The Relationships Among Proprioception, Balance, and Cognitive Perception of Body Awareness in College Students: A Pilot Study

Original Research

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Abstract

Introduction: This pilot study examined the relationships among lower extremity proprioception, balance ability, and perception of body awareness. Researchers also evaluated the influence of sex, sport participation, leg dominance, and previous ankle injury.

Methods: Eighteen participants (F = 11, M = 7) completed the initial testing, with eight (F = 4, M = 4) repeating the mLEPT one week later. Participant characteristics and mBARQ data were collected using an online survey. Measures included proprioception errors on the mLEPT, utilizing distances of 12 and 22 cm, and the Biodex Balance System™ Limits of Stability Test.

Results: For the mLEPT, good reliability was noted for the dominant leg 22 cm distance between trials 1 and 2 for all 18 participants (ICC = 0.83). Moderate test-retest reliability was observed when comparing the averages of day 1 to day 2 for the dominant leg 22 cm distance (ICC = 0.53), and for the overall error when collapsing across conditions (ICC = 0.63). Moderate reliability was also observed for the mBARQ (α = 0.76). Strong inverse relationships between proprioception error and directional control scores were observed, indicating an association between dynamic balance and lower extremity proprioception (r = -0.55-0.54, p = 0.02). Sex, sports participation, leg dominance, and previous ankle injury also influenced proprioception performance. Females displayed better lower extremity proprioception and balance control than males. In addition, participants without previous ankle injury scored higher on the mBARQ, and had better directional control and time to completion, indicating that those without ankle injury had a higher perception of body awareness and better dynamic balance.

Conclusions: Both the mLEPT and mBARQ appear to have moderate reliability. mLEPT performance was strongly associated with dynamic balance measures. In addition, lower mBARQ scale scores in those with previous ankle injury were strongly associated with poorer proprioception. While preliminary findings are promising, a larger follow-up study is needed to determine if the mLEPT and mBARQ are potential quick and inexpensive tools to monitor changes in proprioception during rehabilitation post-injury.

Key Words: kinesthesia, spatial awareness, stability.

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Introduction

Proprioception, also referred to as kinesthesia, is the awareness of one's body in space.[1] As such, somatosensory input from various receptors is integrated and processed in the brain's sensory cortex, allowing for the discrimination of changes in the position and motion of joints and muscles.[1-2] Proprioceptive input accounts for approximately 70% of the sensory input for balance control.[3] Therefore, proprioception is necessary for motor control and balance ability.[2] Both proprioception and balance ability are fundamental to sport and exercise performance as well as the safe and effective execution of motor skills for daily activities.[4] In addition, proprioception and balance ability contribute to the development of body awareness, which includes an internal spatial and structural representation of the body relative to its location, position, orientation, and movement in time and space.[4] Furthermore, proprioception is reliant on an individual's positional sense of their body's location in space, which allows for efficient movement in one's surrounding environment.[5]

Conversely, poor proprioception, balance ability, and body awareness can impair physical performance, and increase the risk of falls and injury.[3] One of the most common acute lower extremity musculoskeletal injuries is ankle sprains with approximately 23-25,000 incidents every day in the United States[6], and a high rate of recurrence.[7-8] Ankle injuries cause damage to joint mechanoreceptors as well as surrounding ligaments, leading to instability and proprioceptive deficits.[8-9] A systematic review by Witchalls et al indicates that poor ankle proprioception is associated with an increased risk of ankle injury.[10] For the knee, ligament sprains and tears, especially of the anterior cruciate ligament (ACL), are one of the most common injuries.[7] Similarly, poor knee proprioception is a risk factor for ACL injury.[7] Moreover, females have a higher rate of lower extremity injury, including ankle sprains and ACL injury.[11] Thus, the assessment of lower extremity proprioception, such as ankle and knee proprioception, may predict injury susceptibility.[12] Identifying injury susceptibility would allow for the inclusion of neuromuscular training and other prevention strategies to reduce the risk of musculoskeletal injury and associated negative effects such as decreased mobility, deficits in proprioception, and chronic pain.[13]

However, several factors other than previous injury can influence proprioception. Cug et al identified the potential influence of sex, limb dominance, and sport participation on dynamic postural control and knee proprioception.[14] While research has inconsistently demonstrated the relationships among these variables, their findings suggest that sports participation did impact postural control, but had no influence on knee proprioception. Furthermore, limb dominance and sex did not affect either measurement. However, the findings of Hu et al suggest that menstrual phases affect lower extremity proprioception with apparently healthy females demonstrating better ankle and knee proprioception than males when hormone concentrations are more stable.[15] In a review by Con Hrysomallis, the balance ability of athletes in different sports was compared, as well as the influence of training and competition status.[16] His findings indicate that individuals who participate in certain sports have better balance abilities with gymnasts having the best, followed by soccer players, recreationally active participants, and basketball players.

To date, proprioception has typically been measured using one of three main technologies, including the thresholds to detection of passive motion (TTDPM), joint position reproduction (JPR), and active movement extent discrimination assessment (AMEDA).[4] Each apparatus varies in reliability ranging from fair to excellent depending on joint angle and injury status. Common disadvantages include cost and bulkiness, as well as limited practicality or usefulness as a tool to assess or train lower extremity proprioception in field or clinical settings. Ofek et al developed a Lower Extremity Position Test (LEPT), as a simple and inexpensive quantitative test to assess lower extremity proprioception. The LEPT included a medium and long distance, utilizing 12 and 22 cm distances in order to standardize the protocol based on the Brief Kinesthesia Test, which uses a short, medium, and long distance to assess upper limb proprioception.[17-18] However, the study did not address various factors that could influence proprioception, which may have impacted their findings.

