Predicting Lower Quarter Y-Balance Test Performance from Foot Characteristics

Context: The Lower Quarter Y-Balance Test (YBT-LQ) is associated with injury risk; however, ankle range of motion impacts YBT-LQ. Arch height and foot sensation impact static balance, but these characteristics have not yet been evaluated relative to YBT-LQ.

Objective: Determine if arch height index (AHI), forefoot sensation (SEN), and ankle dorsiflexion (DF) predict YBT-LQ composite score (CS).

Design: Descriptive cohort.

Setting: Athletic Training laboratory.

Participants: 20 general population [14 ♀, 6 ♂, mean age (SD): 35 (18) years, weight (SD): 70.02 (16.76) kg, Height (SD): 1.68 (0.12) m] participated.

Interventions: AHI Measurement System assessed arch height in 10% (AHI10) and 90% (AHI90) weight bearing (WB). Two-Point Discrim-A-Gon Discs assessed sensation (SEN) at the plantar great toe, 3rd and 5th metatarsal heads. Biplane goniometer and weight bearing lunge tests (WBLT) were used to measure static and weight bearing DF, respectively. The YBT -LQ assessed dynamic single leg balance.

Results: For right limb dynamic single leg balance, AHI90 and SEN were included in the final sequential prediction equation; however, neither model significantly ($p = 0.052$ and 0.074) predicted variance in YBT-LQ-CS. For left limb dynamic single leg balance, both SEN and WBLT were included in the final sequential prediction equation. The regression model (SEN and WBLT) significantly ($p = 0.047$) predicted 22% of the variance in YBT-LQ CS.

Conclusions: This study demonstrates that foot characteristics may play a role in YBT-LQ CS. We did not assess limb dominance in this study; therefore, we are unable to determine which limb would be the stance versus kicking limb. However, altered SEN and weight bearing DF appear to be contributing factors to YBT-LQ CS.

Key Words: Y-Balance Test, YBT-LQ, dorsiflexion range of motion, arch height index, AHI, plantar sensation

The Lower Quarter Y Balance Test (YBT-LQ) is a clinical movement screening test aimed at assessing dynamic balance. The YBT-LQ utilizes unilateral stance while reaching in three reach directions, anterior, posteromedial, and posterolateral to assess both a composite reach score and asymmetry assessment in each of the three reach directions. The composite score is computed by adding all 3 reach directions together and then normalizing to leg length. The asymmetry score assesses the difference between the right and left reaching. This tool has been associated with injury risk across various populations.[1–4]

Prior to the development of the YBT-LQ, which is an instrumented version of the modified star excursion balance, the modified star excursion balance test assessed dynamic balance in high school athletes; finding, in female basketball players, a composite score of less than 94% and greater than 4cm anterior reach asymmetry was related to noncontact injury.[1] In male collegiate football players, a player with a modified star excursion balance test composite score of less than 89.6% was 3.5 times more likely to get injured[2], and in a large cohort of college division I athletes, a YBT-LQ anterior reach asymmetry on of more 4cm was associated with 2.33 greater risk of noncontact injury.[3] Since these initial 3 articles[1–3] which demonstrated a relationship between dynamic balance and injury or injury risk, 5 subsequent studies have indicated no association between performance on the YBT-LQ and injury;[5–9] while one study demonstrated that soccer players with posteromedial reach asymmetry of greater than 4cm were 3.86 times more likely to experience a lower extremity injury.[4] Conflicting findings in the association between dynamic balance and injury or injury risk could be related to factors known to influence dynamic balance such as ankle range of motion.

