Article

Effect of Toe Type on Static Balance in Ballet Dancers

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OBJECTIVES: Some forefoot shapes are ideal for pointe work in ballet. Egyptian-type, with the hallux being longest and the remaining toes decreasing in size, and Greek-type, with the second toe longer than the hallux, are considered less optimal for pointe work. Square-type, with the second toe the same length as the hallux, is considered optimal. This study compared postural stability in the bipedal stance, *demi pointe*, and *en pointe* between ballet dancers with the two toe types using a stabilometer. **METHODS:** This study included 25 Japanese ballet academy dancers who had received ballet lessons for at least 6 years. Toes were categorized into Egyptian-type (n=14) and square-type (n=11). Bipedal stance, *demi pointe*, and *en pointe* were tested. Center of pressure (COP) parameters were calculated from ground-reaction forces using two force plates: total trajectory length (LNG), velocities of anterior-posterior (V_{AP}) and medial-lateral directions (V_{ML}), and maximum range displacement in the anterior-posterior (MAX_{AP}) and medial-lateral directions (MAX_{ML}). Mann-Whitney U-tests were used to examine differences in COP parameters. **RESULTS:** There were no differences in parameters during bipedal stance or *demi pointe*. However, dancers with Egyptian-type toes had significantly greater LNG (p<0.01), V_{ML} (p=0.01), MAX_{ML} (p<0.01), and MAX_{AP} (p=0.03) during *en pointe*. **CONCLUSIONS:** Ballet dancers with Egyptian-type toes demonstrated greater displacement in the medial-lateral and anterior-posterior directions during *en pointe*. Ballet dancers should be aware of toe types and sway character to optimize ballet training and balance. *Med Probl Perform Art* 2020;35(1):35–41.

DANCERS are required to achieve a high level of balance control.[1] Some reports suggest that ballet dancers have better postural stability than other athletes and healthy controls.[2]

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Most ballet movements require two specific *relevé* positions of the feet, i.e., *demi-pointe* and *en-pointe*. In both positions, dancers are required to stand on their forefeet. The metatarsophalangeal (MTP) joints of the first to fifth toes are extended for *demi-pointe* (Fig. 1a) and minimally flexed for *en-pointe* (Fig. 1b). In *demi-pointe*, positioning of the feet on the metatarsals and phalanxes raises the center of gravity and displaces the weight of the body forward on the transversal arch,[3,4] so that the body weight rests on the metatarsals and toes.[5]

During *en-pointe*, dancers wear pointe shoes. The outside of pointe shoes surrounding the forefoot is called the toe box, which is made from tightly packed layers of paper and fabric glued together. The sole is constructed from leather, and the shank is comprised of leather, plastic, cardstock, or layers of glue-hardened burlap. The fabric ribbons and elastic bands secure the pointe shoes to the foot.[6] Inside a pointe shoe, the toes are squeezed together, and the forefoot is supported by the interior sides of the toe box. Not all ground reaction forces transmit through the tips of the toes, but there is support from the forefoot system as a whole. The phalanxes are placed almost vertically in continuation with the metatarsals, which reduces the area of floor support to the first three toes.[7]

In past literature examining pointe work from the point of view of toe length, the ideal foot for dancing *en pointe* has been described as a square foot in which the hallux and second toe are of the same length, because it more evenly distributes peak pressure between the tips of the toes and the interior part of the toe platform.[8–11] In contrast, the Egyptian-type foot, where each of the lateral four toes is shorter than its medially adjacent neighbor, is considered less optimal for *en-pointe* because all floor contact occurs through the tip of the hallux and the load concentration becomes too large and thus painful.[8] The Greek-type foot, in which the second toe is longer than the hallux, is also considered less optimal because it is not biomechanically ideal for the pointe position.[9.10]

Postural stability is a whole body phenomenon. It is the ability to maintain the center of gravity when the center of mass is horizontally within the base of support.[12] In static balance, the base of support remains fixed while the center of gravity moves. In this case, the sense of balance maintains the center of gravity within the base of support

