Comparison of Plantar Sensitivity, Dynamic Balance, and Lower Extremity Joint Range of Motion Between Experienced Female Ballet Dancers and Female Non-Dancing Athletes

A Cross-Sectional Study

Martin Alfuth, PT, PhD, MA, Julia Luetkecosmann, PT, and Axel Knicker, PhD

Abstract

Objectives: Ballet dancers may increasingly use plantar sensory feedback to control foot position and movement during dance activities. Balance and joint range of motion (ROM) are important factors in ballet and may be related to plantar sensation in ballet dancers. Data on related functions of female ballet dancers compared to female non-dancing athletes are sparse. The aims of the study were twofold: 1. the relationships between plantar sensitivity and dynamic balance as well as between joint ROM and dynamic balance were determined in experienced female ballet dancers and female non-dancing athletes; and 2. the differences of plantar sensation, joint ROM of the lower limb, and dynamic balance between experienced female ballet dancers and female non-dancing athletes were investigated.

Study Design: In this cross-sectional study, 21 subjects (11 experienced female ballet dancers and 10 female non-dancing athletes; median age: 23, range: 11 years; median body height: 1.7 m, range: 0.2 m; median body mass: 59 kg, range: 36 kg) were included. Plantar sensitivity was determined by Semmes-Weinstein monofilaments, active ranges of motion of the hip, knee, and ankle joints were measured using a goniometer and dynamic balance was assessed by the Y-Balance test. Correlations between outcome measures were determined in both groups. Outcome measures were compared between ballet dancers and non-dancing athletes using parametric or non-parametric statistical tests ($\alpha = 0.5$).

Results: For the fifth metatarsal head and the heel, higher correlations between plantar sensitivity and Y-Balance test scores in non-dancing athletes compared to ballet dancers were found. Higher correlations between joint ROM and Y-Balance test scores were determined for certain movements in non-dancing athletes compared to ballet dancers. A significantly lower cutaneous threshold was only found for the fifth metatarsal head in ballet dancers compared to non-ballet dancers ($p < 0.05$). Range of motion was significantly higher in ballet dancers for almost all movements ($p < 0.05$). Ballet dancers showed significantly higher normalized scores of the Y-Balance test ($p \le .001$).

Conclusions: Results of correlation analyses may indicate that non-dancing athletes increasingly must rely on plantar sensation of the fifth metatarsal head and the heel while maintaining dynamic balance compared to ballet dancers, especially in posterolateral direction of the Y-Balance test. Active joint range of motion of the lower extremity and dynamic balance differ between female ballet dancers and non-dancing athletes. Plantar sensitivity is not different for most of the assessed localizations.

Ballet dancers need a high level of postural control, because ballet is characterized by movements that demand only a small base of support.[1] Furthermore, dancers need to be aware of ankle position during different ballet poses.[2] Proprioceptive and sensory information from the flexor ankle muscles and the plantar foot are jointly used to control human erect posture.[3] Thereby, the plantar cutaneous mechanoreceptors provide information supporting the regulation of postural control.[4] Moreover, healthy individuals modulate lower leg stiffness in response to sensory information about the surface beneath the foot from the plantar foot, the joints, and lower extremity muscles.[5-7] In addition to changing and holding ballet positions, ballet involves turning, jumping, hopping, and landing,[8-10] where the foot frequently contacts the ground. Consequently, ballet dancers may increasingly use plantar sensory feedback to control foot impact during jumping, hopping, and landing, as well as keep-

Martin Alfuth, PT, PhD, MA, Niederrhein University of Applied Sciences, Faculty of Health Care, Therapeutic Sciences, Krefeld, Germany, and German Sport University Cologne, Department of Further Education, Cologne, Germany. Julia Luetkecosmann, PT, Niederrhein University of Applied Sciences, Faculty of Health Care, Therapeutic Sciences, Krefeld, Germany. Axel Knicker, PhD, German Sport University Cologne, Institute of Movement and Neurosciences, Cologne, Germany.

Correspondence: Martin Alfuth, PT, PhD, MA, Niederrhein University of Applied Sciences, Faculty of Health Care, Therapeutic Sciences, Reinarzstrasse 49, 47805 Krefeld, Germany; martin.alfuth@hs-niederrhein.de.

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ing balance, more frequently than non-dancing individuals. Results regarding the influence of textured or spiky surfaces during standing in different ballet positions on postural balance underpin the use of plantar sensory feedback in ballet dancers.[11,12] Ballet can be performed barefoot or with different types of ballet shoes or slippers,[13,14] which may account for an increased use of plantar sensory feedback during dancing and an adaptation of the somatosensory system, including foot sole mechanoreceptors, compared with other sports where shoes with thicker and harder soles are worn. Different demi-pointé positions barefoot induced increased stability with increased plantar contact areas, reduced center of pressure excursion areas, and decreased center of pressure excursions in anterior-posterior direction compared to wearing slippers.[13] The increased plantar contact areas during barefoot conditions may induce an activation of more mechanoreceptors enabling greater stimulation with an improved plantar feedback than in the shod condition.

