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Original Article

Foot arch height, toe flexor strength, and dynamic balance ability in collegiate female dancers and non-dancers

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Abstract. [Purpose] To characterize the foot arch height, toe flexor strength, and dynamic balance ability of collegiate female dancers and age-matched non-dancers. [Participants and Methods] This study included 20 healthy college-aged female dancers (21.6 ± 0.8 years) and 20 age-matched females (19.7 ± 1.0 years) with no previous experience in sports as non-dancers. Foot arch height was determined by measuring the height of the navicular tuberosity in the standing position using a ruler. Toe flexor strength was measured while seated on a chair using a toe grip dynamometer. Dynamic balance ability was evaluated based on the reach distance measured using a professional Y-balance test kit. [Results] The collegiate dancers had higher foot arches, greater toe flexor strength, and longer Y-balance test reach distance than the non-dancers. [Conclusion] The foot arch height, toe flexor strength, and dynamic balance ability of collegiate female dancers were adapted through years of training and were superior to those of non-dancers.

Key words: Collegiate female dancer, Foot structure and function, Dynamic balance ability

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INTRODUCTION

Dance is a body movement performed to an accompaniment, and dancers hone their ability to control their bodies through daily training. The physiology and fitness of dancers are just as important as their skill development because of the physical demands placed on the dancer by contemporary choreography and performance schedules[1)]. Dancers train either barefoot or while wearing thin-soled shoes. Their foot structure and function are thought to develop specifically through repetitive plantar flexion–dorsiflexion movements and landing following jumping movements. Modern dancers often experience movement-related ankle joint and foot injuries[2–5)]. Therefore, understanding the foot structure and function of healthy dancers may provide helpful information for screening lower limb injuries.

Previous studies reported that people who habitually live barefoot or with minimal footwear have greater toe flexor strength (TFS) and higher foot arches than those who habitually wear shoes[6–8)]. Therefore, foot structure and function may be closely related. A previous study of dancers hypothesized that the flexor hallucis longus, which straddles the ankle and metatarsophalangeal joints, would be more developed and that TFS would be more significant in dancers because of the frequent elevation of the heels with the fingertips on the floor. However, no difference in TFS was found between dancers and non-dancers[9)]. Another study reported significantly greater toe flexor force in dancers than in non-dancers, suggesting that dancers' feet were structurally altered due to extensive training[10)]. Thus, there is no consensus regarding TFS in dancers. A study found that dancers were better than non-dancers at maintaining balance on a demi-pointe with single-leg support[9)]. However, because balance measurement is a static measurement, it is possible that non-dancers are not proficient in the

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demi-pointe position; therefore, dynamic balance measurement in a state where both are equally proficient is necessary.

The Star Excursion Balance Test (SEBT) and Y-Balance Test (YBT) are dynamic balance tests that are performed in sports to measure the distance when the reaching leg is maximally reached anteriorly, posteriorly medially, and posteriorly laterally in a one-legged stance. Lower limb muscle strength and ankle dorsiflexion flexibility are related to the reach distance in SEBT[11–13]. Therefore, YBT can evaluate dynamic balance ability by integrating lower extremity muscle strength and ankle joint flexibility. These characteristics have not been previously reported in collegiate female dancers.

The present study aimed to compare and characterize the foot arch height (FAH), TFS, and dynamic balance ability of collegiate female dancers versus age-matched female non-dancers. It was previously reported that judo athletes who practiced daily on tatami mats while barefoot had better TFS than the non-judo athletes[14]. Therefore, focused training with loads placed on the foot for extended periods may alter foot structure and function and dynamic postural control ability. We hypothesized that collegiate female dancers acquire superior foot structure and function and dynamic balance ability through daily dance training.

PARTICIPANTS AND METHODS

The present study included 20 healthy college-aged female contemporary dancers of a university dance club (dancers) and 20 age-matched females with no previous sports experience (non-dancers). The purpose of the study, methods, and risks associated with the measurements were explained in detail to the participants, who provided written consent to participate in the study. The study was conducted following the guidelines of the Ethical Review Committee of Nippon Sport Science University (Approval No. 018-H043).