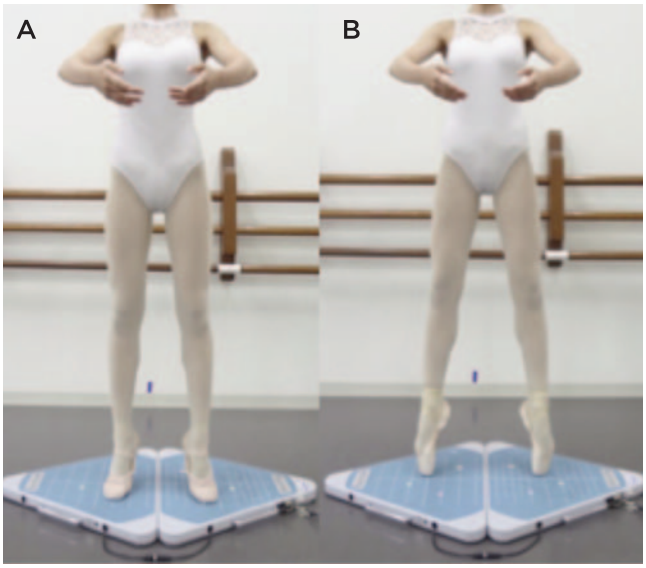

FIGURE 1. A, In *demi pointe,* the metatarsophalangeal (MTP) joints of the first to fifth toes are extended. **B**, In *en pointe,* the MTP joints of the first to fifth toes are flexed minimally.

defined by the feet, whereas in dynamic balance, both center of gravity and base of support are in constant in motion, and the center of gravity are never aligns itself to the base of support during the stance phase of the movement.[13] These proprioceptive tasks of static (e.g., single or bipedal *relevé*) and dynamic balance and turning (e.g., pirouette) are required in functional dance activities and improve the dancer's proprioception and performance.[14,15] Professional ballet dancers especially have more accurate proprioceptive feedback about lower limb position in space as well as center of gravity in relation to base of support.[16]

Multisensory information and motor mechanisms are involved in maintaining balance. It can be studied by recording the movement of the center of pressure (COP).[2] Consequently, the byproduct of these subsystems working together is expressed by the moving COP. The foot plays a role not only in supporting the body and contacting the ground surface, but it also has a large number of sensitive receptors on the sole that are directly involved in the management of posture and movement.[14] Several studies have focused on the plantar receptors of the somatosensory system and balance and postural control.[12,17–20]

To the best of our knowledge, the relationship between postural stability of ballet dancers and their toe types has not been quantitatively investigated. Therefore, this study aimed to investigate the postural stability of ballet dancers according to the dancers' toe length using a stabilometer. Our hypothesis was that the Egyptian-type foot, in which each of the lateral four toes is shorter than its medially adjacent neighbor, would demonstrate larger moving area of the COP on static balance compared to the square-type foot, where the hallux and second toe are of the same length, due to concentration of notably high pressure on the tips and the hallux.

METHODS

Participants

A total of 63 Japanese ballet academy students admitted between April 2012 and April 2015 to the ballet academy at Kyoto were enrolled in this cross-sectional study. All ballet dancers answered a questionnaire about their previous injuries and ballet training experience. Seventeen dancers who reported pain at the time of responding to the questionnaire or who had experienced injuries of the lower extremities in the past were excluded (Fig. 2).

All participants' footprints were obtained from plantar images in the bipedal stance (BS) with the Foot Look (FOOTLOOK Inc., Fukuoka, Japan), which is a device for plantar image measurement that has a scanner capable of high-speed scanning of the plantar surface of the foot.[21] Footprints were measured and evaluated, and 9 dancers with hallux valgus angle >15°,[21] 5 flat-foot dancers with a Staheli Arch Index (SAI) >1.0, 5 cavus-foot dancers with a SAI of 0,[22] and 2 dancers with Greek-type foot were excluded. Finally, 25 participants who had ballet training for at least 6 years were included in this study (Fig. 2). Based on Beighton score criteria of 4/9 or higher, no dancers were considered to be hypermobile.[23,24] All participants provided informed consent, and this study was approved by our Ethics Committee of Osaka Medical College (approval no. 1816).