It was suggested that ballet training leads to a shift of visual feedback to a reliance on somatosensory feedback arising from the feet and lower limbs for regulating postural control.[15-17] Furthermore, an enhanced brain capacity in the motor area of the foot was found in professional ballet dancers compared to handball players, indicating a sports-specific neuro-cortical adaptation.[18] However, it has not been clarified whether ballet dancers also develop a different sensitivity of the somatosensory system, including plantar cutaneous sensation, compared to non-dancing athletes.

Plié, pointé, demi-pointé, and first arabasque are prevalent ballet positions that require extreme joint range of motion (ROM) and may, therefore, stress tendons and ligaments around the numerous joints of the lower extremity.[10] Ballet dancers show larger ROM in the joints of the leg than non-dancers and even joint hypermobility.[19] An amplified ROM was particularly reported for knee extension as well as hip flexion, external leg rotation, and abduction,[20] which are emphasized movements in ballet.[10] A supernormal ankle plantar flexion along with decreased ankle dorsiflexion was also reported in ballet dancers.[21] Age and dance experience seem to be factors associated with ROM in this population.[20,22]

Study results suggest that lower extremity joint ROM and plantar sensation contribute to balance ability.[23,24] The Star Excursion Balance Test (SEBT) and the Y-Balance test have been used to determine physical performance and to compare balance ability between different sports as well as to detect athletes at increased risk for injury of the lower limb.[25,26] Female ballet dancers showed higher reach distances in medial and posteromedial directions of the SEBT than non-dancing athletes, indicating a better balance ability.[27] A recent study reported that plantar forefoot sensation and weightbearing dorsiflexion ROM may be associated with the composite score of the Y-Balance test in adults.[23] Furthermore, ankle dorsiflexion at 0° and 90° knee flexion was significantly correlated with nearly all directional scores of the Y-Balance test in young recreationally active adults.[24] A significant correlation was also found between hip flexion active ROM and posterolateral, posteromedial, and composite directional scores.

High demands on somatosensation, flexibility, and postural control in ballet lead to the questions of whether differences in plantar foot sensation may exist in ballet dancers compared to non-dancing athletes and whether relationships between plantar foot sensation, dynamic balance, and active ROM of the leg are evident in ballet dancers. This knowledge may be relevant for understanding functional adaptations in response to ballet as well as for the development of screening protocols and interventions for the prevention and rehabilitation of injuries in ballet or other sports.

Therefore, the first aim of this study was to determine the relationships between plantar foot sensitivity and dynamic balance as well as between joint ROM and dynamic balance in experienced female ballet dancers and in female non-dancing athletes. The second aim was to investigate the differences in plantar sensation, joint ROM of the lower limb, and dynamic balance between experienced female ballet dancers and female non-dancing athletes.

It was hypothesized that plantar foot sensitivity is correlated with dynamic balance, joint ROM is related to dynamic balance in experienced female ballet dancers, and plantar sensation, joint ROM, and dynamic balance are different in experienced female ballet dancers compared to female non-dancers.

Material and Methods

Participants

From a convenience sample, 11 experienced female ballet dancers (median age: 22 years, range: 11 years) from two regional dancing schools and 10 recreationally active female non-dancing athletes (median age: 23 years, range: 6 years) from the local university and fitness centers in the region volunteered to participate in this study. Demographic and anthropometric data, including sex, age, height, and body mass were collected using a self-constructed questionnaire. Additionally, the subjects were asked for their history of injury and surgery, disorders or diseases as well as ballet and sport experience (years), ballet and sport activities per week, and ballet and sport duration per lesson or training session (Table 1).

Inclusion and Exclusion Criteria

Inclusion criteria were female sex, an age between 18 and 30 years to exclude adolescence, a regular ballet or sport activity of at least twice a week and, for the ballet dancers, a ballet experience of at least 5 years.[28] Subjects were excluded if they reported a traumatic injury of the lower extremity with or without surgery within the past 12 months or had acute or chronic pain states or complaints and diseases or disorders that could have influenced outcome measurements. Furthermore, the non-dancers were excluded if they reported any ballet

Table 1 Demographic and Anthropometric Data of Subjects with Significance of Differences Between Experienced Female Ballet Dancers and Female Non-Dancing Athletes

Parameter	Female Ballet Dancers (n = 11) Median (Min; 25th; 75th; Max)	Female Non-Dancing Athletes (n = 10) Median (Min; 25th; 75th; Max)	Total (n = 21) Median (Min; 25th; 75th; Max)	P-value
Age(years)	22 (18; 19.5; 22.5; 29)	23 (19; 23; 23.8; 25)	23 (18; 20; 23.5; 29)	0.10
Body height (m)	1.7 (1.6; 1.6; 1.7; 1.7)	1.7 (1.6; 1.7; 1.8; 1.8)†	1.7 (1.6; 1.6; 1.7; 1.8)	< 0.01
Body mass (kg)	53 (42; 51.5; 54.5; 71)	65.5 (55; 62.5; 73.8; 78)‡	59 (42; 53; 68; 78)	< 0.001
Body mass index (BMI) (kg/m²)	19.6 (17.5; 18.7; 21.1; 25.2)	22.5 (19.5; 20.9; 24.4; 26.4)†	20.7 (17.5; 19.4; 23; 26.4)	0.01
Ballet/sports experience (yrs)	13 (5; 9.5; 16; 19)	4.5 (1; 4; 5.8; 8)‡	8 (1; 4.5; 13.5; 19)	< 0.001
Exercise frequency (days/week)	5 (3; 4.5; 5; 5)	2.8 (2; 2; 3.4; 5)†	4 (2; 2.8; 5; 5)	< 0.01
Exercise duration (minutes/week)]	90 (90; 90; 90; 180)	90 (60; 90; 112.5; 120)	90 (60; 90; 105; 180)	0.63

