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Lower Extremity Horizontal Work But Not Vertical Power Predicts Lower Extremity Injury in Female Collegiate Dancers

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Abstract

Dancers often perform powerful and explosive movements that require adequate lower extremity(LE) activity in horizontal and vertical directions. We examined if these measures were interrelated and whether they predicted LE injury status in dancers using binary logistic regressions and Receiver Operator Characteristic(ROC) curve analyses. Forty-three collegiate female dancers(18±0.7yrs; 162.6±5.9cm; 59.4±7.1kg) performed Single Leg Hop(SLH,m), and Vertical Jump(VJ,cm) tests. SLH and VJ distances were used to calculate SLH_norm (as a % of body height) and Vertical Power(vPower,watts). LE injuries and dance exposure hours(DEhr) were recorded for 16 weeks. Dancers had 51 injuries resulting in a 3.7/1000 DEhr injury incidence rate(95% CI:2.7-4.7). 20 dancers were injured, while 23 remained injury-free. Injured dancers had significantly lower SLH_norm than non-injured dancers(t=2.7, p=.009, 85.2±11.2% vs. 76.8±8.4% respectively), but vPower was similar(t=0.6,p=.53, injured=2632.0±442.9 watts, non-injured=2722.7±480.0 watts). SLH_norm, but not vPower significantly predicted injury status $\chi^2(1,43)=5.9$, p=.02. Specifically, a SLH_norm cut-off value of 78.2% identified dancers at injury risk(AUC=.73, SE=.08, p=.01, 95%CI=.57-.89, Sensitivity=.75, Specificity=.70). However, vPower was not able to identify dancers at risk(p=.36). vPower had moderate relationships with SLH_norm(r=.31, p=.04). Compared to injured dancers, non-injured dancers had greater SLH_norm but similar vPower. Only SLH_norm predicted injury status in female collegiate dancers. Thus, the SLH test may possibly predict LE injury risk in dancers. Strength and conditioning coaches can prospectively use baseline SLH test screenings to identify dancers whose SLH is less than 78.2% of their height as these dancers may have increased probability of LE injury risk. Coaches can then include horizontal direction exercises when designing training programs and examine if these programs reduce LE injury risk in female collegiate dancers.

Key Words: Fitness Screening, Lower Body Performance, Hops, Vertical Jumps

INTRODUCTION

Dancing is a physically challenging activity (3), with the majority of all dance related musculoskeletal injuries being lower extremity (LE) injuries (4,19,25,35) . Jumping and landing are associated with LE injury (34), and dancers regularly perform these explosive vertical and horizontal jumping and hopping motions when dancing (32,41). These motions are one of the main reported causes of injury in dancers (1,26). Specifically, Allen et al. (1) reported that after the 'cannot recall' or 'other' mechanism of injury in ballet dancers, jumps accounted for the largest proportion of injury mechanisms. Dancers thus need adequate LE performance and power to dance successfully without getting injured.

While reduced LE muscle power has been previously associated with increased injuries in contemporary dancers (4,25), these studies relied on self-reported injuries. Similarly, while some researchers (40) found that increases in LE strength and power resulted in reduced injury incidence, others (37) noted that that LE power could not predict injury in ballet dancers. Generally, the current published literature examining relationships between LE strength and power and injury incidence in dancers has methodological limitations and is inconclusive about the relationships among these factors.

LE-intensive power requiring activities like horizontal and vertical hop and jump motions are common in dance. While the body uses similar LE muscles (e.g. gluteal, hamstrings, quadriceps, triceps surae muscles) to perform these motions (7,13), the majority of published screening protocols in dance have focused on vertical direction (vertical jump tests, hop tests) (26,29,39) and not horizontal direction tests (e.g. triple hop tests) (21). Horizontal and vertical

LE performance measures are positively correlated (16), and lower body muscle function measures can influence sprint performance in athletes (33). However, whether a similar relationship exists in dancers is still unclear. Overall, little published evidence exists examining potential interrelationships between LE horizontal and vertical performance and the influence of these measures on LE injury in dancers. Understanding these relationships would help strength and conditioning coaches choose appropriate exercises to include in training programs to improve their clients' performance and reduce their LE injury risk.

Thus, the primary aim of the present study was to examine whether there were differences in LE horizontal single leg hop distance and vertical power between injured and non-injured dancers, and if these variables could predict injury status in female collegiate dancers. The secondary aim was to examine whether horizontal hop distance and vPower were related in female collegiate dancers.