Measurements

Measurements of differences between the end of the hallux and second toe were taken from the footprints positioned so that the second toe and calcaneum were in a straight

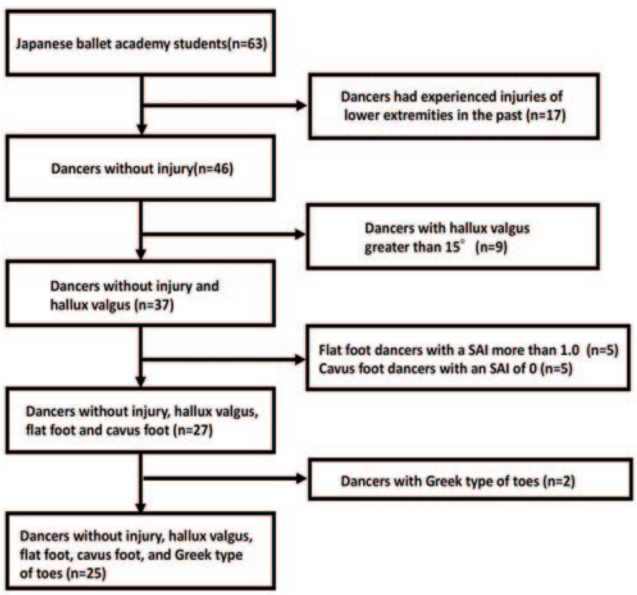

FIGURE 2. Study enrollment subject accountability tree.

line (Fig. 3). Line a connected the two points (the posterior edge of the calcaneus and anterior edge of the second toe). The distance between the two intersecting lines (b, c) drawn perpendicularly from each ends of the hallux (line b) and the second toe (line c) to the first line (line a) was measured[25] (Fig. 3).

In this study, the types of toes were classified into three groups based on whether they had a shape ideal for pointe work according to previous research.[8–11] We defined Egyptian-type foot when the hallux is longest and the distance between the two lines of the hallux (line b) and second toe (line c) is >2 mm; Greek-type when the second toe is >2 mm longer than the hallux; and square-type when the distance between the two lines of the hallux (line b) and second toe (line c) is 2 mm or less. Two dancers in this population had Greek-type feet and were excluded them from the present study. Therefore, the hallux protrusion Egyptian-type (n=14) and square-type (n=11) were studied.

This method showed excellent intra-rater reliability in a study by Davidson et al.[26] as well as one by Martínez-Cepa et al.[25] The foot-type classification was performed by two orthopedic surgeons (KT and ST). Both assessors were blind to foot-type classification and stability scores. Intra- and inter-observer reliabilities for the classifications were evaluated using Cohen's kappa statistics. According to Landis and Koch's method,[27] strength of agreement was defined based on the kappa value: 0.00–0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; and 0.81–1.00, almost perfect.

FIGURE 3. Three types of toes: A, Egyptian-type toes: the hallux is longest and the distance between the two lines of the hallux (line b) and the second toe (line c) is >2 mm. B, Square-type: the distance between the two lines of the hallux (line b) and the second toe (line c) is 2 mm or less. C, Greek-type toes: the second toe is >2 mm longer than the hallux.

Experimental Tasks

Center of pressure (COP) parameters were calculated based on ground-reaction force data collected using a stabilometer consisted of two force plates (GP-6000; Anima Co., Tokyo, Japan) which quantified postural stability at 50 Hz over 10 seconds. Two force plates were designed to assess the movement of the COP as the center of gravity in a horizontal plane, using three vertical load sensors placed at the corners of an isosceles triangle.[28] The coordinates of the points of action obtained from each plate were converted to two force plate coordinates. Composited total load coordinates of the points of action on both plates were defined as the line segment of each of the coordinates divided internally by the specific ratio of each force plate.

