Communication

The Relationship between Balance Confidence and Center of Pressure in Lower-Limb Prosthesis Users

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Abstract: Background: Agreement between the activities-specific balance confidence scale (ABC) and center of pressure (CoP) in prosthesis users is still very much unknown. The purpose of this study was to investigate the agreement between ABC and CoP in lower-limb prosthesis users. Methods: Twenty-one individuals with lower-limb prostheses were recruited. Participants were provided with the ABC scale and performed static balance tasks during eyes opened (EO) and eyes closed (EC) conditions whilst standing on a force platform. Pearson product moment coefficients between CoP displacements and ABC scores were performed. Participants were also stratified by those who had better ($\geq$80 on ABC scale) and less (<80 on ABC scale) perceived balance confidence. Displacement was compared using an independent t-test with Cohen's d to estimate effect size with alpha set at 0.05 for these tests. Results: There was a significant inverse moderate relationship between eyes opened displacement (EOD) (18.3 $\pm$ 12.5 cm) and ABC (75.1 $\pm$ 18.3%), $r = _{(19)} -0.58$, $p = 0.006$, as well as eyes closed displacement (ECD) (37.7 $\pm$ 22.1 cm) and ABC, $r = _{(19)} -0.56$, $p = 0.008$. No significant difference in EOD ($t_{(19)} = 1.36$, $p = 0.189$, $d = 0.61$) and ECD ($t_{(19)} = 1.47$, $p = 0.156$, $d = 0.66$) was seen between those with greater and less balance confidence. Conclusions: Self-report and performance-based balance outcome measures are recommended when assessing lower-limb prostheses users.

Keywords: prosthetics; balance; confidence; ABC; center of pressure; CoP; postural sway

1. Introduction

Loss of the lower-limb greatly effects a person's quality of life and hampers daily activities [1]. Persons with lower-limb amputations undergo musculoskeletal and motor-related visual cortex changes that may alter balance [2,3], and increase their risk of falling [4,5]. Lower limb prostheses avail opportunities for these individuals to return to independent living and essential activities of daily living [6]. An ability to continuously adjust the body's center of mass, anticipate perturbations and compensate accordingly remains a challenge for lower-limb prosthesis users. Passive protheses lack degrees of freedom and users must adopt new balance and coordination techniques through the integration of visual, vestibular and motor control systems [7]. In addition, the majority of persons wearing prostheses are older adults with comorbidities that further challenge balance [8–10].

Preservation of balance can be aided by proper prosthetic alignment and componentry [11], and even vibrotactile feedback [12]. Postural control can be assessed by measuring standing postural sway [13,14], as well as performance-based and self-report outcome measures [15,16]. Self-report balance confidence during daily activities can indicate mobility of using a prosthesis [17]. The activities-specific balance confidence (ABC) scale evaluates a person's belief in their ability to perform an activity [18]. The instrument has been used to understand amputee balance confidence [19,20], and has been tested for validity on

performance-based mobility measures of balance [20–23]. An ABC score of at least 77% out 100 is also suggested as a minimum score of balance confidence in lower-limb prosthesis users [17]. Alternatively, the center of pressure (CoP) trajectory may be recorded using force platforms to track real-time pressure of the resultant ground reaction forces beneath the feet [24]. Evaluating the displacement of this CoP may give insight into an individual's risk of falling [25]. However, despite the cost-effectiveness and ease of use of the ABC, it cannot provide quantitative measures of balance postural control.

Force platforms are a de facto standard and provide precise indices of CoP but are costly and restricted to motion analysis laboratories. The HUMAC Balance System (CSMi, Stoughton, MA, USA) is a valid portable and clinically oriented force platform [26]. The instrument has been used to explore postural sway of persons with anterior cruciate ligament (ACL) injury and lower-limb prosthesis [27,28]. Together, the ABC scale and instrumented postural sway make clinically useful outcome measurements. However, self-reports may be affected by recall or social-desirability bias [29,30]. Despite some exploring the agreement between the ABC and CoP in non-prosthesis users [31,32], few reports in lower-limb prosthesis users exists. Thus, the purpose of this study was to investigate the agreement between the widely used self-report ABC scale and instrumented postural sway in lower-limb prosthesis users.