Previous research has established the relationship between measures of proprioception and balance ability.[4, 19-20] However, few studies have investigated the associations between proprioception and injury as well as proprioception and sport performance. Furthermore, the researchers did not find any previous studies that included both quantitative and psychometric measures to examine the association between proprioception and body awareness in young adults. Therefore, the aim of this pilot study was to investigate the relationships among lower extremity proprioception using a modified LEPT (mLEPT),[17] balance ability utilizing the Biodex™ Limits of Stability Test (LOS),[21] and self-reported responses to a modified Body Awareness Rating Questionnaire (mBARQ)[22] in apparently healthy college students. The researchers hypothesized that better proprioception would be correlated with better balance, and that higher scores on the mBARQ would be associated with fewer proprioception errors. Secondly, the researchers evaluated the reliability of their mLEPT as well as the influence of sex, sport participation, leg dominance, and previous ankle injury on lower extremity proprioception, balance ability, and body awareness.

Scientific Methods

Participants

The researchers recruited students at a medium-sized, rural university in the Mideast United States using course learning management system emails and social media posts by the student researcher. Inclusion criteria included: 1) being 18-24 years of age, 2) being apparently healthy, and 3) having no known neurological or orthopedic limitations of the lower extremity that would affect their performance. Due to the time constraints for data collection, menstrual cycle phase for females was not included as a criterion. Interested participants were invited to sign up for a 30-minute session using an embedded link to a Google form. This study was approved by the Murray State University Institutional Review Board. All participants provided written informed consent. Nineteen students volunteered to participate in the study. However, one female participant did not meet all of the inclusion criteria, so she was excluded from the study. Due to time constraints and availability, eight participants were randomly selected to repeat the mLEPT one week after the initial testing date.

Protocol

Testing dates were scheduled mid-week in the late afternoon in the exercise physiology laboratory. Researchers described the procedures and provided an opportunity to answer questions. After completing the written informed consent and liability waiver, participants completed an online survey created with Qualtrics XM (Provo, UT). Similar to the Cug et al study, participant characteristics included self-reported sex, sport participation, and leg dominance. In addition, age and previous history of lower extremity ankle injury were included. The survey also incorporated 14 items from the original 66-item BARQ, which was developed to evaluate body awareness in individuals with chronic musculoskeletal pain[22], which can be a long-lasting effect of injury. The selected questions focused on bodily sensations and awareness related to sitting, standing, and whole-body movement (see Table 3). The questionnaire utilized a 5-point Likert scale where 5 = strongly agree, and 1 = strongly disagree. To reduce acquiescence bias, six of the selected questions were reverse worded and then reverse scored. Participants were instructed to select the rating that best indicated how each statement applied to them, and not to spend too much time on any statement. An average score was calculated for each participant's cognitive perception of body awareness. Next, participants completed the mLEPT and LOS in no order, depending on the availability of the testing areas.

The mLEPT used in this pilot study utilized foam poster boards secured with tape. Similar to the Ofek et al tool[17] a horizontal start line, and two additional lines at 12 and 22 cm from the start line were drawn, representing a medium and long distance, respectively. In addition, a vertical line separating placement of the right and left foot was added. Whereas the procedures by Ofek et al aimed to eliminate tactile sensory input, the current mLEPT used nylon ironing mesh positioned over the lines and attached with push pins, and standardized sock thickness by having the participants wear knee-high hose to increase cutaneous sensory input during passive movement. To perform the test, participants were seated on the front ½ of a standard classroom chair with knees bent at approximately 110°. This position was selected to allow participants with shorter leg lengths to maintain foot contact with the mLEPT board throughout the test, specifically the 22 cm long distance. The mLEPT was then placed on the floor in front of the chair to allow the hallux of each foot to be aligned with the start line (see Figure 1). A researcher verbally described the testing procedures. Next, a black sleep mask was applied over the participant's eyes as a blindfold. Participants completed one familiarization trial and were instructed to passively allow their foot to glide across the surface of the ironing mesh. The tester slid one foot forward to either the 12 or 22 cm endpoint, and back to the start line. Next, the tester slid the same foot forward, and the participant told the tester to stop when they perceived that their foot had reached the designated endpoint. Proprioception error was determined using the mean absolute difference between the perceived and actual endpoints (12 and 22cm distances) measured with a Gulick tape measure (Creative Health Products, Ann Arbor, MI), and recorded to the nearest half cm (0.5 cm). Each participant completed two trials of the mLEPT, using both 12 and 22 cm endpoints on both legs. The four leg/distance conditions were randomly ordered. After completing the initial data collection, a randomized subset of eight participants was identified to repeat the mLEPT the following week, using the same lab schedule and procedures.

