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RESEARCH ARTICLE

Lower Limb Asymmetry Evaluation Using the Balance Tracking System (BTrackS) Single Leg Stance Protocol

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ABSTRACT. Single Leg Stance (SLS) balance testing is a common means of determining lower limb asymmetries in motor behavior. The Balance Tracking System (BTrackS) Balance Plate is a low-cost, portable force plate for objectively obtaining balance measurements. The present study provides the first known balance results for the BTrackS SLS protocol. BTrackS SLS testing was conducted on 161 young adults (90 women, 71 men) according to the test's standardized instructions. Specifically, participants performed one-legged (left or right) stance on the BTrackS Balance Plate for four, (2 practice, 2 actual) 20 s trials. SLS test outputs included total Center of Pressure path length and absolute symmetry index. Results showed that women had better SLS performance than men and that both sexes performed better on the actual compared to practice trial. Systematic one-sample t-tests of the Absolute Symmetry Index measures showed that a difference of 16% or greater between legs represented asymmetric performance. These results have clear value for individuals using BTrackS SLS testing to evaluate potential asymmetries. Additionally, these findings agree with previous reports showing sex differences favoring women on tests of static balance, and validate the use of a practice trial in the BTrackS SLS protocol.

Keywords: balance, unipedal standing, single leg stance, lower limb, asymmetry

INTRODUCTION

The human body demonstrates notable anatomical symmetry consisting of paired limbs, sensory organs and cerebral hemispheres. This higher-order symmetry has been shown to manifest itself in the performance of voluntary movements, particularly those that involve coupled actions of the upper and lower limbs (Goble et al., 2003; Goble & Brown, 2008; Sadeghi et al., 2000; Swinnen, 2002). For the lower limbs, it has been reported that performance differences of less than 10% are typically observed between the left and right legs, a phenomenon known as the "10% rule". The 10% rule is based on studies showing that individuals with inter-limb differences greater than 10% on highly coupled tasks such as running, jumping and walking have an increase in injury incidence (Gilliam et al., 1979; Grace et al., 1984).

To what extent the 10% rule applies to more unilateral, uncoupled tasks of the lower limbs remains unclear. The Single Leg Stance (SLS) test is a unilateral motor task that has commonly been utilized as a means of investigating "healthy" symmetry (Paillard & Noé, 2020). The SLS test consists of an individual standing as still as possible with one leg in contact with the ground, while the other leg is held off the ground through knee and/or hip flexion. There are two primary ways that SLS test are assessed. Most practically, SLS performance can be measured using a stopwatch to determine the amount of time (up to 60 s) that an individual can maintain balance without placing the elevated foot on the ground. This method is cost-effective, and easy to implement, but has clear ceiling effects that serve to limit the accuracy/reliability of its results (Condon & Cremin, 2014; Muehlbauer et al., 2014).

The second means of SLS performance assessment is a more sophisticated approach using force plate technology. Force plates objectively measure balance by sensing, with high accuracy/reliability, the amount of body sway an individual demonstrates during static standing activities. Specifically, a metric known as Center of Pressure (CoP) is calculated based on the weighted average of vertical forces created by an individual while standing on the force plate. CoP is a proxy for body center of mass location and CoP displacement represents control of body sway in such a fashion that generation of smaller CoP displacement values by an individual indicate better balance ability.

Despite their general acceptance as the "gold standard" for balance assessment, use of force plates for SLS testing has traditionally been modest. This is due to two main contributing factors—high cost and poor portability. Fortunately, new generation force plates now exist that address these barriers, providing a practical and more accessible solution for researchers and clinicians (Walsh et al., 2021). One such technology, the Balance Tracking System (BTrackS) Balance Plate, provides an SLS test protocol with several unique features. Indeed, the BTrackS SLS test is short in duration, consisting of just four, 20 s trials. The protocol also quantifies left and right foot differences in SLS using a software-based calculation of the Absolute Symmetry Index (ASI).

Given that there is no known study of the BTrackS SLS protocol to date, the present study sought to provide the first evaluation of performance data from BTrackS SLS testing. To accomplish this, a large sample of healthy men and women were asked to perform left

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versus right leg stance standing conditions according the standardized BTrackS SLS test instructions. It was hypothesized that greater asymmetry would be seen between left and right legs compared to the 10% rule, due to the unilateral, uncoupled nature of SLS testing. It was also predicted that women would have better SLS performance than men and that performance would be better following the pre-defined practice trial in the SLS protocol. Taken together, these results would have substantial value for researchers and clinicians using the BTrackS SLS protocol to determine potential asymmetries that might exist beyond what is typical in healthy young adults.