2. Materials and Methods

2.1. Procedures

This study was approved by the Texas A&M University-San Antonio Institutional Review Board (Log#2021-38) and 21 participants between the ages of 34 and 75 years signed an informed consent form and participated in this study, Table 1. Requirements to participate were 18 years of age and older with a lower-limb amputation. Most (n = 9) participants experienced limb loss from trauma, while others experienced infection (n = 3), cancer (n = 3), diabetes (n = 2), Charcot–Marie–Tooth (n = 2), and congenital problems (n = 2). Participants were regular prosthesis users (0.5 to 60 years) with the ability to read and write in English.

Table 1. Participant characteristics.

Characteristics	Total (N = 21)	Male (n = 14)	Female (n = 7)
Age (y)	53.5 ± 12.8	51.7 ± 11.8	57.3 ± 14.8
Height (cm)	171.9 ± 9.2	176.6 ± 5.9	162.6 ± 7.4
Mass (kg)	89.7 ± 22.4	97.3 ± 16.1	74.3 ± 26.5
Amputation Duration (years)	15.7 ± 17.0	17.8 ± 17.5	11.7 ± 16.6
Classification			
Right Transtibial	4	3	1
Left Transtibial	8	5	3
Right Transfemoral	1	1	
Left Transfemoral	1	1	
Bilateral Transtibial	3	1	2
Bilateral Transfemoral	1	1	
Bilateral Knee Disarticulation	1	1	
Other	2	1	1

Note: Values are (m ± sd). Other; right hip disarticulation with left transtibial.

Height was measured while wearing prostheses and shoes to the nearest 0.1 cm using a stadiometer (Seca® 213, Hamburg, Germany) and body mass was measured to the nearest 0.1 kg using a digital scale (DETECTO, Webb City, MO, USA). Thereafter, participants then provided their balance self-efficacy measures using the ABC scale after which they performed a postural control assessment using the HUMAC balance system.

2.2. Measures

The 16-item ABC Scale was administered to understand participant balance confidence. The ABC asks participants to score their level of balance confidence for a series of tasks. A scale of 0% to 100% is used with 0% meaning no confidence and 100% indicating most confident. The item responses are summed and divided by 16 to tally an overall mean score [18]. The ABC has evidence of test–retest reliability [16], and content and convergent validity in prosthesis users [33].

The HUMAC balance system was used to evaluate participant postural control. The system has evidenced validity with criterion force plates [26]. Prior to testing, a calibration procedure was performed to insure precise recording of CoP. Each participant performed two static standing balance tests on the HUMAC platform with their normal (preferred) base of support for both trials. Participants stood on the HUMAC platform, which did not move against the floor, with arms to their sides in their normal standing posture. The use of assisted devices such as crutches or canes were not permitted. A 5 cm × 5 cm sheet of colored paper was attached to the wall at eye level 150 cm from the platform as a focal point for each participant. Participants mounted the platform and stood quietly on the HUMAC, and two separate 30 s double-limb supported standing balance tests were performed; eyes opened (EOD) and eyes closed (ECD). During these tests four linear strain gauge sensors sampled data at ~100 Hz [34,35]. Data analysis was performed in the HUMAC accompanying software. Variables of interest were center of pressure displacements in centimeters (cm) of the elliptical area as eyes opened displacement (EOD) and eyes closed displacement (ECD).

2.3. Statistical Analysis

IBM SPSS v29 (IBM Corp, Armonk, NY, USA) was used to calculate Pearson product moment coefficients between the HUMAC displacements and ABC scores. Participants were also divided by those who had higher ($\geq$80 on the ABC scale) or lower (<80 on the ABC scale) perceived balance after which displacement was compared using an independent *t*-test with Cohen's d to estimate effect size. An independent *t*-test was also used to compare displacement in those with a unilateral transtibial amputation vs. those with transfemoral/multiple limb amputation, as well as those with loss by trauma compared to loss by other. Correlation coefficients were also computed to assess the relationship between BMI and displacement. Alpha was set at 0.05 for these tests.