Hoch et al[10] were the first to demonstrate that the anterior reach direction of the SEBT was influenced by ankle dorsiflexion range of motion such that the weight bearing lunge explained 28% of the variance in the normalized anterior reach. Kang et al.[11] supported these findings, indicating that ankle dorsiflexion during the weight bearing lunge test was significantly correlated with the normalized anterior reach, explaining approximately 65% of the variance. In a kinematic assessment of the YBT-LQ, Kang et al.[12] reported that ankle dorsiflexion during the YBT-LQ performance predicted 50% of the variance in the normalized anterior reach. Additionally, active ankle dorsiflexion at full knee extension and 90° knee flexion were significantly correlated with YBT-LQ performance.[13]

The findings on ankle dorsiflexion, as it relates to YBT-LQ, provide some insight into factors that appear to contribute to dynamic balance abilities; however, there are likely other factors that contribute to balance. Both foot sensation and arch height affect static balance although these have yet to be assessed for their potential impact on dynamic balance. Decreased static balance performance was demonstrated after ice water submersion of the plantar aspect of the foot that reduced plantar cutaneous sensation measured via two-point discrimination in healthy individuals[14] and Semmes-Westin monofilaments in individuals with chronic ankle instability[15]. Additionally, individuals with supinated or pronated foot type(s) performed worse on static single leg stance than those with neutral feet.[16] Further, females with low medial longitudinal arch, as classified by the arch height index, performed worse on static balance than females with a normal medial longitudinal arch.[17] Given the known impact of dorsiflexion range of motion on dynamic balance and the potential impact of foot posture and foot sensation on dynamic balance, the purpose of this study was to investigate the relationship between lower extremity characteristics (AHI, DF ROM, forefoot sensation) and dynamic balance performance. We hypothesized that abnormal AHI, decreased DF ROM, and decreased forefoot sensation would predict decreased balance performance, specifically a reduction in the YBT-LQ composite score.

Methods

Study Design

This study was a descriptive study design and was approved by the institutional review board of XXXXX. Predictor variables included arch height index, foot sensation, passive ankle dorsiflexion range of motion (DF ROM), and weight bearing DF ROM. The criterion variable was the Lower Quarter Y-Balance Test (YBT-LQ) composite score (CS).

Participants

Twenty participants (Table 1) volunteered to participate in the study. To be included in the study, participants had to be at least 18 years old and a member of the XXXXX community. Any potential participant with a self-reported head cold or vestibular dysfunction, a self-reported lower extremity injury within the past month, or a self-reported concussion within the past 3 months was excluded from the study. Prior to participation, the study was reviewed with all participants, and any questions were answered. Further, all participants reviewed and signed an informed consent form prior to the initiation of any data collection.

Procedures

Participants first completed a health history questionnaire to screen for inclusion/exclusionary criteria. Height and weight were measured with a physician scale and stadiometer (Healthometer Professional 402KL, Boca Raton, Fl). Participants then randomly choose the order of testing for the predictor and criterion variables: arch height index, foot sensation, passive DF ROM, weight bearing DF ROM, and YBT-LQ. To facilitate randomized choosing of testing order, cards with each of the test names on them were placed face down on a plinth before the participant entered the test area; the participant was asked to pick up the cards one at a time and hand them to the investigator. The order in which the participant picked up the cards was the order of testing.

The Arch Height Index Measurement System tool (Figure 1) was used to measure the arch height index of both feet for each of the participants. The tool consists of a digital caliper (Model #93293, Cen-Tech, Harbor Freight Tools, Carmarillo, CA 93011) with a fixed point attached to a 1.2 x 5.0 x 10.0 cm plastic block which holds the caliper in a vertical position and a sliding metal rod attached to the moving point of the caliper to allow the assessment of arch height. A scale (Healthometer 402KL, Boca Raton, Fl) was used to measure the participant's body weight. The participant stood at 10% and 90% of their weight to assess AHI.[18] Due to its high reliability and validity the dorsum height at one half of the foot length was divided by the truncated foot length at 10% (reliability ICC= 0.81, validity ICC=0.844) and 90% (reliability ICC= 0.88, validity ICC=0.851) weight bearing.[18]