25th = 25th percentile; 75th = 75th percentile; *$p < 0.05$; †$p \leq .01$; ‡$p \leq .001$.

dancing experience in the past. Activities, such as yoga or Pilates were allowed. All of the subjects met the inclusion criteria and provided written informed consent prior to study enrollment. The study was reviewed and approved by the local ethics committee (Nr. 034/2019). The STROBE 2007 statement (Strengthening the Reporting of Observational Studies in Epidemiology) was used for reporting in this study.[29]

Measurement of Plantar Sensitivity

Before starting the assessments, the testing leg and foot was selected at random using concealed envelopes to account for possible effects of side specific differences of plantar sensation between both feet.[30] Leg dominance was not considered because it does not influence single-leg balance testing.[31] To the best of the authors' knowledge, ambiguous or no results of the influence of leg dominance exist for lower limb ROM[32] and plantar foot sensation measurements, respectively. Foot sole temperature was measured at the middle of the foot sole using a non-contact infrared thermometer (DT-8861). Room temperature was controlled using a calibrated commercial thermometer.

Plantar cutaneous sensation to light touch was assessed using a set of 20 calibrated Semmes-Weinstein monofilaments (Baseline® Tactile™ Monofilaments, New York, USA) at four locations of the foot sole (heel, first metatarsal head, fifth metatarsal head, and great toe).[33] The locations at the forefoot may be especially important in ballet dancers because of the high amount of work in demi-pointé during dancing[10] with an emphasis on weightbearing actions.[34] In addition, the metatarsal area includes afferent units of the different cutaneous receptor types with large receptive fields and foot sole receptors show a background activity only when they are loaded.[34]

The foot locations were determined as described by Perry[33] to standardize locations for each subject and marked with a waterproof pen to ensure testing the same point of each location. The locations were assessed in a random order to reduce possible learning effects. The subject lay in prone position on a treatment bench with the feet off the border of the bench. The Semmes-Weinstein monofilament with the index number 4.31 (2.0 gram) was used as the starting filament of the test sequence. The nylon filament was applied perpendicular to the skin three times until bending to a c-shape. The tester announced each application by saying "now" within the following 5 seconds before touching the skin. The filament was held in position until the subject gave clear verbal response ("Yes" or "No").[35] To determine the subject's individual threshold, the 4-2-1 algorithm was used,[36,37] which is considered reliable.[37] If the subject detected the stimulus at least two times correctly, the filament four sizes below (index number 3.61 = 0.4 gram) was chosen. Otherwise, the filament four sizes above (index number 5.07 = 10.0 gram) was used. Then, the filament size was either increased if the stimulus was not detected or decreased if the stimulus was detected by two steps until a turnaround point was obtained. Finally, the filament size was either decreased if the stimulus was felt or increased if the stimulus was not felt by single steps. If a stimulus was not detected correctly at least two out of three times, the next filament above was considered the subject's individual threshold for the respective localization. Randomized null stimuli, by giving verbal announcement without applying a stimulus, were included in the assessment to increase accuracy.

Measurement of Lower Extremity Active Range of Motion

Active ROM was measured for the hip, knee, and ankle joints by neutral zero method[38] using a goniometer (Baseline® Plastic Goniometers, Fabrication Enterprises, White Plaines, New York, USA) with the subject lying in supine or prone position or seated. No warm-up was performed prior to measurements. Hip flexion, extension, abduction, and adduction as well as knee flexion and extension were measured using a universal goniometer with a side-length of about 30 cm,[39,40] ankle dorsiflexion and ankle plantar flexion were assessed using a goniometer with a side-length of about 20 cm.[41] Goniometric measurements using short and long arm goniometers were found to have excellent intra- and intertester reliability (ICC > .98)[39,42] and a minimum important difference of 14° and 10°, respectively.[39] Concurrent validity was reported with ICC and r values between .97 and .99,[42] respectively. For the measurement of hip flexion (supine) and extension (prone), the axis of rotation of the goniometer was positioned at the manually palpated greater trochanter of the femur. The stationary arm of the goniometer was aligned along the trunk with the shoulder serving as the point of orientation. The moving arm of the goniometer was aligned along the femur pointing to the lateral epicondyle. For abduction and adduction measurements, the subject was positioned in supine position and the axis of rotation of the goniometer was placed at the unilateral anterior superior iliac spine.[43] The stationary arm was aligned along the transverse line across the anterior superior iliac spines of the pelvis. The moving arm was positioned along the midline of the thigh pointing to the center of the patella. The subject was asked to move as far as possible without rotating the pelvis, which was controlled by the assessor. Range of motion measurements of knee flexion and extension were completed according to Lenssen et al.[44] and to Jones et al.[45] Thereby, the subject was positioned in supine position[44] and the axis of rotation was at the lateral epicondyle.[45] The stationary arm was aligned along the femur pointing to the greater trochanter, and the moving arm was aligned along the fibula pointing to the lateral malleolus.[44,45] Plantar flexion and dorsiflexion ROM of the ankle was measured according to the description by Greene et al.[46] The subject was positioned in a seated position on the treatment bench with the knee at a right angle. Furthermore, the ankle was placed at a right angle with the heel resting on the bench. The axis of rotation of the goniometer was at the center of the malleolus lateralis. The stationary arm was positioned along the tibia pointing to the head of the fibula and the moving arm was aligned along the fifth os metatarsalis. The mean out of three trials of ROM measurements was used for further data analysis.

