place greater demands on body systems responsible for maintaining balance and could be more sensitive at identifying balance deficits in patients compared to static tests.

Although balance responses to external perturbations are being measured, the reliability of these measures has not been established. Examining reliability is important if these measures are to be used to compare groups or examine change over time in response to disease progression or treatment. Furthermore, evidence exists that there is a learning effect in balance responses to external perturbations which could negatively impact reliability [14,18]. Therefore, the primary objective was to examine test-retest reliability of a balance testing protocol that includes external perturbations in healthy adults. Secondary objectives were to compare test-retest reliability between perturbation and non-perturbation tasks, and to comprehensively examine test-retest reliability of different CoP measures.

2. Methodology

2.1. Study design and participants

Healthy participants between 18 and 50 years of age were recruited using convenience sampling for this test-retest reliability study. They were recruited from the local community using advertisements and word of mouth. Exclusion criteria included: recent lower extremity injury (< 1 year), current lower extremity pain, previous lower extremity fracture, previous reconstructive surgery in the lower extremity, balance deficits (e.g. vestibular dysfunction), medical conditions affecting balance, and neurological conditions. Written, informed consent was obtained from participants and the study was approved by the local research ethics board.

A sample size calculation was performed using data from a previous test-retest reliability study of healthy participants that demonstrated intraclass correlation coefficients (ICC) greater than 0.80 for most CoP derived measures during non-perturbation balance conditions [7,19]. The required sample was 33 participants assuming ICC = 0.80, 95% confidence interval rate of 0.25, and two visits. To account for potential drop-out, a 5% attrition rate was added resulting in 35 participants. One participant did not complete both visits. Thus, 34 participants (18 women) were included in analyses. The sample had a mean (standard deviation) age of 23(2) years, height of 1.72 (0.08) m, weight of 63.93 (9.52) kg, and body mass index of 21.5 (2.2) kg/m^2.

2.2. Data collection

Data were collected over two visits separated by three to 14 days. Testing was performed on a force plate (OR6-6-2K-7575, AMTI) sampled at 1000 Hz securely attached to a custom perturbation platform (H2W Technologies) and these equipment moved in unison. The perturbation platform can translate in anterior-posterior and medial-lateral directions. Four reflective markers were placed on the force plate corners to determine when force plate translation began and ended. Reflective marker position was recorded using an eight camera system (T20, Vicon) sampled at 100 Hz. Marker and force plate data were recorded using commercial software (Vicon Nexus v1.8.5).

Ten balance conditions were examined. This included six perturbation conditions with eyes open: 1) double leg stance with anterior perturbation, 2) double leg stance with posterior perturbation, 3) double leg stance with right perturbation, 4) double leg stance with left perturbation, 5) single leg stance with anterior perturbation, and 6) single leg stance with posterior perturbation. Non-perturbation conditions included: 7) double leg stance with eyes open, 8) double leg stance with eyes closed, 9) single leg stance with eyes open, and 10) single leg stance with eyes closed. The balance conditions were based on pilot testing and previous studies [8,12,14,18,20], and were tasks that participants could consistently complete. Participants were placed at the center of the force plate, barefoot with feet at shoulder width, and hands on hips. They were instructed to stare at a marked X on the wall at eye level, and they wore a safety harness. For single leg stance conditions, test leg was randomly chosen (17 right, 17 left) and it was the same leg for both visits. The non-study knee was bent to 90° with 0° of hip flexion, while the study knee remained in slight flexion. Data recording for double leg stance conditions lasted 35 s with no rest between trials; single leg stance conditions lasted 15 s and a standard rest period of 20 s was provided between these trials. Also, participants were allowed additional rest as required and they were prompted to take this rest to minimize fatigue. For perturbation conditions, external perturbations occurred within the first 3 s of data recording, which was chosen by an investigator. External perturbation parameters were initially based on previous research, but were modified based on pilot testing; the platform accelerated at a maximum of 600 mm/s^2 with an amplitude proportional to each participant's body height (perturbation amplitude = 0.06 × height) [14,18]. Each condition was performed three times, for a total of 30 trials [21]. If the participant was unable to maintain the position (i.e. fall, step) during a given trial, it was discarded and restarted. Participants had two attempts to successfully complete each trial. The number of discarded trials was recorded.

2.3. Procedure

Demographic information was collected including age, sex, height, weight, and body mass index. The testing protocol was explained to participants and they completed one practice trial for each condition at the beginning of the first visit. Practice was provided since previous studies have found differences between the first trial and subsequent