Original Research

The Effect of Single-Leg Stance on Dancer and Control Group Static Balance

ELISABETH A. KILROY*, OLIVIA M. CRABTREE*, BRITTANY CROSBY*, AMANDA PARKER*, and WILLIAM R. BARFIELD‡[1]

[1]Department of Health and Human Performance, College of Charleston, Charleston, SC, USA

*Denotes undergraduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 9(2): 110-120, 2016. The purpose of this study was to compare kinetic differences of static balance between female dancers (D) with at least seven years of dance experience and female non-dancers (ND) who were typical college students. Participants were tested in single-leg stance. Both the dominant leg (DL) and non-dominant leg (NDL) were tested with the participants shod (S) and barefoot (BF). Kinetic variables (vertical, medio-lateral [ML], antero-posterior [AP] maximum ground reaction forces (GRF), and center of pressure (COP) ML and AP) were measured by a Bertec force platform at 1000 Hz with participants S and BF. Each subject's stance was measured over 3 x 30-second intervals. No significant differences ($p \geq 0.05$) existed between groups for height, body mass, or age. Significant differences existed between groups for balance time, AP GRF in both BF and S conditions for both DL and NDL, and ML GRF in BF NDL and S DL and NDL conditions. D and ND in BF and S conditions with DL and NDL static stance demonstrate different AP and ML GRF when balancing over a 30-second time interval. Data may suggest that ND are more prone to lose their balance. Further investigation is warranted to understand whether individuals in the rehabilitative field and athletic populations can use dance therapy for injury prevention and rehabilitation.

KEY WORDS: Female, kinetics, dominant, non-dominant

INTRODUCTION

Several external and internal factors influence an individual's ability to balance, including genetics, the state of vestibular apparatus, age, the area of support, center of mass positioning, emotional state, strength, coordination, flexibility, frequency of participation in motor activities, and training status. Independent of these factors, static and dynamic balance continues to be an indispensable motor skill because it is at the center of all human movement (30). Not only is falling risk a result of poor balance, the ability to maintain balance is necessary to complete activities of daily living both safely and correctly (25) as well as to excel in sport-specific activities.

The definition of balance is most often related to the goals of the present investigation. Because balance is required during movement as well as during stance, several laboratory measures have defined two major types of balance. Dynamic balance is the preservation of an upright body position throughout locomotion (30), whereas static balance is the process of maintaining the center of mass vertically over the base of support with minimal movement (22) while maintaining specific poses for an extended period of time (30). Our study focused exclusively on static balance since the literature has shown that collegiate females (gymnasts and soccer players) do not differ in terms of static and dynamic balance for single and double leg stance on stiff and compliant surfaces (8). Further, although the definition of a stable body position includes the ability to maintain and return to the proper positioning of body segments during the execution of a task or following a perturbation (30), our study only included the components of static balance that demonstrated minimal movement during a specified pose. Center of pressure (COP) measurements have been shown to be a reproducible measure of static balance (17).

The ability to minimize displacement of the COP while maintaining an upright stance during proper orientation or desired locomotion is controlled by the central nervous system. Further, because the central nervous system processes afferent input from visual, vestibular, and somatosensory systems the utilization of multiple senses provides for greater balance ability. When one of the sensory inputs is reduced or eliminated other systems compensate for the loss. Of the three systems though, it is common for the somatosensory input to dominate the balancing task (12).

Dance training strengthens the accuracy of the somatosensory system and effectively shifts the vision-dominated, sensorimotor control of balance to an internal-based system of reference (12, 19). Therefore, the way dancers adjust in static and dynamic circumstances and self-correct body positioning is a function of strength, responsiveness of their proprioceptive system (18), and advanced spatial skills (4, 12, 16).

Due to enhanced balance abilities seen among dancers the purpose of this study was to determine if dancers demonstrate better single-leg static balance ability compared with non-dancers. Specifically, we hypothesized that dancers would show better static single-leg balance over the prescribed 30 second time interval more efficiently than non-dancers, would have lower excursion of the COP and would keep their ground reaction force (GRF) balance more lateral and anterior indicating better balance over the four conditions. The four conditions were static balance on the (1) dominant leg (DL), (2) non-dominant leg (NDL), (3) shod (S) and (4) barefoot (BF).

