An Initial Evaluation of Results from the Balance Tracking System (BTrackS) Single Leg Stance Protocol

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Abstract

Background: The Single Leg Stance (SLS) test of static balance is a common means of assessing left versus right lower limb asymmetry. Recently, a SLS protocol was made available for the Balance Tracking System (BTrackS) Balance Plate, a low-cost, portable force plate for objective balance measurement.

Research Question: The present study sought to generate an initial set of balance results for the BTrackS SLS test.

Methods: BTrackS SLS tests were conducted on 161 young adults (90 women, 71 men) between the ages of 18 and 29. Participants stood as still as possible the BTrackS Balance Plate for four (2 practice, 2 actual), 20s trials with hands on hips. The first and third trial were performed standing on the left foot, while the second and fourth trials were performed on the right foot.

Results: An ANOVA for Total Center of Pressure (CoP) Path Length (i.e. body sway) found women had better SLS results then men, and that performance improved from practice to actual trials. Analysis of an Absolute Symmetry Index (ASI) measure showed that a difference of 16% or greater between legs (higher than the 10% rule) represented the threshold for asymmetric performance beyond the average adult.

Significance: These results have practical value for those researchers and clinicians using the BTrackS SLS, informing decisions involving the presence or absence typical lower limb symmetry. Additionally, they support the use of a practice trial in the BTrackS SLS protocol and agree with previous results showing sex differences favoring women on tests of static balance.

1. Introduction

The human body demonstrates clear structural symmetry consisting of paired limbs, sensory organs and cerebral hemispheres. Despite this, the control and execution of voluntary movement differs between the left and right sides of the body, particularly for the upper [1] and lower [2,3] limbs. With respect to the latter, it has been assumed that performance differences between the left and right legs should not exceed 10% in typical individuals, also known as the "10% rule". The 10% rule was determined based on studies showing an increase in injuries for individuals beyond the 10% threshold [4,5]. To date, the 10% rule has been applied primarily to bilateral lower limb activities with a high degree of coupling such as running and walking.

With respect to unilateral, uncoupled movements, the Single Leg Stance (SLS) test has commonly been employed as a means of symmetry investigation [6]. 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 main ways to assess performance on the SLS performance. The first is using a stopwatch to determine the amount of time (up to 30s or 60s) that an individual can maintain balance without placing the elevated foot on the ground. In a study investigating SLS performance in a netball club, Clark and Mullally implemented this method to measure balance until participants failed to maintain balance [7]. This method is cost-effective and easy to implement, but has clear ceiling effects that serve to limit the accuracy/reliability of its results [8,9]. This method is also based on researcher perception, and provides minimal insight on lower limb movement while standing still.

A second, more sophisticated means of determining SLS test performance is via a force plate balance assessment. Force plates objectively measure balance by sensing, with high accuracy/reliability, the amount of body sway an individual demonstrates during balance activities.

Specifically, a metric known as Centre 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 therefore represents body sway. In this case, smaller CoP displacement values indicate less body sway and better balance ability.

Despite being accepted as a “gold standard” for balance assessment, use of force plates for SLS testing has traditionally been modest due to two main 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 [10]. One such technology, the Balance Tracking System (BTrackS) Balance Plate, recently released a SLS test protocol for asymmetry testing. The BTrackS SLS test consists of four 20s trials alternating between left and right foot standing. Following testing the software generates a measure of performance symmetry between the legs in the form of an Absolute Symmetry Index (ASI).

While the SLS test is popular to assess asymmetries, there is limited literature to establish whether the 10% rule can be applied to indicate good health. Regardless, there is a multitude of information reported by the literature on leg preference and differences between the lower limbs. Seven studies have demonstrated no significant differences between right and left leg performance [7, 8, 11-16]. Five demonstrate better balance on the right leg, and one found better performance on the left leg [7,13,15, 17-19]. While these address findings with lower limb differences, more is needed to address the applicability of the 10% rule.