3. Results

There was a significant inverse moderate relationship between EOD testing (46.5 $\pm$ 31.8 cm) and ABC (75.1 $\pm$ 18.3%), $r = {}_{(19)}-0.58$, $p = 0.006$, as well as ECD testing (95.7 $\pm$ 56.2 cm) and ABC, $r = {}_{(19)}-0.56$, $p = 0.008$, Figure 1.

There was no significant difference in EOD between those with greater (34.7 $\pm$ 17.8 cm) and less (53.8 $\pm$ 36.7 cm) balance confidence, $t_{(19)} = -1.36$, $p = 0.189$, $d = -0.61$, nor in ECD between those with greater (73.2 $\pm$ 49.8 cm) and less (109.5 $\pm$ 57.3 cm) balance confidence, ($t_{(19)} = -1.47$, $p = 0.156$, $d = -0.66$), Figure 2.

When comparing balance between those with unilateral transtibial amputations vs. those with transfemoral/multiple limb amputations, there was no significant difference between the groups with eyes open (36.1 $\pm$ 21.6 cm and 57.9 $\pm$ 38.1 cm, respectively), $t_{(19)} = 1.37$, $p = 0.255$, $d = -0.71$, and eyes closed (80.1 $\pm$ 65.5 cm and 113.2 $\pm$ 40.1 cm, respectively), $t_{(19)} = 1.03$, $p = 0.321$, $d = -0.59$, Figure 3. This same trend was also reflected in balance confidence (82.9 $\pm$ 16.8% and 66.4 $\pm$ 16.5%, respectively), $t_{(19)} = 0.073$, $p = 0.789$, $d = -0.99$.

