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ORIGINAL RESEARCH

LOWER EXTREMITY HYPERMOBILITY, BUT NOT CORE MUSCLE ENDURANCE INFLUENCES BALANCE IN FEMALE COLLEGIATE DANCERS

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ABSTRACT

Background: Dance is a physically demanding activity, with almost 70% of all injuries in dancers occurring in the lower extremity (LE). Prior researchers report that muscle function (e.g. muscle endurance) and anatomical factors (e.g. hypermobility) affect physical performance (e.g. balance) and can subsequently influence LE injury risk. Specifically, lesser core muscle endurance, balance deficits, and greater hypermobility are related to increased LE injury risk. However, the potentials interrelationships among these factors in dancers remain unclear.

Purpose: The purposes of this study were to examine the relationships among core muscle endurance, balance, and LE hypermobility, and determine the relative contributions of core muscle endurance and LE hypermobility as predictors of balance in female collegiate dancers.

Study Design: Cross-sectional

Methods: Core muscle endurance was evaluated using the combined average anterior, left, and right lateral plank test time scores(s). LE hypermobility was measured using the LE-specific Beighton hypermobility measure, defining hypermobility if both legs had greater than 10° knee hyperextension. Balance was measured via the composite anterior, posterolateral, and posteromedial Star Excursion Balance Test (SEBT) reach distances (normalized to leg length) in 15 female healthy collegiate dancers (18.3±0.5yrs, 165.5±6.9cm, 63.7±12.1kg). Point-biserial-correlation-coefficients examined relationships and a linear regression examined whether core endurance and hypermobility predicted balance ($p \leq .05$).

Results: LE hypermobility (Yes; $n = 3$, No; $n = 12$) and balance (87.2±8.3% leg length) were positively correlated $r(14) = .67$, ($p = .01$). However, core endurance (103.9±50.6 s) and balance were not correlated $r(14) = .32$, ($p = .26$). LE hypermobility status predicted 36.9% of the variance in balance scores ($p = .01$).

Conclusion: LE hypermobility, but not core muscle endurance may be related to balance in female collegiate dancers. While LE hypermobility status influenced balance in the female collegiate dancers, how this LE hypermobility status affects their longitudinal injury risk as their careers progress needs further study. Overall, the current findings suggest that rather than using isolated core endurance-centric training, clinicians may encourage dancers to use training programs that incorporate multiple muscles - in order to improve their balance, and possibly reduce their LE injury risk.

Level of Evidence: 2b

Key Words: Beighton Score, lower body, plank tests, Star Excursion Balance Test

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INTRODUCTION

Dancing is a physically challenging activity.[1,2] Dancers reportedly have a 90% lifetime injury incidence rate,[3] with around 70% of all dance-related injuries occurring in the lower extremity (LE).[4–6] Prior researchers have noted that neuromuscular (e.g. muscle endurance), anatomical (e.g. hypermobility) factors can influence motor performance (e.g. balance ability) and subsequently influence LE injury risk.[7–12]

The core musculature is important for stabilizing the LE during movement,[13,14] and can influence LE injury risk.[15] The muscles that collectively comprise the core include the transversus abdominis/internal obliques, rectus abdominus, external obliques, multifidus, and erector spinae muscles.[13,16] Researchers[12,16] have examined the effects of trunk and core-specific factors including proprioception on LE injury risk using logistic regression modeling. These researchers found that these factors were able to predict ligamentous knee injury (91% sensitivity, 68% specificity), and were able to predict knee injury risk with 84% accuracy, knee ligament injury risk with 89% accuracy, and anterior cruciate ligament injury risk with 91% accuracy in female athletes. As the terms core and trunk are often used interchangeably in the literature, for the current study the authors operationalized core endurance as the time that participants could maintain plank positions as described previously.[17,18] Generally, higher scores on core musculature tests indicate better LE control during activity and may decrease LE injury risk.[12,15,16]

Balance and neuromuscular stability deficits also increase LE injury risk.[7,9,11,19] As postural stability and balance are often used interchangeably, for this study the authors operationalized balance as the ability to maintain postural stability while standing on one leg and performing a reach with the other leg as described when performing the Star Excursion Balance Test (SEBT).[20] Poor SEBT performance can predict increased LE injury risk, with prior researchers[11] reporting that female athletes with lower (< 94% Leg Length, LL) reach distances are 6.5 times more likely to sustain a LE injury than female athletes with higher (> 94% LL) reach distances.[11] Generally, previous researchers note that individuals with worse balance have a greater LE injury risk than those with better balance,[11] and that improved balance decreases LE injury risk.[7,8,11]

Increased hypermobility can alter proprioception & balance,[21,22] and is related to increased LE injury risk.[10] In a systematic review and meta-analyses of generalized joint hypermobility and LE joint injury risk during sport, Pacey et al. reported that participants with generalized joint hypermobility had an increased risk of knee joint injury.[10] Although dancers often are reported to be hypermobile,[21,23] relatively little literature has examined if this hypermobility is an asset or liability.[21,23] Some researchers[24] have noted that when injured, female dancers with joint hypermobility syndrome had to stop dancing for longer periods of time than those without joint hypermobility syndrome. However, others[25] have not found any differences in injury rates between hypermobile and non-hypermobile dancers.