Measurement of Dynamic Balance

Dynamic balance was measured using the Y-Balance test.[25] The subject stood with the testing leg barefoot on the stance platform of the test kit with the most distal portion of the great toe at the starting line and with the hands resting on the iliac crests. The subject was instructed to move the target (reach indicator) with the free limb along the pipe as far as possible in anterior, posteromedial, and posterolateral directions. Six trials were performed in each direction. The first three trials served to familiarize the subject with the task. The following three trials were recorded from the tape measure (5 millimeter increments) of the respective pipe at the edge of the reach indicator, at the point where the most distal aspect of the foot approached, and used for further analysis. The subject was asked to maintain balance during the trials and to recapture the starting position after each trial. A trial was discarded and repeated if the subject touched the floor with the free limb, slipped with the supporting foot, fell off the stance platform, lost contact to the reach indictor while moving it until the maximum reach position was achieved, kicked the reach indicator forward, placed the foot on the top of the reach indicator, or failed to recapture the starting position under control.[25] Leg length was determined with the subject supine according to the method described by Plisky et al.[25] to normalize reach distances of anterior, posteromedial, and posterolateral directions to leg length. Therefore, reach distances were divided by leg length and multiplied by 100 in order to express the respective reach distance as a percentage of leg length. Additionally, means of these normalized values were calculated. Furthermore, the composite score was determined by calculating the sum of the three reach distances divided by three times leg length and then multiplied by 100. The reliability of the Y-Balance test was confirmed previously.[25] All measurements were completed in a well-lit quiet room of a physical therapy practice or the dancing schools, respectively, from February to April 2019.

Statistical Analysis

Data were tested for normal distribution using Shapiro-Wilk tests and histograms. Because of the predominantly non-parametric nature of the data of plantar sensitivity and ROM, the Mann-Whitney U Test was applied to test significance of differences of these outcome variables between female ballet dancers and non-dancing athletes. The data of the Y-Balance test were parametric, and therefore the independent samples t-test was used to test significance of differences between groups. Levene's test was used to test equality of variances prior to performing the t-test.

Spearman's rho was used to determine correlations between variables of plantar sensation and dynamic balance within the group of female ballet dancers (n = 11), female non-dancing athletes (n = 10), and for all subjects (n = 21), as well as between ROM and dynamic balance within the group of female ballet dancers (n = 11) and female non-dancing athletes (n = 10). A correlation coefficient (r_S) of zero indicated no correlation between outcome variables, a correlation coefficient of .00 to .25 was considered little, a coefficient of .26 to 0.49 low, a coefficient of .50 to 0.69 moderate, a coefficient of .70 to 0.89 high, and a coefficient of .90 very high.[47] An alpha level of $\alpha = .05$ was used for all tests. For the calculation of correlations, Bonferroni correction was used to account for multiple testing. Therefore, the local significance limit was set to p = .001. IBM SPSS Statistics software version 25 (IBM, Armonk, New York, USA) was used for statistical analysis.

Results

Plantar Sensitivity

Room temperature and foot sole temperatures during measurements did not differ between groups ($U = 42.0$, $Z = -0.933$; $U = 34.5$, $Z = -1.451$, $p > 0.05$). The descriptive results of foot sole sensitivity measurements are pre-

Table 2 Plantar Cutaneous Thresholds to Light Touch of Experienced Female Ballet Dancers Compared to Female Non-Dancing Athletes as well as Room and Foot Sole Temperature During Measurements

Variable	Ballet Dancers (n = 11) Median (Min; 25th; 75th; Max)	Non-Dancing Athletes (n = 10) Median (Min; 25th; 75th; Max)	P-value
PCT great toe	3.61 (2.44; 2.83; 3.84; 4.31)	3.73 (2.83; 3.32; 4.02; 4.17)	0.23
PCT MTH I	3.61 (2.83; 3.42; 4.01; 4.56)	3.61 (2.83; 3.27; 4.15; 4.17)	0.97
PCT MTH V	3.22 (2.83; 3.03; 3.73; 4.31)	4.08 (3.22; 3.61; 4.14; 4.31)	0.04*
PCT heel	3.61 (2.83; 3.03; 3.84; 4.31)	4.08 (3.22; 3.67; 4.08; 4.31)	0.11
Room (°C)	22.3 (19.6; 22.0; 22.3; 23.1)	21.9 (21.1; 21.9; 22.0; 23.2)	0.37
Foot sole (°C)	34.5 (33.5; 34.0; 35.4; 36.0)	34.1 (32.4; 33.9; 34.4; 34.8)	0.16

PCT = Plantar cutaneous threshold; MTH = Metatarsal head; °C = Temperature; Min = minimum; 25th = 25th percentile; 75th = 75th percentile; Max = maximum; SD = Standard deviation; 95% CI = 95% Confidence interval; *p < 0.05.