MATERIALS AND METHODS

Participants

Participants for this study included 90 young women (mean ± SD age = 21.3 ± 1.8 years) and 71 young men (mean ± SD age = 21.8 ± 2.0 years) between the ages of 18 and 28 years. Participants gave written, informed consent and self-reported having no known balance impairment at the time of testing to the test administrator. Data was collected at multiple testing sites that included health fairs, community centers, fitness gyms, religious settings, and educational institutions, among others. Ethical approval for this human subjects research was obtained from the local University Institutional Review Board. All procedures were in accordance with the Declaration of Helsinki.

Procedures

Equipment for this study consisted of the BTrackS Balance Plate and BTrackS Assess Balance Advanced software (see Figure 1). The BTrackS Balance Plate is a US Food and Drug Administration registered medical device that is lightweight (<7Kg) and portable. The force plate measures 0.4 × 0.6 m, has been validated against laboratory-grade force plates, and has high accuracy/reliability for measuring COP data (Goble et al., 2018; O'Connor et al., 2016; Richmond et al., 2018). The BTrackS Assess Balance Advance software was run on a windows laptop, which provided an interface for profile creation, test administration, and result interpretation. Minimal training was required to learn how to administer the BTrackS SLS protocol. Test administrators became proficient through multiple training sessions, by which an experienced user guided them through the testing of practice participants and interpretation of results.

Prior to data collection, the BTrackS Balance Plate was leveled on a hard surface using built-in height adjustable legs. The Plate was interfaced via USB to a laptop running the most recent version of BTrackS Assess Balance Advanced software (version 6.5.12) and a participant profile was created within the application. Testing then commenced following the standardized, pre-determined order of trials specified within the software. In total there were four, 20 s trials that began and ended with an auditory tone. The sequence of trials was such that the participant performed two initial "practice" trials followed by two trials that were deemed "actual" trials. The first practice and actual trial were performed on the left foot (see Figure 2a), while the second practice and actual trial were completed on the right foot (see Figure 2b). During trials, participants were instructed to lift their opposite foot at least 6 inches off the ground and to be as still as possible while standing on the plate. Participants were also asked to keep their hands on their hips. In the very rare case where a participant lost balance and stepped off the plate, the trial was stopped and redone. Occasionally (∼1 out of 10 tests), "touchdowns" of the elevated foot occurred and were allowed as long as the participants stance foot remained stable on the plate. The touchdowns were recorded as deflections in COP by the BTrackS Assess Balance Advanced software, as has been previously validated for SLS force plate conditions (Chang et al., 2014).

FIGURE 1. Equipment used in this study included the BTrackS Balance Plate (bottom right) and BTrackS Assess Balance software running on a Windows laptop (top left).

Data Analysis

BTrackS SLS results were constrained to those outputted by the BTrackS Assess Balance Advanced software, as would be typical of real-world users. These consisted of Total CoP Path Length, which is a proxy for the magnitude of body sway, and ASI. Total CoP Path Length was determined by first quantifying point to point CoP Path Lengths according to the following formula:

$$CoP\ Path\ Length = \left((CoPx2 - CoPx1)^2 + (CoPy2 - CoPy1)^2 \right)^{0.5}$$