Height was measured using a one-step height meter (seca 217; seca Nihon Co., Ltd., Chiba, Japan), and weight and body fat percentage were measured using a body composition InBody Dial (InBody H20B; InBody Japan, Tokyo, Japan).

FAH was measured in the standing position as follows (Fig. 1A). First, the foot length was measured using a measuring tape from the heel to the tip of the toe. The length from the heel to the first metatarsal bone head was defined as the foot length excluding the toes. Next, the participant's navicular tuberosity was marked with a pen[14]. A ruler was used to measure the height of the navicular tuberosity, and the vertical distance from the floor to the navicular tuberosity was recorded as FAH[14, 15]. The navicular height is used as an index of the medial longitudinal arch[14, 15]. The navicular height was normalized by dividing the value by the foot length, excluding the toes. The average values of three measurements of each foot were calculated, and then the values for each foot were averaged.

TFS was measured while seated on a chair using a toe grip dynamometer (T.K.K. 3364b; Takei Scientific Instruments Co., Ltd., Niigata, Japan)[14–17] (Fig. 1B). All participants performed warm-up exercises, such as preparation and stretching, before the measurements. The participants were instructed to sit on a chair with their feet placed on the toe grip dynamometer,

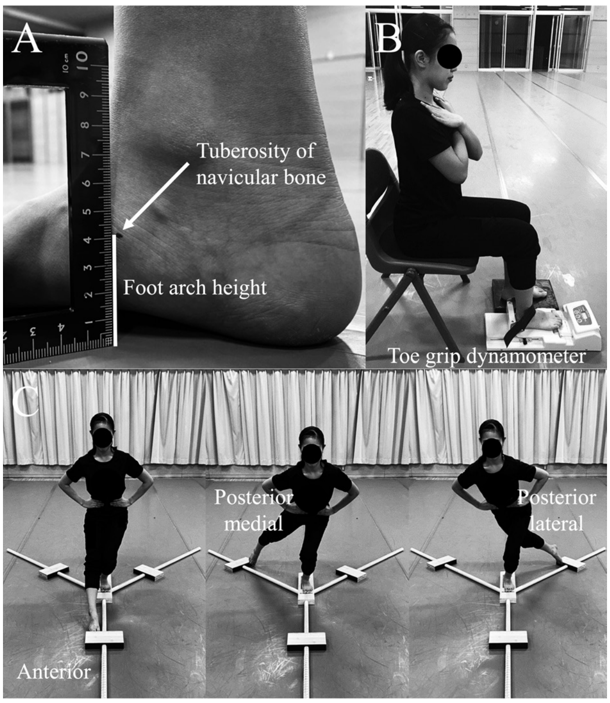

Fig. 1. Experimental setup. (A) Foot arch height. (B) Toe flexor strength. (C) Y-balance test.

their heels in a fixed position with a stopper, and the ankles with a non-stretch strap. They were then instructed to cross their arms in front of their chest to keep them constant. The knee and hip joints were adjusted to 90 degrees. The opposite foot was placed next to the toe grip dynamometer. The participants exerted submaximal force approximately three times before exerting maximum toe flexion force. To measure maximum TFS, the participants exerted maximum force for approximately 3 s. The average value of three measurements was used as the representative value of each participant. The relative TFS to body weight was calculated using the following equation:

$$\text{Relative TFS (\%)} = \text{TFS (kg)} / \text{body weight (kg)} \times 100$$

