Effect of Integrated Training on Balance and Ankle Position Sense in Ballet Dancers

Chai-Wei Lin
National Cheng Kung University Department of Biomedical Engineering
Yi-An Chen
National Cheng Kung University Department of Biomedical Engineering
Yu-Lin You
National Cheng Kung University College of Medicine, Department of Physical Therapy
Tzu-Chan Wu
National Cheng Kung University College of Medicine, Department of Physical Therapy
Cheng-Feng Lin (connie@mail.ncku.edu.tw)
National Cheng Kung University College of Medicine https://orcid.org/0000-0002-2466-0156

Research article

Keywords: plyometric, proprioception, core stability, ballet dancers, ankle sprain

Posted Date: September 23rd, 2020

DOI: https://doi.org/10.21203/rs.3.rs-79394/v1

Abstract

Background: Ballet dancers are at high risk of ankle sprain. As a result, effective training programs are required for ballet dancers to minimize injury occurrence and improve their balance ability. Our purpose was to investigate the effects of a 6-week integrated training program on the ankle joint position sense and postural stability in ballet dancers.

Methods: Twenty-nine female ballet dancers were recruited to the study. Sixteen of the dancers underwent a 6-week integrated training program consisting of plyometric, proprioception and core stability exercises. The remaining ballet dancers performed no additional training, but continued regular ballet practice as usual. For both groups, ankle joint position sensing tests were performed before and after training. Furthermore, for the training group, the postural stability was assessed by measuring the average speed of the center of pressure (COP) and the maximum ankle joint displacements while performing *grand plie* (deep squatting) and *releve en demi-pointe* (standing on balls of foot) movements.

Results: After 6 weeks, both groups showed significantly smaller absolute ankle joint reposition errors in plantarflexion and eversion. Furthermore, the training group showed a significantly smaller ankle joint reposition error in dorsiflexion. The training group also showed a significantly slower average COP speed and smaller maximum COP displacement in the medial-lateral direction.

Conclusions: The 6-week integrated training program improved the ankle joint position sense in dorsiflexion and the postural control in the medial-lateral direction while performing *grand-plie* and *releve en demi-pointe* movements. Thus, this integrated training program can be suggested for dancers in order to improve ankle position sense and postural stability during ballet movements.

Background

Ballet requires intensive training to reach the demanded aesthetic standards. Consequently, ballet dancers are under intense physical and psychological demands during training, rehearsal and performance [1]. The physical demands imposed on dancers are exacerbated by insufficient warm-up or cool-down periods, inadequate stretching exercises, and deficient training [2]. Such improper practices may lead to micro-trauma of the soft tissues (i.e., the ligaments, tendons, or muscles). Furthermore, the accumulation of these micro-traumas over time increases the risk of injury and may potentially affect the dancer's performance, or even end their career. Many studies have shown that ballet dancers are at a greater risk of injury to the ankle or foot than other performers or athletes due to the higher demands placed on the ankle and foot during the execution of ballet movements [2–4]. Among all the injuries suffered by ballet dancers, one of the most common is ankle sprain; accompanied by residual symptoms such as pain, muscle weakness, delayed neuromuscular response, and impaired proprioception function. Thus, proper training programs aimed at minimizing ankle injuries and improving the balance ability are essential in maintaining the health and performance of ballet dancers.

Proprioception plays an essential role in ensuring a smooth and coordinated movement of the body by providing a conscious or unconscious awareness of the joint position [5]. Proprioception of the ankle joints is particularly important to ballet dancers in maintaining postural stability in response to perturbations or challenging movements (e.g., single-leg standing or jump-landing). Consequently, proprioception training is widely applied to ballet dancers with ankle sprain in order to improve or regain the function of the proprioception receptors around the ankle joint [5–8].

Plyometric exercise is an intensive exercise consisting of fast and powerful movements reacted from eccentric contraction of the muscles followed immediately by quick concentric contraction. The effects of plyometric exercise on performance and injury prevention have been widely studied in many sports, including soccer, basketball and volleyball [9–11]. Brown et al. [9] compared the effects of six-week plyometric training and six-week traditional weight training in basketball players and found that both training programs improved the muscle strength of the lower extremities and the power-related variables. However, the effects of plyometric exercise on balance control were not investigated. Plyometric exercise of the lower extremities generally involves repetitive jump-landing movements and agility tasks with rapid changes of direction[12]. Such movements actuate the mechanical or proprioception receptors on the ligaments of the foot or tendons around the ankle joint, and are thus of great potential benefit in improving the position sense of the ankle joint and enhancing the balance ability accordingly.

Core stability exercise (or core strengthening) is a widely used training program for improving athletic performance or preventing injury [13]. A greater stability of the core region provides the foundation for an improved force generation and transition of the extremities, and therefore plays a key role in improving postural stability [14, 15] and sports performance [16–18].

As described above, the ankle joint in ballet dancers is subjected to intense physical demands during the execution of ballet movements. Consequently, effective training programs are essential to prevent injuries to the ankle joint (particularly strains) and improve the balance ability accordingly. Previous studies have shown that plyometric exercise, proprioception training and core stability strengthening are effective techniques for minimizing the risk of injury and improving the performance in many different types of sports [19]. The present study speculates that such training programs may also benefit ballet dancers. Accordingly, an integrated six-week ballet training program is devised consisting of plyometric exercise, proprioception training and core stability exercise. The effectiveness of the proposed program is evaluated by measuring the average speed of the center of pressure (COP) and maximum ankle joint displacements of ballet dancers while performing *grand plie* (deep squatting) and releve en demi-pointe movements before and after the training program, respectively. It is hypothesized that the ballet dancers will exhibit an improved ankle joint position sense and ballet movement performance after receiving the proposed training program and will therefore suffer a lower risk of ankle strain.