Balance ability was measured using the Biodex Balance System™ (Biodex Medical Systems Inc., Shirley, New York). The LOS[21] was selected, using the most stable platform setting of 12. The hold time was set to 0.25 seconds. To perform the test, the participants stepped onto the platform with their shoes on and aligned their feet on the grid as indicated on the console screen based on their height. The LOS screen displayed a dot in the center of the grid, and eight dots of varying distances from the center to form a circular pattern on the outside of the grid within a directional sway envelope (see Figure 1). The green cursor indicated the participant's center of pressure. Following instructions, the participant had to shift his or her center of pressure from the center dot to one of the outside dots and back to the center, hovering over each dot for a minimum of 0.25 seconds. Participants were instructed to keep their arms by their sides and avoid using the handlebars for assistance. To complete one trial, this pattern was repeated for each of the eight dots in a randomized order. Participants were instructed to complete the three trials as quickly and accurately as possible. The first trial was used as a familiarization trial. A rest interval of 10 seconds was allowed between trials. The Biodex Balance System™ determined the time to completion for each trial and provided a directional control score (DCS) for each dot, which were averaged for an overall DCS. A researcher also recorded the number of balance errors committed, such as movements of the arms or feet, during each trial on the data collection sheet.

Statistical Analysis

Data were analyzed using SPSS version 27 (Armonk, NY). Data are presented as means ± standard deviation (SD). Differences in error between trials of the mLEPT were assessed using a 2x2x2 (trial [1 and 2] x distance [12 and 22 cm] x leg dominance [dominant and non-dominant]) repeated measures ANOVA. As participants were assessed on the same parameters over multiple timepoints, a repeated measures ANOVA was selected. Pairwise comparisons with Bonferroni adjustments of main effects were assessed. A one-way repeated measures ANOVA was used to assess differences between LOS trials, with pairwise comparisons using Bonferroni adjustments used to assess the main effect. As an aim of the study was to assess the repeatability of the mLEPT across multiple trials, an intraclass correlation coefficient (ICC) was used. ICCs (2,1) were calculated to assess reliability of the mLEPT and LOS trials. Thresholds for reliability were as follows: poor (<0.50), moderate (0.50-0.75), good (0.75-0.90), and excellent (>0.90).[23] One-way ANOVAs analyzed differences between trials for each condition of the mLEPT. Pearson product-moment correlation coefficients were calculated to assess the relationships between proprioception error on the mLEPT, LOS measures, and mBARQ scale scores, with correlations classified as small (0.1-0.3), moderate (0.3-0.5), strong (0.5-0.7), and very strong (>0.7).[24] Internal consistency and reliability of mBARQ questions were assessed using Cronbach's alpha (α) using the following thresholds: low reliability (<0.7), moderate reliability (0.7-0.9), strong reliability (>0.9).[23] In addition, a Pearson product-moment correlation analyzed the relationship between mBARQ question subsets using the above listed correlation classifications. Lastly, the influence of sex, current sport participation, gymnastics participation, and previous ankle injury on mLEPT and LOS performance was assessed through repeated measures ANOVA, with one-way ANOVAs used to follow up significant interactions. An independent samples t-test compared mBARQ scores between those with and without previous ankle injury. Due to the pilot sample size, Hedges' g effect sizes were calculated to assess standardized mean difference, with the following criteria used: trivial (<0.20), small (0.20-0.50), medium (0.50-0.80), large (0.80-1.30), and very large (>1.30).[25] Statistical significance was set a priori at $p \leq 0.05$.

Results

Eighteen participants (F = 11, M = 7) completed initial testing, with eight (F = 4, M = 4) repeating the mLEPT one week after initial testing. Mean age, leg dominance, previous ankle injury, sport participation, and gymnastics participation are displayed in Table 1.

Table 1. Participant characteristics.

	Total (n = 18)	**Female (n = 11)**	**Male (n = 7)**
Age (years)	21.3 ± 1.1	21.1 ± 1.3	21.6 ± 0.8
Right Leg Dominance (%)	16 (89)	11 (100)	5 (71)
Previous Ankle Injury (%)	9 (50)	5 (45)	4 (57)
No previous ankle injury	9 (50)	6 (55)	3 (43)
Dominant leg ankle injury	2 (11)	2 (18)	0 (0)
Non-dominant leg ankle injury	3 (17)	0 (0)	3 (43)
Ankle injury to both legs	4 (22)	3 (27)	1 (14)
Current Sport Participation (%)	4 (22)	2 (18)	2 (29)
Previous Gymnastics Participation (%)	4 (22)	4 (36)	0 (0)

Age is presented as mean ± SD. Other variables are presented as the number of yes responses, and corresponding percentages.

mLEPT

Eighteen participants initially completed two trials, each consisting of four leg/distance conditions. Proprioception error was determined using the mean absolute difference between the perceived and actual endpoints of each trial at the 12 cm and 22 cm distances. The differences in the amount of proprioception error between trials at 12 and 22 cm distances for the dominant and non-dominant leg were assessed. A 2x2x2 repeated measures ANOVA indicated no three or two-way interactions between trial, distance, or leg dominance (p = 0.20-0.92, η_p^2 = 0.001-0.09). When collapsing across trial and leg dominance, a significant main effect for distance was found (p = 0.037, g = 0.56), indicating less proprioception error for the 22 cm condition (1.3 ± 0.6 cm) as compared to the 12 cm condition (1.6 ± 0.6 cm).