METHODS

Experimental Approach to the problem

We used a prospective study design to examine horizontal hop distance (using the single leg hop test) and vertical power (using the vertical jump test) in female collegiate dancers. The tests were performed in a single session. An in-house certified athletic trainer recorded LE injuries and dance exposures over 16 weeks. The local university Institutional Review Board approved the study, and all participants gave their written, informed consent before taking part in the study.

Participants

Forty-three collegiate female dancers (age = 18 $\pm$ 0.7 years; height = 162.6 $\pm$ 5.9 cm; mass = 59.4 $\pm$ 7.1 kg, dance experience = 12.7 $\pm$ 3.8 years) participated in the study. All participants were dance majors in a program that emphasizes modern dance but all dancers had prior experience in other dance styles including, but not limited to ballet, jazz, and hip-hop dance. Participants danced 25.6 $\pm$ 5.6 hours weekly (including dance classes, rehearsals, and performances). The dancers' anthropometric data were collected; age was recorded to nearest whole year, height was measured to the nearest millimeter using a Seca 216 Stadiometer, (Scale Co. Inc, Brooklyn, NY) and body mass to the nearest 0.1kg using a digital scale (Precision Digital Bathroom Scale, HealthTools LLC, Mahwah, NJ). We ensured that the dancers were healthy and had no issues that would impair their ability to perform the tests.

Injury and Dance Exposure

Injuries were defined based on prior recommendations for surveillance of dance injuries as '*any physical complaint sustained by a dancer resulting from company (sic) performance, rehearsal, or technique class and resulting in a dancer injury report and triage, irrespective of the need for medical attention or time-loss from dance activities*' (9). Dance exposure (DEhr) was calculated using estimations based on academic class times, rehearsal and choreography times, and performance schedules. Specifically, 1 DEhr was defined as participation in 1 hour of dance (including class, rehearsals, performances, choreography). All injury data were recorded over a 16-week time period. While the anatomical locations of all injuries were recorded, the present study only reports LE injuries (toes-foot, ankle-lower leg, knee, and hip-thigh). Injury incidence was calculated as the number of injuries per 1,000 DEhr with 95% confidence intervals (CI) (2).

Single Leg Hops

Single Leg Hops (SLH) horizontal performance was measured using the SLH test as described in previous literature (30). Dancers first stood on one leg with their big toe at a marked starting line. They carried out a single hop, covering as much distance as possible horizontally, and landed on the same leg. SLH distance (m) was measured from the starting line to the participants' heel (30). Dancers' arms were unconstrained during the hop. The trial was repeated if (1) the dancer's contralateral foot touched the floor, (2) the dancer lost balance, or (3) the dancer took additional hops after the single hop. Dancers performed 3 successful trials on each leg, alternating between sides to prevent fatigue. Then we normalized the hop distance to the dancers' height (SLH_norm, % height) to reduce the effects of inter-individual anthropometric variations. The mean of the greatest left and right leg distances were used for calculating SLH_norm.

vPower

vPower was calculated using the vertical jump (VJ) test (27). Standing on a Just Jump Mat (Probotics, Huntsville, AL), participants began in an upright posture with their feet shoulder width apart and arms above their head before moving to a semi-squat position. Then, they swung their arms forward above their head as they jumped straight up into the air landing on both feet. Via microswitches embedded in the mat, time in the air is measured and from this measure, the system calculates the vertical jump height using the formula: height of body center of gravity = $(t^2 \times g)/8$, where $g = 9.81\ m \cdot s^{-2}$ and t is air time in seconds (27). Participants performed three vertical jumps (cm) and the mean was calculated. vPower (watts) was calculated using a previously published equation (20) that accounts for participants' body mass and height to reduce the effects of individual anthropometric variation. The equation is vPower (watts) = 78.5 x VJ (cm) + 60.6 x body mass (kg) – 15.3 x height (cm) – 1308.

Statistical Analyses

To examine the primary aim of the present study, an independent samples t-test was used to compare differences between injured vs. non-injured dancers, a binary logistic regression was used to examine if SLH_norm and vPower could predict injury status, and Receiver Operator Characteristic (ROC) curve analyses to identify the measures associated with an elevated injury risk and established cut-off point at the score that maximized sensitivity and specificity. To test the secondary aim, we used a Pearson-product-moment-correlation to examine the relationship between SLH_norm and vPower. An 0.05 *a priori* alpha level was set for all tests, and the PASW 24.0 software (IBM Corp, Armonk, NY) was used to conduct all analyses.