The purpose of the present study was to generate the first set of balance results for the BTrackS SLS test. Specifically, a relatively large sample of healthy men and women performed left versus right leg stance conditions according the BTrackS SLS test protocol. 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. This result would inform use of the BTrackS SLS for determining “typical” performance in clinical/research settings. It was also predicted that there would be no significant group-wide performance difference between left versus right leg stance conditions. This hypothesis was based on evidence in previous literature indicating an overall lack of limb differences on SLS tests [6].

2. Methods

2.1 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. Data was collecting 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-based research was obtained from the Institutional Review Board of Oakland University, and all procedures were in accordance with the Declaration of Helsinki.

Experimental Equipment and Procedures

The equipment for this study consisted of the BTrackS Balance Plate and BTrackS Assess Balance Advanced software (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 x 0.6 m and has high accuracy/reliability for measuring COP data [20-22]. The BTrackS Assess Balance Advance software was run on a windows laptop, which provided an interface for profile creation, test administration, and result interpretation. Due to the user-friendly nature of the software, minimal training was required to learn how to administer the BTrackS SLS protocol. Indeed, test administrators became proficient within several "training" sessions guided by an experienced user.

Prior to testing, the BTrackS Balance Plate was leveled on a hard surface using built-in height adjustable legs. The Plate was then interfaced with the laptop running the software via a USB connection, and a profile was created within the BTrackS Assess Balance Advanced software. Following this setup, testing commenced consisting of four, 20s trials that began and ended with an auditory tone. The sequence of trials was standardized such that the first two trials were "practice" trials, and the last two trials were "actual" trials. The first and third trials were performed while standing on the left foot (Figure 2a) and the second and fourth trials were completed on the right foot (Figure 2b). Below are the specific software instructions for the protocol:

> You are about to perform the BTrackS Single Leg Stance Test. This test consists of two, 20 second trials of standing on your left leg and two, 20 second trials of standing on your right leg. For each trial, you will stand as still as possible on the BTrackS Balance Plate with your eyes open, hands on your hips, one foot centered in the middle of the BTrackS Balance Plate and one foot raised at least six inches off the plate. You will hear a tone at the beginning and end of each trial. Your test result will compare the Center of Pressure path length from the forces you placed on the plate during the second left and right leg stance trials. A difference of more than 15% indicates an asymmetry between the left and right stance conditions.

During the trials, participants were instructed to lift there 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. If a participant lost balance, such that they stepped off the plate, the trial was redone.

<u>Data Analysis</u>

BTrackS SLS testing results were determined by the BTrackS Assess Balance Advanced software. These results consisted of Total CoP Path Length measure, which is a proxy for the magnitude of body sway and an ASI. Total CoP Path Length was determined by first quantifying point to point CoP Path Lengths according to the following formula:

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

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. BTrackS has a manufacturer-specified collection frequency of 25Hz, resulting in 500 data points for each 20s trial.

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

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

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.

Statistical main effects and interactions for Total CoP Path Length were assessed according to the factors Sex (Women vs Men), Leg (Right vs Left) and Trial Type (Practice vs Actual) using a 3x2 Analysis of Variance (ANOVA). Repeated measures were implemented where appropriate. For the ASI measure, a one-way ANOVA was first conducted to determine differences based on

Sex (Women vs Men). Following that, a one sample t-test was applied to determine if the mean ASI value was significantly different from 10%, as would be ascribed by the 10% rule. Further, a series of one-sample t-tests was performed to establish the lowest ASI value that was significantly greater than the mean ASI. This value represents the SLS threshold for determining asymmetry in performance for healthy young adults. Analyses were conducted in SPSS (IBM, Armonk, NY) with significance of $p<0.05$.

3. 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. less sway) 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, there were no significant differences between the amount of asymmetry displayed on the BTrackS SLS 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 paired t-testing showed the lowest value significantly greater than the mean ASI performance of healthy young adults in this study was 16% ($t_{160} = -2.9$, $p < 0.01$). Table 1 demonstrates the results of that t-testing, indicating the range of values representing no significant difference between the average ASI was 12-15%.