Table 3 Active Joint Range of Motion (ROM) of Experienced Female Ballet Dancers Compared to Female Non-Dancing Athletes

Range of motion	Ballet Dancers (n = 11) Median (Min; 25th; 75th; Max)	Non-Dancing Athletes (n = 10) Median (Min; 25th; 75th; Max)	P-value
Hip flexion (°)	140 (130; 137.5; 145; 155)	120 (110; 116.3; 123.8; 135)	< 0.001‡
Hip extension (°)	40 (30; 35; 42.5; 55)	20 (10; 15; 25; 30)	< 0.001‡
Hip abduction (°)	45 (35; 37.5; 45; 50)	32.5 (25; 30; 35; 40)	0.001‡
Hip adduction (°)	25 (20; 20; 25; 30)	20 (15; 16.3; 23.8; 30)	0.078
Knee flexion (°)	140 (135; 140; 142.5; 145)	135 (120; 130; 135; 140)	0.002†
Knee extension (°)	10 (10; 10; 15; 15)	5 (0; 5; 8.8; 10)	< 0.001‡
Ankle plantar flexion (°)	75 (65; 70; 75; 80)	40 (30; 36.3; 43.8; 55)	< 0.001‡
Ankle dorsiflexion (°)	15 (15; 15; 25; 25)	12.5 (5; 10; 18.8; 20)	0.046*

Min = minimum; 25th = 25th percentile; 75th = 75th percentile; Max = maximum; SD = Standard deviation; 95% CI = 95% Confidence interval; *p < 0.05; †p ≤ 0.01; ‡p ≤ 0.001.

Table 4 Y-Balance Test Scores of Experienced Female Ballet Dancers Compared to Female Non-Dancing Athletes

Y-Balance Test Score	Ballet Dancers (n = 11) Median (Min; 25th; 75th; Max)	Ballet Dancers (n = 11) Mean (SD; 95% CI)	Non-Dancing Athletes (n = 10) Median (Min; 25th; 75th; Max)	Non-Dancing Athletes (n = 10) Mean (SD; 95% CI)	P-value
Anterior	71.5 (65.9; 69.0; 72.4; 84.0)	71.5 (4.8; 68.7, 74.4)	61.3 (55.7; 58.4; 66.5; 74.2)	62.8 (5.7; 59.2, 66.3)	0.001*
Posteromedial	113.5 (99.3; 105.2; 120.6; 127.1)	112.8 (9.4; 107.2, 118.4)	97.0 (88.7; 90.2; 100.6; 108.1)	96.7 (6.6; 92.6, 100.8)	< 0.001*
Posterolateral	112.8 (103.9; 110.3; 120.4; 132.7)	115.5 (8.6; 110.4, 120.6)	94.1 (76.4; 87.1; 107.3; 110.1)	95.2 (12.1; 87.7, 102.8)	< 0.001*
Composite	104.7 (95.4; 98.1; 108.3; 122.5)	105.0 (8.2; 100.1, 109.9)	87.1 (75.9; 80.0; 94.8; 96.4)	87.0 (8.0; 82.0, 91.9)	< 0.001*

Min = minimum; 25th = 25th percentile; 75th = 75th percentile; Max = maximum; SD = Standard deviation; 95% CI = 95% Confidence interval; *$p \le .001$.

sented in Table 2. A significantly lower cutaneous threshold was found for the fifth metatarsal head in ballet dancers compared to non-ballet dancers (U = 26.5, Z = -2.034, $p < 0.05$).

Active Range of Motion

Descriptive data of the measurements of ROM are displayed in Table 3. Active ROM was significantly higher in ballet dancers compared to non-dancing athletes for almost all movements (hip flexion: U = 3.5, Z = -3.662, $p < 0.001$; hip extension: U = 0.5, Z = -3.867, $p < 0.001$; hip abduction: U = 11.5, Z = -3.135, $p = 0.001$; knee flexion: U = 14.0, Z = -3.012, $p < 0.01$; knee extension: U = 9.0, Z = -3.423, $p < 0.001$; ankle plantar flexion: U = 0.0, Z = -3.907, $p < 0.001$; and ankle dorsiflexion: U = 28.0, Z = -1.997, $p < 0.05$).