In general, greater core muscle endurance and better balance is related to decreased LE injury risk, while greater hypermobility is related to increased LE injury risk. Dancers are a group of physically active individuals who commonly suffer LE injury. Still limited literature exists examining the potential interrelationships relationships among core endurance, hypermobility, and balance in dancers. As the current authors wanted to examine how muscular and anatomical factors affect performance, we chose core muscle endurance and LE hypermobility as the predictor variables and balance as the predicted outcome measure for the study. Thus, the purposes of this study were to examine the relationships among core muscle endurance, balance, and LE hypermobility, and determine the relative contributions of core muscle endurance and LE hypermobility as predictors of balance in female collegiate dancers.

METHODS

Participants and Informed Consent

Fifteen healthy female collegiate modern dancers (18.3 $\pm$ 0.5 years, 165.5 $\pm$ 6.9 cm, 63.7 $\pm$ 12.1 kg, dance experience = 12.5 $\pm$ 4.6 years) participated in the study. All participants were volunteer dance majors and recruited from the same dance class at the university. While most dancers reported some prior injury in the past, at the time of testing they were injury free and did not have report any pain or issues that would affect their ability to perform the study tests. The local Institutional Review

Board approved all testing procedures and all participants provided informed consent. The authors used a cross-sectional study design. All tests were performed in a single session. The same examiners measured the same task for all participants.

Balance

Balance was measured via the Star Excursion Balance Test (SEBT) – and specifically – the Y-balance components of the test using previously published methods.[18] The test required participants to first assume a single-leg stance, and then maximally reach along marked lines using the other leg while keeping the stance leg stable at the center of a grid, and then return the reach leg back to the center without losing balance.[20,26] For this study, participants performed reaches in three reach directions: (a) anterior (b) posterolateral, and (c) posteromedial (Figure 1a, 1b, and 1c) in that order. The same investigator taught all participants to perform the test using both verbal instruction and demonstration, and participants were allowed three practice trials in each direction before actual test performance.[18] Participants first performed right leg and then left leg reaches, three times each. Participants took a 15-second rest interval between each trial in the same direction and on the same leg, and a one-minute rest interval when changing feet and among different directions.[18] So an exemplar trial order and rest period interval was as follows: right leg anterior trial one – 15-second rest interval – right leg anterior trial two – 15-second rest interval – right leg anterior trial three – 1-minute rest interval (switching directions); then right leg posteromedial trial one – 15-second rest interval – right leg posteromedial trial two, and so on until all they completed all reaches in all directions.[18] A trial was not counted and asked the participant to repeat it if: (a) the participant was unable to maintain single leg stance, (b) the heel of the participants' stance foot did not remain in contact with the floor, (c) the participants' weight shifted onto the reach foot, or (d) the participant did not maintain start and return positions each for one second. The reach distances for the three trials in each direction were averaged and normalized to % leg length (LL). LL was measured from the anterior superior iliac spine to the medial malleolus.[11,27,28] SEBT scores were combined across all directions bilaterally and this composite score was used for analyses.[18]

Core Endurance

Core endurance was measured using plank tests in three positions: anterior (Figure 2a), right (Figure 2b) and left (Figure 2c) lateral using procedures described in prior literature.[17,18] Participants first performed a single practice trial for a few seconds to confirm that they were able to successfully attain the test position. Then participants performed one recorded test trial. The maximum time (seconds, s) that the participants were able to hold and maintain the correct test position was recorded. The same examiner visually determined the end of all tests.