METHODS

Participants

Following approval by the Institutional Review Board, recruitment for potential participants began. Two questionnaires and a consent form were completed by those who volunteered as participants. In order to be included in the study participants were required to complete a pre-participation survey as well as score a 70 percent or greater on the standardized Lower Extremity Functional Scale (LEFS). The pre-participation survey helped identify whether a participant had any known neurological conditions or symptoms that would interfere with the demonstration of static balance. Questions that were included in the survey that identified medications that could alter balance or cause dizziness as well as visual deficits that could interfere with balance. Because the survey was given immediately prior to the testing period, we further asked if adequate amounts of food had been consumed since this could potentially alter balance performance and negatively affect concentration and focus. The LEFS determined who was qualified to participate in the study since decreased functioning of the lower limb may affect balance. This survey was 20 questions specifically regarding the ability to perform everyday tasks. The score for the survey was calculated using the equation below:

$$\text{Maximal Function (\%)} = \frac{\text{LEFS}}{80} \times 100$$

The lower the score, the greater the disability.

We recruited seven female dancers (D) from the college Dance Department and seven female non-dancers (ND) from the School of Education, Health and Human Performance at the college. All participants were between the ages of 18 and 23. Inclusion criteria for D included seven years or more of dance experience as well as participation on the collegiate level dance team. Individuals in the ND control group had less than one year of dance experience or no experience at all.

Protocol

Single-leg stance required participants to keep their hands on their hips, their eyes facing forward, and the foot of the non-testing leg held at knee level. Their gaze had to remain fixed on an X that was taped two meters away at the individual's eye level. This position can be found in Figure 1.

Figure 1. The proper demonstration of single-leg stance as defined by this study includes hands on hips, eyes facing forward, and the foot of the non-testing leg held at knee level while gaze had to remain fixed on an X that was taped two meters away at the individual's eye level. The DL and NDL were determined for by asking the ND subjects which foot she used to kick a soccer ball. The foot used to kick a soccer ball was the DL. The DL for D was the supporting leg for turns. The rationale behind using different criteria for the DL and NDL between the controls and the dancers was because dancers most commonly turn on their dominant leg due to greater strength and coordination on the dominant side.

COP was defined as the resulting position of the force vector for all vertical GRFs measured by the force plate. COP_{AP} and

COP_{ML} represented the excursion of the COP measured in the antero-posterior direction (AP) and medio-lateral directions (ML), respectively.

Total balance time represented the average time of the three trials that the subject maintained single-leg stance. Each subject had a total balance time for each of the four conditions.

Maximum GRFs included the GRF in the AP direction (F_y), the GRF in the ML direction (F_x), and the GRF in the vertical direction (F_z). The GRF coordinate system for the force plate was positive (+) for anterior and negative (-) for the posterior direction. Positive (+) was the sign for the medial direction and negative (-) for the lateral direction.

Maximum GRF variables for the three planes were normalized by dividing the resultant force vectors by subject body weight (GRF/Subject Weight in Newtons).

The force platform was Bertec Type 4060 (Columbus, Ohio). The dimensions of the force plate measured 600 mm by 1200 mm. In each corner, a piezoelectrical transducer measured the reaction forces occurring in the AP, ML, and vertical planes. Data from the transducer were filtered with a low-pass 12 Hz filter using a fourth order zero-lag Butterworth frequency and processed by an analogue-to-digital converter, thereby eliminating high-frequency noise. These data were then transferred to the microcomputer and saved to the data collection software. The sampling frequency for the force plate was 1000 Hz.

Single-leg stance was demonstrated to each of the 14 participants immediately prior to testing. Participants were evaluated in four testing conditions: single-leg stance on the DL with and without an athletic shoe and single-leg stance on the NDL with and without an athletic shoe. Athletic shoe type was not standardized. Subject shoe familiarity provided for no learning effect of different and unfamiliar shoe types among subjects, thereby optimizing shod balance. The order in which each test was performed was randomized for each subject.