4. Discussion

The present study sought to produce an initial set of balance results for the BTrackS SLS test from a large sample of healthy men and women. With respect to Total CoP Path Length, the results showed better performance by women versus men, and on actual versus practice trials. There was no significant difference between left and right legs. Further, an ASI measure revealed that the mean SLS result across men and women was significantly higher than the 10% rule. Specifically, an ASI value of 16% or greater on the BTrackS SLS test was found to indicate performance that is more asymmetric than that of the typical young adult.

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 [23-27]. While a possible explanation for this result could lie in the anthropometric differences between men and women, large-scale normative data approaches have found that general body size factors (i.e. height, weight, BMI) explained less than 2% of performance on the BTrackS Balance Test and modified Clinical Test of Sensory Integration and Balance (mCTSIB) respectively [26,27]. Alternatively, 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 threshold for sensing cutaneous/somatosensory stimuli on the bottom of the foot is lower in women than men [28].

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 [8,29]. In contrast, a recent 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 [30]. Researchers studying the SEBT test found that 4-6 practice trials are enough before a participant begins to experience a learning effect [30]. 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 [1,2]. 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 the average young adult. While greater research is needed to understand the mechanism underlying this finding, a possible explanation lies in the type of task BTrackS SLS testing represents. Specifically, BTrackS SLS is a unilateral movement activity where the left are right limbs are performing tasks independently without notable coupling. There is an increase in postural constraints, with a weight transfer to the testing leg that can result in alterations in balance performance [31]. A unilateral stance like the SLS also requires more neural control over the trunk and lower limb due to the increased constraints [31]. In contrast, much of the previous work emphasizing the 10% rule has focused on bilaterally coupled activities such as walking or running.

There are several limitations to the present study that are worth of note 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. In addition, 100% adherence to protocol instructions may not have been achieved by all participants, as oversight was seen by individuals trained on BBT testing rather than the authors.

Furthermore, the sample in the present study 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. Indeed, follow-up studies are planned that aim to obtain a more balanced sample that targets specific age ranges and disease characteristics.

A third limitation would deal with a lack of multiple testing conditions. This study only looked at asymmetries with the participants standing directly on the BTrackS place, with eyes open. The literature does incorporate alterations to SLS stance protocols, by implementing an eyes closed condition and the use of a foam pad [8]. Findings with these alterations demonstrate a deterioration of balance performance as the difficulty of the task increases [8]. Future research may call for a need to implement similar methods to the BTrackS SLS protocol in a way that can validate the reliability of asymmetry findings.

5. Conclusion

In conclusion, this present study provided an initial set of results for the recently developed BTrackS SLS test protocol. No significant differences were present between right and left stance conditions as a group. Women outperformed men, and participants improved from practice to actual trial data. While sex and trial type differences in Total CoP Pathlength align well with previous research, the amount of asymmetry shown by typical young adults was significantly greater than the 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 should provide a better standard of evaluation for results in both the laboratory and clinical settings.

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Figure Legends

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).

Figure 2. Testing positions for the BTrackS SLS test protocol. A) Participants stood on their left foot with right foot lifted up off the BTrackS Balance Plate for Trials #1 and #3.B) Participants stood on the right foot with left foot lifted off the BTrackS Balance Plate for Trials #2 and #4. In all trials eyes were open and hands were placed on the hips.

Figure 3. Demonstrates the two main effects determined by the ANOVA of Total CoP Path Length. The first main effect was that women had significantly less postural sway (i.e. Lower Total CoP Path Length) than males. The second main effect was a significant decrease in Total CoP Path Length from the practice to actual trial.

Table Legends

Table 1. Results of bootstrap analysis, showing that the range of values representing no significant difference from the average ASI was 12-15%. These values are indicated in bold font.


BALANCE
BTrackS Assess Balance
Start Protocol
View Results
Manage Profiles
Contribute Data

Figure 1.