Methods

Participants

Thirty female ballet dancers were recruited from a college dance department. The dancers were divided into two groups, namely a training group (N=17, age: 17.63 ± 1.46 years) and a control group (N=13; age: 17.08 ± 1.19 years). All of the dancers had a classical ballet training history of at least seven years (training group: 10.19 ± 2.48 years; control group: 8.77 ± 2.77). Participants with a history of balance and vestibular problems, or any other impairment which might potentially affect their balance, or any acute inflammation or pain that affected their performance at the physical screening stage, were excluded. The study was designed in accordance with ethical protocols and all the participants read and signed a formal consent form approved by the university Institutional Review Board prior to joining the study. One participant dropped out from the training program due to time conflicts and thus the training group was reduced to 16 dancers. In addition, four members of the training group reported previous ankle sprain more than 4.5 years ago and did not have another onset of ankle sprain since then.

Instrumentation

The joint position sense of the ballet dancers was evaluated using a bi-axis electrogoniometer (GA 150, Biometrics, UK) placed around the ankle joint. The electrogoniometer signals were recorded by instruNet software through an analog-to-digital box (iNet-100, instruNet, USA). The three-dimensional trajectories of the reflective markers placed on the participants were captured at a sampling rate of 100 frames per second by a videographic acquisition system consisting of eight CCD cameras (Eagles, Motion Analysis Corporation, USA). In addition, the center of pressure (COP) positions of the participants' feet were detected by a force plate (9281B Kistler Instrument Corp., Switzerland) at a rate of 1000 samples per second. The videographic data and force plate data were time-synchronized to 1000 Hz using a linear interpolation method.

Procedure

All of the participants received joint position sense tests and balance ability tests during ballet movements at baseline and after six-week training. The training group underwent a six-week training program and home training program. By contrast, the control group had no additional intervention. Both groups continued their regular ballet training throughout the experimental period.

The absolute errors of the active ankle joint reposition sense were measured in 10° dorsiflexion, 20° plantarflexion, 10° eversion, 10° inversion and 20° inversion in the dominant leg. (Note that the dominant leg was determined as the leg used preferentially by the participants in performing forward hops.) In conducting the measurement process, the dancers sat on a custom-made chair with hip and knee flexion at 90° and trunk erected. The axis of motion in the sagittal plane (i.e., dorsiflexion and plantarflexion) was taken as the line passing through the lateral and medial malleolous with the ankle in the neutral position. By contrast, the motion of the ankle in the frontal plane (i.e., eversion and inversion) was tested with the ankle in slight plantarflexion. The participants were asked to close their eyes during the tests to avoid visual cues. The participant's ankle was placed passively to the target angle and maintained at the placed angle for 5 seconds. The ankle was then repositioned passively to the initial position by the same investigator. Once the ankle was restored to the initial position, the participant was instructed to reposition the ankle actively to the target angle and maintain the ankle in that position for 5 seconds.

Reflective markers were placed on the bilateral anterior superior iliac spine (ASIS) and sacrum of all the participants in the training group. The participants were asked to stand on a large piece of paper in the ballet first position (Figure 1) and the outlines of the feet were then drawn on the paper. The foot length was defined as the distance between the tip of the second toe and the mid-heel position. Similarly, the turnout angle was defined as the angle between the lines constructed by the second toes and mid-heels of the two feet [20]. The participants put on ballet slippers and then performed 20-second *releve en demi-pointe* and 20-second *grand-plie* movements on the force plate. The ballet *releve en demi-pointe* movement commenced from the ballet first position and involved raising the heels up to demi-pointe within 5 seconds, maintaining this position for 10 seconds, and then returning to the initial position within 5 seconds (Figure 1). The *grand-plie* movement also began from the ballet first position, and involved deep squatting with heel-off within 5 seconds, maintaining the deep squatting position for 10 seconds, and then returning to the initial position within 5 seconds (Figure 2). For both movements, auditory cues were delivered by a metronome to control the movement speed. In addition, three successful trials were obtained for both movements.

The six-week integrated training program consisted of plyometric exercise, proprioception training, and core stability training (1 hour per day, 3 days per week) (Table 1). In every training session, the participants were asked to warm up by performing 5-minute cycling at a self-selected speed followed by bilateral hamstring and calf muscle stretching. The training group additionally received a home training program consisting of gastrocnemius and hamstring stretching, ankle muscle strengthening, core muscle training, and plyometric exercises (Table 2).

Data reduction and analysis

Data reduction was performed using a self-written algorithm programmed in MATLAB 7.0 (The Mathworks Inc., USA). The absolute errors of the ankle joint reposition sense were determined at 10° dorsiflexion, 20° plantarflexion, 10° eversion, 10° inversion and 20° inversion in the dominant leg. In assessing the ballet movements, the vertical heights of the ASIS and sacrum markers were used to define the different phases in the *grand-plie* and *releve en demi-pointe* movements. For analysis purposes, the *grand-plie* movement was divided into five phases, namely a 5-second lowering phase from the initiation of movement to the lowest sacrum position; a 10-second squatting phase (divided into three sub-phases: pre-equilibrium, equilibrium and post-equilibrium) with the pelvic markers in the lowest position; and a 5-second rising phase from the squatting position to the original standing position. The *releve en demi-pointe* movement was similarly divided into five phases, namely rising, pre-equilibrium, equilibrium, post-equilibrium, and lowering.