Each subject performed single-leg stance with her supporting leg on the center of the force plate. The force plate was on an elevated, flat, and stable surface to reduce the amount of vibrations from the ground and surroundings. For each of the four conditions, participants balanced for 30 seconds. In order to obtain a valid measurement, each subject had three trials for each condition. However, if a subject could not maintain the single-leg stance for this period, termination of the trial occurred and the balancing time was recorded. The criteria for termination was defined as the removal of the foot from the opposite knee, the removal of the hands from the hips, the placement of the foot on the ground (or "toe-tapping"), or the demonstration of a forward movement by the supporting leg.

We controlled for the effect that external and environmental conditions could have on our measurements. Specifically, we limited the number of individuals in the room to only the experimenters and the subject because of the disruption that surrounding movements could have on the subject's demonstration of balance. Excess noise was also limited as testing took place in a solitary room. Also, the room was consistently well-lit and of the same temperature and humidity.

Statistical Analysis

Data analysis was conducted through IBM SPSS Version 19 for Windows (Chicago, IL). Prior to statistical analysis, individual data were normalized to body weight. Because the data were normally distributed, independent t-tests were performed on the directional GRF, COP, and total balance times for all four conditions. A Bonferroni correction was applied to the original alpha level of ($p \leq 0.05$) due to the increased risk of Type I statistical error from the performance of multiple independent paired comparisons; the adjusted alpha level was 0.05/5= 0.01. The independent t-tests included comparisons for dancer BF DL versus NDL, dancer S DL versus NDL, non-dancer BF DL versus NDL, non-dancer S DL versus NDL, dancer versus non-dancer BF DL, dancer versus non-dancer BF NDL, dancer versus non-dancer S DL, and dancer versus non-dancer S NDL.

RESULTS

In Table 1, the demographics of the seven dancers and seven controls are shown. There were no statistical differences between groups ($p \geq 0.05$).

Table 1. Subject demographics.

Variable	Dancers (n = 7)	Non-Dancer (n = 7)
Age (years)	21.14 ± 1.57	20.29 ± 1.50
Height (cm)	167.88 ± 4.64	166.07 ± 4.36
Body Mass (kg)	63.54 ± 14.15	75.74 ± 33.20

Note. The values for each variable are the mean, plus and minus the standard deviation.

Significant differences existed between groups for balance time (D 30.0±0.0s; ND 28.5±5.9s $p \leq 0.03$). In 6 of the 84 trials for the non-dancer group, single-leg stance was not maintained for the entire 30-second duration. Statistically significant differences also existed for: AP GRF in BF DL (D -0.009±0.057 N; ND -0.149±0.067 N $p \leq 0.001$) and NDL (D -0.069±0.062 N; ND -0.188±0.105 N $p \leq 0.001$); ML GRF in BF NDL (D -0.012±0.015 N; ND 0.013±0.025 N $p \leq 0.001$); AP GRF in S DL (D -0.011±0.061 N; ND -0.162±0.041 N $p \leq 0.001$); ML GRF in S DL (D -0.003±0.015 N; ND 0.018±0.006 N $p \leq 0.001$); AP GRF in S NDL (D -0.080±0.041N; ND -0.168±0.097 N $p \leq 0.001$); and, ML GRF in S NDL (D -0.008±0.012 N; ND 0.012±0.013 N $p \leq 0.001$) as shown in Tables 2 and 3.

Within group analyses for dancer and non-dancers can be found in Tables 4 and 5. Statistically significant differences existed among dancers for: AP GRF in BF (DL -0.009±0.057; NDL -0.069±0.062 $p \leq 0.001$) and S (DL -0.010±0.062; NDL -0.080±0.041 $p \leq 0.001$); and, COP_{AP} in BF (DL 0.00001±0.00003; NDL -0.00004±0.00006 $p \leq 0.001$) and S (DL 0.00002±0.00004; NDL -0.00005±0.00005 $p \leq 0.002$). Statistically significant differences existed among non-dancers for: COP_{ML} in BF (DL 0.00002±0.00003; NDL -0.000002±0.00003 $p \leq 0.013$) and S (DL 0.00004±0.00002; NDL 0.000002±0.00003 $p \leq 0.001$).

DISCUSSION

Between group analyses for the BF condition can be found in Table 2. For the DL, a significant difference was found in the AP directional GRF between dancers and non-dancers. Non-dancers showed

Table 2. Between group analysis for barefoot condition on dominant and non-dominant legs.