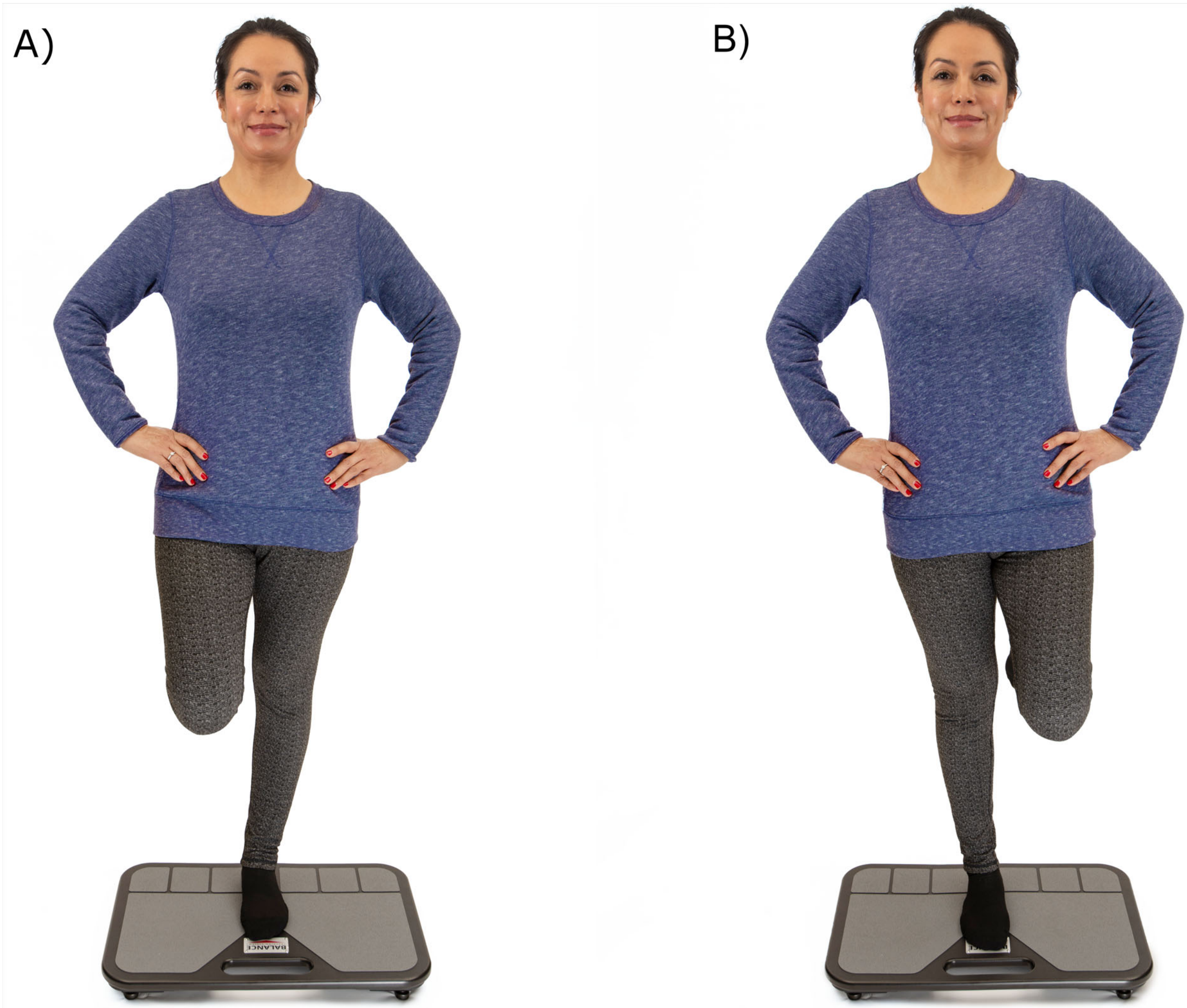

FIGURE 2. Testing positions for the BTrackS SLS test protocol. A) Standing on the left foot with right foot lifted up off the BTrackS Balance Plate. B) Standing on the right foot with left foot lifted off the BTrackS Balance Plate. In all trials the participant's eyes were open and hands were placed on the hips.

where, CoP_{x2} and CoP_{x1} are adjacent time points in the CoP_x (medial/lateral) time series and CoP_{y2} and CoP_{y1} are adjacent time points in the CoP_y (anterior/posterior) time series. The sum of all CoP Path Lengths (i.e. displacement) was then determined to get Total CoP Path Length.

ASI was calculated by determining the percentage difference in performance between the legs for all participants according to the following formula:

$$\mathbf{ASI}\% = \left| \frac{\boldsymbol{L-R}}{\left(\frac{\boldsymbol{L+R}}{2}\right)} \mathbf{x}100\% \right|$$

where *L-R* represents the difference in Total CoP Path Length between the Left (L) and Right (R) leg conditions, and $\frac{L+R}{2}$ indicates the average Total CoP Path Length between Left (L) and Right (R) leg conditions. For these analyses, higher ASI values are indicative of a greater asymmetry between legs (Błażkiewicz et al., 2014).