The COP positions during the *grand-plie* and *releve en demi-pointe* movements were determined from the virtual acting points of the ground reaction forces. The average speed of the COP in each phase of the movement was computed as the total trajectory length traveled by the COP divided by the corresponding time. The ellipse area was determined as the area enclosing 95% of the COP positions, and was formed by linear curve fitting of the axes. The COP displacements were normalized to the corresponding *turnout* angle (θ) and average foot length (*l*) to eliminate the influence of inter-participant differences, i.e.,

$$NCOP_{AP} = \frac{COP_{AP}}{l \times \cos\frac{\theta}{2}},$$

$$NCOP_{ML} = \frac{COP_{ML}}{l \times \sin\frac{\theta}{2}},$$

where *N*COPAP denotes the normalized COP displacement in the anterior-posterior direction, while NCOPML denotes the normalized COP displacement in the medial-lateral direction. The COP parameters for analysis included the average COP speed, the COP 95% ellipse area, the normalized maximal COP displacement, and the standard deviation (SD) of the COP displacement in the anterior-posterior and medial-lateral directions in each phase of the corresponding ballet movement.

The variables of interest included the absolute errors of the active joint reposition sense of the ankle and the aforementioned COP measures. An independent student t-test was used to compare the baseline between the two groups prior to training. In addition, the paired student t-test was used to test for differences between the pre-training test and post-training test results for the training group. The significance level was set as 0.05 in every case. All of the statistical analyses were performed using commercial SPSS software (Vs. 17.0; SPSS Inc., USA).

Results

Joint position sense

There was no significant difference in the ankle joint reposition sense of the two groups at baseline for 10° dorsiflexion (p=0.066), 20° plantarflexion (p=0.391), 10° inversion (p=0.786), 20° inversion (p=0.767) and 10° eversion (p=0.965). After training, the training group showed smaller absolute repositioning errors in 10° dorsiflexion (p=0.007), 20° plantarflexion (p=0.002) and 10° eversion (p=0.011). However, no significant difference was observed between the pre- and post-training repositioning errors in 10° and 20° inversion (Table 3). After 6 weeks of regular training, the control group showed lower absolute repositioning errors for 20° plantarflexion (p= 0.020) and 10° eversion (p= 0.017). However, no significant difference was found between the repositioning errors for 10° (p= 0.416) and 20° (p= 0.579) inversion or 10° dorsiflexion (p=0.649) (Table 3).

COP measures in *releve en demi-pointe*

The training group showed a slower average COP speed in the rising (p=0.011), pre-equilibrium (p=0.023) and equilibrium phases after training. The training group also showed a smaller maximum displacement in the medial-lateral direction during the pre-equilibrium phase (p=0.004) and a smaller SD of the COP displacement in the anterior-posterior direction during the lowering phase (p=0.034). However, no significant difference was observed in the 95% COP ellipse area, maximum displacement in the anterior-posterior direction, or SD of the displacements in the medial-lateral direction after training (Table 4).

COP measures in *grand-plie*

The training group showed a slower average COP speed in the lowering (p=0.018), pre-equilibrium (p=0.003), equilibrium (p=0.009) and post-equilibrium (p=0.011) phases after training. The training group also showed smaller maximum displacements of the COP in the medial-lateral direction during the lowering (p=0.004), pre-equilibrium (p=0.044) and post-equilibrium (p=0.011) phases. The training group additionally showed a smaller SD of the displacements in the medial-lateral direction during the lowering (p=0.002), pre-equilibrium (p=0.014), equilibrium (p=0.046) and post-equilibrium (p=0.017) phases. However, no significant difference was observed between the pre- and post-training values of the 95% COP ellipse area, maximum displacement of the COP, and SD of the COP displacements in the anterior-posterior direction (Table 5).

Discussion

Ankle joint reposition sense

The 6-week integrated training program had a positive effect on the ankle joint reposition sense in dorsiflexion. The improvement in the reposition sense can be attributed most likely to the elements in the 6-week integrated training program involving dorsiflexion movements (e.g., deep squatting) on the foam mat or air discs. The execution of dorsiflexion movements on such unstable surfaces actively triggers the proprioceptive mechanoreceptors around the ankle joint and gives rise to an improved joint reposition sense as a result. Similarly, the plyometric training exercises involved continuous jump-landing tasks, in which the dancers were required to react quickly in the landing period, thereby actuating the proprioception function of ankle dorsiflexion to enhance the pre-stretching effect of the muscles and increase the contraction force for the following jump motion. Thus, it appears that both plyometric training and proprioception exercises are beneficial in improving the ankle joint position sense in ankle dorsiflexion.

Both groups (i.e., training and control) showed an improved ankle joint position sense in plantarflexion and eversion after six weeks. In other words, routine ballet training in itself (i.e., no other additional training) appears to be sufficient to improve the repositioning ability of the ankle in plantar flexion and eversion. A previous study investigated the ankle joint replication of gymnasts and non-gymnasts and found that the gymnasts had a superior replication performance [18]. It was suggested that this was the natural consequence of the long-term effect of gymnast training [21]. Other studies have suggested that a superior joint replication ability may be associated particularly with movements such as single-leg standing; characterized by extreme ankle plantarflexion [19]. Ballet dancers' ankle joints are often required to bear the entire weight of the body in extreme positions, such as demi-pointe (i.e., standing on the metatarsal heads) or full pointe (i.e., standing on tip-toes). Standing in these extreme positions requires full ankle plantarflexion combined with slight ankle eversion to maintain stability. Consequently, the medial side of the forefoot takes a larger proportion of the weight bearing. This in turn suppresses lateral deviation of the COP and reduces the risk of lateral ankle sprain. Overall, therefore, the improved position sense in ankle plantarflexion and eversion observed in both groups in the present study may be the natural result of regular ballet training rather than the integrated training program.

No improvement was observed in the ankle joint reposition sense in inversion following the training process. Notably, this contradicts the hypothesis of the present study that the training program can prevent episodes of ankle sprain. It is speculated that the insignificant training effect may be the natural result of regular ballet training. In particular, when performing heel-rise movements in ballet pointe shoes, ballet dancers are instructed to balance on the tips of two or three toes with the foot positioned away from the ankle inversion position. Consequently, the ankles are routinely placed either neutrally or at slight eversion, and hence the effect of training on the ankle inversion position sense is inevitably reduced.