Main effects for trial and leg dominance were not significant (p = 0.107-0.388, η_p^2 = 0.044-0.145). During day 1 of testing, good reliability was noted between the first and second trials for the dominant leg 22 cm condition for all 18 participants ($ICC_{2,1}$ = 0.83 [0.60-0.93]) (see Table 2). During day 2 of testing, eight participants repeated the mLEPT, completing a total of four trials. Reliability across all four trials individually was assessed with moderate reliability also noted for the dominant leg 22 cm condition ($ICC_{2,1}$ = 0.51 [0.17-0.84]), and poor reliability was noted for other leg/distance combinations ($ICC_{2,1}$ < 0.50). When test-retest reliability (day 1 [the averages of trials 1 and 2] vs day 2 [the averages of trials 3 and 4]) was assessed, moderate reliability was again noted for the dominant leg 22 cm condition ($ICC_{2,1}$ = 0.53 [-0.30-0.89]), as well as for overall mean error when collapsing across all leg/distance conditions ($ICC_{2,1}$ = 0.63 [0.13-0.91]). In addition, the influence of sex on proprioception performance was assessed. When collapsing across trial, distance, and leg dominance, a main effect for sex was noted, with females displaying less proprioception error than males (1.2 ± 0.5 cm vs 1.9 ± 0.4 cm, p = 0.004, g = 1.54).

LOS

Differences in directional control score (DCS), time to completion, and number of balance errors committed between trials were assessed. Results indicated no significant differences between trials for DCS (trial 1: 24.2 ± 6.0, trial 2: 24.6 ± 6.1, p = 0.80, η_p^2 = 0.004), time to completion (trial 1: 66.8 ± 10.6 sec, trial 2: 66.1 ± 13.4 sec, p = 0.784, η_p^2 = 0.005), or number of balance errors (trial 1: 1.1 ± 1.4 errors, trial 2: 0.8 ± 1.7 errors, p = 0.260, η_p^2 = 0.074). Moderate reliability was observed between trials 1 and 2 for DCS ($ICC_{2,1}$ = 0.59 [0.18-0.83], p = 0.005) and time to completion ($ICC_{2,1}$ = 0.60, [0.18-0.83], p = 0.004), with good reliability observed for the number of balance errors ($ICC_{2,1}$ = 0.87 [0.68-0.95], p < 0.001). In addition, the influence of sex on balance performance was assessed. When collapsing across trials, females displayed better balance ability, with a higher DCS (26.6 ± 4.2 vs 20.9 ± 5.3, p = 0.021, g = 1.18) and faster times to completion (62.3 ± 10.1 sec vs 72.9 ± 8.7 sec, p = 0.038, g = 1.04). No sex differences were observed for balance errors committed (p = 0.906, g = 0.06).

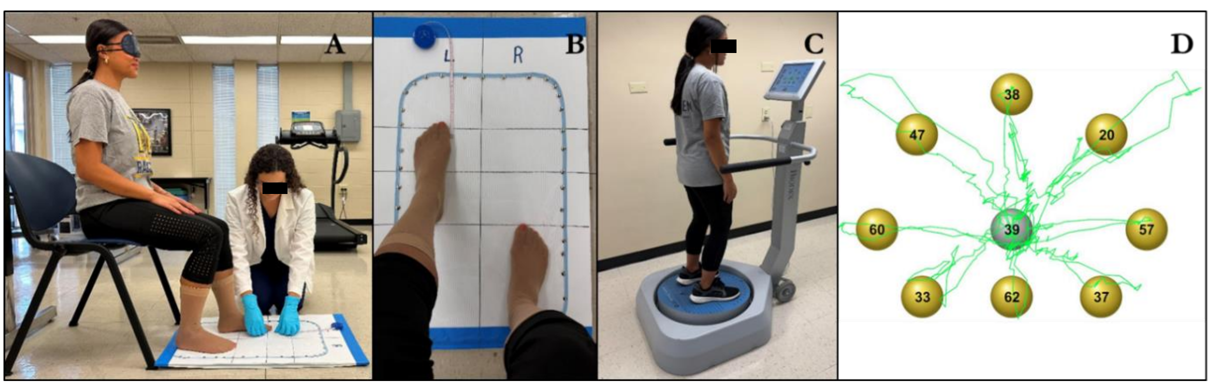

Figure 1. Administration of the LEPT test (A), with a depiction of scoring for the 22 cm condition for the left leg (B). Participant completing the LOS test (C), with a representative report, including the composite DCS depicted in the center (D).