Those who lost their limbs from trauma had significantly better EOD (11.3 $\pm$ 4.3 cm) compared to those who experienced limb loss by other means (23.6 $\pm$ 14.2 cm), $t_{(19)} = -2.5$, $p = 0.022$, $d = -1.10$, however, this was not evident for ECD (28.3 $\pm$ 17.5 cm and 44.7 $\pm$ 23.2 cm respectively), $t_{(19)} = -1.7$, $p = 0.092$, $d = -0.78$, Figure 4. There was also no significant
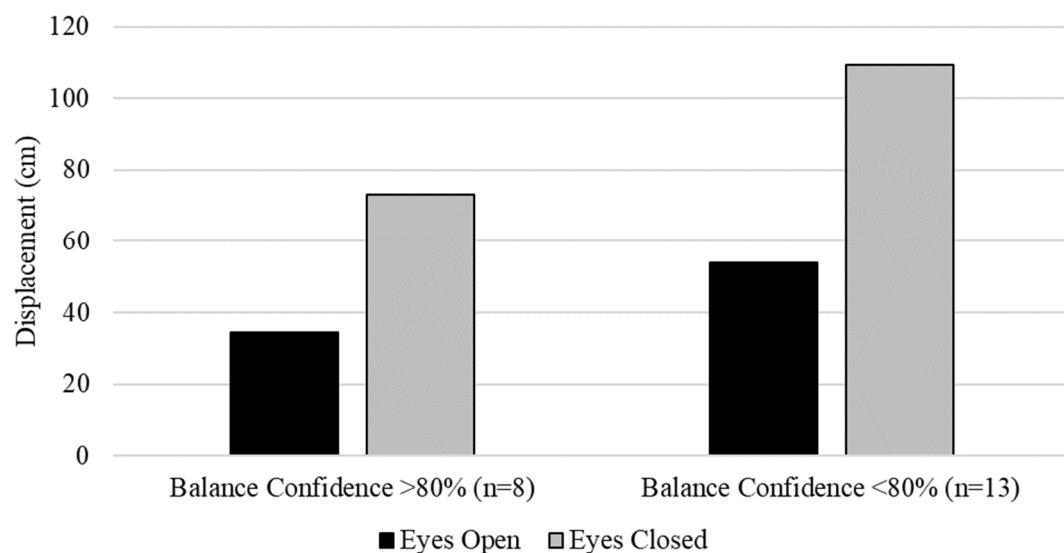
difference in ABC between those with loss by trauma (80.9 ± 15.2%) and by other means (70.7 ± 19.8%), $t_{(19)} = 1.3$, $p = 0.212$, $d = 0.57$.
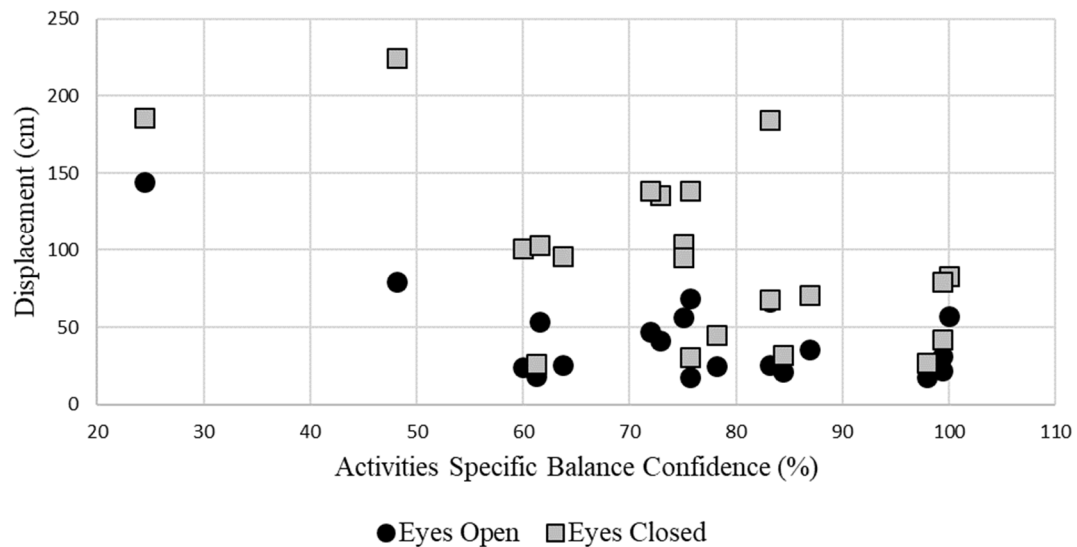

Figure 1. Those who had lower displacement were more likely to have greater confidence in their balance during both eyes open and eyes closed trials, $p < 0.05$.


Figure 2. While those with greater balance confidence displaced 19.1 cm less during EOD testing than those with lower confidence, and 36.3 cm less during ECD testing; these differences were not significant ($p > 0.05$).

## Measured Displacement between Amputation Category
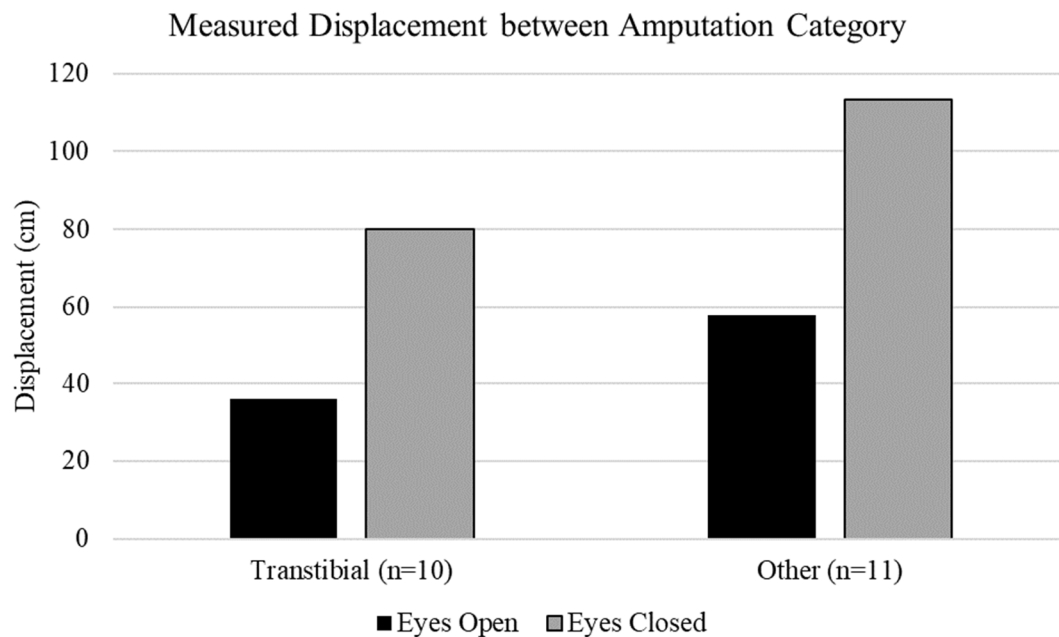
Figure 3. During EOD testing, those with unilateral amputation displaced 21.8 cm less than those with other (transfemoral/multiple limb amputation), and 33.1 cm less during ECD testing, neither of which were significant, $p > 0.05$.