RESULTS

Over the study period there were 13,760 dance exposures. Twenty-three dancers remained injury-free and 20 dancers were injured during the study time. We recorded 51 injuries resulting in an overall 3.7/1000 DEhr injury incidence rate (95% CI: 2.7-4.7) or 1.19 $\pm$ 1.53 injuries/dancer. The types, locations, and nature of lower extremity injuries in female collegiate dancers are presented in Table 1.

Table 1 approximately here

Injured dancers had significantly lower SLH_norm than non-injured dancers (t=2.7, p=.009), but there was no significant difference in vPower between the groups (t=0.6, p=.53) (Table 2).

Table 2 approximately here

The regression model reported that SLH_norm, but not vPower, significantly predicted injury incidence status $\chi^2(1,43) = 5.9$, $p = .015$, Nagelkerke $r^2 = .21$. It correctly classified 70% of those who were not injured and 70% of those who were injured for an overall 70% success rate.

Similarly, the ROC curve analysis (Figure 1) revealed that SLH_norm was able to identify dancers at injury risk (AUC = .73, SE = .08, p = .01, 95% CI = .57 - .89). The cut-off point that maximized sensitivity (0.75) and specificity (.70) was SLH_norm = 78.2% height. This SLH_norm value accurately identified 15 of the 20 dancers that were injured and 17 of the 23 dancers that remained injury-free. (Table 3).

Figure 1 and Table 3 approximately here

vPower was not able to identify dancers at injury risk (AUC = .58, SE = .09, p = .36, 95% CI = .41-.76).

The secondary aim to examine the relationship between SLH_norm and vPower reported a moderate relationship ($r=.31$, $p<.04$).

DISCUSSION

Dancers regularly perform hops and jumps within class, rehearsal and performance (41). These motions account as one of the main reported causes of injury in dancers (1,26). The injury incidence data from the present study (3.7/1000 dance hour exposures) are somewhat at the higher range of the injury incidence rates previously noted in dancers (range 0.18-4.6/1000 hours of dance exposure), though the incidence per dancer (1.19 $\pm$ 1.53 injuries) is similar to that previously reported (1,2,10,14). It is important to note that the surveillance period in the present study was shorter (16 weeks) compared to the annual surveillance periods in the majority of previous studies. Recognizing that there is a general consensus that a majority of injuries in dance are to the LE (4,19,25,35), we note that in that the present study we only reported LE injuries, excluding other injuries. If we had included all injuries, the injury incidence as expressed per 1000hrs or per dancer may have been different.

A possible reason for the findings of higher LE injury incident rates could be the more inclusive definition of injury in the present study. Specifically, both time loss and non-time loss injuries were included in the analyses, whilst previous studies have only included time loss injuries thereby reducing the overall recorded injuries in these previous studies. When examining injury rates in dancers, it is important to include all instances where dancers seek medical attention. This is because studying these records will allow for a more precise calculation of the actual medical needs, and the subsequent burden of injury in dancers. The use of a time loss only definition may underestimate the total injuries requiring medical attention and not account for dancers who can still participate in dance class, rehearsal or performance while having an injury that is receiving treatment but does not completely stop them from dancing.

The dance exposures in the current study period included dance technique and choreographic workshops. Allen et al. (1) reported a greater injury incidence during class and rehearsal phases than during performance periods, which is the opposite of that generally reported in sport settings (11,17). This is mainly because in dance, the technique and choreographic classes are where new movements are explored and practiced, thus dancers likely have a higher element of risk during these exposures. Dance performance on the other hand is the presentation of learned movements within a closed environment that therefore has a lower element of injury risk.

The link between LE muscle function and injury incidence has been somewhat previously demonstrated in dance, with stronger dancers having a lower injury incidence than their weaker counterparts (25,40), therefore LE horizontal and vertical direction performance are useful variables to monitor in this population. Within the current study, there was no statistical difference in vertical power between the injured and non-injured dancers. However injured dancers produced significantly less SLH_norm distances than their non-injured counterparts. The regression analysis model highlighted this finding by correctly classifying 70% of those who were injured.