Statistical Analysis

Statistical main effects and interactions for Total CoP Path Length were assessed using a 3×2 Analysis of Variance (ANOVA) according to the factors Leg (Right vs Left), Sex (Women vs Men) and Trial Type (Practice vs Actual). Repeated measures were implemented where appropriate. For the ASI measure, a one-way ANOVA was first conducted to determine any differences based on Sex (Women vs Men). Following that, a one sample t-test was applied to determine if the mean ASI value

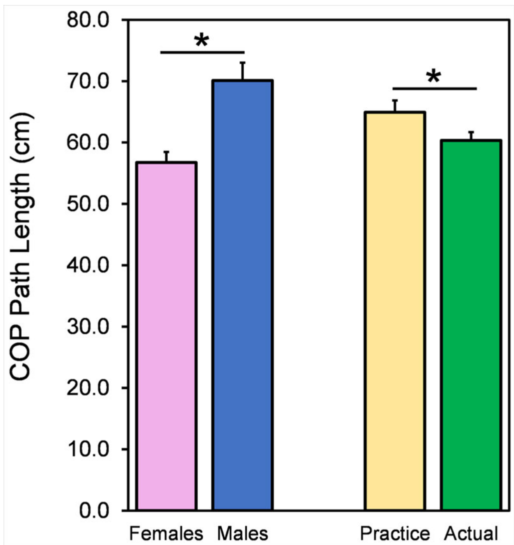

FIGURE 3. The two main effects determined by ANOVA for the Total CoP Path Length dependent measure. On the left, significantly less postural sway (i.e. Lower Total CoP Path Length) is shown for females versus males across leg and trial type conditions. On the right, a significant decrease in Total CoP Path Length is shown from the practice to actual trial regardless of sex or leg condition.

was significantly different from 10%, as would be ascribed by the 10% rule. Additional, systematic one-sample t-tests were performed to establish the lowest ASI value that was significantly greater than the mean ASI. The resulting value represented the SLS threshold for determining asymmetry in performance for healthy young adults. Analyses were conducted in SPSS (IBM, Armonk, NY) with significance of $p < 0.05$.

RESULTS

Two significant main effects were found based on the ANOVA model for Total CoP Path Length results. First, as shown in Figure 3, women had significantly lower Total CoP Path Lengths (i.e. better balance) than men, regardless of Leg or Trial Type ($F_{1,159}$=27.8, $p < 0.001$). Secondly, performance across leg and sex factors showed significantly less sway (i.e. lower Total CoP Path Length) in the Actual versus Practice trial ($F_{1,159}$=16.3, $p < 0.001$). There was no significant main effect demonstrating a difference between the left and right legs ($F_{1,159}$=0.7, $p = 0.39$) and no interactions between Sex, Leg and Trial type factors (all comparisons $F_{1,159}$<1.6, $p > 0.2$).

According to the ASI ANOVA, no significant differences existed between the amount of asymmetry displayed by men and women ($F_{1,159}$=0.2, $p = 0.69$). In this case, collapsed data across sexes was used, resulting in a mean ± SD ASI value of 13.5%±11.2%. One sample t-testing found that this mean ASI was significantly larger than the 10% value purported by the "10% rule" (t_{160}=4.0, $p < 0.001$). Further, systematic one-sample t-testing showed the lowest value significantly greater than the mean ASI performance of healthy young adults was 16% (t_{160}=-2.9, $p < 0.01$). That is, individuals with an ASI greater than 15% were significantly worse than the average test result.

DISCUSSION

The BTrackS SLS test is a short duration means of objectively assessing lower limb asymmetries in motor behavior using "gold standard" technology. The aim the present study was to provide the first evaluation of performance on this protocol, using a large sample of healthy adults. Based on the Total CoP Path Length measure, better performance was seen in women versus men, and on actual versus practice trials. Despite this, the ASI for men and women did not significantly differ on actual trials, and was significantly higher than that suggested by the 10% rule. Specifically, it was shown that asymmetries up to 15% are typical of healthy young adults and, as such, ASI values of 16% or greater should be interpreted as being representative of significant limb asymmetry.