Measured Displacement between Categories of Limb Loss
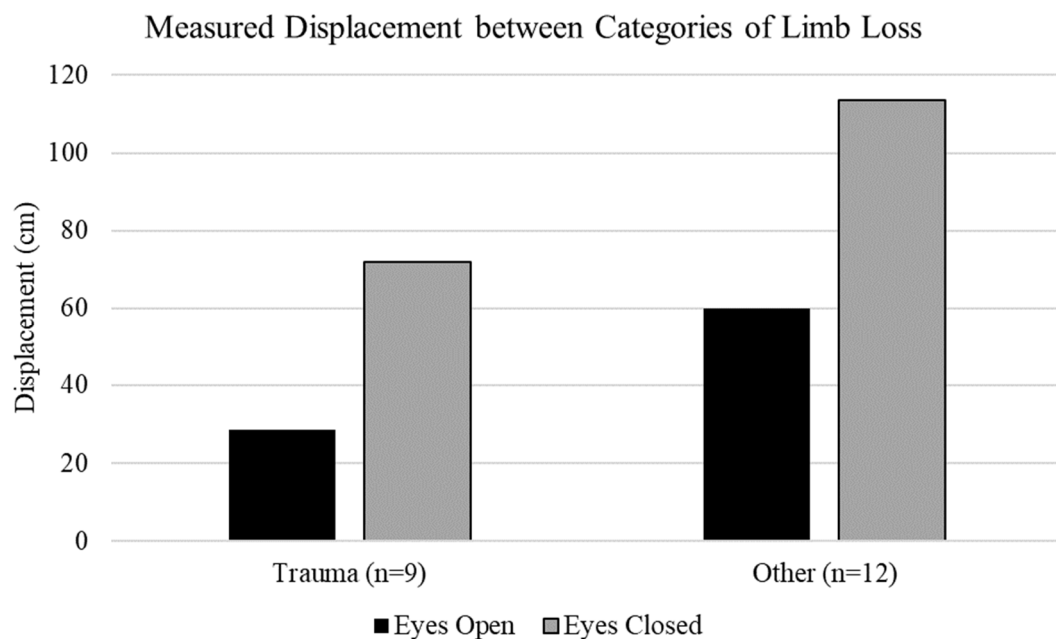
Figure 4. The difference in EOD (31.2 cm) between those who experienced limb loss from trauma was significant compared to those who experienced limb loss for other reasons ($p = 0.022$). The difference during ECD (41.9 cm) was not significant, $p = 0.092$.