Previous published data have also highlighted the benefits of horizontal hop tests as an indicator of underlying pathology or recovery success. For example, Witchalls et al.(38) noted the test could differentiate between those with and without ankle ligamentous instability and Logerstedt et al.(30) used the test to predict successful outcomes 6-months post Anterior Cruciate Ligament reconstruction. In contrast, vPower (vertical jump height) could not predict LE injury status in the present study, while others (4) have found it associated with injury incidence. It must be noted that the protocols differed slightly between our study and this previous report. Specifically, Angioi et al.(4) relied on self-report injuries. Also, in their project for the vertical jump dancers did not use their arms, and started and finished the vertical jump in first position of ballet (i.e. heels together and legs externally rotated). Overall, these methodological differences may have partially influenced the contrasts between our findings and those noted by Angioi et al.

In a recent systematic review of functional performance tests (e.g. hop tests, vertical jumps) for knee function and their relationship with injury, Hegedus et al.(18) found little published research examining the relationships of SLH or VJ tests and their ability to predict knee injury risk. In contrast, the ROC analyses revealed a single leg hops cut-off point of 78.2% of the dancers' own height with 75% sensitivity and 70% specificity.

Secondary calculation of likelihood ratios (31) also revealed the negative likelihood ratio [(1-sensitivity)/ specificity] was 0.83. As per McGee, (31) the practical implication of this number is negligible. However, the positive likelihood ratio [sensitivity/(1-specificity)] was 2.5. The practical implication of this finding is that for individuals who jump less than 78.2% of their height in single leg hop distances at baseline, their probability to have the outcome (i.e. LE injury over a 16-week time-frame in this study) would increase 15-20%. Overall, there seems to be some predictive value of lesser single leg hop distances in determining lower body injury risk in dancers.

Thus, overall our findings lend support to the use of the SLH test as a possible screening test for LE injury risk assessment. Specifically, strength and conditioning coaches should identify on their clients who jump less than 78.2% of their height in single leg hop distances when conducting baseline physical fitness assessments or screenings and then include horizontal direction exercises when designing training programs to examine if these programs reduce LE injury risk in female collegiate dancers. Still, given our preliminary finding, there still remains a need for additional prospective longitudinal studies to determine if LE horizontal hop and power tests can actually predict LE injury risk in dancers and other physically active populations.

In the current study, we used the SLH and VJ tests to measure LE horizontal and vertical performance respectively as they are reliable, with low measurement errors and can be easily administered with minimal training and equipment (8,22,30). The SLH values (SLH distances: 1.26 $\pm$ .15 m) noted in the current study are comparable to those in prior reports in athletic females (1.3 $\pm$ 0.2 m) (23). The dancers' mean VJ height (36.6 $\pm$ 5.22 cm) noted in this study are slightly higher than previously reported measures in athletic females (29.9 ± 7.1 cm) (23) and female collegiate dancers (around 33 cm) (12). It has been previously reported that SLH distances and vPower are strongly correlated in athletic populations (*r* range = .70 –to –.94) (15,16) as both tests use similar muscles (7) though the current study showed a weaker relationship (*r*=.31). This finding could be partially explained by the differing test requirements.

The VJ requires muscle activity to drive the body vertically upward (6,12,23). Conversely, the SLH requires muscle activity to drive the body anteriorly in the horizontal direction with a hop (23). Thus, despite similar muscles being used by the body for both tasks, muscle activation onsets and amplitude levels likely differed between the tests. Prior researchers (23) have noted that despite similar muscles being used by the body for both horizontal and vertical LE tasks, muscle activation onsets and amplitude levels likely differs between these tasks. Other researchers (36) also report that vertical jump and horizontal hop tests do not measure the same functional components, and thus suggest that both vertical jump and horizontal hop tests should be paired to comprehensively assess LE functional performance.

Taken together with previous reports, the practical application of our findings is that strength and conditioning coaches should use horizontal direction hop tests when screening dancers. Still, the correlations we noted between vertical and horizontal LE measures suggest that these tests measure related but different components of LE function, and researchers should further examine these relationships. Coaches should also include horizontal direction exercises when designing training programs to study if these can reduce dancers' LE injury risk.

The current study has some limitations including the lack of generalizability of the results outside of the current participant group. While SLH_norm significantly predicted LE injury status in this relatively short study period (16 weeks), further studies are required over longer time periods. Also, the equation we used in the study to calculate VJ peak power has an r^2 value of .91 (20) and so there is some unexplained variance not accounted for by this equation. Still given that the equation does explain over 90% of the variance in power, we feel reasonably confident that the equation generally represents vertical power. While we used the SLH and VJ tests in the current study, we do acknowledge other LE functional tests (e.g. triple hops for distance, crossover hops) exist in the published literature. For example, medial hops have been reported to be able to distinguish between painful and normal hips in dancers (21). Moreover, though our participants performed the SLH (30) and VJ (27) as per directions in prior work, dancers performed the SLH on one foot and the VJ on two legs, which may have possibly influenced our overall results. Overall, future investigators should examine which LE tests are applicable in terms of predicting performance and injury risk in a range of dance genres and across other physically active populations. Understanding these relationships better may help strength and conditioning practitioners to design training programs to improve performance and decrease injury risk.