Ballet movement assessments

The effects of training on the postural stability of the ballet dancers were observed by measuring the speed and displacements of the COP during *releve en demi-pointe* and *grand-plie* movements. The training group showed a slower COP average speed after the training program; thereby indicating a more stable posture. The improved postural stability may stem from a greater core stability and improved joint position sense. For example, a previous study investigated the transient effect of core stability exercises on postural sway, and found that core stability exercises reduce the range of COP displacements in the medial-lateral direction and decrease the COP speed during quiet standing [15]. Furthermore, the co-contraction of the back extensor muscles and abdominal muscles induced in the core exercises in the training program may result in an improved torso stability, which also tends to reduce the COP speed during the ballet movements[22]. In addition to a slower COP speed, the ballet dancers also showed an improved joint position sense after training. In a previous study, it was shown that participants with functional ankle instability (FAI) exhibited a poorer ankle joint position sense and greater COP displacement [23], and thus, the poor ankle joint position sense is related to greater COP displacement. The improved postural control in the current study inferred that the training program prescribed in the present study improved the joint position sense of the ankle.

The training group showed both a lower absolute displacement of the COP in the medial-lateral direction and a smaller SD of the COP displacements after the training program. Previous studies have reported that improved postural stability in the medial-lateral direction but not in the anterior-posterior direction is associated with the use of different balance strategies in the two directions. In particular, in side-by-side stance, balance in the anterior-posterior direction is maintained mainly by the ankle joint, whereas in the medial-lateral direction, balance is maintained predominantly by the hip abductor/adductor [24]. The core stability exercises prescribed in the integrated training program increase the muscle strength around the hip joints. Consequently, both the absolute values of the COP displacement in the medial-lateral direction and the SD values improve significantly after training.

A previous meta-analysis review reported that proprioception exercises can improve subjective instability and functional outcomes such as the Foot and Ankle Disability index and Star Excursion Balance test [25]. The ballet dancers in the current study showed improved stability when performing ballet movements. The smaller maximum COP displacement observed in the medial-lateral direction after training may be correlated with the improved position sense of dorsiflexion and plantarflexion caused by the more sensitive detection of ankle motion with the foot in the turnout position [26]. It may also be explained in part by the findings of previous studies that the reduced acuity of position sense in basketball players is associated with a greater co-contraction of the plantarflexor/dorsiflexor muscles and an increased impact during drop-landing [27].

Plyometric exercise involves two main adaptations, namely peripheral and central. In peripheral adaptation, the stretch sensitivity of the Golgi tendon organs (GTOs) is heightened, and hence the muscle spindle contributes more afferents to the central nervous system, together with better proprioception [19]. The continuous jumping movements prescribed in the current training program involve the gastrocnemius muscle as the primary muscle. In other words, the muscle spindles of the gastrocnemius are the primary stimulated targets. This may explain the improved postural stability of the dancers observed in the medial-lateral direction after 6-week training since the plantarflexor and dorsiflexor with turnout are the primary muscles responsible for controlling postural stability in medial-lateral sway during *grand-plie* and *releve* movements. Central adaptation results from the anticipatory movements required to execute the plyometric exercises prescribed in the training program. For example, the preparation for serial jumping movements facilitates the activity of the central nervous system and hence enhances the sensitiveness of the muscle spindles to position changes.

Limitations

In the present study, the training group underwent two assessments, namely pre- and post-training in both ankle joint reposition sense and ballet movement assessments. However, the control group received only baseline assessment for position sense. Hence, it is unlikely to observe the changes in the control group.

Conclusion

This study has investigated the effectiveness of an integrated training program involving proprioception, plyometric and core stability exercises in improving the neuromuscular control of the ankle joint in ballet dancers with the aim of minimizing the risk of ankle sprain during ballet movements. The results have shown that the training program improves the ankle joint reposition sense in dorsiflexion and plantarflexion. Moreover, the training program results in an improved postural control in the medial-lateral direction when performing ballet deep squatting (*grand-plie*) and standing on balls of foot (*releve*) movements.

Declarations

Ethics approval and consent to participate

Ethical approval has been obtained from the Institutional Review Board of National Cheng Kung University Hospital, Taiwan

Consent for publication：No applicable

Competing interests：The authors declare that they have no competing interests

Funding：No applicable

Authors' contributions：Conceptualization, CW Lin, CF Lin; Methodology, CW Lin, YA Chen, TC Wu, and CF Lin; Software, CW Lin, YA Chen, YL You, and CF Lin; Formal Analysis, CW Lin, YL You, TC Wu, and CF Lin; Investigation, CW Lin, YA Chen, and CF Lin; Writing – Original Draft Preparation, CW Lin, CF Lin; Writing – Review & Editing, CW Lin, YL You, and CF Lin

Acknowledgements：No applicable

Availability of data and materials：All relevant data are within the paper.

References

1. Koutedakis Y and Jamurtas A, *The dancer as a performing athlete: physiological considerations.* Sports Med, 2004. **34**(10): p. 651-61.
2. Byhring S and Bo K, *Musculoskeletal injuries in the Norwegian National Ballet: a prospective cohort study.* Scand J Med Sci Sports, 2002. **12**(6): p. 365-70.
3. Gamboa JM, et al., *Injury patterns in elite preprofessional ballet dancers and the utility of screening programs to identify risk characteristics.* J Orthop Sports Phys Ther, 2008. **38**(3): p. 126-36.
4. Bronner S and Brownstein B, *Profile of dance injuries in a Broadway show: a discussion of issues in dance medicine epidemiology.* J Orthop Sports Phys Ther, 1997. **26**(2): p. 87-94.
5. Kynsburg A, et al., *Changes in joint position sense after conservatively treated chronic lateral ankle instability.* Knee Surgery, Sports Traumatology, Arthroscopy, 2006. **14**(12): p. 1299-306.
6. Huang PY, et al., *Lower extremity biomechanics in athletes with ankle instability after a 6-week integrated training program.* J Athl Train, 2014. **49**(2): p. 163-72.
7. Hiller CE, Kilbreath SL, and Refshauge KM, *Chronic ankle instability: evolution of the model.* J Athl Train, 2011. **46**(2): p. 133-41.
8. Caldemeyer LE, Brown SM, and Mulcahey MK, *Neuromuscular training for the prevention of ankle sprains in female athletes: a systematic review.* Phys Sportsmed, 2020: p. 1-7.