Finally, there was no significant relationship between EOD (46.5 ± 31.8 cm) and BMI (30.1 ± 6.6), $r =_{(19)} -0.26$, $p = 0.251$, as well as ECD (95.7 ± 56.2 cm) and BMI, $r =_{(19)} -0.058$, $p = 0.803$, Figure 5.
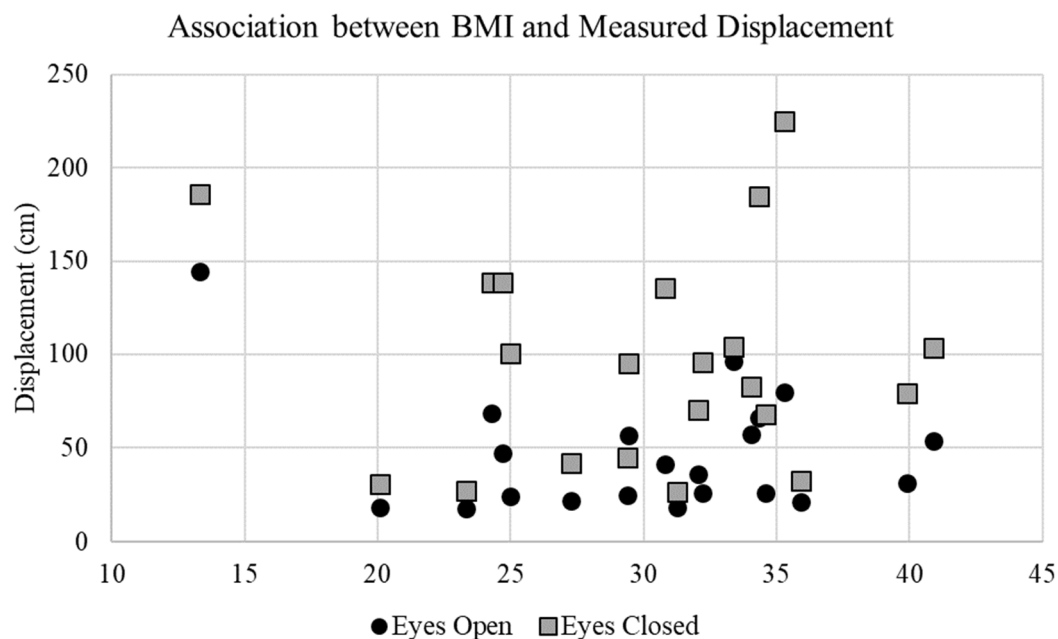
Figure 5. There was no relationship between BMI in displacement for both EOD and ECD, *p* < 0.05.

4. Discussion

In this study, we investigated the relationship of balance confidence and instrumented postural control. An inverse moderate relationship between user self-reported balance and center of pressure displacement was observed, suggesting that those who had greater confidence in their balance were also more likely to have less displacement. Confidence of balance is easily evaluated through patient-reported outcome measurements such as the ABC scale [18]. The ABC scores in our study (75.1 ± 18.3%) were higher than those seen in a sample of four hundred and thirty-five lower-limb amputees 63.8% [36], and in an ABC of 70% seen in transtibial amputees [37].

Predictive thresholds for ABC scores in lower-limb prosthesis users are still unknown. Myers et al. reported that scores <50% on the ABC scale should be indicative of low-level functioning [38]. However, an 80% score or better has been suggested as a minimum that individuals should achieve, as other scholars have witnessed high functioning for persons with these balance confidence indices [38]. Some scholars have used a cut-off ABC score of 77% in lower-limb prosthesis users [17], and others have suggested a score of ≤65% as predictive of whether a lower-limb prosthesis user would be a community ambulator at 1-year follow up [39]. Scores of 64.2% in those with multiple sclerosis (MS) [40], 60.5% in persons with vestibular disorders, 79.8% in community dwellers [41], and 95.1% in able-bodied persons have also been reported [42]. To further identify the link between confidence and performance-assessed balance, we stratified participants into groups according to Meyers et al. (1998), using the criteria of 80% confidence [38]. Under these criteria, our findings indicate that CoP displacement was not significantly different; however, the moderate effect size indicates the possible utility of using the ABC scale for clinicians to assess their clients.