Further, although all dancers included were healthy at time of testing and had no issues that impaired their ability to perform the tests, whether any previous injuries may have altered their physical performance and may possibly influence their subsequent injury risk needs further study. While dancers' participation in training programs can improve dance performance (5,24,37), and implementing on-site medical care in a modern dance company can reduce workers compensation cases (10), there is still a lack of epidemiological, screening, and intervention studies in dancers. Thus, if targeted prospective strength and conditioning exercise programs that include LE horizontal training enhance performance and reduce injury incidence in dancers remains unclear. Combining our findings with prior research also highlights the challenges described previously (28) of arriving to a general consensus for injury incidence recording methodologies in dancers.

Overall, injured dancers had significantly lesser horizontal lower extremity SLH distances than non-injured dancers, but there was no difference between the two groups in vertical power. Lower extremity single leg hop distance was able to predict injury risk in collegiate dancers. Thus, the SLH test may be a good baseline screening test for LE injury risk assessment. Intervention training studies need to be implemented to see if targeted LE training programs that also include horizontal movement exercise can decrease LE injury risk in dancers and other physically active populations.

PRACTICAL APPLICATIONS

Lower extremity horizontal single leg hop distance was able to predict injury risk in collegiate dancers. Overall, the SLH test may be a good screening test for LE injury risk in dancers. Specifically, strength and conditioning coaches can prospectively use baseline SLH test screenings to identify their dancers whose single hop distance is less than 78.2% of their height as these dancers may have increased probability of LE injury risk. Coaches can then include horizontal direction exercises when designing training programs and examine if taking part in these programs reduce LE injury risk in female collegiate dancers.

REFERENCES

1. Allen, N, Nevill, A, Brooks, J, Koutedakis, Y, and Wyon, M. Ballet injuries: injury incidence and severity over 1 year. *J Orthop Sports Phys Ther* 42: 781–790, 2012.

2. Allen, N, Nevill, AM, Brooks, JHM, Koutedakis, Y, and Wyon, MA. The effect of a comprehensive injury audit program on injury incidence in ballet: a 3-year prospective study. *Clin J Sport Med* 23: 373–378, 2013.

3. Ambegaonkar, JP. Dance medicine: at the university level. *Dance Res J* 37: 113–19, 2005.

4. Angioi, M, Metsios, G, Koutedakis, Y, Twitchett, E, and Wyon, MA. Physical fitness and severity of injuries in contemporary dance. *Med Probl Perform Art* 24: 26–29, 2009.

5. Angioi, M, Metsios, G, Twitchett, EA, Koutedakis, Y, and Wyon, M. Effects of supplemental training on fitness and aesthetic competence parameters in contemporary dance: a randomised controlled trial. *Med Probl Perform Art* 27: 3–8, 2012.

6. Angioi, M, Metsios, GS, Twitchett, E, Koutedakis, Y, and Wyon, M. Association between selected physical fitness parameters and esthetic competence in contemporary dancers. *J Dance Med Sci* 13: 115–123, 2009.

7. Begalle, RL, Distefano, LJ, Blackburn, T, and Padua, DA. Quadriceps and hamstrings coactivation during common therapeutic exercises. *J Athl Train* 47: 396–405, 2012.

8. Booher, LD, Hench, KM, Worrell, TW, and Stikeleather, J. Reliability of three single-leg hop tests. *J Sport Rehabil* 2: 165–170, 1993.

9. Bronner, S, Ojofeitimi, S, and Mayers, L. Comprehensive surveillance of dance injuries: A proposal for uniform reporting guidelines for professional companies. *J Dance Med Sci* 10: 69–80, 2006.

10. Bronner, S, Ojofeitimi, S, and Rose, D. Injuries in a modern dance company: effect of comprehensive management on injury incidence and time loss. *Am J Sports Med* 31: 365–373, 2003.

11. Brooks, J, Fuller, C, Kemp, S, and Reddin, D. A prospective study of injuries and training amongst the England 2003 Rugby World Cup squad. *Br J Sports Med* 39: 288–293, 2005.