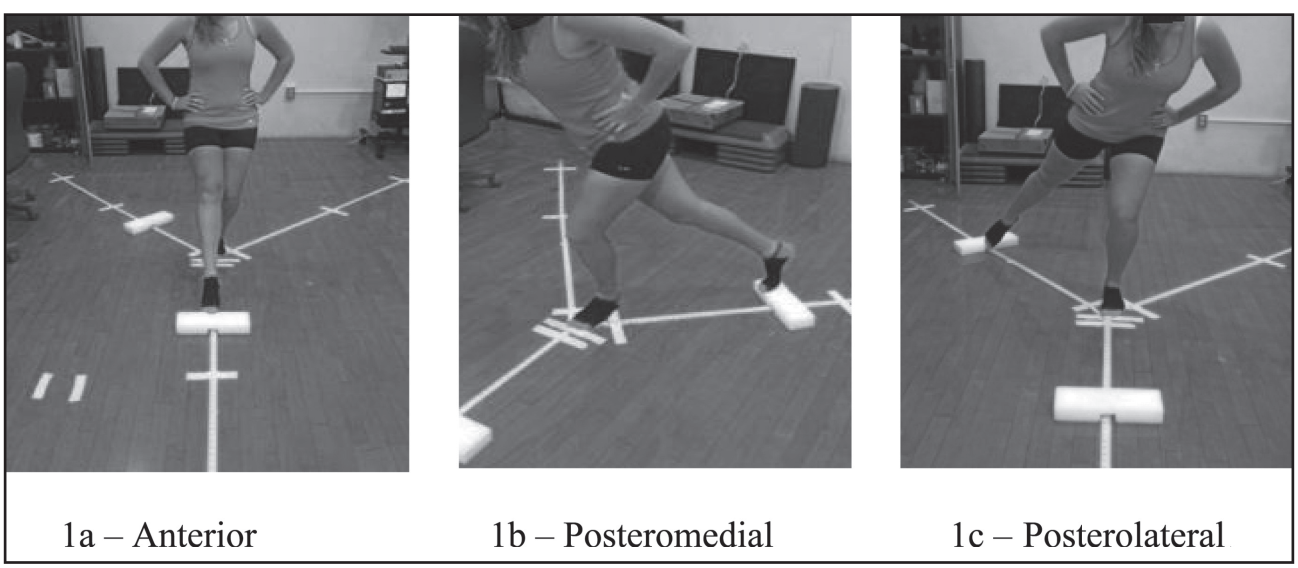

Figure 1. Star Excursion Balance Test (SEBT) Directions (1a) Anterior Reach Direction, (1b) Posteromedial Reach Direction and (1c) Posterolateral Reach Direction

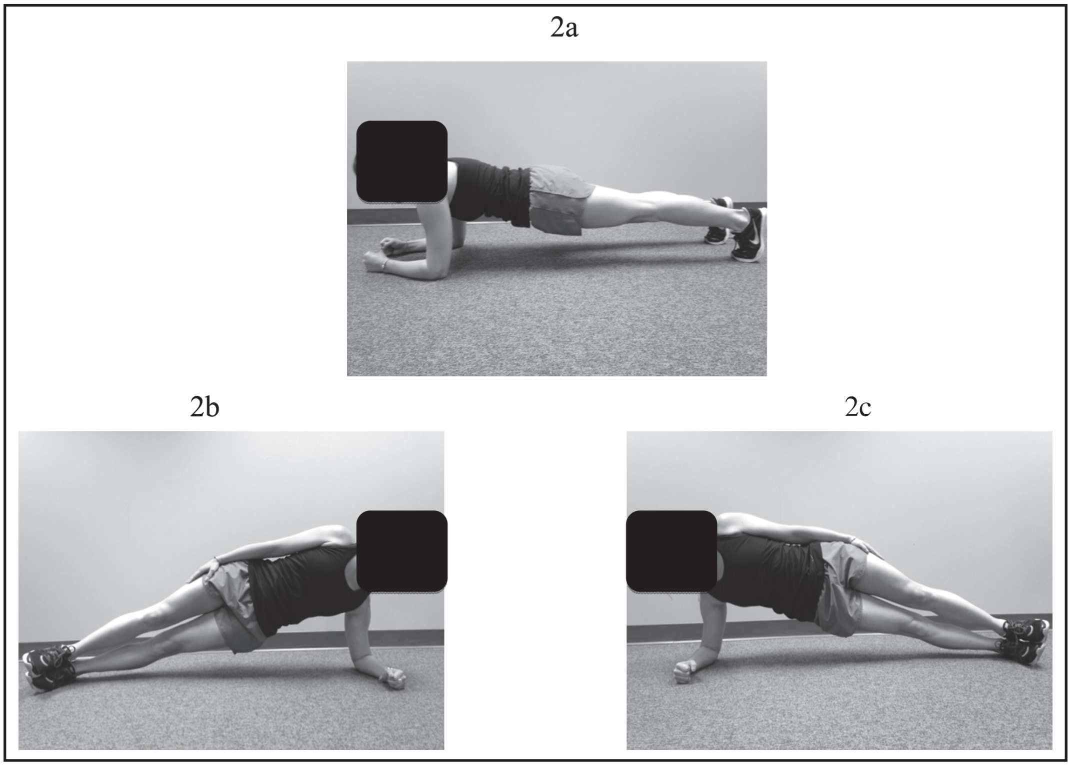

Figure 2. Core Strength-endurance Tests (2a) Anterior Plank Test, (2b) Right Plank Test and (2c) Left Plank Test