Dynamic Balance

Descriptive data of the Y-Balance test are presented in Table 4. Ballet dancers showed significantly higher normalized scores in all directions of the Y-Balance test compared to non-dancing athletes (anterior: t(19) = 3.822, $p = 0.001$; posteromedial: t(19) = 4.488, $p < 0.001$; and posterolateral: t(19) = 4.448, $p < 0.001$). The composite score was significantly higher in ballet dancers compared to non-ballet dancers (t(19) = 5.065, $p < 0.001$).

Correlations Between Measurements of Plantar Sensitivity and Dynamic Balance and Active Range of Motion in Female Ballet Dancers

Little to low and no significant positive as well as negative correlations were observed between the thresholds of all foot sole localizations and the normalized scores of the Y-Balance test in female ballet dancers [range: r_s = .374, $p > 0.05$ (first metatarsal head, composite score) to r_s = -.316, $p > 0.05$ (fifth metatarsal head, anterior)]. Moreover, there were little to low and no significant positive and negative correlations between measurements of ROM and Y-Balance test scores in dancers [range: r_s = .406, $p > 0.05$ (hip abduction, composite score) to r_s = -.397, $p > 0.05$ (knee flexion, anterior)].

Correlations Between Measurements of Plantar Sensitivity and Dynamic Balance and Active Range of Motion in Female Non-Dancing Athletes

Little to moderate and no significant negative correlations [range: r_s = -.044, $p > 0.05$ (first metatarsal head, posteromedial) to r_s = -.644, $p > 0.05$ (fifth metatarsal head, posterolateral)] between the thresholds of all foot sole localizations and nearly all normalized scores of the Y-Balance test were found. However, a high, but not significant negative correlation was detected between the threshold of the heel and the score of the posterolateral direction of the Y-Balance test (r_s = -.765, $p > 0.05$). There were little to moderate and no significant positive and negative correlations between measurements of ROM and Y-Balance test scores in non-dancing athletes [range: r_s = .609, $p > 0.05$ (hip flexion, anterior) to r_s = -.133, $p > 0.05$ (hip adduction, posterolateral)].

Correlations Between Measurements of Plantar Sensitivity and Dynamic Balance in All Subjects

Considering all subjects, there were low to moderate and no significant negative correlations between the fifth metatarsal head and all Y-Balance test scores (anterior: r_s = -.607, $p > 0.05$; posteromedial: r_s = -.448, $p > 0.05$; posterolateral: r_s = -.609, $p > 0.05$; composite score: r_s = -.566, $p = 0.007$) and between the heel and all Y-Balance test scores (anterior: r_s = -.441, $p > 0.05$; posteromedial: r_s = -.314, $p > 0.05$; posterolateral: r_s = -.472, $p > 0.05$; composite score: r_s = -.427, $p > 0.05$). All other correlations were little to low.

Post Hoc Power Analysis

A post hoc power analysis (G*Power 3.1.9.4, Duesseldorf, Germany) based on α = .05, the identified effect size for plantar cutaneous threshold of the fifth metatarsal head (d = 1.1) from a one-tailed Wilcoxon-Mann-Whitney-test (two groups), and a sample size of n = 21 (ballet dancers: n = 11; non-dancing athletes: n = 10) revealed a test power of 0.77. The effect size was calculated using mean and standard deviation of the respective variable of the respective group (ballet dancer: 3.4 ± 0.5; non-dancing athletes: 3.9 ± 0.4).

Discussion

In the present study, relationships between plantar sensitivity and dynamic balance as well as joint ROM and dynamic balance were investigated in ballet dancers and non-dancing athletes. Furthermore, plantar sensitivity, joint ROM, and dynamic balance were compared between experienced female ballet dancers and non-dancing athletes. Plantar sensitivity of fifth metatarsal head, joint ROM of the hip, knee, and ankle, as well as dynamic balance significantly differed between ballet dancers and non-dancing athletes.

Plantar Sensitivity

Foot sole sensitivity was hypothesized to differ between ballet dancers and non-dancing athletes. However, in the present study, a significantly lower perception threshold of cutaneous mechanoreceptors was only identified for the fifth metatarsal head. Previous results showed no differences in plantar sensitivity between female ballet dancers and matched untrained controls.[48] Although Semmes-Weinstein monofilament testing was used, more sites were assessed, and the method of applying the stimulus as well as the evaluation differed from the method and evaluation of the present study. Keeping the various challenging positions in ballet may require precise afferent feedback from plantar cutaneous mechanoreceptors, and the afferents in the glabrous skin of the foot sole are regarded decisive for relaying the foot's contact with the ground.[34] Plantar sensitivity is considered important for the control of balance because of the exclusive capability to code for changes in pressure beneath the foot resulting from changes in the center of pressure movement.[33] Therefore, postural reflexes could be initiated that would enable an increased, stable posture,[33] which is essential in ballet.[1] The lateral aspect of the foot, including the fifth metatarsal head, may play an important role in maintaining posture, as errors in motor control or perturbation of posture can result in loss of posture by provoking the center of mass to be shifted beyond limits of lateral stability.[49] Furthermore, a high sensation of the fifth metatarsal head may be particularly important to avoid ankle injuries, because the first and fifth metatarsal heads were found to be two of three localizations that showed a decreased sensation to light touch in people with chronic ankle instability compared to copers and healthy controls.[50,51]

A better sensation for all foot sole localizations in ballet dancers was expected, however, the heel, first metatarsal head, and great toe did not demonstrate lower cutaneous thresholds compared to non-dancing athletes. Corns, callus, and blisters at the skin of the foot are typical for ballet dancers.[52] Since some female ballet dancers in the present study showed some callus at these locations, it may have influenced the plantar cutaneous thresholds to light touch.