	Dancer		Non-Dancer		
	Mean	SD	Mean	SD	p-value
		Dominant Leg			
F_{ap}[1]	**-0.009**	**0.057**	**-0.149**	**0.067**	**0.001**
F_{ml}[2]	-0.002	0.015	0.009	0.023	0.095
F_z[3]	-0.750	0.505	-0.957	0.069	0.093
COP_{ap}	0.001	0.003	0.004	0.005	0.645
COP_{ml}	0.002	0.003	0.002	0.003	0.762
		Non-Dominant Leg			
F_{ap}[1]	**-0.069**	**0.062**	**-0.188**	**0.105**	**0.001**
F_{ml}[2]	**-0.012**	**0.015**	**0.013**	**0.025**	**0.001**
F_z[3]	-0.838	0.348	-0.969	0.026	0.121
COP_{ap}	-0.004	0.006	-0.003	0.007	0.783
COP_{ml}	0.001	0.002	-0.002	0.003	0.049

Note. [1]antero-posterior; [2]medio-lateral; [3]vertical. F_y, F_x, F_z units are in newtons, COP units are m

greater posterior GRF compared with dancers. For the NDL, significantly different GRF was found in both the AP and ML directions. Specifically, non-dancers demonstrated greater posterior-directed GRF compared with dancers as well as more GRF directed medially compared to the dancer group, which exhibited lateral GRF .

Between group analyses for the S condition can be found in Table 3. For both the DL and NDL, significant GRF differences were found in both the AP and ML directions. These significant differences were the result of non-dancers demonstrating greater posterior GRF compared with the dancers. Also, while dancers demonstrated a lateral GRF in the F_{ml} plane, a medially GRF was

Table 3. Between group analysis for shod condition on dominant and non-dominant legs.

	Dancer		Non-Dancer		
	Mean	SD	Mean	SD	p-value
		Dominant Leg			
F_{ap}[1]	**-0.011**	**0.061**	**-0.162**	**0.041**	**0.001**
F_{ml}[2]	**-0.003**	**0.015**	**0.018**	**0.006**	**0.001**
F_z[3]	-0.913	0.172	-0.952	0.035	0.355
COP_{ap}	0.002	0.004	-0.002	0.004	0.092
COP_{ml}	0.001	0.003	0.004	0.002	0.019
		Non-Dominant Leg			
F_{ap}[1]	**-0.080**	**0.041**	**-0.168**	**0.097**	**0.001**
F_{ml}[2]	**-0.008**	**0.012**	**0.012**	**0.013**	**0.001**
F_z[3]	-0.895	0.217	-0.983	0.067	0.128
COP_{ap}	-0.005	0.005	-0.001	0.006	0.053
COP_{ml}	0.009	0.003	0.002	0.003	0.493

Note. [1]antero-posterior; [2]medio-lateral; [3]vertical. F_y, F_x, F_z units are in newtons, COP units are m seen among non-dancers. More posterior GRF in both BF and S conditions indicates a greater loss of balance in the non-dancer group since, when in a static stance. Sensory awareness in movement has received increased interest in sports and clinical literature as a feed-forward and feedback mechanism which may by extension contribute to static balance (6). The greater medial GRF for non-dancers in the BF and S conditions may also indicate more global instability. Further, for the DL, a statistical trend (p=0.019) was observed for the COP_{ml}. Non-dancers had a more medial COP, which we believe is indicative of greater perturbation, and therefore instability. It is also important to note that in the shod NDL condition, COP_{ap} distances were different from each other, but did not reach significance (p = 0.053). In this condition, dancers showed more posterior GRF, which is difficult to explain.

Since strength and proprioception play an essential role in injury prevention (3), current athletic shoe construction may hinder balance ability without shoes. Athletic shoes are often designed with features that enhance stability of the foot and body which is important for prevention and protection against injury (31). There is evidence however that the rigid constraints of a traditional athletic shoe contribute to a lack of muscle development and proprioception (23). Because dancers perform movements primarily without shoes, it is possible that poor balance in the shod condition among dancers may be due to loss of sensory information that is available only when barefoot.