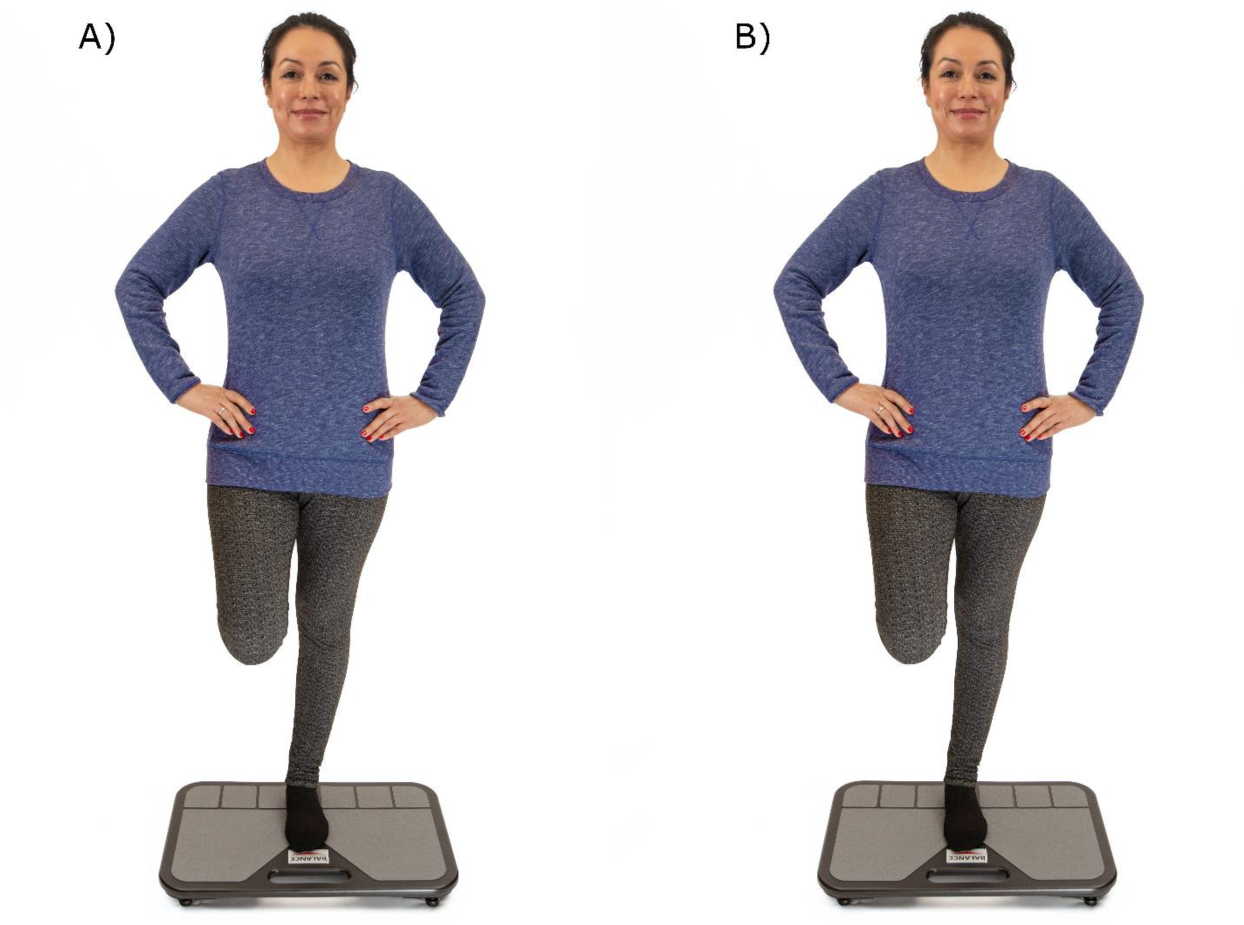

Figure 2.