Relationships Between mLEPT, LOS, and mBARQ Scores

Scale scores for the mBARQ were calculated by totaling the scores for each of the 14 questions to include six reverse-scored items, with a higher score indicating better self-perception of proprioception (see Table 3). Reliability of the survey questions was assessed and determined to be moderate (α = 0.76). As six questions were reverse-worded, Pearson product moment correlations compared the relationship between subset scores, with a strong relationship between subsets observed (r = 0.61, p = 0.007). Additionally, the relationships among proprioception error on the mLEPT, LOS measures, and mBARQ scale scores were evaluated. As moderate-to-good reliability was found for LOS measures between trials 1 and 2, the average scores for DCS (24.4 ± 5.4), time to completion (66.4 ± 10.7 sec), and errors committed (0.9 ± 1.5 balance errors) between trials 1 and 2 were used. Significant relationships between proprioception error and LOS measures were found (see Figure 2). Directional control scores shared moderate-to-strong negative correlations with proprioception error in the dominant leg 12 cm trial 1 ($r = -0.54$, $p = 0.02$), the non-dominant leg 12 cm trial 1 ($r = -0.55$, $p = 0.02$), and the non-dominant leg 22 cm trial 2 ($r = -0.48$, $p = 0.04$). This indicates that higher directional control is associated with less proprioception error. Moderate-to-strong positive correlations were observed between time to completion and the non-dominant leg 22 cm trial 2 ($r = 0.53$, $p = 0.02$) as well as the dominant leg 12 cm trial 1 ($r = 0.49$, $p = 0.04$), and between the number of balance errors committed and proprioception error for the dominant leg 12 cm trial 1 ($r = 0.53$, $p = 0.02$). This indicates that those who committed more proprioception errors had longer time to completion as well as more balance errors for the LOS. However, no significant relationships were found between mBARQ scale scores and proprioception error ($r = -0.37$-0.34, $p = 0.13$-0.97), or between mBARQ scale scores and LOS measures ($r = -0.17$-0.10, $p = 0.49$-0.69), indicating that cognitive perception of body awareness was not associated with measures of proprioception or balance performance.

Table 2. Reliability measures for the mLEPT and LOS.

	Mean ± SD				ICC (95% CI)	SEM	Difference
mLEPT (n = 18)	**Trial 1**	**Trial 2**					p-value
Dominant Leg 12 (cm)	1.8 ± 1.1	1.1 ± 0.8			-0.21 (-.055-0.24)	1.07	0.08
Non-dominant leg 12 (cm)	1.9 ± 1.3	1.6 ± 1.2			-0.14 (-0.59-0.35)	1.33	0.50
Dominant Leg 22 (cm)	1.3 ± 1.1	1.4 ± 1.1			0.83 (0.60-0.93)	0.45	0.59
Non-dominant leg 22 (cm)	1.4 ± 0.7	1.1 ± 0.7			0.45 (0.02-0.75)	0.54	0.23
Overall Error (cm)	1.6 ± 0.7	1.3 ± 0.5			0.40 (-0.03-0.72)	0.71	0.11
mLEPT Test-Retest (n = 8)	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**			
Dominant Leg 12 (cm)	1.4 ± 0.7	1.2 ± 1.0	1.0 ± 0.5	1.2 ± 1.0	0.05 (-0.20-0.54)	0.82	0.84
Non-dominant leg 12 (cm)	2.0 ± 1.5	2.4 ± 1.1	1.6 ± 1.2	1.3 ± 1.2	-0.01 (-0.19-0.45)	1.26	0.32
Dominant Leg 22 (cm)	1.9 ± 1.0	1.8 ± 1.0	2.2 ± 1.4	1.4 ± 1.0	0.51 (0.17-0.84)	0.78	0.31
Non-dominant leg 22 (cm)	1.6 ± 0.9	1.0 ± 0.7	1.7 ± 2.1	2.5 ± 1.2	0.23 (-0.04-0.67)	1.18	0.11
Overall Error (cm)	1.7 ± 0.8	1.6 ± 0.4	1.6 ± 0.9	1.6 ± 0.7	0.49 (0.12-0.84)	0.53	0.97
mLEPT Test-Retest (n = 8)	**Day 1 average**		**Day 2 average**				
Dominant Leg 12 (cm)	1.3 ± 0.5		1.1 ± 0.6		0.40 (-0.36-0.84)	0.42	0.40
Non-dominant leg 12 (cm)	2.2 ± 0.8		1.4 ± 0.7		0.32 (-0.16-0.78)	0.60	0.02
Dominant Leg 22 (cm)	1.8 ± 1.0		1.8 ± 1.1		0.53 (-0.30-0.89)	0.71	1.00
Non-dominant leg 22 (cm)	1.3 ± 0.7		2.1 ± 1.5		0.16 (-0.41-0.72)	1.07	0.17
Overall Error (cm)	1.6 ± 0.5		1.6 ± 0.8		0.63 (-0.13-0.91)	0.39	0.85
LOS (n = 18)							
DCS	24.2 ± 6.0	24.6 ± 6.1			0.59 (0.18-0.83)	3.84	0.80
Time to Completion (sec)	66.8 ± 10.6	66.1 ± 13.4			0.60 (0.18-0.83)	7.66	0.78
Balance Errors	1.1 ± 1.4	0.8 ± 1.7			0.87 (0.68-0.95)	0.58	0.26

Data are presented as mean ± SD. mLEPT values are expressed as cm of error. DCS values are expressed as a composite score without units. Time to completion is expressed as seconds. Balance errors are expressed as the number of balance errors committed. ICC = intraclass correlation coefficient, 95% CI = 95 % confidence intervals, SEM = standard error of the measurement. SEM values are expressed in the corresponding units for the given variable. $P < 0.05$ indicates significant differences between trials occurred.