In the within group analyses there were more statistical differences within the dancer group, indicating more variability in DL and NDL, as seen in Tables 4 and 5. Dancers were statistically different in the AP GRF in both the BF and S conditions. Specifically, the results found that dancers show more posterior GRF in the NDL, which would support the concept of greater instability on the non-dominant side and more stability on the dominant side. The COP_{AP} was also statistically different between DL and NDL in BF and S conditions among dancers. Both indicated more posterior deviation on the NDL, which supports the notion that the NDL shows greater instability when shod and barefoot. Lastly, the BF NDL ML GRF showed a statistical trend (p = 0.016). Although dancers had more lateral GRF on the non-dominant side, both measures support the position that a dancer's balance is directed more laterally.

Among the non-dancers the only statistically significant differences were found in the COP_{ML} for both BF and S conditions. Specifically, a more lateral deviation was observed in the COP_{ML} for the NDL when barefoot. This finding seems unusual considering dancers seem to direct their GRF and COP more lateral to maintain balance, yet in the non-dancers, the BF condition shows more laterality for the NDL, which would indicate greater stability for this side. In the S condition, there was less medial deviation in the NDL than in the DL, which again indicates greater stability for the NDL than the DL. The higher number of statistically significant differences between the DL and NDL within the dancer group may lead to the conclusion that a dancer's balance is not equally distributed between DL and NDL. It is important to recognize, though, that the less variability in these measures for non-dancers may be because they have poor balance in both legs, and therefore, differences cannot be demonstrated.

The results from two different studies demonstrate the impact that dance activity and associated movements have on enhancing static balance. Ricotti and Ravaschio measured static balance three times over a course of six months in three homogenous groups of 9-year-old soccer athletes (29). For single-leg stance, there were no significant improvements in the dominant limb's COP area values neither for the group involved in soccer activity only nor for the group involved in soccer and swimming activity over the 6-month period. The group involved in the soccer and break dance activity, however, demonstrated a significant improvement in COP area values at month 0 and month 6 for the dominant limb. Further, for the non-dominant limb, the combination of soccer and break dance activity yielded a greater number of significant differences in COP area values between month 6 and month 2 as well as between month 4 and month 2 (29). Stanković M and Radenković showed enhanced balance among 39 male and female school age children among those involved in a dance program (30).

In our study, it is evident that the seven or more years of dance experience increased balance ability when performing single-leg stance. Although there was not a defined pattern of COP measurements in the ML and AP directions between dancers and non-dancers throughout all four conditions, dancers consistently demonstrated less deviation in the AP and ML GRF during BF and S conditions compared to non-dancers. Ambeganokar and colleagues also showed that dancers demonstrated significantly greater balance than non-dancers, especially statically (1). Our results of a subject's ability to maintain single-leg static balance for a 30-second duration is closely related to the results shown by Ambeganokar et al. In our study dancers were able to maintain single-leg stance on the dominant and non-dominant limb for the entire 30-second duration while non-dancers were unable to do so in 6 of the 84 trials.

Many authors support the notion that balance plays an important role in sport-specific movements and injury reduction both of which are needed for dance success (15, 22). Between dancers and soccer players, dancers performed significantly better on tasks measuring sway index during single-leg stance on stable and unstable surfaces (15, 17, 22).

Postural control, balance, coordination, proprioception and consistency in movement patterns are successful dance characteristics and are also linked to reduced risk of ankle injury, re-injury and ACL tears (5, 15, 16, 20, 32-34). Diminished or exaggerated proprioceptive responses may be the direct result of musculoskeletal injury and surgical interventions (5, 16, 27). A deficit in proprioception, independent of its extent, will compromise postural control, and therefore, offset balance and increase injury risk (11, 13, 26). Failure to restore proprioception in the lower extremity following surgery and rehabilitation, even if the athlete regains complete strength, will increase the risk for re-injury because of the joint instability that is perceived by the individual (16, 21).

Further, peripheral and central alterations in function, including joint laxity and instability, misalignment, localized weakness, diminished muscle reaction time, and altered center motor programming (4, 22, 24) may result if proprioceptive deficits are left untrained. Thus, extending proprioceptive training and balance protocols used in dance for treatment of lower-extremity injuries may decrease the risk of injury since proprioceptive training is believed to be beneficial in preventing injuries in the lower extremity, protecting against re-injury, and reducing recovery time (4, 22, 35).