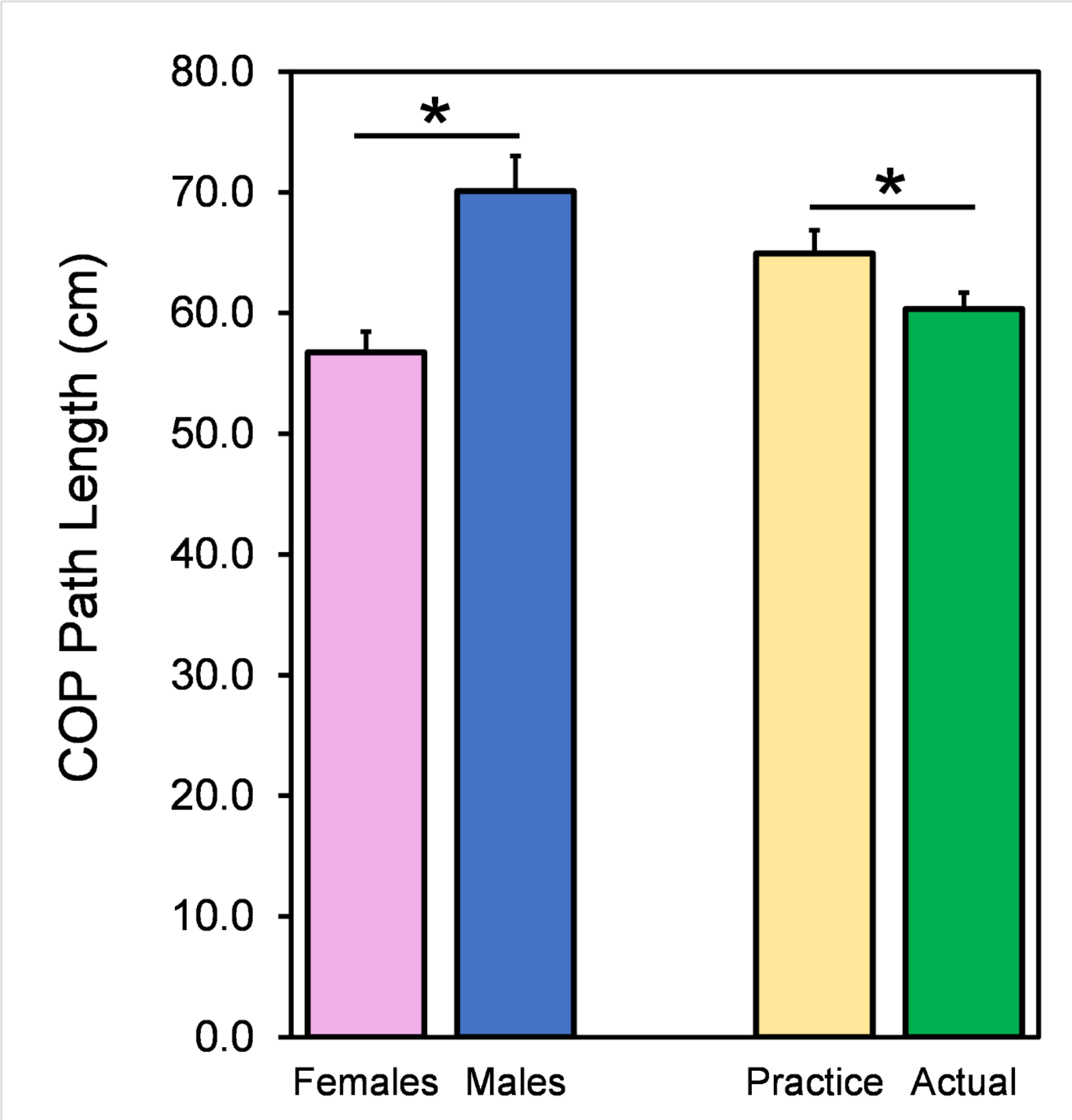
COP Path Length (cm)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
*
*
Females
Males
Practice
Actual

Figure 3.

	t	df	p
0	15.3	160	0.000
1	14.2	160	0.000
2	13	160	0.000
3	11.9	160	0.000
4	10.8	160	0.000
5	9.6	160	0.000
6	8.5	160	0.000
7	7.4	160	0.000
8	6.2	160	0.000
9	5.1	160	0.000
10	4.0	160	0.000
11	2.8	160	0.000
12	1.7	160	**0.094**
13	0.6	160	**0.583**
14	-0.6	160	**0.559**
15	-1.7	160	**0.087**
16	-2.9	160	0.005
17	-4.0	160	0.000
18	-5.1	160	0.000
19	-6.3	160	0.000
20	-7.4	160	0.000

Table 1.