12. Brown, A, Wells, T, Schade, M, L, Smith, D, and Fehling, P. Effects of plyometric training versus traditional weight training on strength, power, and aesthetic jumping ability in female collegiate dancers. *J Dance Med Sci* 11: 38–44, 2007.

13. Charoenpanich, N, Boonsinsukh, R, Sirisup, S, and Saengsirisuwan, V. Principal component analysis identifies major muscles recruited during elite vertical jump. *ScienceAsia* 39: 257–64, 2013.

14. Ekegren, CL, Quested, R, and Brodrick, A. Injuries in pre-professional ballet dancers: Incidence, characteristics and consequences. *J Sci Med Sport* 17: 271–275, 2014.

15. Gustavsson, A, Neeter, C, Thomeé, P, Silbernagel, KG, Augustsson, J, Thomeé, R, et al. A test battery for evaluating hop performance in patients with an ACL injury and patients who have undergone ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 14: 778–788, 2006.

16. Hamilton, RT, Shultz, SJ, Schmitz, RJ, and Perrin, DH. Triple-hop distance as a valid predictor of lower limb strength and power. *J Athl Train* 43: 144–151, 2008.

17. Hawkins, R and Fuller, C. A prospective epidemiological study of injuries in four English professional football clubs. *Br J Sports Med* 33: 196–203, 1999.

18. Hegedus, EJ, McDonough, S, Bleakley, C, Cook, CE, and Baxter, GD. Clinician-friendly lower extremity physical performance measures in athletes: A systematic review of measurement properties and correlation with injury, part 1. The tests for knee function including the hop tests. *Br J Sports Med* 49: 642–648, 2015.

19. Jacobs, CL, Hincapié, CA, and Cassidy, JD. Musculoskeletal injuries and pain in dancers: a systematic review update. *J Dance Med Sci* 16: 74–84, 2012.

20. Johnson, D and Bahamonde, R. Power output estimate in university athletes. *J Strength Cond Res* 10: 161–66, 1996.

21. Kivlan, B, Carcia, C, Clemente, F, Phelps, A, and Martin, R. Reliability and validity of functional performance tests in dancers with hip dysfunction. *Int J Sports Phys Ther* 8: 360–369, 2013.

22. Kockum, B and Heijne, AI-LM. Hop performance and leg muscle power in athletes: Reliability of a test battery. *Phys Ther Sport* 16: 222–227, 2015.

23. Kollock, R, Van Lunen, BL, Ringleb, SI, and Oñate, JA. Measures of functional performance and their association with hip and thigh strength. *J Athl Train* 50: 14–22, 2015.

24. Koutedakis, Y, Hukam, H, Metsios, G, Nevill, A, Giakas, G, Jamurtas, A, et al. The effects of three months of aerobic and strength training on selected performance- and fitness-related parameters in modern dance students. *J Strength Cond Res* 21: 808–812, 2007.

25. Koutedakis, Y, Khaloula, M, Pacy, PJ, Murphy, M, and Dunbar, G. Thigh peak torques and lower-body injuries in dancers. *J Dance Med Sci* 1: 12–15, 1997.

26. Laws, H. Fit to Dance 2 - Report of the second national inquiry into dancers' health and injury in the UK. London: Newgate Press, 2005.

27. Leard, JS, Cirillo, MA, Katsnelson, E, Kimiatek, DA, Miller, TW, Trebincevic, K, et al. Validity of two alternative systems for measuring vertical jump height. *J Strength Cond Res* 21: 1296–1299, 2007.

28. Liederbach, M, Hagins, M, Gamboa, JM, and Welsh, TM. Assessing and Reporting Dancer Capacities, Risk Factors, and Injuries: Recommendations from the IADMS Standard Measures Consensus Initiative. *J Dance Med Sci* 16: 139–153, 2012.

29. Liederbach, Marijeanne. Screening for functional capacity in dancers designing standardized, dance-specific injury prevention screening tools. *J Dance Med Sci* 1: 93–106, 1997.

30. Logerstedt, D, Grindem, H, Lynch, A, Eitzen, I, Engebretsen, L, Risberg, MA, et al. Single-legged hop tests as predictors of self-reported knee function after anterior cruciate ligament reconstruction: the Delaware-Oslo ACL cohort study. *Am J Sports Med* 40: 2348–2356, 2012.