A strongly loaded foot sole region with callus in several dancers in the sample would have had a significantly higher cutaneous threshold (i.e., decreased sensitivity) than the same foot sole region without callus in other dancers of the sample, thus leading to a high variability in the sensitivity threshold for the respective foot sole region. Different variability between foot sole regions would be present when a certain foot sole region exhibits a high variation between subjects' sensitivity thresholds compared to another foot sole region that shows less variation between subjects' sensitivity thresholds. However, the lack of considerably high and different variability (interquartile range)[53] of sensitivity thresholds within and between foot sole regions (Table 2) did not indicate a significant influence of callus in determining plantar cutaneous thresholds.

Low correlations between plantar sensitivity and Y-Balance test scores were found in the group of ballet dancers, indicating that plantar sensitivity was not related to dynamic balance in female ballet dancers in the present study. Dynamic balance tests, such as the SEBT and the Y-Balance test, need strength, flexibility, and proprioception,[25] and mechanoreceptors seem to play a minor role for maintaining postural control in female ballet dancers. However, since the sample size was small, this conclusion cannot be generalized to the whole population of dancers. It may rather serve as a preliminary finding that needs to be further investigated using a larger sample size. The results of the non-dancing athletes and all subjects revealed moderate to high negative correlations between plantar sensitivity of the fifth metatarsal head (r_S = -.644 and r_S = -.609, respectively) as well as the heel (r_S = -.765 and r_S = -.472, respectively) and mainly the scores of the posterolateral direction of the Y-Balance test. That means a lower threshold of the respective foot sole location, representing a better sensitivity, is related to a higher Y-Balance test score, representing a better dynamic balance ability, especially in posterolateral direction. While performing the Y-Balance test in the posterolateral direction, plantar loading beneath the supporting foot may shift laterally and posteriorly compared to posteromedial and anterior directions, respectively. Non-dancing athletes showed significantly lower scores in the Y-Balance test, and the higher correlations between plantar sensation of the fifth metatarsal head as well as the heel and the posterolateral direction compared to ballet dancers may indicate that non-dancing athletes may have to increasingly rely on foot sole mechanoreceptors to control dynamic balance. However, this needs to be further investigated.

Joint Range of Motion

Flexibility contributes to unilateral dynamic balance.[25] In the present study, active joint ROM was significantly larger in female ballet dancers than in non-dancing athletes for almost all movements. As reported by Russell et al.,[54] ballet poses, such as en pointe, require an extreme plantar flexion, which exerts a high stress on the ankle joint and the surrounding structures. Active non-weightbearing ankle dorsiflexion and plantar flexion (15° and 75°, respectively) of female ballet dancers in the present study were comparable to results of Russell et al.[54] who reported values of 17° ± 1.3° and 77° ± 2.5°, respectively. The slightly higher plantar flexion may be explained by the higher mean dance experience of about 4 years with a respective adaptation of the ankle joint and surrounding tissue.

Active hip flexion and knee extension as well as hip abduction ROM was significantly increased in female ballet dancers compared to non-dancing athletes, which is in line with previous reports on passive ROM measurements.[20] Passive hip adduction ROM was lower in ballet dancers compared to non-dancers.[55] This finding cannot be confirmed for active ROM of hip adduction based on the present results. However, the difference between the groups was not statistically significant. Overall, the heterogeneous scientific literature in dance[56] with a lack of standardized tests and measures for assessing dancer abilities,[57] including flexibility,[20] hinders valid comparisons to results from other studies.

In young female ballet dancers aged 9 to 11 years, active ROM was considered higher than passive ROM as a result of higher muscle strength,[58] which can also be assumed for experienced adult dancers. Therefore, muscle strength seems to be an important factor that could elucidate the significantly higher active ROM for almost all movements in the group of ballet dancers compared to non-dancing athletes.[58-60] Ballet dancers are allocated to the high-muscle-low-fat group with higher bone mineral density that is attributed to increased weightbearing physical activity.[61,62] The higher training frequency of ballet dancers in the present study and high demands on postural control during several poses in ballet dancing may support this hypothesis. However, it was reported that muscles of ballet dancers include a high percentage of slow twitch (type I) muscle fibers and show lower muscle strength in the quadriceps and hamstrings compared to weight-predicted normal values measured by isokinetic dynamometry.[20] Little to low or little to moderate and no significant correlations were found between Y-Balance test scores and joint ROM measurements within the groups of female ballet dancers and non-dancing athletes, respectively, indicating that these functions were not related for the subjects of the respective group exclusively.