For the anterior plank test, participants assumed a push-up posture in the down position: legs together, lower leg in contact with a mat with ankles plantarflexed, back straight, hands shoulder width apart, head up. Time recording was stopped when any segment of the participants' body did not remain parallel to the floor as described in prior literature.[17]

To perform the left lateral plank test, participants placed their feet one on top of the other, their right arm perpendicular to the floor, with the elbow resting on the mat and the left arm across the chest with the left hand on the right shoulder. Participants used a similar position for the right lateral musculature plank test, with the left arm perpendicular to the floor. The time point when the participants could not maintain a straight line between the trunk or lower body (thigh or shank) segments on visual observation was recorded by the investigator.[18] The average score of three tests was used for analyses.

Hypermobility

The lower extremity-specific item on the previously published Beighton Hypermobility tests (knee hyperextension $>10^\circ$ goniometry) was performed bilaterally and used to classify participants as LE hypermobile or not for this study.[23,29] Specifically, participants were operationally defined as not LE hypermobile if one or neither knee hyperextended greater than 10° and LE hypermobile if both their knees hyperextended greater than 10°. The same investigator determined LE hypermobility for all participants.

STATISTICAL METHODS

Point-biserial-correlation-coefficients examined relationships among core endurance, LE hypermobility, and balance. A stepwise linear regression examined whether core endurance and LE hypermobility predicted balance. The relationships' strength was operationalized using previous guidelines, where 0.00-0.25 = little or no relationship; 0.26-0.50 = fair relationship; 0.51-0.75 = moderate to good relationship, and 0.76-1.00 = good to excellent relationship.[30]An 0.05 alpha level was set *apriori* and the PASW 20.0 software (IBM Corp, Armonk, NY) was used conduct all analyses.

RESULTS

Three dancers (18.0 ± 0.0 years, 160.8 ± 8.4 cm, 58.2 ± 11.4 kg, dance experience = 14.3 ± 1.2 years)

Table 1. *Star Excursion Balance Test (SEBT) Scores (% Leg Length) and Core Endurance Scores (s) (Means + SD).*

Test	Side	Direction	Mean	*SD*
SEBT	Right			
		Anterior	70.1	9.1
		Posteromedial	96.7	7.5
		Posterolateral	95.6	10.5
Average of Right Side Reaches			**87.5**	**9.0**
SEBT	Left			
		Anterior	69.9	8.8
		Posteromedial	97.1	9.3
		Posterolateral	94.7	10.6
Average of Left Side Reaches			**87.2**	**9.6**
Overall Composite Average of Right and Left Reaches			**87.2**	**8.3**
Core Endurance		Anterior Plank	170.8	78.7
		Right Lateral Plank	75.7	37.8
		Left Lateral Plank	65.1	35.2
Overall Average of all three Plank Tests			**103.9**	**50.6**

were LE hypermobile, while 12 dancers (18.3 ± 0.5 years, 166.7 ± 6.4 cm, 65.1 ± 12.3 kg, dance experience = 12.0 ± 5.0 years) did not demonstrate LE hypermobility. See Table 1 for overall participants' descriptive statistics. LE hypermobility and balance (87.2 ± 8.3% LL) were positively correlated $r(14) = .67$, $p = .01$ to each other. However, core endurance (103.9 ± 42.5 sec) and balance (87.2 ± 8.3% LL) were not correlated $r(14) = .32$, $p = .26$.

The regression analyses revealed that LE hypermobility significantly predicted 36.9% of the variance in balance ($F_{1,13} = 9.20$, $p = .01$; standardized beta coefficient = .644, standard error = 6.58). LE hypermobility status was statistically coded with not LE hypermobile status = 0 and LE hypermobile status = 1. The regression model analyses resulted in the following equation: Balance score = 12.9 (LE hypermobile status) + 84.6. So theoretically, if a dancer's balance score – if she were *not* LE hypermobile – was 84.6% LL [12.9 * (0) + 84.6], then her balance score – if she *were* LE hypermobile – would be [12.9 * (1) + 84.6] = 97.5 % LL.

DISCUSSION

Primary Findings

The primary findings of the current study were that LE hypermobility and balance showed moderate to good positive correlations in collegiate female dancers. Core endurance and balance were not correlated in female dancers. LE hypermobility, but not core endurance, influenced balance in the study dancers.