31. McGee, S. Simplifying likelihood ratios. *J Gen Intern Med* 17: 646–649, 2002.

32. Orishimo, KF, Liederbach, M, Kremenic, IJ, Hagins, M, and Pappas, E. Comparison of landing biomechanics between male and female dancers and athletes, part 1: Influence of sex on risk of anterior cruciate ligament injury. *Am J Sports Med* 42: 1082–1088, 2014.

33. Seitz, LB, Reyes, A, Tran, TT, Saez de Villarreal, E, and Haff, GG. Increases in lower-body strength transfer positively to sprint performance: a systematic review with meta-analysis. *Sports Med* 44: 1693–1702, 2014.

34. Shimokochi, Y and Shultz, SJ. Mechanisms of Noncontact Anterior Cruciate Ligament Injury. *J Athl Train* 43: 396–408, 2008.

35. Smith, TO, Davies, L, de Medici, A, Hakim, A, Haddad, F, and Macgregor, A. Prevalence and profile of musculoskeletal injuries in ballet dancers: A systematic review and meta-analysis. *Phys Ther Sport* 19: 50–56, 2016.

36. Swearingen, J, Lawrence, E, Stevens, J, Jackson, C, Waggy, C, and Davis, DS. Correlation of single leg vertical jump, single leg hop for distance, and single leg hop for time. *Phys Ther Sport* 12: 194–198, 2011.

37. Twitchett, E, Brodrick, A, Nevill, AM, Koutedakis, Y, Angioi, M, and Wyon, M. Does physical fitness affect injury occurrence and time loss due to injury in elite vocational ballet students? *J Dance Med Sci Off Publ Int Assoc Dance Med Sci* 14: 26–31, 2010.

38. Witchalls, JB, Newman, P, Waddington, G, Adams, R, and Blanch, P. Functional performance deficits associated with ligamentous instability at the ankle. *J Sci Med Sport* 16: 89–93, 2013.

39. Wyon, MA. Testing the Aesthetic Athlete. In: Testing the Aesthetic Athlete. In: Winter E, Jones A, Davison R, Bromley P, Mercer T, eds. Sport and Exercise Physiology Testing Guidelines: British Association of Sport and Exercise Science Testing Guidelines (Vol. 2).London and New York: Routledge, Taylor and Francis Group, 2007. pp. 249–262

40. Wyon, MA, Koutedakis, Y, Wolman, R, Nevill, AM, and Allen, N. The influence of winter vitamin D supplementation on muscle function and injury occurrence in elite ballet dancers: a controlled study. *J Sci Med Sport* 17: 8–12, 2014.

41. Wyon, MA, Twitchett, E, Angioi, M, Clarke, F, Metsios, G, and Koutedakis, Y. Time motion and video analysis of classical ballet and contemporary dance performance. *Int J Sports Med* 32: 851–855, 2011.

FIGURES

Figure 1: ROC curve Analysis of Lower Extremity Single Leg Hop Distance (SLH_norm, % height) and Lower Extremity Injury Occurrence in Female Collegiate Dancers (N = 43)

Note: Area Under the Curve AUC = .73, SE = .08, p = .01, 95% Confidence Interval (CI) = .57 - .89

Table 1: Type, Location, and Nature of Lower Extremity Injuries in Female Collegiate Dancers

		Frequency	Percent
Type of Injury			
	Sprain	11	21.6
	Strain	11	21.6
	Tendinitis	8	15.7
	Contusion	3	5.9
	Bursitis	1	2
	Chondromalacia	2	3.9
	Spur	2	3.9
	Other	4	7.8
	Plantar Fasciitis	1	2
	Inflammation	6	11.8
	Friction Syndrome	2	3.9
Location of Injury			
	Toes-Foot	10	19.6
	Ankle-Lower Leg	15	29.4
	Knee	8	15.7
	Hip-Thigh	18	35.3
Nature of Injury			
	Acute	14	27.5
	Chronic	37	72.5
Total		**51**	**100**