In our study, a coefficient of −0.58 and −0.56 (eyes open and closed, respectively) between balance confidence and balance performance was observed. Much of the scholarship has explored the ABC's ability to evaluate the effect of exercise interventions or prosthetic rehabilitation [43–46]. However, few studies have reported associations of the ABC with performance-based balance and mobility measures. In lower-limb prosthesis users, a moderate inverse correlation (−0.48) between the ABC and balance performance (L-test functional mobility (L-Test)) has been reported [47]. In community-dwelling individuals, a moderate inverse correlation (−0.69) (timed up and go (TUG)) and a strong positive correlation (0.86) (Bergs balance scale (BBS)) have been observed [48].

In addition, a preliminary study showed that the BBS had a significant association with the ABC scale in LLP [49]. For persons with multiple sclerosis (MS), the Spearman's correlation coefficient between the ABC and single limb balance, as measured in seconds, was 0.72. However, when compared with more challenging dynamic balance, an inverse correlation of -0.70 was observed. Similarly, when our participants were presented with the additional challenge of the EC condition, a correlation between ABC and balance performance of -0.56 was observed. For individuals with Parkinson's disease, a moderate correlation of 0.50 with the BBS and a moderate inverse correlation of -0.37 with TUG were observed [50]. Taken together, these studies show the importance of measuring both self-report balance and performance-based balance in persons with musculoskeletal conditions.

Moreover, although studies have revealed associations between ABC with performance-based outcome measures, few have made comparisons to a portable force plate in lower-limb prosthesis users. Instrumented force measurements offer additional quantitative indices of postural control in prosthesis users [51]. Performance measures such as the BBS have shown a moderate to good inverse correlation with CoP in older adults (-0.77 EO and -0.88 EC) [52], as well as in those having experienced a stroke (-0.25 EO, -0.49 EC) [53]. Our CoP data revealed a greater displacement of CoP during the eyes closed condition compared with the eyes opened condition (37.7 ± 22.1 cm vs. 18.3 ± 12.5 cm, respectively). This is consistent in prosthesis users with increasingly challenging balance tasks (CoP 42.59 cm to 121.55 cm) [54]. Hermodsson et al., and Nadollek et al. also found blindfolding to increase CoP displacement in lower-limb prosthesis users [55,56]. Importantly, a review by Ku and colleagues of balance control in LLP identified a dearth of literature exploring associations between balance confidence and postural sway [7].

This study also reported additional comparisons in balance between those with unilateral and higher/multiple limb amputations, and well as comparing different amputation etiologies. Performance trends for those with unilateral lower-limb amputations were better than those with higher/multiple lower-limb amputations, and those with amputation caused by trauma performed better than those receiving amputations from other causes. It is noted that these differences were not significant; however, effect sizes were moderate to large, thereby suggesting the possibility of these differences being real with a greater sample size.

This study has a number of limitations which may affect the study implications. Our sample of prosthesis users was predominantly males wearing transtibial prostheses. Users with transfemoral prostheses may have lowered balance confidence (60.89%) vs. TT (64.90%) users [36]. Moreover, even though balance confidence is an important index of function, mobility is more often linked with the quality of life of lower-limb prosthesis users [57]. Instruments such as the Prosthetic Limb Users Survey of Mobility (PLUS-M) is also a valid means of understanding function [58,59]. Velocity and frequency domains of CoP were not assessed but may offer a means of understanding fall risk and postural control in lower-limb prothesis users [51]. Moreover, we measured outcomes on one occasion, which may not represent day-to-day fluctuations in balance confidence and performance, nor were participants' physical activity, rehabilitation, or engagement in sport reported.

5. Conclusions

This study offers insight into the associations of balance confidence with actual balance performance in lower-limb prosthesis users. Clinicians should consider the utility of applying both self-report as well as performance-based balance outcome measurements during clinical practice. This study has applications for those who may opt to utilize the ABC scale for the assessment of balance in lower-limb prosthesis users. Our study adds to the growing body of literature seeking to understand the relationship of instrumented balance measurement and balance confidence in lower-limb prosthesis users. Future research may explore the effect of amputation level, prosthetic componentry, as well as anterior/posterior CoP displacement and velocity as it relates to balance confidence.

Research can also explore the effect of specific etiologies, such as dysvascular, infection, etc., on balance confidence and performance.

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