LE Hypermobility and Balance

Twenty percent (3/15) of the study dancers were LE hypermobile. The authors purposefully chose only LE specific measures for the operational definition of hypermobility because of the interest in examining whether these LE specific measures influenced LE balance. If the dancers' hypermobility status was classified using the unabridged 9-point Beighton score criteria that also uses trunk and upper body measures to classify participants' hypermobility (> 4/9), 46.7% (7/15) of the study dancers would have been categorized as hypermobile, close to the 2-44 % hypermobility ranges in dancers noted by previous researchers.[25,31,32] Based on the 9-point Beighton score, the LE hypermobile dancers' Beighton score was 5.3 ± 0.6, the non-LE hypermobile dancers' Beighton score was 2.8 ± 1.5, and overall all dancers' Beighton score was 3.3 ± 1.8.

In the study participants, LE hypermobility and balance were positively related, and hypermobility status predicted 36.9% of the variance in their balance scores. Specifically, the LE hypermobile dancers had better balance than the non-hypermobile dancers. This finding was unexpected as prior researchers[33,34] have indicated that increased hypermobility is associated with decreased proprioception. Part of the explanation for this finding may lie in the actual demands of the SEBT. The SEBT requires participants to reach as far as they can with one leg – and examines their functional stability strength limits and neuromuscular control.[35] Previous researchers have found that individuals with hypermobility syndrome had higher passive knee ranges of motion than healthy controls.[36] Thus, while the current authors did not explicitly record range of motion, the hypermobile participants in the current study may have had increased knee range of motion as reported in previous work,[36] allowing them to reach farther on the SEBT. Still, how this knee hypermobility allows participants to maintain balance while reaching farther needs additional study.

How LE hypermobility status affects LE injury risk also remains unclear. Briggs et al.[24] noted that while 50% of their hypermobile dancers had at least one tendon injury, only 21% of non-hypermobile dancers had at least one tendon injury. Also, they found that while 61% of hypermobile dancers took time off from dancing due to injury, only 32% of non-hypermobile dancers took time off for injury. The researchers suggested that although joint hypermobility may be associated with a better chance of getting selected as a dancer at the beginner levels, it may also be associated with higher injury risk and/or prolonged periods of recovery post-injury at elite levels.[24] Combining the participant demographics of collegiate level dancers in the current study with this prior literature, it appears that while the LE hypermobile dancers in the current study may currently have better balance, they may be more vulnerable to greater LE injury risk as they progress in their dance careers.

The participants' SEBT composite scores (87.2 ± 8.3% LL) were similar to previously reported score ranges (87.9 to 89.4 % LL) in female collegiate athletes.[18,20] Plisky et al.[11] have reported that > 4 cm side-to-side differences in anterior reach scores predicted injury status in various sports. While the current authors did not examine LE injury, the dance participants' anterior (right side = 87.5 ± 9.0, left side = 87.2 ± 9.6) and overall (right side = 70.0 ± 9.1, left side = 69.9 ± 8.8) reaches were remarkably symmetrical. One possible explanation for this observation could be that performing modern dance may be bilaterally challenging and thus not have required the dancers in the current study to have a dominant lower extremity, resulting in bilaterally symmetrical scores. Further, the study participants' composite reach scores (87.2 ± 8.3 were also close to 89.6% LL cut-off score reported by Butler et al.[7] as the score below which an athlete was 3.5 more times likely to get injured than one who scored more. Thus, compared to prior literature, the dancers in the current study neither demonstrated side-side asymmetry nor had scores predictive of increased LE injury risk.

Another factor to consider when comparing the current findings with those of McCormack et al.[21] is the genre of dance performed by participants. The dancers in McCormack et al.'s study were ballet dancers, while the dancers in the current study were primarily modern/contemporary dancers. Similar to other types of athletics, where different sports have differing physical demands and subsequently different injury patterns (e.g. in tennis versus wrestling), different dance genres also have differing physical demands and injury patterns.[2] Ballet dancers often perform repetitive LE-centric movements are whereas modern/contemporary dancers often incorporate more upper and whole body movements.[2,37] Therefore, it is possible that the physical demands of ballet may have placed hypermobile ballet dancers in the McCormack et al. study at different injury risk than the modern/contemporary dancers in the current study. The clinical implication of this finding is that clinicians should consider their dancers' genre demands when treating them and designing training programs for them. Specifically, LE training programs can improve balance[38] and decrease LE injury risk.[39] Clinicians can thus identify hypermobile dancers early before the dancers become injured and design programs that use multiple muscle groups to improve their dancers' balance and possibly positively impact dancers' LE injury risk.