9. Thomas K, French D, and Hayes PR, *The effect of two plyometric training techniques on muscular power and agility in youth soccer players.* J Strength Cond Res, 2009. **23**(1): p. 332-5.
10. Vescovi JD, Canavan PK, and Hasson S, *Effects of a plyometric program on vertical landing force and jumping performance in college women.* Phys Ther Sport, 2008. **9**(4): p. 185-92.
11. Myer GD, et al., *Neuromuscular training improves performance and lower-extremity biomechanics in female athletes.* J Strength Cond Res, 2005. **19**(1): p. 51-60.
12. Lee HM, Oh S, and Kwon JW, *Effect of Plyometric versus Ankle Stability Exercises on Lower Limb Biomechanics in Taekwondo Demonstration Athletes with Functional Ankle Instability.* Int J Environ Res Public Health, 2020. **17**(10).
13. Willardson JM, *Core stability training: applications to sports conditioning programs.* J Strength Cond Res, 2007. **21**(3): p. 979-85.
14. Holmich P, et al., *Exercise program for prevention of groin pain in football players: a cluster-randomized trial.* Scandinavian journal of medicine & science in sports, 2010. **20**(6): p. 814-21.
15. Kaji A, et al., *Transient effect of core stability exercises on postural sway during quiet standing.* Journal of strength and conditioning research / National Strength & Conditioning Association, 2010. **24**(2): p. 382-8.
16. Sato K and Mokha M, *Does core strength training influence running kinetics, lower-extremity stability, and 5000-M performance in runners?* Journal of strength and conditioning research / National Strength & Conditioning Association, 2009. **23**(1): p. 133-40.
17. Asplund C and Ross M, *Core stability and bicycling.* Current sports medicine reports, 2010. **9**(3): p. 155-60.
18. Wells GD, Elmi M, and Thomas S, *Physiological correlates of golf performance.* Journal of strength and conditioning research / National Strength & Conditioning Association, 2009. **23**(3): p. 741-50.
19. Swanik KA, et al., *The effects of shoulder plyometric training on proprioception and selected muscle performance characteristics.* J Shoulder Elbow Surg, 2002. **11**(6): p. 579-86.
20. Hamilton D, et al., *Dance training intensity at 11-14 years is associated with femoral torsion in classical ballet dancers.* Br J Sports Med, 2006. **40**(4): p. 299-303; discussion 303.
21. Aydin T, et al., *Proprioception of the ankle: a comparison between female teenaged gymnasts and controls.* Foot Ankle Int, 2002. **23**(2): p. 123-9.
22. Lin CW, et al., *A comparison of ballet dancers with different level of experience in performing single-leg stance on retire position.* Motor Control, 2014. **18**(2): p. 199-212.
23. Cho BK and Park JK, *Correlation Between Joint-Position Sense, Peroneal Strength, Postural Control, and Functional Performance Ability in Patients With Chronic Lateral Ankle Instability.* Foot Ankle Int, 2019. **40**(8): p. 961-968.
24. Winter DA, et al., *Unified theory regarding A/P and M/L balance in quiet stance.* J Neurophysiol, 1996. **75**(6): p. 2334-43.

25. Postle K, Pak D, and Smith TO, *Effectiveness of proprioceptive exercises for ankle ligament injury in adults: a systematic literature and meta-analysis.* Man Ther, 2012. **17**(4): p. 285-91.
26. Hughes T and Rochester P, *The effects of proprioceptive exercise and taping on proprioception in subjects with functional ankle instability: a review of the literature.* Phys Ther Sport, 2008. **9**(3): p. 136-47.
27. Fu SN and Hui-Chan CW, *Are there any relationships among ankle proprioception acuity, pre-landing ankle muscle responses, and landing impact in man?* Neurosci Lett, 2007. **417**(2): p. 123-7.

Tables

Table 1. Exercise program

Week	Proprioception training	Plyometric exercise	Core stability	Others
1	Standing on the foam with *demi-plie* & *grand- plie* (10)	Line jump (forward-to-backward, and side-to-side) (20*2)	Abdominal bracing (10s*10) Bridging exercise with one foot on the air bag and one foot on the mat (10*2) Swiss-ball (basic bounce, heel raising bounce, and toe raising bounce) (30)	Towel squeezing (3s*20)
2	One-leg-standing on the foam with *Arabesqu*e (10*2) Two-leg-standing on wobble board (clockwise and counter-clockwise) (5)	Two-legged jump from mat to 10-cm stage with firm surface (forward-to-backward, and side-to-side) (20)	Bridging exercise with each foot on air bag (10*2) Swiss-ball exercise (alphabetic sitting on mat, bouncing with front and side foot tap) (30)	Towel squeezing (4s*20)
3	One-leg-standing on foam with free-leg with sand bag and alphabetic movement (1*2) Two-leg-standing on wobble board (clockwise and counter-clockwise) (5)	Two-leg jump from mat to 15-cm stage with firm surface (forward-to-backward, and side-to-side) (20) Ankle jump (40)	Bridging exercise with crossed-leg on the air bag (10*2) Swiss-ball exercise (leg march on ball with each bounce, and alphabetic standing on foam)	Towel squeezing exercise with 1 kg sandbag (5s*20)
4	One-leg-standing on mat with eye-closing Standing on the pair of air-bags in *2nd position* and perform the *demi-plié*	Two-leg jumping from mat to 15-cm stage with mat surface (forward-to-backward, and side-to-side) (20) Ankle jump (20) Scissors jump (10)	Bridging exercise with figure-four-leg on the air bag Swiss-ball exercise (alphabetic sitting on airbag, hop around ball)	Towel squeezing exercise with 1.5 kg sandbag (6s*20)
5, 6	One-leg-standing with eye-closed on foam (10s*6) Standing on the two air-bags and *grand-plié* (10)	One-leg jumping from firm surface to 10-cm stage (10) One-leg continuous jump in S-shape (10) Squat-tuck jump (10)	Bridge exercise with limb movement with BOSU beneath back (10*2) Elbow-support on BOSU with trunk straight (week 5:	Towel squeezing exercise with 2 kg (week 5: 7s*20; week 6: 8s*20)