In athletes with recurrent ankle sprains, proprioceptive testing has shown that some with recurrent ankle sprains have lower ankle joint position sense compared with individuals without such injuries (7, 28). Following knee and ankle injury in athletes, proprioceptive training improves postural stability (14), flexibility (13), joint position sense, and faster muscle reaction time (24). It is important to note, though, that the ability to reduce the risk of specific injuries in specific sports through proprioceptive balance training remains unclear due to the inclusions of strength and agility throughout the training programs (3, 9).

For example, Ambegaonkar and colleagues sought to understand why female dancers have lower ACL injury rates compared with physically active females (1). Prior to the study, the authors believed that better balance by experienced dancers contributed to decreased musculoskeletal injury risk. The authors concluded that the examination of balance between dancers and non-dancers does not provide a complete explanation regarding why physically active females experience higher ACL injury rates compared with dancers. ACL injury risk is multifaceted, with balance and proprioception being important components, however joint structure, including the direction and magnitude of the destabilizing force, the rate at which loads are applied, and joint position all contribute to risk. Therefore, balance appears to be one of several components that contributes to ACL injury. Static testing conditions that use a fixed base of support may not translate into the functionally dynamic movements that occur in sport. Thus, an athlete may not demonstrate a deficiency in balance ability during static conditions when in fact one exists throughout his movement patterns (15). Selective destabilization of a joint through the incorporation of perturbations in balance training should also be included in the protocol for rehabilitation (10). The application of graded, controlled forces across injured joints is effective in activating higher neural centers that evoke postural synergies, reducing injury potential (2, 5), allowing the center of mass to remain over the base of support..

Following this study, we hoped to better understand how dance impacted balance and whether or not these results could be applied to lower-extremity rehabilitation. Our study defined balance as the ability to maintain a specified pose for a duration of 30 seconds as well as the ability to demonstrate minimal movement throughout this time interval. More specifically minimal movement was understood as a decrease in posterior and medial GRF and deviation in the COP. The duration that an individual maintained single-leg stance also highlighted static balance ability. Rehabilitation should provide balance training as a major component in both rehabilitation as well as pre-season injury prevention programs for their athletes.

REFERENCES

1. Ambegaonkar JP, Caswell SV, Winchester JB, Shimokochi Y, Cortex N, Caswell AM. Balance comparisons between female dancers and active nondancers. Res Q Exerc Sport 84(1): 24-29, 2013.

2. Aston-Miller JA. Proprioceptive thresholds at the ankle: implications for the prevention of ligamentous injury. In S.M. Lephart & F.H. Fu (Eds.). Proprioception and neuromuscular control in joint stability. Urbana, IL: Human Kinetics, 2000.

3. Bahr R, Lian O, Bahr IA. A twofold reduction in the incidence of acute ankle sprains in volleyball after the introduction of an injury prevention program: a prospective cohort study. Scan J Med Sci Sports 7: 172– 177, 1997.

4. Baltaci G, Kohl HW. Does proprioceptive training during knee and ankle rehabilitation improve outcome? Physical Therapy Reviews 8: 5-16, 2003.

5. Batson G. Update on proprioception considerations for dance education. J Dance Med Sci 13(2): 35-41, 2009.

6. Bitter F, Hillier S, Civetta L. Change in dexterity with sensory awareness training: a randomized controlled trial. Percept Mot Skills 112(3): 783-798, 2011.

7. Boyle J, Negus V. Joint position sense in the recurrently sprained ankle. Aust J Physiother 44: 159-163, 1998.

8. Bressel E, Yonker JC, Kras J, Heath EM. Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastic athletes. J Athl Train 42(1): 42-46, 1985.

9. Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A. Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. Knee Surg Sports Traumatol Arthrosc 4: 19-21, 1996.

10. Chmielewski TL, Hurd WJ, Snyder-Mackler L. Elucidation of a potentially destabilizing control strategy in ACL deficient non-copers. J Electromyogr Kinesiol 15: 83-92, 2005.

11. Cornwall MW, Murrell P. Postural sway following inversion sprain of the ankle. J Am Podiatr Med Assoc 81: 243-7, 1991.