A two-point discriminator disc (Baseline 12-1492, Quakertown, PA) was used to measure foot plantar sensation (ICC = 0.86)[19]. The two plastic octagon shaped discs measure a different range of labeled fixed two-point intervals ranging from 1mm to 15mm.[20] The first interpoint distance was 15mm and the patient was instructed to say "yes" if they feel the points and indicate if they feel 1 or 2 points.[20] The participant was occasionally touched with only one point to ensure the participant did not know whether a 2-point stimulus was always delivered. The interpoint distance was decreased in 1mm increments until the participant was unable to correctly indicate whether one or two points have touched them simultaneously, or until they were unable to sense the points. The test was repeated 2 times to confirm the results. If there was a change between the first two trials, the test was repeated a third time. No more than 3 trials were completed. The best of the three scores was used for analysis. The three sites that were the plantar aspect of the great toe, the head of the 3rd and the head of the 5th metatarsals.[21] The three sites were averaged together for each foot to create two separate composite forefoot sensation scores for the right and left feet.

A biplane goniometer (Patterson Medical/Sammons Preston, SKU: SNRC7570, Warrenville, IL) was used to measure passive ankle dorsiflexion range of motion (DF ROM) as this tool has demonstrated less variation in measuring repeated ankle dorsiflexion[22] (Figure 2). The axis of the goniometer was standardized at the plantar lateral heel, the stable arm was formed by a line extending from the fibular through the lateral malleolus, and the mobile arm was the lateral border of the biplane goniometer's transverse plane platform, which corresponded to and supported the plantar surface of the foot. A biplane goniometer was used to measure passive ankle dorsiflexion as it enables proper subtalar joint position to ensure dorsiflexion is occurring at the talocrural joint and it is more reliable that a standard goniometer.[22]

The Weight Bearing Lunge Test (WBLT) was used to measure weight bearing DF ROM for both legs of each participant (Figure 3). First the tester placed a piece of white cloth tape perpendicular to the wall as well as along the wall, perpendicular to the floor. The participant positioned their foot on the floor so that their heel and their great toe were aligned with the tape. The starting position was standing with the heel in contact with the ground, the knee in line with the second toe, and the great toe 10 cm away from the wall. The participant then lunged forward so their knee touched the tape on the wall. They were allowed to hold the wall for balance. If the participant was successful in touching their knee to the wall without lifting their heel, their foot was moved away from the wall 1 cm at a time until the participant was unable to touch the wall with their knee without lifting their heel from the ground. The maximum distance was be measured to the nearest 1cm. A tape measure (McCoy-Retractable Fiberglass Tape Measure, 27111801, Maryland Heights, MO) was fixed to the floor to measure dynamic ankle DF ROM during the WBLT. The tester measured the distance from the wall to the tip of the great toe as this measure of ankle dorsiflexion has very high intra-rater reliability (ICC= 0.98)[23] and inter-rater reliability (ICC=0.99)[24].

The Y-Balance Test (Move2Perform, Functional Movement Systems) was used to measure balance performance for both legs of each participant; the procedures were adapted from Smith et al.[3] (Figure 4). All participants watched an instructional video, which demonstrated the YBT-LQ testing procedure, to standardize instructions and control for the potential learning effect. Each participant was then be asked to remove their shoes and socks and to place the most distal end of their longest toe of their stance leg at the red line on the testing platform. They completed 4-6 practice trials in the anterior reach direction with their right leg, then 4-6 in the same direction with their left leg. If the participant plateaued after 4 trials, they were permitted to stop the practice trials. This same sequence occurred for the posteromedial and posterolateral directions. The participant was told that the following errors will result in a failed attempt and repeat of a trial: loss of balance resulting in movement of the stance leg off the platform or the reaching leg to touch the floor, loss of contact with the reach indicator during an attempt or placing the foot on top of the indicator. After the practice trials, leg length was measured in a supine position from the inferior aspect of the anterior superior iliac spine to the distal medial malleolus. The participant then completed their three successful test reaches in each of the three directions following the same procedures as the practice trials. The furthest successful reach attempt in each direction was recorded and a normalized composite score was created for each limb.