In addition, participants were separated by previous ankle injury status to determine if ankle injury influenced the relationships between mBARQ scale scores, proprioception error, and LOS measures. Although differences in mBARQ scale scores did not reach statistical significance between those with and without previous ankle injury, a moderate effect size suggests those with previous ankle injury scored lower (52.6 ± 6.2 vs 56.2 ± 5.8, $p = 0.22$, $g = 0.58$). In the participants without previous ankle injury, a very strong negative relationship was found between mBARQ scale scores and proprioception error in the non-dominant 22 cm condition trial 2 ($r = -0.73$, $p = 0.026$), suggesting previous ankle injury may negatively influence cognitive perception of body awareness. Furthermore, for participants without previous ankle injury, mBARQ scale scores shared a strong positive relationship (r = 0.61, p = 0.08) and a strong negative relationship (r = -0.69, p = 0.04) with average DCS score and average time to completion, respectively, indicating better dynamic balance performance in those with higher perceived body awareness. For those with previous ankle injury, very strong or strong positive relationships were observed between mBARQ scale score and proprioception error in the non-dominant 12 cm trial 1 (r = 0.80, p = 0.01) and between mBARQ scale scores and the dominant 22 cm trial 1 (r = 0.67, p = 0.05). A strong negative relationship was observed between mBARQ scale score and the dominant 12 cm trial 2 (r = -0.61 p = 0.08). In those with previous injury, mBARQ scale scores were not related to LOS measures.

The Influence of Sport Participation and Ankle Injury

The influence of current sport participation, previous gymnastics participation, and previous ankle injury on mLEPT and LOS performance was also assessed. Participation in gymnastics was assessed as previous literature has indicated higher levels of proprioception and balance among gymnasts.[16, 29] Four participants reported previous gymnastics participation, four participants reported current sport participation, and nine participants indicated a previous ankle injury (see Table 1). Repeated measures ANOVAs with either gymnastics participation, sport participation, or previous ankle injury as a between-subjects factor were run to assess the influence of each factor on proprioception error (2x2x2 [trial x distance x leg dominance]) and LOS (one-way [trial]) measures. Sport participation was divided into athletes vs. non-athletes for analysis, with anyone self-reporting current participation in a sport put in the athlete category. While no differences between athletes and non-athletes were observed for LOS measures (p = 0.12-0.50), non-athletes committed fewer balance errors in trial 2 when compared to trial 1(.9 ± 1.4 vs 0.5 ± 1.2 balance errors, p = 0.04, g = 0.81), suggesting a learning effect. Sport participation appeared to influence proprioception error in the dominant leg, with athletes displaying less error in the dominant leg when compared to the non-dominant (1.0 ± 0.5 cm vs 1.8 ± 0.8 cm, p = 0.004, g = 1.01). Non-athletes saw no difference in error between legs (1.5 ± 0.7 cm vs 1.4 ± 0.5 cm, p = 0.58, g = 0.17).

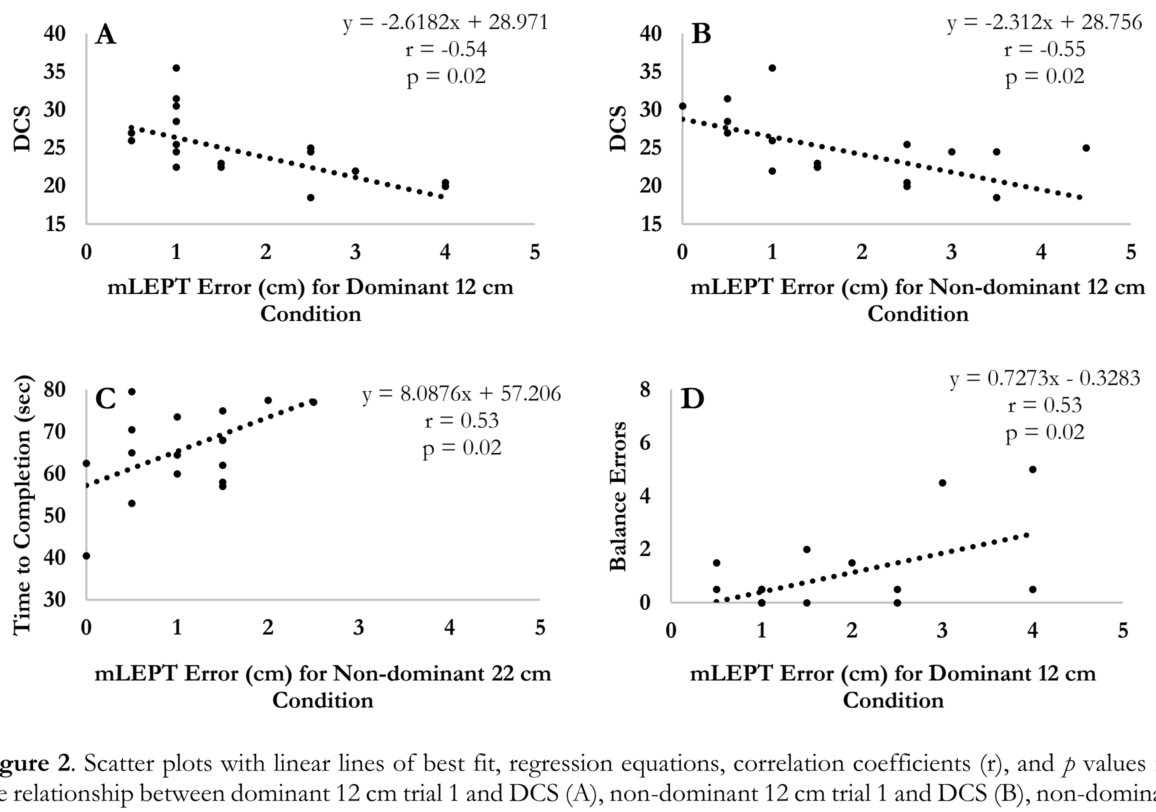

Figure 2. Scatter plots with linear lines of best fit, regression equations, correlation coefficients (r), and p values for the relationship between dominant 12 cm trial 1 and DCS (A), non-dominant 12 cm trial 1 and DCS (B), non-dominant 22 cm trial 2 and LOS time to completion (C), and dominant 12 cm trial 1 and LOS balance errors (D).