12. Crotts D, Thompson B, Nahom M, Ryan S, Newton, R. Balance abilities of professional dancers on select balance tests. J Orthop Sports Phys Ther 23: 12-17, 1996.

13. DeNoronha M, Refshauge KM, Herbert RD, Kilbreath SL, Hertel J. Do voluntary strength, proprioception, range of motion, or postural sway predict occurrence of lateral ankle sprain? Br J Sports Med, 40(10): 824-828, 2006.

14. Eils E, Rosenberg D. A multi-station proprioceptive exercise program in patients with ankle instability. Med Sci Sports Exerc 33: 1991-1998, 2001.

15. Emery CA. Is there a clinical standing balance measurement appropriate for use in sports medicine? A review of the literature. J Sci Med Sport 6(4): 492-504, 2003.

16. Ergen E, Ulkar B. Proprioception and ankle injuries in soccer. Clin Sports Med 27(1): 195-217, 2008.

17. Gerbino PG, Griffin ED, Zurakowski D. Comparison of standing balance between female collegiate dancers and soccer players. Gait Posture 26(4): 501-507, 2007.

18. Golomer E, Dupui P, Monod H. Dynamic patterns of postural sway in ballet dancers and track athletes. Eur J Appl Physiol 76: l40-147, 1997.

19. Golomer E, Cremieux J, Dupui P, Isableu B, Ohlmann T. Visual contribution to self-induced body sway frequencies and visual perception of male professional dancers. Neurosci Lett 267(3): 189–192, 1999.

20. Holme E, Magnusson SP, Becher K, Bieler T, Aagaard P, Kjaer M. The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. Scand J Med Sci Spor 9(2): 104-109, 1999.

21. Hrysomallis C. Relationship between balance ability, training and sports injury risk. Sports Med 37(6): 547-556, 2007.

22. Hrysomallis C. Balance ability and athletic performance. Sports Med 41(3): 221-232, 2011.

23. Jackman RW, Kandarian SC. The molecular basis of skeletal muscle atrophy. Am J Physiol Cell Physiol, 287(4): 834-843, 2004.

24. Karlsson J, Andreasson GO. The effect of external ankle support in chronic lateral ankle joint instability: an electromyographic study. Am J Sports Med 20: 257-26l, 1992.

25. Ku PX, Abu Osman NA, Yusof A,Wan Abas B. Biomechanical evaluation of the relationship between postural control and body mass index. J Biomech 45(9): 1638–1642, 2012.

26. Leanderson J, Eriksson E, Nilsson C, Wykman A. Proprioception in classical ballet dancers: a prospective study of the influence of an ankle sprain on proprioception of the ankle joint. Am J Sports Med 24(3): 370-374, 1996.

27. Lephart SM, Pincivero DM, Giraido JL, Fu FH. The role of proprioception in the management and rehabilitation of athletic injuries. Am J Sports Med 25:130-137, 1997.

28. Refshauge KM, Kilbreath SL, Raymond J. Deficits in detection of inversion and eversion movements among subjects with recurrent ankle sprains. J Orthop Sports Phys Ther 33: 166-176, 2003.

29. Ricotti L, Ravaschio A. Break dance significantly increases static balance in 9 years-old soccer players. Gait Posture 33: 462-465, 2011.

30. Stanković M, Radenković O. The status of balance in preschool children involved in dance program. Research Kinesiol 40(1): 113-116, 2012.

31. Stewart L, Gibson JN, Thomson CE. In-shoe pressure distribution in “Unstable” MBT shoes and flat-bottomed training shoes: a comparative study. Gait Posture 25(4): 648-651, 2007.

32. Tropp H, Ekstrand J, Gillquist J. Stabilometry in functional instability of the ankle and its value in predicting injury. Med Sci Sports Exerc 16: 64-66, 1984.

33. Tropp H, Askling C, Gillquist J. Prevention of ankle sprains. Am J Sports Med 2(13): 259-262, 1985.

34. Wester JU, Jespersen SM, Nielsen KD, Neumann L. Wobble board training after partial sprains of the lateral ligaments of the ankle: A prospective randomized study. J Orthop Sports Phys Ther 23: 332-336, 1996.

35. Willems T, Witvrouw E, Verstuyft J, Vaes P, De Clercq D. Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. J Athl Train 37: 487-493, 2002.