Plantar flexion ROM of non-dancing athletes in the present study was about 10° less than normative values,[54] which may be explained by factors such as a variety of sport activities or occupations, different body composition, and different functional capabilities. Active movements are performed by voluntary muscle contraction and need the integrity of sensory and motor nerves, sound muscles, a free joint motion, and the willingness of the participant.[63] The mean and standard deviation of non-weightbearing ankle dorsiflexion was 8° ± 4.1° in non-dancing participants aged 18 to 66 years, which was considered normative.[64] The higher range of age may explain the decreased dorsiflexion compared to the results of the present study. Active hip flexion ROM in female non-dancing athletes in the present study (120°) was similar to passive hip flexion ROM in female college freshman athletes (122.0 ± 10.5, n = 262),[65] demonstrating that the results of the present study were comparable to results from the literature. The slight differences between active ROM of hip flexion in the non-dancing athletes of the present study and passive ROM in the college athletes can be attributed to different load applications of active and passive ROM measurements.[66]

Dynamic Balance

As expected, significantly higher mean scores on the Y-Balance test in ballet dancers (anterior: 71.5; posteromedial: 112.8; posterolateral: 115.5; composite score: 105.0) compared to non-dancing athletes (anterior: 62.8; posteromedial: 96.7; posterolateral: 95.2; composite score: 87.0) were found, which underlines the hypothesis that ballet dancers adapt to postural demands of their activity. Kenny et al.[67] reported mean normalized composite scores of 85.3 cm (left side) and 85.4 cm (right side) in pre-professional ballet dancers at a median age of 15 years (range: 11 to 19 years). The younger age of ballet dancers and inclusion of a small number of male participants may have accounted for the lower values compared to the present results.

Non-dancing athletes demonstrated a composite score less than 94% of their limb length, indicating that they may be about 6.5 times more likely to sustain an injury of the lower extremity.[26] Bulow et al.[68] used the Y-Balance test in a cohort of 25 adolescent females between the ages of 12 and 18 years who participated in a variety of sports. Normalized anterior, posteromedial, and posterolateral scores were slightly higher and the composite score considerably higher compared to scores of non-dancing athletes in our study. Similar results were reported in adolescent female athletes (ages 12 to 14 years).[69] Pubertal growth is considered to constrain sensorimotor function,[70] however, the present results do not support this thesis with respect to Y-Balance test performance. It has to be noted that comparisons of Y-Balance test scores between adolescents and adults should be interpreted with caution.[68]

Limitations

The small sample of convenience including only adult female ballet dancers and the cross-sectional design do not allow for a generalizability of the results. This was supported by the failure of 80% of test power in the result of plantar sensitivity measurement of the fifth metatarsal head. Furthermore, anthropometric data and data of dance and sport experience and training frequency differed significantly between groups, which may have limited results. The group of non-dancing athletes included subjects from diverse sporting activities, allowing the comparison of results on a more broad-based population of athletes. Only sensitivity to light touch [i.e. thresholds of slowly adapting receptors (SA-I)[34]] was measured. Whether these receptors contribute to balance and movement regulation is not finally clarified. Vibration stimulation would have been required to evaluate the contribution of fast adapting receptors (FA I and FA II) that contribute to foot and ankle proprioception.[71] The current results do not provide information as to whether the differences in the measured functions between female ballet dancers and non-dancing athletes have an influence on dance or sport performance and injury prevention.

Practical Implications

Overall, the results may be useful for dance teachers, physical therapists, and physicians for developing screening protocols to effectively assess the functional condition of female ballet dancers. Particularly the Y-Balance test seems to be a useful standardized tool for the assessment of dynamic balance ability and for comparison with athletes performing different sports. Elements of ballet could be integrated into training sessions of other sports in order to enhance balance ability and, therefore, to reduce a potentially higher risk for lower extremity injuries. It was hypothesized that a first-time injury to the lateral ankle can result in mechanical impairment to the local cutaneous mechanoreceptors or sensory territories of the respective nerves.[50,51] Conversely, a high sensitivity may be related to a fast afferent transmission of sensory information, resulting in an increased motor response with increased muscle activity during a jump stabilization task in unaffected individuals. Therefore, an implication of interventions increasing afferent feedback to the central nervous system via plantar cutaneous mechanoreceptors would be helpful to accelerate muscular responses and to augment their accuracy.[72] Exercises from ballet may represent such interventions and could be recommended to improve dynamic balance not only for ballet dancers but also for athletes participating in other sports. The assessment of the plantar sensitivity of the fifth metatarsal head could also be included in screening protocols of balance ability.

Conclusions

Results of correlation analyses may indicate that non-dancing athletes increasingly must rely on plantar sensation of the fifth metatarsal head and the heel while maintaining dynamic balance compared to ballet dancers, especially in the posterolateral direction of the Y-Balance test. The findings of the comparison of functions between ballet dancers and non-dancing athletes in this study may indicate that active joint ROM of the lower extremity and dynamic balance differ between female ballet dancers and non-dancing athletes, however, plantar sensitivity does not for most of the assessed localizations. The increased plantar sensitivity of the fifth metatarsal head could be important to improve the balance ability of female ballet dancers compared to non-dancing athletes and requires further investigation. A meaningful relationship between plantar sensitivity and dynamic balance was, however, not revealed in the group of female ballet dancers, which challenges this hypothesis.

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