Similar to current sport participation, previous gymnastics experience appeared to influence proprioception error with gymnasts displaying better proprioception in the dominant leg when compared to non-dominant (1.0 ± 0.2 cm vs 1.7 ± 0.6 cm, p = 0.02, g = 0.79), with no difference between legs for non-gymnasts (1.5± 0.7 cm vs 1.4 ± 0.6 cm, p = 0.80 g = 0.08). No differences in LOS or mLEPT performance were observed between gymnasts vs. non-gymnasts when collapsing across distance and trial.

Previous ankle injury status also appeared to influence proprioception error. For participants without previous injury, there was less proprioception error in the non-dominant leg 22 cm condition when compared to the non-dominant 12 cm condition (1.2 ± 0.7 cm vs 2.1 ± 0.8 cm, p = 0.001, g = 1.06). In addition, there was less proprioception error observed in the dominant leg 12 cm condition when compared to the non-dominant leg 12 cm condition (1.4 ± 0.6 cm vs 2.1 ± 0.8 cm, p = 0.006, g = 0.80). For LOS performance, previous ankle injury did not influence DCS score (p = 0.11, $\eta_p^2 = 0.16$) or balance errors (p = 1.00, $\eta_p^2 = 0.00$); however, time to completion was influenced (p = 0.04, η_p^2 = 0.24). No differences were found between those with and without previous ankle injury for either trial (p = 0.35-0.39, g = 0.40-0.44). However, a moderate effect size suggests those without previous ankle injury saw a reduction in time to completion from trial 1 to trial 2 (69.0 ± 13.7 sec vs 63.00± 11.8 sec, p = 0.09, g = 0.68), suggesting a learning effect. However, those with previous injury saw no difference in time across trials (64.6 ± 6.2 sec vs 69.1 ± 14.7 sec, p = 0.19, g = 0.39).

Table 3. mBARQ items.

1	I pay attention to the way I move.	**8**	I am not aware of my habit positions.*
2	My muscles are often tense without me knowing why.*	**9**	Body signals help me find my limits.
3	I never sit comfortably.*	**10**	I am stable on my feet.
4	I am able to coordinate my body.	**11**	My body sensation helps me find comfortable positions.
5	I avoid paying too much attention to the way I move.*	**12**	I usually move smoothly.
6	I sense if my joints are tense or flexible.	**13**	I am not aware of how I'm standing.*
7	In standing, my feet have good contact with the ground.	**14**	I avoid sensing my body.*

Questions marked with an asterisk (*) contained reverse wording to reduce the risk of acquiescence bias, dividing the questions into two subsets.

Discussion

The aim of this pilot study was to investigate the relationships among lower extremity proprioception, balance ability, and cognitive perceptions of body awareness. In evaluating lower extremity proprioception, 18 participants initially completed two trials of the mLEPT on both legs, using both 12 and 22 cm endpoints representing a medium and long distance, respectively. The range in proprioception error between the perceived vs. actual endpoints at the 12 and 22 cm distance was -4.5 cm to +3.5 cm (-1.8 in to +1.4 in). The actual endpoint was underestimated in 65% of the total completed leg/distance conditions, overestimated in 23%, and accurately estimated in 12%. Overall, there was less error associated with the 22 cm distance. Borsa et al found that individuals displayed greater joint acuity when the knee was moving toward the end-range of extension.[26] In addition, Fuentes and Bastian evaluated upper limb task accuracy using a variety of elbow and shoulder angles.[28] Their results also demonstrated that task accuracy was related to joint angle and limb endpoint position, which may be due to the linear relationship between muscle spindle and cutaneous afferent activity to muscle stretch with increased receptor activity as the joint approaches an extreme position. The current findings support that improved proprioception is associated with limb endpoint position for the lower extremity. In addition, the increased cutaneous sensory input during passive movement on the mLEPT may have been an influencing factor.

The relationship between proprioception and balance ability was evaluated based on mLEPT and LOS performance. The findings of this study support that there is a strong association between proprioception and balance ability.[19-20] Overall, less proprioception error, particularly for the 12 cm condition, was associated with better directional control, faster time to completion, and fewer balance errors committed. The researchers also assessed the influence of sex on balance. Females displayed better balance ability based on directional control and time to completion, while there was no sex difference observed for the number of balance errors committed. Previous sport participation, including gymnastics, did not affect balance ability, which contradicts previous findings,[14] possibly due to the small number of participants self-reporting either current sport participation or previous gymnastics experience. Moreover, the findings of Hrysomallis suggest that balance ability is related to competition level; however, in the current study training level was not evaluated. In addition, ankle injury status did influence balance; those without previous ankle injury had faster times to completion. Directional control and balance errors were not affected.