Statistical Analyses

The descriptive statistics were calculated for all predictor and criterion variables. A multiple regression analysis (SPSS 23) established the relationship between predictor (AHI10, AHI90, SEN, passive and weight bearing DF ROM) and criterion (YBT-LQ CS) variables. Tests of multicollinearity were assessed with tolerance, variance inflation factor, and correlations between predictor variables. The alpha level was set at 0.25 when all predictors were simultaneously entered into the regression equation to determine which variables may be most predictive of YBT-LQ CS. After which, only those satisfying the aforementioned criteria were entered into the final sequential prediction equation; $p < 0.05$. Two separate right and left limb regression analyses were developed.

Results

Twenty participants from the general population [14 ♀, 6 ♂, mean age (SD): 35 (18) years, weight (SD): 70.02 (16.76) kg, height (SD): 1.68 (0.12) m] took part in this study. The descriptive statistics were calculated and reported as the means ± standard deviations (Table 1). Due to multicollinearity between AHI10 and AHI90, AHI10 was removed from the regression equation. On the right limb, both AHI90 and SEN met the criteria for predictive of YBT-LQ CS during the multiple regression (Table 2); these two predictors were entered into the final sequential regression; however, they resulted in a non-significant r^2 (Table 3). On the left limb, both WBLT and SEN met the criteria for predictive of YBT-LQ CS during the multiple regression (Table 2); these two predictors were entered into the final sequential regression resulting in a significant r^2 (Table 4).

Discussion

The purpose of this study was to investigate the relationship between lower extremity characteristics (AHI, DF ROM, Foot sensation) and balance performance. Our findings suggest that forefoot sensation (SEN) and weight bearing dorsiflexion (WBLT) impact dynamic balance as these two factors explained 22% of the variance in YBT-LQ CS calculation in this study.

We hypothesized that abnormal AHI, decreased dorsiflexion range of motion (DF ROM), and decreased SEN would predict decreased balance performance, specifically a reduction in the YBT-LQ CS. Our hypothesis was partially supported in that SEN and WBLT significantly contributed to performance of the YBT-LQ CS on the left limb in this sample. These results suggest an inverse relationship between both decreased forefoot SEN and decreased DF ROM and YBT-LQ CS; such that as SEN values increased (worse forefoot sensation) YBT-LQ CS decreased, while as DF ROM increased YBT-LQ CS decreased. The finding that those with decreased forefoot sensation had decreased dynamic balance is not surprising given previous literature[14,15] that altered plantar sensation resulted in decreased static balance. However, we believe this is the first study to demonstrate that altered forefoot sensation negatively impacts dynamic balance. From a clinical perspective, this may suggest that clinicians should consider assessing forefoot plantar cutaneous sensation in patients with decreased dynamic balance. Perhaps clinicians may want to consider plantar foot massage and/or mobilization interventions in patients with decreased dynamic balance and forefoot plantar cutaneous sensation as this intervention has been demonstrated to improve static balance in patients with chronic ankle instability[25] and dynamic balance in patients with type II diabetes mellitus[26]. Further, a Thai foot massage technique has been found to improve balance, foot range of motion, and plantar sensation in patients with diabetes and peripheral neuropathy.[27] A combined treatment of foot massage and mobilization of the feet and ankles was found to improve one leg balance and Timed Up and Go test in elderly patients.[28]