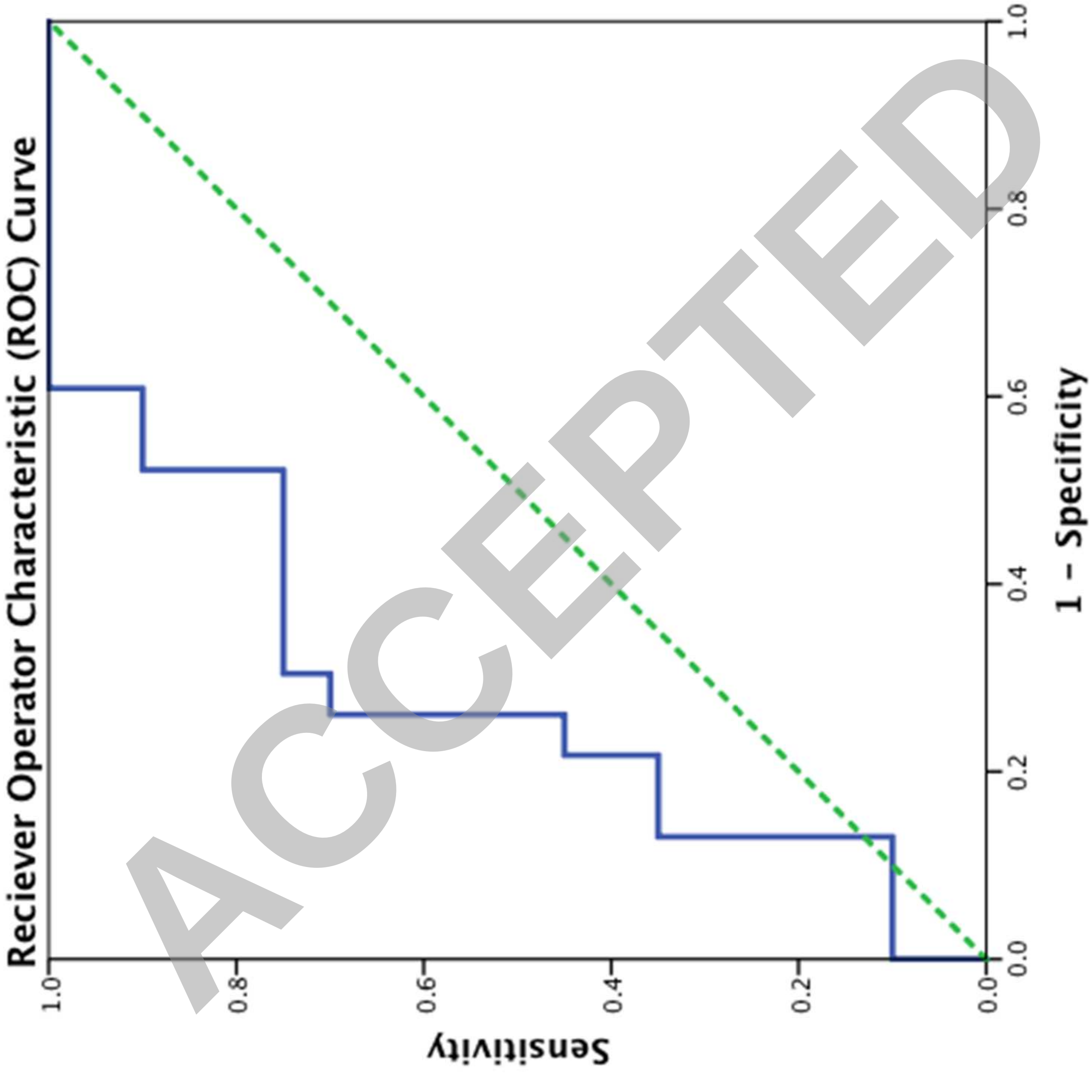
Table 2: Single Leg Hop (SLH) and Vertical Jump (VJ) Test Measures of the Non-Injured (n = 23), Injured (n = 20) and Combined (N = 43) Female Collegiate Dancers (M + SD)

Test	**Non-Injured**	**Injured**	**Combined**
SLH Raw Distances (m)	1.33 + .17	1.19 + .13	1.26 + .15
SLH_norm (% height)	85.2 + 11.2	76.8 +8.4	81.3 + 10.7
VJ Height (cm)	36.21 + 6.1	37.06 + 4.34	36.64 + 5.22
vPower (watts)	2722.7 + 480.0	2632.0 + 442.9	2686.2 + 463.9

Table 3: Single Leg Hop Distances (SLH_norm, % height)* Cut-off score and Lower Extremity Injury Occurrence in Female Collegiate Dancers (N=43) 2 x 2 Table

SLH_norm	**Non-Injured (n)**	**Injured (n)**
Greater than 78.2%	17	5
Lesser than 78.2%	6	15
Totals	**23**	**20**

* Note: SLH_norm = Single Leg Hop Distance/ Participant Height



Reciever Operator Characteristic (ROC) Curve
Sensitivity
1 – Specificity
0.0
0.2
0.4
0.6
0.8
1.0
ACCEPTED