	Catch sandbag while standing on the BOSU (week 5: 1 kg sandbag; week 6: 3 kg sandbag) (30)	Cone jump with 3 cones (forward and side-to-side) (5*2)	double-leg support, week 6: one-leg support) Swiss-ball (alphabetic sitting with one foot on BOSU (2), full jumping jacks (30), sitting skier (30))
BOSU: Both sides utilized balance trainer			

Table 2. Home program

Week	Flexibility	Muscle strength of ankle	Deep muscle of foot	Core stability	Balance / Agility
1	Gastrocnemius stretch (30s*9) Hamstring stretch (30s*9)	Ankle invertor, evertor, dorsiflexor, plantarflexor with orange thera-band (5s*30)	Towel squeezing (3s*30)	Abdominal hallowing (10s*30)	NA
2	Same as week 1	Same as week 1	Towel squeezing with 0.5 kg weight on towel (3s*30)	Abdominal hallowing (10s*30) Cat-camel exercise (60)	NA
3	Same as week 1	Ankle invertor, evertor, dorsiflexor, plantarflexor with green theraband (5s*30)	Same as week 2	Cat-camel exercise (60)	NA
4	Same as week 1	Same as week 3	Same as week 2	Bird-dog exercise (10s*30)	Deep squatting with *turnout* (15s*15) Single-leg standing with arm motion (15s*15)
5	Same as week 1	Ankle invertor, evertor, dorsiflexor, plantarflexor with blue theraband (5s*30)	Same as week 2	Supine with reciprocal leg motion (60) Side bridge (45s*30)	NA
6	Same as week 11	Same as week 5	Same as week 2	Supine with reciprocal leg motion (60) Side bridge (45s*30)	Lateral jumping (30)

Table 3
Mean ± SD of absolute error of active joint reposition sense in dominant-leg (°)

		Training group	*Control group*
10° dorsiflexion	PRE	**3.13** ± **3.77**	1.94 ± 1.41
	POST	**1.69** ± **1.26**	1.76 ± 2.08
	Effect size	**0.51**	0.10
20° plantarflexion	PRE	**4.57** ± **3.18**	**5.20** ± **3.56**
	POST	**2.72** ± **1.98**	**4.01** ± **3.47**
	Effect size	**0.70**	**0.34**
10° inversion	PRE	1.57 ± 1.16	1.66 ± 1.81
	POST	1.38 ± 1.10	1.35 ± 1.29
	Effect size	0.17	0.20
20° inversion	PRE	1.78 ± 1.34	1.88 ± 1.55
	POST	1.94 ± 1.31	2.09 ± 1.88
	Effect size	0.12	0.12
10° eversion	PRE	**1.43** ± **1.35**	**1.45** ± **1.85**
	POST	**0.91** ± **0.69**	**0.72** ± **0.53**
	Effect size	**0.49**	**0.54**

PRE: pre-training; POST: post-training; difference between test-time (**$p < 0.05$**);

Table 4
COP parameters in the training group during *releve en demi-pointe*

Phase		*Average speed (cm/s)*	*95% ellipse area (cm^2)*	*Normalized maximum displacement*		*SD of displacement*	
				Anterior-posterior	**Medial-lateral**	**Anterior-posterior**	**Medial-lateral**
rising	PRE	**9.650** ± **2.335**	1.700 ± 0.731	0.200 ± 0.088	0.083 ± 0.032	0.083 ± 0.032	0.034 ± 0.010
	POST	**8.474** ± **0.895**	1.626 ± 0.622	0.181 ± 0.067	0.070 ± 0.023	0.077 ± 0.032	0.030 ± 0.009
	Effect size	**0.24**	0.47	0.19	0.47	0.19	0.42
pre-equilibrium	PRE	**9.440** ± **3.041**	1.303 ± 1.071	0.132 ± 0.043	**0.078** ± **0.042**	0.063 ± 0.025	0.030 ± 0.015
	POST	**8.220** ± **1.434**	0.917 ± 0.461	0.119 ± 0.045	**0.063** ± **0.023**	0.054 ± 0.022	0.023 ± 0.008
	Effect size	**0.30**	0.44	0.38	**0.44**	0.38	0.58
equilibrium	PRE	8.550 ± 2.737	0.726 ± 0.468	0.117 ± 0.060	0.061 ± 0.034	0.050 ± 0.018	0.022 ± 0.009
	POST	7.580 ± 1.090	0.719 ± 0.441	0.114 ± 0.055	0.051 ± 0.016	0.051 ± 0.027	0.019 ± 0.006
	Effect size	0.05	0.38	0.04	0.38	0.04	0.39
post-equilibrium	PRE	8.231 ± 2.666	0.638 ± 0.472	0.109 ± 0.033	0.058 ± 0.029	0.048 ± 0.017	0.021 ± 0.008
	POST	7.564 ± 1.193	0.702 ± 0.388	0.107 ± 0.037	0.052 ± 0.020	0.048 ± 0.018	0.020 ± 0.008
	Effect size	0.06	0.24	< 0.01	0.24	< 0.01	0.13
lowering	PRE	10.460 ± 2.616	2.543 ± 1.499	0.229 ± 0.126	0.115 ± 0.048	**0.094** ± **0.049**	0.043 ± 0.015
	POST	10.268 ± 2.803	2.453 ± 1.719	0.213 ± 0.102	0.114 ± 0.062	**0.076** ± **0.029**	0.042 ± 0.019
	Effect size	0.14	0.02	0.45	0.02	**0.45**	0.06