Participants wore soft slippers made of canvas for performing bipedal-stance and *demi-pointe* and pointe shoes with silicone gel toe caps (SLPAD, MILBA, Japan) for *en-pointe* measurements. Dancers wore their own pointe shoes, to which they accustomed themselves to for at least 1 month in the same class daily. These shoes had ribbons that had been sewn on in the same manner as typically worn for pointe work. They were asked to stand on a force plate and follow instructions according to marks with tapes on the platforms which were measured at their legs parallel and 30° angle of external rotation while performing the three experimental tasks. Each trial comprised 10 seconds for each task, done with the eyes open.[29]

- First, postural stability in the bipedal-stance was measured. During the bipedal-stance task, the dancers stood with their legs parallel and 15 cm apart and their arms at their sides.
- During the *demi-pointe* task, the dancers stood in a ballet first position. To prevent the range of motion of the hips and knees from affecting postural stability, the lower extremities were limited to 30° angle of external rotation, ankles were in maximum plantar flexion, and MTP joints were extended (Fig. 1a).
- Lastly, for the *en-pointe* task, participants started from standing at a 30° angle and rose to en pointe, ankles were in maximum plantar flexion, and MTP joints were minimally flexed (Fig. 1b). For the two ballet postures of *demi-pointe* and *en-pointe*, the arms were in first position *en avant*.

The following parameters were recorded: total length of trajectory (LNG in cm); velocities of the COP displacement in the anterior-posterior (V_{AP}, in cm/sec) and medial-lateral directions (V_{ML}, in cm/sec); total distance travelled by the maximum range of COP displacement in the anterior–posterior (MAX_{AP}, in cm) and medial-lateral directions (MAX_{ML}, in cm). V_{AP} and V_{ML} were used to describe subjects' postural behavior and represented the amount of activity required to maintain stability.[30] These parameters were analyzed according to ballet postures and type of toes.

Data Analysis

For statistical analyses, JMP® software (ver. 11, SAS Institute Inc., Cary, NC, USA) was used. The variables were

TABLE 1. Baseline Demographic Results in Dancers with Egyptian-type and Square-type Toes

	Egyptian-type (n=14, 56%)	Square-type (n=11, 44%)	p-Value
Age (yrs)	17.36±1.39	17.45±1.92	0.75
Body height (cm)	158.21±5.95	160.26±5.46	0.24
Body mass (kg)	51.85±6.58	50.25±9.26	0.46
Body mass index (kg/m^2)	20.73±2.59	19.50±3.00	0.38
Hallux valgus angle, R side (°)	8.97±3.26	10.65±2.30	0.20
Hallux valgus angle, L side (°)	10.76±2.54	11.30±3.41	0.48
Longitudinal arch (Staheli index), R side	0.54±0.17	0.59±0.13	0.48
Longitudinal arch (Staheli index), L side	0.54±0.13	0.58±0.20	0.35
Foot width, right side (cm)	8.72±0.53	8.77±0.29	0.81
Foot width, left side (cm)	8.54±0.55	8.64±0.35	0.51
Foot length, right side (cm)	23.68±1.36	23.40±0.09	0.60
Foot length, left side (cm)	23.72±1.32	23.52±0.79	0.98
Age at first ballet lesson (yrs)	5.07±1.44	5.64±2.11	0.63
Ballet experience (yrs)	12.29±2.37	11.82±2.96	0.83
Age when pointe shoes were first used (yrs)	9.79±1.53	9.36±1.63	0.65
Beighton score	3.14±0.53	3.36±0.81	0.41

first tested for normality with Shapiro-Wilk tests. All dependent variables were tested for distribution normality and equality of variances and were analyzed using non-parametric tests because they showed non-normal distributions. The Mann-Whitney U-test was used to evaluate the two toe-types (Egyptian-type, square-type) in the bipedal-stance, *demi-pointe*, and *en-pointe* tasks for the COP parameters: LNG, MAX_{ML}, MAX_{AP}, V_{ML}, and V_{AP}. Continuous data were expressed as means and ranges. For all tests, $p<0.05$ was considered significant.