The finding that women had lower Total CoP Path Length (i.e. less sway) than men on the BTrackS SLS test protocol is in line with numerous studies across a variety of balance protocols (Allison et al., 2015; Era et al., 2006; Goble et al., 2019; Goble & Baweja, 2018; Rozzi et al., 1999). A possible explanation for this result could lie in the anthropometric differences between men and women, however, large-scale normative data approaches have found that body size factors (i.e. height, weight, BMI) only explain <2% of performance on the BTrackS Balance Test and modified Clinical Test of Sensory Integration and Balance (mCTSIB) respectively (Goble et al., 2019; Goble & Baweja, 2018). In such instances, it has been proposed that the advantage expressed by women on force plate balance assessments is a function of greater sensory feedback processing ability. In particular, it has been shown that women have a lower threshold (i.e. higher sensitivity) for cutaneous and somatosensory stimuli on the bottom of the foot than men (Halonen et al., 1986).

Total CoP Path Length was significantly lower in the actual versus practice trials of the BTrackS SLS test. This finding validates the use of a practice trial to help account for familiarization effects associated with performing a novel task such as SLS. Some previous studies investigating SLS have included practice trials, but have not addressed the impact the trials have on the results of data collected (Ageberg et al., 2001; Muehlbauer et al., 2014). In contrast, a study that investigated the Star Excursion Balance Test (SEBT) suggested that testing reliability is moderate or better after a participant has an adequate number of practice trials (Gribble et al., 2013). To what extent additional practice trials on the BTrackS SLS test might further improve the accuracy and/or reliability of results is currently unknown, but future work is planned to explore this possibility.

The ASI findings in this study were incongruent with the 10% rule advocated in previous literature on lower limb symmetry (Gilliam et al., 1979; Grace et al., 1984). Indeed, the average young adult tested in this study had significantly greater than 10% asymmetry between left and right leg SLS performance, with a threshold of 16% ASI needed to show asymmetric performance beyond that of the average young adult. Greater research is needed to understand the mechanism underlying this finding, however, a possible explanation lies in the nature of SLS testing. Specifically, SLS is a unilateral movement activity where the left and right limbs are performing tasks independently without notable coupling. In contrast, much of the previous work emphasizing the 10% rule has focused on bilaterally coupled activities such as walking or running.

LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

There are several limitations to the present study that are worth noting and addressing in future research efforts. First, testing occurred at multiple sites rather than in a single lab setting. Although this approach had the benefit of allowing for a larger, more diverse sample of participants to be tested, environmental differences likely added "noise" to the overall results. Second, the protocol in this study was "fixed", as it was pre-determined by the standardized protocol built into the BTrackS Assess Balance Advance software. In this case, the left foot stance condition always preceded the right foot stance condition, and it is unclear whether there was some benefit for the right foot stance results based on a previous practice trial by the left foot.

A third limitation of this work was an inability to determine any potential effects due to limb dominance. In this case, however, it is worth noting that there were no significant differences found between left and right foot stance conditions, in a sample that was likely to consist of primarily right leg dominant individuals. Supporting this notion is a recent review study by Paillard and Noé (2020), that found no consistent evidence of a performance difference between dominant and non-dominant limbs on single leg stance tests. The last limitation worth mentioning for this study is that the sample was limited to young adults who self-reported being in good health and having no balance issues at the time of testing. To what extent the results from this population of participants is generalizable across various age ranges and clinical conditions remains unclear. Follow-up studies are planned that will seek to obtain a more representative sample that targets broader participant age ranges and inclusion of disease characteristics.

CONCLUSION

In conclusion, this present study provided the first known set of testing results for the BTrackS SLS protocol. While sex and practice trial differences were seen in Total CoP Path Length that align well with previous research, the amount of asymmetry shown by typical young adults in this study was significantly greater than the previously reported 10% rule. In this case, the results of the present study suggest that a value of 16% or greater should be used as a threshold for determining asymmetry on the BTrackS SLS test protocol. Implementing this recommendation will provide a better standard of evaluation for results in both the laboratory and clinical settings.

DECLARATION OF INTEREST STATEMENT

DJG is eligible for royalties from a patent (OMB 0651-0032) related to the technology used in this study. In addition, he has an equity stake (stock options) in Balance Tracking Systems, Inc. This financial conflict of interest is mitigated by a management plan put in place by his academic institution to ensure the integrity of his research. The authors report no other conflicts of interest in this work.

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