The finding that as DF ROM increased, YBT-LQ CS decreased may be a bit surprising giving previous findings relative to decreased anterior reach in the SEBT[10] and the YBT-LQ[12] in those with decreased dorsiflexion range of motion. Additionally, Kang et al.[11] reported that both the anterior and posteromedial reach were impacted more by dorsiflexion range of motion than the posterolateral reach direction, although they did not explicitly state if the reach directions increased or decreased as a result of more or less dorsiflexion range of motion. It is also possible that the kinematics of more proximal joints, such as the knee and hip[29], play a more important role in dynamic balance than dorsiflexion range of motion alone. Further, increased dorsiflexion range of motion has been found to increase posterior displacement of center of mass.[30] If center of mass was posteriorly displaced during YBT-LQ in our participants it is possible that this could have made the participants feel unstable. Although we do not have kinematic data on our participants, this may provide rationale for our finding that as dorsiflexion, as measured through the WBLT, increased, YBT-LQ decreased. Further, increased dorsiflexion range of motion may increase the muscular system strength demands during performance of the YBT-LQ. Dorsiflexion range of motion has been negatively correlated with squat depth, while dorsiflexor strength was positively correlated with squat depth; both dorsiflexion range of motion and dorsiflexion strength explained 32.4% of the variance in squat depth.[31] This may suggest that although our participants had increased dorsiflexion range of motion, they did not have appropriate strength that is also required to stabilize their center of mass during the YBT-LQ. It is also possible that, although previous research indicated that individual reach directions may be negatively affected by decreased dorsiflexion range of motion, perhaps dorsiflexion range of motion does not have the same effect on the YBT-LQ when considering the composite score. Additionally, on the right limb, DF ROM did not play a role in YBT-LQ CS in this sample. Although not statistically significant ($p = 0.052$), the most influential predictor of YBT-LQ CS performance on the right-side regression equation was AHI90; thus, there may be some reasons to consider not only forefoot sensation and dorsiflexion range of motion, but also AHI90 from a clinical perspective.

AHI has been classified as high ($AHI > 0.356$), normal (0.276-0.355), or low ($AHI \leq 0.275$).[32] In both perimenopausal females[17] and adolescent males[33], lower arches were associated with decreased static balance performance. The participants in our study had a mean AHI90 of 0.251 on the right side and 0.265 on the left side, which would be classified as low arch. The regression suggested that as AHI90 increased so would YBT-LQ performance, which is in line with previous research on static balance performance. Additionally, Tsai et al.[16] reported that individuals with pronated or supinated feet performed worse in static balance; these authors indicated that those with pronated feet appear to have reduced control in the anterior/posterior direction when controlling center of pressure displacement. When considering the movement of the stance limb during the YBT-LQ, there is a need to control movement in the anterior/posterior direction. Although we cannot determine a causal relationship, which is a limitation of our study design, perhaps future researchers should consider arch height in assessments relative to dynamic balance. There are also a number of other factors that can contribute to balance (i.e. visual field disturbances, jaw position) that were not assessed in this study and may be considered in future designs. An additional limitation is that we did not assess limb dominance in this study; therefore, we are unable to determine which limb would be the stance versus kicking limb. There were two testers for this study who practiced together to ensure methods of assessment were consistent between testers and we chose to use methods with high reliability; nonetheless, this may have created a limitation in our design. We are also limited in that our sample was mostly female and may not be generalizable to the entire population; however, we believe this is the first study to investigate the predictability of combined factors of dorsiflexion range of motion, forefoot sensation, and arch height index on dynamic balance.

Conclusion

This study demonstrates that foot characteristics may play a role in YBT-LQ CS. Altered SEN, weight bearing dorsiflexion, and perhaps arch height, appear to be contributing factors to YBT-LQ CS. Future research could expand on these findings by focusing on SEN, AHI90, and WBLT while increasing the sample size to extend external validity.

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Table 1. Average means (SD) for right and left limb predictor and criterion variables

	Right Limb	**Left Limb**
AHI10	0.274 (0.022)	0.287 (0.029)
AHI90	0.251 (0.027)	0.265 (0.026)
Static DF ROM	7 (4) °	9 (5) °
WBLT	10 (2) cm	10 (3) cm
SEN	11 (2) mm	11 (2) mm
YBT-LQ CS	93 (10) %	95 (9) %

AHI10 – arch height index at 10% of body weight
AHI90 – arch height index at 90% of body weight
Static DF ROM – static dorsiflexion range of motion
WBLT – weight bearing lunge test
SEN – forefoot sensation
YBT-LQ CS – Y Balance Test Composite Score