YBT was conducted using a professional Y-balance test kit (Perform Better Japan, Tokyo, Japan) to evaluate dynamic balance ability (Fig. 1C). The professional Y-balance test kit is a measuring instrument that consists of scales on pipes extending in three directions (anterior, 135° posterior medial, and posterior–lateral), with a wooden board that slides on the pipes to record the reach distance. The participants placed their supporting leg in the center of the test kit, with their hands on the hips, extending the contralateral leg as far as possible and then returning to the starting position. The measurer checked and ensured the following points during the test: (1) the participant maintained one-legged support, (2) the heel of the supporting leg did not come off the ground, (3) the weight did not shift to the reaching leg in all three directions, and (4) the reaching leg was returned to the starting position each time[13]. Measurements were taken three times for each leg, and the average value was calculated for each leg, and then the values for each leg were averaged. Each reach distance was normalized by dividing the value by the length of the lower limb (from the superior anterior iliac spine to the medial malleolus), which was measured using a tape measure.

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 27.0. (IBM Corporation, Armonk, NY, USA). All variables were presented as the mean ± standard deviation. The Shapiro–Wilk test was performed to assess the normality of the measured variables before performing statistical analyses. The independent t-test was used to compare the measured variables between the dancers and non-dancers when the normality of the measured variables was confirmed. The Mann–Whitney test was used to compare the measured variables between the dancers and non-dancers when the normality of the measured variables was not confirmed. The effect size r was calculated using Microsoft Excel. Effect sizes were defined as small (0.1), medium (0.3), and large (0.5)[18].

RESULTS

Table 1 shows the comparison of measurements between the dancers and non-dancers. There were no statistically significant differences in height, weight, or percentage body fat between the two groups. Static foot morphology analysis showed that the arch height and normalized arch height were significantly higher in the dancers than in the non-dancers ($p<0.001$ and $p<0.01$, respectively). The dancers had significantly greater TFS and relative TFS than the non-dancers ($p<0.001$ for both). In the YBT, the absolute and relative values of reach distance were significantly higher in all directions for the dancers than for the non-dancers ($p<0.001$ for both).

DISCUSSION

To the best of our knowledge, few studies have investigated TFS in dancers[9, 10]. One study described the potential to measure TFS in clinical practice as a screening tool to guide rehabilitation after injury and determine an appropriate healing period before resuming training[10]. In addition to measuring TFS, measurements of FAH and dynamic balance ability, which are feasible in dance training settings, provide additional helpful information in clinical practice. Therefore, we think it is meaningful to conduct a popular and feasible measurement in collegiate female dancers in Japan. Hence, the FAH, TFS, and dynamic balance ability were compared and characterized between collegiate female dancers and age-matched non-dancers.

Static foot morphology analyses revealed that the arch height and normalized arch height were significantly higher in dancers than non-dancers. Previous studies reported that people who habitually live barefoot or with minimal footwear have higher foot arches than those who habitually wear shoes[6–8]. Thus, our finding of a high foot arch in dancers is consistent with findings of a high foot arch in people who habitually live barefoot or with minimal footwear. It is possible that training over a long dance career (average of 14.6 years) may have changed the foot structure.

The absolute and relative TFS were significantly greater in the dancers than in the non-dancers. Previous studies that compared TFS in dancers and non-dancers showed conflicting results, with some reporting no difference in TFS between dancers and non-dancers[9] and others reporting greater TFS in dancers[10]. The present study found that TFS was greater in dancers than in non-dancers, which is consistent with the findings of a previous study[10], although different measurement devices were used. In a study investigating TFS in Japanese females in their twenties[16], the absolute and relative values were 10.4 kg and 20.0%, respectively. In the present study, dancers had higher absolute and relative values (27.0 kg, 47.6%), although the non-dancers had similar values (14.5 kg, 27.8%). It was previously reported that people who live barefoot or with minimal footwear have more developed intrinsic foot muscles, such as the abductor hallucis and abductor digiti minimi, than those who habitually wear shoes. Dance training involves various movements, such as repetitive plantar flexion–dorsi-