Core Muscle Endurance and Balance

The study participants' side plank core endurance scores (right: 75.7±37.8, left = 65.1±35 s) were similar to prior scores in healthy collegiate (right: 61±33, left = 66±38 s)[40] and resistance trained females (right: 72±31, left = 77±35 s).[41] The current study participants' anterior core endurance scores (170.8±78.7 s) were also close to previously published flexor core endurance scores in healthy collegiate (149±99 s)[40] and resistance trained females (163±106 s).[41] Consistent with prior work, the dance participants' core endurance scores had large standard deviations, possibly due to the nature of the tests that allowed participants to use different strategies to maintain test positions.

Theoretically, the greater the core musculature strength and endurance, the less the body has to compensate to maintain stability during perturbations and movement.[13] However, core muscle endurance and balance were not related in the current study. The study findings are in agreement with other reports that core muscle function is not associated with balance.[18,20] In contrast, Zazulak et al.[12] did find that core stability did predict LE injury risk in female athletes. The difference between these observations may partly be due to the different measures of core function and stability used in these different studies and the lack of consensus in how to measure core stability in all research. Specifically, Ambegaonkar et al. used the McGill plank tests and Gordon et al.[20] used the bent knee-lowering test to measure core function. Both these tests require participants to maintain core stability in a static (plank), or in a slow velocity dynamic position (bent knee lowering test). Conversely, Zazulak et al. used a sudden perturbation and examined the participant's ability to maintain or return to equilibrium after this perturbation in a seated position within a custom-made apparatus that fixed the participants' lower body. Core stability exists in a continuum where there the core muscles need to produce increasing amounts of force over decreasing amounts of time from core endurance to strength to power.[42] The measures used in the current study, and by Gordon et al. and Ambegaonkar et al. were closer to the core endurance spectrum while the measure used by Zazulak et al were closer to the core power spectrum. Thus, it appears that core endurance may be less influential – and rather that core power, reaction ability, and neuromuscular control may be more influential in maintaining LE stability and subsequently have an effect on LE risk during activity.

In addition, Gordon et al. found that that hip external rotator muscle strength was moderately positively correlated to balance (SEBT reach distances).[20] Other researchers have likewise noted that females with greater hip flexor, extensor, and abductor strength had better anterior and posterolateral SEBT scores.[18] The researchers suggested that having females participate in hip muscle strengthening programs might improve their balance scores.[18] Prior researchers also have noted that LE strengthening can improve balance,[28,43] and that balance training, when used as part of a multi-intervention program can decrease LE injury risk.[39] Hip muscle strength may be more influential in altering balance than core endurance. Overall, the practical implication of combining the findings of the current study with prior information is that instead of using extensive core endurance muscle-centric training, clinicians should use integrated training programs – that may include core power and reactive training as part of the program – to improve their dancers' balance and possibly decrease their dancers' LE injury risk.

Some of the limitations of this study include the small sample size (LE hypermobility was identified in only three participants), and the limited generalizability of the study findings to other groups. In the current study, the authors also used anterior and lateral plank tests to examine core musculature. Other tests[15,16,40,44] exist in the literature that examine the 'core'. We specifically chose the plank tests as they are commonly used in the literature,[18,45] are valid global core muscle function measures,[46] and activate the abdominal muscles.[47] Furthermore, plank tests are easy to administer, and it is relatively easy to ensure that participants are using proper technique when performing the tests. Still, whether other tests such as those suggested by McGill[40] may be more appropriate to examine core endurance in dancers needs study. Other muscles may also have influenced core endurance. For example, different dancers may have used their shoulder and leg musculature differently to maintain their bodies in the plank position. Thus, researchers should examine other test positions that isolate the core muscles and those positions that use core muscles as part of a functional chain to examine the core muscles' role in influencing balance and motion. The authors of the current study also chose to use only two of LE-specific items from the 9-item Beighton scale to define LE hypermobility. Thus, the current findings are limited to only the LE and cannot be generalized to overall hypermobility.

The current authors also did not record ranges of motion of the dance participants. As some prior work indicates that ankle dorsiflexion ranges influence SEBT scores,[48] future investigators should examine the role of joint ranges of motion and their influence on balance. While participants did have adequate rest between tests, researchers should also examine whether fatigue may have altered SEBT and core endurance test performance. Finally, while the current authors chose a valid and reliable balance test that allowed for comparisons of the current findings to prior work, future researchers may also consider other tests more closely related to dance movements to examine dancers' balance.

CONCLUSIONS

The results of the current study demonstrated that LE hypermobility, but not core muscle endurance may be related to balance in female collegiate dancers. Although the LE hypermobile dancers in this study had better balance than non LE hypermobile dancers, how this hypermobility affects their LE injury risk as they progress in their dance careers needs longitudinal study. As core muscle endurance was not related to balance, the current findings indicate that rather than using isolated core endurance-centric training, clinicians may encourage dancers to use training programs that incorporate multiple muscles in order to improve their balance, and possibly reduce their LE injury risk.