PRE: pre-training; POST: post-training; difference between test-time (**$p < 0.05$**);

Table 5
COP parameters in the training group during *grand-plie*

phase		*Average speed (cm/s)*	*95% ellipse area (cm^2)*	*Normalized maximum displacement*		*SD of displacement*	
				Anterior-posterior	**Medial-lateral**	**Anterior-posterior**	**Medial-lateral**
lowering	PRE	**10.770 ± 2.467**	4.037 ± 2.255	0.329 ± 0.100	**0.126 ± 0.049**	0.144 ± 0.044	**0.050 ± 0.019**
	POST	**9.507 ± 1.608**	3.368 ± 1.454	0.300 ± 0.083	**0.100 ± 0.030**	0.132 ± 0.045	**0.038 ± 0.009**
	Effect size	**0.61**	0.35	0.32	**0.64**	0.27	**0.81**
pre-equilibrium	PRE	**8.474 ± 2.575**	0.847 ± 0.447	0.122 ± 0.047	**0.061 ± 0.022**	0.054 ± 0.023	**0.026 ± 0.009**
	POST	**7.028 ± 0.765**	0.684 ± 0.344	0.113 ± 0.039	**0.052 ± 0.014**	0.045 ± 0.016	**0.021 ± 0.006**
	Effect size	**0.76**	0.41	0.21	**0.49**	0.45	**0.65**
equilibrium	PRE	**8.073 ± 2.621**	0.528 ± 0.315	0.106 ± 0.036	0.051 ± 0.022	0.043 ± 0.015	**0.021 ± 0.009**
	POST	**6.757 ± 0.754**	0.523 ± 0.331	0.099 ± 0.031	0.045 ± 0.014	0.028 ± 0.017	**0.017 ± 0.006**
	Effect size	**0.68**	0.02	0.21	**0.33**	0.94	**0.52**
post-equilibrium	PRE	**7.950 ± 2.658**	0.512 ± 0.316	0.095 ± 0.034	**0.053 ± 0.020**	0.040 ± 0.016	**0.021 ± 0.008**
	POST	**6.726 ± 0.732**	0.501 ± 0.271	0.096 ± 0.033	0.043 ± 0.013	0.043 ± 0.015)	**0.017 ± 0.008**
	Effect size	**0.63**	0.04	0.03	0.59	0.19	**0.50**
rising	PRE	10.079 ± 2.604	2.674 ± 1.596	0.246 ± 0.095	0.099 ± 0.042	0.116 ± 0.049	0.043 ± 0.018
	POST	9.745 ± 3.989	3.900 ± 5.164	0.280 ± 0.108	0.111 ± 0.142	0.133 ± 0.056	0.042 ± 0.031
	Effect size	0.10	0.32	0.33	0.11	0.32	0.04

PRE: pre-training; POST: post-training; difference between test-time (**p < 0.05**);