Table 2. Forward Multiple Regression Analysis, AHI10 removed; $p < 0.25$

	Right Limb	**Left Limb**
AHI90	p = 0.108	p = 0.833
Static DF ROM	p = 0.669	p = 0.257
WBLT	p = 0.615	p = 0.225
SEN	p = 0.239	p = 0.111

Table 3. Right Limb Stepwise Regression Analysis, $p < 0.05$; a) Includes AHI90 only, b) AHI90 plus SEN

	Right Limb
AHI90[a]	B = 1.611 $p = 0.052$, $r^2 = 0.194$
AHI90, SEN[b]	B = 1.464 B = -0.011 $p = 0.074$, $r^2 = 0.264$

Table 4. Left Limb Stepwise Regression Analysis, $p < 0.05$; a) Includes SEN only, b) SEN plus WBLT

	Left Limb
SEN[a]	B = -0.019 $p = 0.089$, $r^2 = 0.105$
SEN, WBLT[b]	B = -0.020 B = -0.012 $p = 0.047$, $r^2 = 0.220$

Figure 1. AHI Measurement System

$$AHI = \frac{Dorsum\ Height\ @\ ½\ Foot\ Length}{Truncated\ Foot\ Length}$$

Figure 2. Static DF ROM measurement

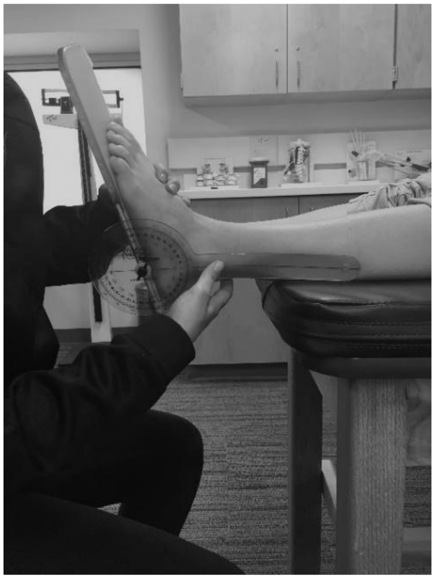
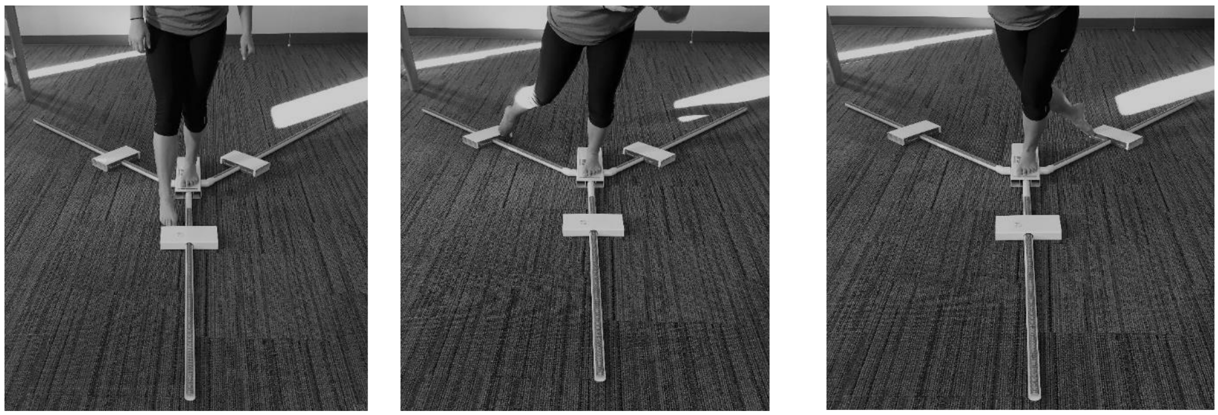


Figure 3. Weight Bearing Lunge Test (WBLT) position

Figure 4. YBT Performance



Anterior Reach Posteromedial Reach Posterolateral Reach