REFERENCES

1. Ambegaonkar JP, Caswell SV. Dance program administrators' perceptions of athletic training services. *Athl Ther Today*. 2009;14(3):17-9.
2. Solomon R, Micheli L. Technique as a consideration in modern dance injuries. *Phys Sportsmed*. 1986;14(8):83-90.
3. Luke A, Kinney S, d' Hemecourt P, Baum J, Micheli L. Determinants of injuries in young dancers. *Med Probl Perform Art*. 2002;17:105-112.
4. Ambegaonkar JP. Dance medicine: at the university level. *Dance Res J*. 2005;37(2):113-19.
5. Ekegren CL, Quested R, Brodrick A. Injuries in pre-professional ballet dancers: Incidence, characteristics and consequences. *J Sci Med Sport*. 2014;17(3):271-275.
6. Shah S, Weiss DS, Burchette RJ. Injuries in professional modern dancers: Incidence, risk factors, and management. *J Dance Med Sci*. 2012;16(1):17-25.
7. Butler RJ, Lehr ME, Fink ML, Kiesel KB, Plisky PJ. Dynamic balance performance and noncontact lower extremity injury in college football players: an initial study. *Sports Health*. 2013;5(5):417-422.
8. Gribble PA, Hertel J, Plisky P. Using the Star excursion balance test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. *J Athl Train*. 2012;47(3):339-357.
9. Hrysomallis C. Relationship between balance ability, training and sports injury risk. *Sports Med Auckl NZ*. 2007;37(6):547-556.
10. Pacey V, Nicholson LL, Adams RD, Munn J, Munns CF. Generalized joint hypermobility and risk of lower limb joint injury during sport: A systematic review with meta-analysis. *Am J Sports Med*. 2010;38(7):1487-1497.
11. Plisky PJ, Rauh MJ, Kaminski TW, Underwood FB. Star excursion balance test as a predictor of lower extremity injury in high school basketball players. *J Orthop Sports Phys Ther*. 2006;36(12):911-919.
12. Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. Deficits in neuromuscular control of the trunk predict knee injury risk: A prospective biomechanical-epidemiologic study. *Am J Sports Med*. 2007;35(7):1123-30.
13. Borghuis J, Hof A, Lemmink K. The importance of sensory-motor control in providing core stability. *Sports Med*. 2008;38(11):893-916.

14. Hodges PW, Richardson CA. Contraction of the abdominal muscles associated with movement of the lower limb. *Phys Ther*. 1997;77(2):132-142; discussion 142-144.

15. Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IM. Core stability measures as risk factors for lower extremity injury in athletes. *Med Sci Sports Exerc*. 2004;36(6):926-934.

16. Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. The effects of core proprioception on knee injury: A prospective biomechanical-epidemiological study. *Am J Sports Med*. 2007;35(3):368-73.

17. Allen BA, Hannon JC, Burns RD, Williams SM. Effect of a core conditioning intervention on tests of trunk muscular endurance in school-aged children. *J Strength Cond Res*. 2014;28(7):2063-2070.

18. Ambegaonkar JP, Mettinger LM, Caswell SV, Burtt A, Cortes N. Relationships between core endurance, hip strength, and balance in collegiate female athletes. *Int J Sports Phys Ther*. 2014;9(5):604-616.

19. Olmsted L, Carcia C, Hertel J, Shultz S. Efficacy of the star excursion balance tests in detecting reach deficits in subjects with chronic ankle instability. *J Athl Train*. 2002;37(4):501-506.

20. Gordon AT, Ambegaonkar JP, Caswell SV. Relationships between core strength, hip external rotator muscle strength, and star excursion balance test performance in female lacrosse players. *Int J Sports Phys Ther*. 2013;8(2):97-104.

21. McCormack M, Briggs J, Hakim A, Grahame R. Joint laxity and the benign joint hypermobility syndrome in student and professional ballet dancers. *J Rheumatol*. 2004;31(1):173-178.

22. Donaldson PR. Does generalized joint hypermobility predict joint injury in sport? A review. *Clin J Sport Med*. 2012;22(1):77-78.

23. Grahame R, Jenkins JM. Joint hypermobility-asset or liability? A study of joint mobility in ballet dancers. *Ann Rheum Dis*. 1972;31(2):109-111.

24. Briggs J, McCormack M, Hakim AJ, Grahame R. Injury and joint hypermobility syndrome in ballet dancers - A 5-year follow-up. *Rheumatol Oxf Engl*. 2009;48(12):1613-1614.

25. Klemp P, Learmonth ID. Hypermobility and injuries in a professional ballet company. *Br J Sports Med*. 1984;18(3):143-148.