There has been conflicting evidence regarding the influence of sports participation, limb dominance, and sex on proprioception. One explanation may be the use of varying methodologies and instrumentation. Specifically, the findings of Cug et al suggest that sports participation, limb dominance, and sex did not affect knee proprioception.[14] However, in the current study, those individuals who participated in sports displayed less proprioception error on the mLEPT in the dominant leg when compared to the non-dominant. In addition, there was no significant difference in proprioception performance between those with previous gymnastics experience vs. non-gymnasts. The findings of Aydin et al support that gymnasts have better proprioception than non-gymnasts but did not demonstrate a significant difference in proprioception based on limb dominance.[29] Yet, the current findings of this pilot study suggest that gymnasts have less proprioception error in the dominant leg when compared to non-dominant, while non-gymnasts demonstrated no difference between legs. Differences in proprioception based on sports participation may be associated with adaptations in muscle spindle activity and motor learning due to training.[30] In terms of the effect of sex on joint acuity and proprioception, changes in female sex hormones during different phases of the menstrual cycle may affect neuromotor control and proprioception.[15] While the current study did not evaluate menstrual cycle phase, the results may support Hu's findings that healthy adult females displayed better lower limb proprioception than males.[15]

The current study also aimed to evaluate the reliability of a modified lower extremity proprioception test, based on Ofek et al.[17] Similar to their study, the mean error between trials was not significantly different; however, that study reported poor reliability for both legs and distances (12 and 22 cm) for young subjects 21-27 yr. In the current study, good reliability was found between trials 1 and 2 for the dominant leg 22 cm condition during day 1 of testing. The subset of eight participants who repeated the mLEPT completed four trials with moderate reliability noted for the dominant leg 22 cm condition and approached moderate reliability when the overall error across trials was assessed. In examining test-retest reliability between day 1 and day 2, moderate reliability was again noted for the dominant leg 22 cm, and for overall error when collapsing across all leg/distance conditions. Poor reliability was found for all other leg/distance conditions. Factors that may have influenced proprioception error during passive movement include differences in joint position due to leg length as well as alterations in movement velocity between conditions.[26-27] While the current study was a modification of the Ofek, et al LEPT[17], 3-5 trials are frequently used in studies assessing limb proprioception, and should be a consideration in future research.[4]

Finally, the relationships among the mBARQ scale score, proprioception, and balance ability were evaluated, as well as the influence of previous ankle injury on proprioception. In those without previous injury, less proprioception error on the mLEPT was observed across various leg/distance conditions. Again, alterations to muscle spindles and mechanoreceptors due to training and/or injury status may account for these differences.[7-9, 31] Therefore, future research should aim for a larger heterogeneous sample, and control for training status and injury history, as well as menstrual cycle phase in females. The mBARQ had moderate reliability, and the two subsets were strongly correlated, indicating that the validity of the questionnaire was not confounded by acquiescence bias. The participants scored an average of 54.4 out of 70, with higher scores indicating better self-perception of proprioception. Overall, there was no significant relationship between the mBARQ score and mLEPT performance, or between the mBARQ score and LOS measures. However, since the original BARQ was developed to evaluate body awareness in individuals with chronic musculoskeletal pain[22], the researchers evaluated the influence of previous ankle injury on mBARQ scores, and the relationships with mLEPT and LOS performance. Although differences in mBARQ scores did not reach statistical significance, a moderate effect size suggests that those with previous ankle injury did score lower, indicating poorer perception of body awareness. For those participants without previous ankle injury, a higher mBARQ score was strongly associated with better directional control, faster time to completion, and less proprioception error on the mLEPT for the non-dominant 22 cm condition. Conversely, for those participants with previous ankle injury, a lower mBARQ score was strongly associated with poorer performance on the mLEPT for various leg/distance conditions. However, the mBARQ scores for these participants were not related to LOS measures and balance ability.

Currently, there is no universal research methodology used to assess proprioception in the lower extremity, to include controlling for various confounding factors, which leads to conflicting evidence in the literature. Limitations of this study as well as other factors that should be addressed in future studies include using a larger heterogeneous sample and allowing for 3-5 trials per condition. The participant characteristics collected should be expanded to include detailed information on previous ankle and knee injuries, training status, and the menstrual cycle phase for females. Finally, the participants' leg length should be measured, and the starting knee angle as well as knee velocity should be standardized. In addition, the researchers would continue to utilize the stockings to control sock thickness but would eliminate the ironing mesh from the mLEPT board and use active joint position detection instead of passive.

Conclusions

The results of this pilot study suggest moderate reliability for both the mLEPT and mBARQ. In addition, there was a strong relationship between mLEPT performance and LOS balance measures. Furthermore, females displayed better lower extremity proprioception as well as balance control than males. Previous sports participation and limb dominance also influenced proprioception performance. While the preliminary findings of this pilot study are promising, they are tenuous due to the small sample size with potential bias as well as limited external validity. Given the affordability, portability, and simplicity of the mLEPT, a larger follow-up study may produce results to support the use of this protocol to quickly assess lower extremity proprioception and provide an economical tool for neuromuscular training in field and clinical settings. Similarly, future research with a larger sample should evaluate if the mBARQ could be used as a quick and simple tool to detect and monitor differences in perceived body awareness in those with lower extremity injury and/or proprioception deficits, which may be useful in a rehabilitative setting.

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