Table 1. Comparison of measurements between the dancers and the non-dancers

	Dancers (n=20)			Non-dancers (n=20)		Statistical test	Effect size
	Mean	SD		Mean	SD		r
Physical characteristics							
Age (years)	21.6	0.8	***	19.7	1.0	Mann–Whitney	0.70
Dance career (years)	14.6	4.7					
Height (cm)	159.5	5.8		158.1	6.3	t-test	0.12
Body weight (kg)	57.2	6.9		52.6	8.4	t-test	0.29
Body fat (%)	24.7	5.7		27.3	6.5	t-test	0.21
Static foot morphology							
Total foot length (cm)	23.4	0.9		23.0	0.8	t-test	0.24
Truncated foot length (cm)	18.6	1.4		18.0	1.2	t-test	0.23
Foot arch height (cm)	4.4	0.5	***	3.9	0.4	t-test	0.52
Normalized foot arch height (%TFL)	23.6	2.0	**	21.6	2.2	t-test	0.44
Toe flexor strength							
Toe flexor strength (kg)	27.0	4.9	***	14.5	3.9	t-test	0.82
Relative toe flexor strength (%BW)	47.6	8.9	***	27.8	7.7	t-test	0.77
Y-balance test reach distance							
Leg length (cm)	86.3	3.6	**	83.1	3.0	t-test	0.44
Anterior (cm)	60.1	3.9	***	48.0	8.0	t-test	0.76
Posteromedial (cm)	101.4	9.6	***	80.6	9.8	t-test	0.74
Posterolateral (cm)	102.5	9.4	***	80.8	10.2	t-test	0.75
Composite (cm)	264.0	19.9	***	209.4	26.2	Mann–Whitney	0.74
Normalized anterior (%LL)	69.7	4.9	***	57.7	9.7	Mann–Whitney	0.63
Normalized posteromedial (%LL)	117.4	10.3	***	97.0	11.9	Mann–Whitney	0.71
Normalized posterolateral (%LL)	118.8	10.5	***	97.3	12.0	Mann–Whitney	0.73
Normalized composite (%LL)	102.0	7.3	***	84.0	10.4	Mann–Whitney	0.72

***$p<0.001$, ** $p<0.01$.
TFL: Truncated foot length; BW: Body weight; LL: Leg length.

flexion movements and landing following jumping movements. It is inferred that the dancers had excellent TFS due to the development of the intrinsic foot muscles because they use many movements in the metatarsophalangeal joint.

In the YBT, the absolute and relative values of reach distance were higher in the dancers than in the non-dancers in all directions. In a previous study of 40 female college athletes participating in lacrosse and soccer who were the same age as the participants in the present study[13], the normalized composite of the SEBT was 87.97%, with high values (102.0%) in dancers and low values (84.0%) in non-dancers. In a study that analyzed the kinematics of the SEBT, greater anterior reach distance was associated with greater hip and knee flexion of the stance leg, and greater posterior medial and lateral reach distance was associated with greater hip flexion of the stance leg[19]. Therefore, it was inferred that the female dancers had better hip and knee joint flexion strength and flexibility. In addition, a previous study reported that the risk of lower limb disability was 6.5 times higher when the composite reach distance of the SEBT was <94.0% of the limb length[20]; therefore, regular use of SEBT or YBT may be beneficial for injury prevention[21].

This study had several limitations. First, the dancers were recruited from one university; therefore, the results may reflect the training regimen of this university. However, because the dancers had dance careers of 14.6 ± 4.7 years, their training before entering college developed their foot structure and function and their dynamic balance ability. Second, because the study only included female dancers, future studies should similarly investigate male dancers. Finally, further studies are required to measure the cross-sectional area of the intrinsic and extrinsic muscles of the foot and lower extremities that affect the TFS of dancers using magnetic resonance imaging and ultrasound to investigate the effects of long-term dance training on muscle development.

In conclusion, the results suggest that the FAH, TFS, and dynamic balance ability of collegiate female dancers were adapted through years of training and were superior to those of non-dancers.

Conflicts of interest

None.

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