26. Demura S, Yamada T. Proposal for a practical star excursion balance test using three trials with four directions. *Sport Sci Health*. 2010;6(1):1-8.

27. Kinzey SJ, Armstrong CW. The reliability of the star-excursion test in assessing dynamic balance. *J Orthop Sports Phys Ther*. 1998;27(5):356-360.

28. Filipa A, Byrnes R, Paterno MV, Myer GD, Hewett TE. Neuromuscular training improves performance on the star excursion balance test in young female athletes. *J Orthop Sports Phys Ther*. 2010;40(9):551-558.

29. Grahame R. Joint hypermobility - Clinical aspects. *Proc R Soc Med*. 1971;64(6):692-694.

30. Portney LG. *Foundations of Clinical Research: Applications to Practice*. 3rd ed. Upper Saddle River, NJ: Pearson/Prentice Hall; 2009.

31. Day H, Koutedakis Y, Wyon MA. Hypermobility and dance: A review. *Int J Sports Med*. 2011;32(7):485-489.

32. Roussel NA, Nijs J, Mottram S, Van Moorsel A, Truijen S, Stassijns G. Altered lumbopelvic movement control but not generalized joint hypermobility is associated with increased injury in dancers. A prospective study. *Man Ther*. 2009;14(6):630-635.

33. Hall MG, Ferrell WR, Sturrock RD, Hamblen DL, Baxendale RH. The effect of the hypermobility syndrome on knee joint proprioception. *Br J Rheumatol*. 1995;34(2):121-125.

34. Smith TO, Jerman E, Easton V, et al. Do people with benign joint hypermobility syndrome (BJHS) have reduced joint proprioception? A systematic review and meta-analysis. *Rheumatol Int*. 2013;33(11):2709-2716.

35. Sibley KM, Beauchamp MK, Van Ooteghem K, Straus SE, Jaglal SB. Using the systems framework for postural control to analyze the components of balance evaluated in standardized balance measures: a scoping review. *Arch Phys Med Rehabil*. 2015;96(1):122-132.e29.

36. Fatoye F, Palmer S, Macmillan F, Rowe P, van der Linden M. Proprioception and muscle torque deficits in children with hypermobility syndrome. *Rheumatol Oxf Engl*. 2009;48(2):152-157.

37. Ambegaonkar JP, Caswell SV, Winchester JB, Caswell AA, Andre MJ. Upper-body muscular endurance in female university-level modern dancers: a pilot study. *J Dance Med Sci*. 2012;16(1):3-7.

38. Rasool J, George K. The impact of single-leg dynamic balance training on dynamic stability. *Phys Ther Sport*. 2007;8(4):177-184.

39. McGuine TA, Keene JS. The effect of a balance training program on the risk of ankle sprains in high school athletes. *Am J Sports Med*. 2006;34(7):1103-1111.

40. McGill SM, Childs A, Liebenson C. Endurance times for low back stabilization exercises: Clinical targets for testing and training from a normal database. *Arch Phys Med Rehabil*. 1999;80(8):941-944.

41. Hanney WJ, Kolber MJ, Pabian PS, Cheatham SW, Schoenfeld BJ, Salamh PA. Endurance times of the thoracolumbar musculature: reference values for female recreational resistance training participants. *J Strength Cond Res Natl Strength Cond Assoc*. 2016;30(2):588-594.

42. Rickman AM, Ambegaonkar JP, Cortes N. Core stability: implications for dance injuries. *Med Probl Perform Art*. 2012;27(3):159-164.

43. Leavey VJ, Sandrey MA, Dahmer G. Comparative effects of 6-week balance, gluteus medius strength, and combined programs on dynamic postural control. *J Sport Rehabil*. 2010;19(3):268-287.

44. Cowley P, Swensen T. Development and Reliability of Two Core Stability Field Tests. *J Strength Cond Res*. 2008;22(2):619.

45. Stickler L, Finley M, Gulgin H. Relationship between hip and core strength and frontal plane alignment during a single leg squat. *Phys Ther Sport Off J Assoc Chart Physiother Sports Med*. 2015;16(1):66-71.

46. Tong TK, Wu S, Nie J. Sport-specific endurance plank test for evaluation of global core muscle function. *Phys Ther Sport Off J Assoc Chart Physiother Sports Med*. 2014;15(1):58-63.

47. Ekstrom RA, Donatelli RA, Carp KC. Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. *J Orthop Sports Phys Ther*. 2007;37(12):754-762.

48. Hoch MC, Staton GS, McKeon PO. Dorsiflexion range of motion significantly influences dynamic balance. *J Sci Med Sport*. 2011;14(1):90-92.