Figures

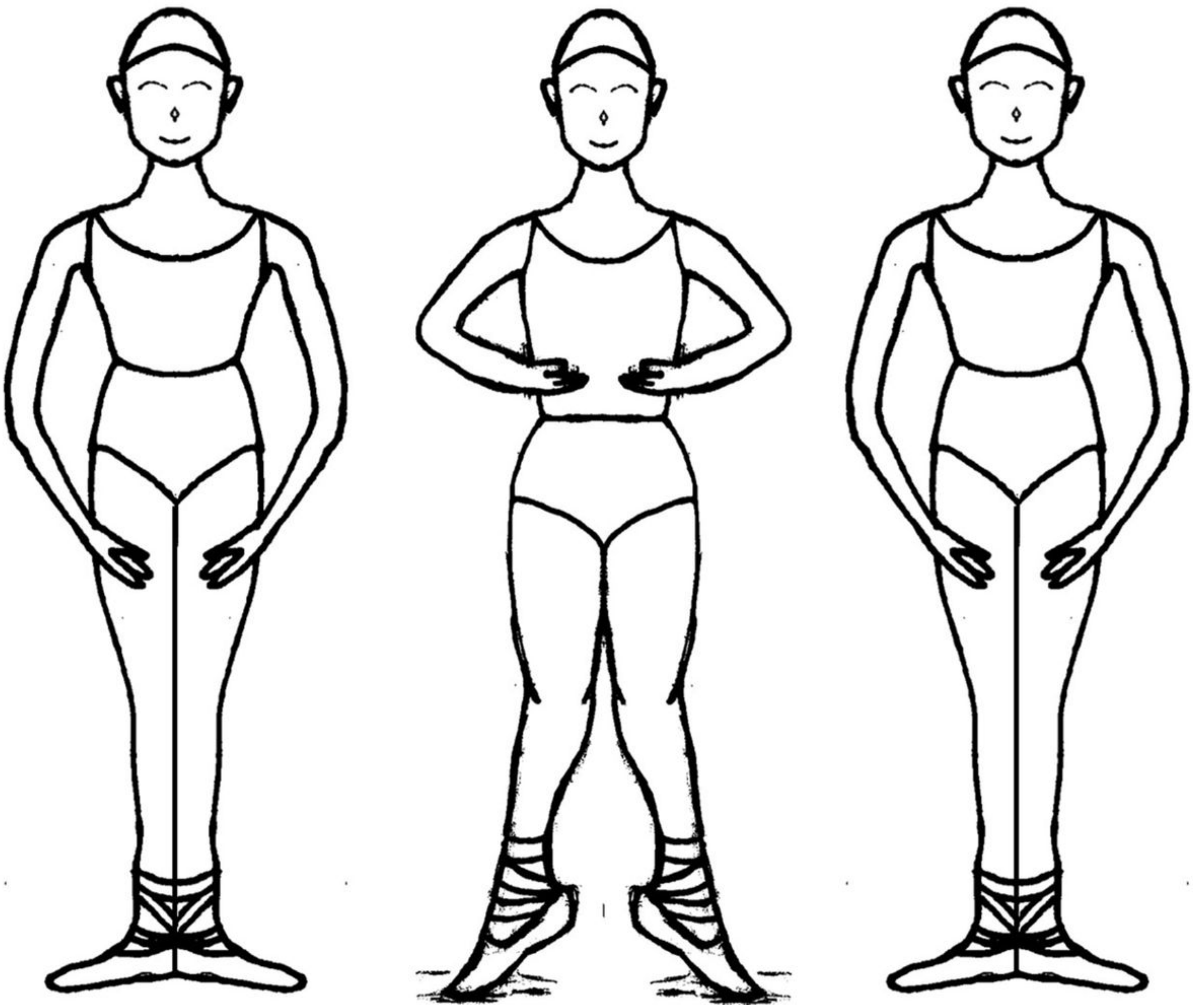

Figure 1

Releve en demi-pointe

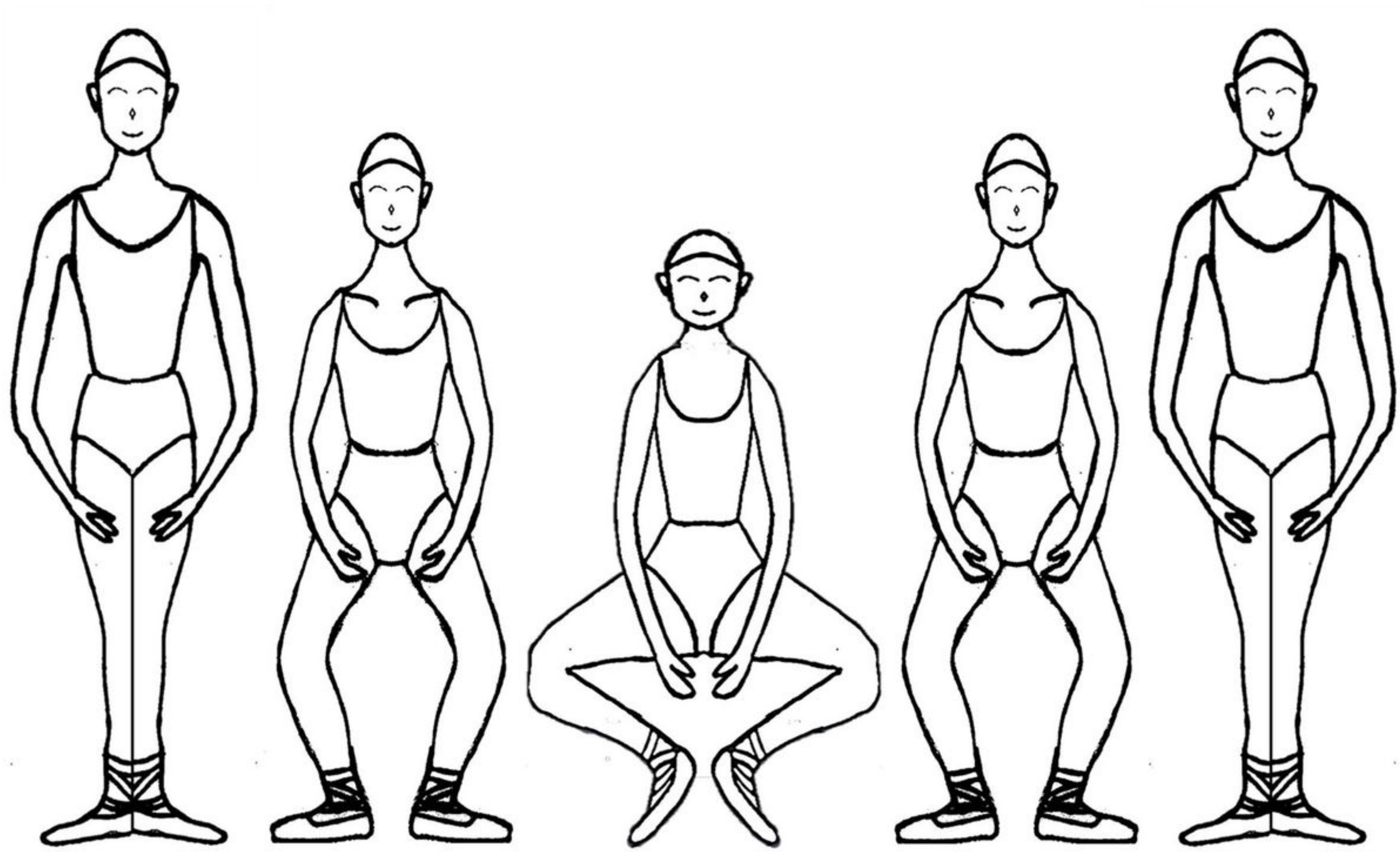

Figure 2

Grand-plie