RESULTS

All participants were female, between 16 and 22 years of age (mean age, 17.4 ± 1.6 yrs; height, 159.1 ± 5.7 cm; mass, 51.1 ± 7.7 kg) (Table 1). The numbers of participants with Egyptian-type and square-type toes were 14 (56.0%) and 11 (44.0%), respectively. There were no significant differences in age, body height, body mass, body mass index, foot compositions, and dance experience of ballet in the two groups.

For reliability testing of the toe categories, intra-observer agreement was 0.90 ($p<0.01$; 95% confidence interval [CI], 0.72–1.00), and the inter-observer agreement was 0.92 ($p<0.01$; 95% CI, 0.77–1.00). Both agreements were classified as almost perfect.

For comparative analysis of postural stability between two toe types, there were no differences in LNG, V_{ML}, V_{AP}, MAX_{ML}, and MAX_{AP} in the two toes-types during bipedal-stance and *demi-pointe*. However, during *en-pointe*, the LNG, V_{ML}, MAX_{ML}, and MAX_{AP} of Egyptian-type toes were significantly greater than those of square-type toes (Table 2, Fig. 4).

TABLE 2. Comparative Analysis of Postural Stability with Toe Types

Posture	Egyptian-type (n=14, 56%)	Square-type (n=11, 44%)	p-Value
Bipedal stance			
LNG (cm)	1.05±0.38	0.96±0.38	0.36
V_{ML} (cm/sec)	0.06±0.03	0.05±0.03	0.30
V_{AP} (cm/sec)	0.07±0.02	0.07±0.02	0.55
Max_{ML} (cm)	0.14±0.08	0.10±0.06	0.17
Max_{AP} (cm)	0.14±0.06	0.12±0.05	0.41
Demi pointe			
LNG (cm)	2.13±0.79	2.03±0.38	0.87
V_{ML} (cm/sec)	0.11±0.05	0.10±0.02	0.96
V_{AP} (cm/sec)	0.16±0.06	0.15±0.03	0.93
Max_{ML} (cm)	0.14±0.05	0.12±0.03	0.62
Max_{AP} (cm)	0.16±0.05	0.16±0.04	0.96
En pointe			
LNG (cm)	3.46±0.80	2.68±0.51	<0.01*
V_{ML} (cm/sec)	0.25±0.10	0.18±0.04	0.01*
V_{AP} (cm/sec)	0.18±0.06	0.15±0.05	0.70
Max_{ML} (cm)	0.32±0.17	0.18±0.06	<0.01*
Max_{AP} (cm)	0.16±0.03	0.13±0.03	0.03*

*Significant difference ($p<0.05$) between two types of toes.

DISCUSSION

To the best of our knowledge, the effect of toe type on balance control in ballet dancers has not been studied previously. This is the first study to evaluate quantitatively the effect of toe type on postural stability. In the present study, there were no significant differences in postural stability between the two toe types during bipedal-stance and *demi-pointe*. However, during *en-pointe*, the dancers with Egyptian-type toes had greater COP displacement in the maximal medial-lateral and anterior-posterior directions compared to the dancers with square-type toes. Thus, toe type affected postural stability in medial-lateral and anterior-posterior displacement during *en-pointe*.

Several researchers have stated that the ideal foot for dancing *en-pointe* is one wherein the hallux and second toe are the same length, square-type,[8–11] because this allows weight to be evenly disturbed across the two medial toes. Furthermore, another researcher has stated that the Egyptian-type, where each of the lateral four toes is shorter than its medially adjacent neighbor, is unsuitable for pointe work, because it results in intense pressure on the hallux,

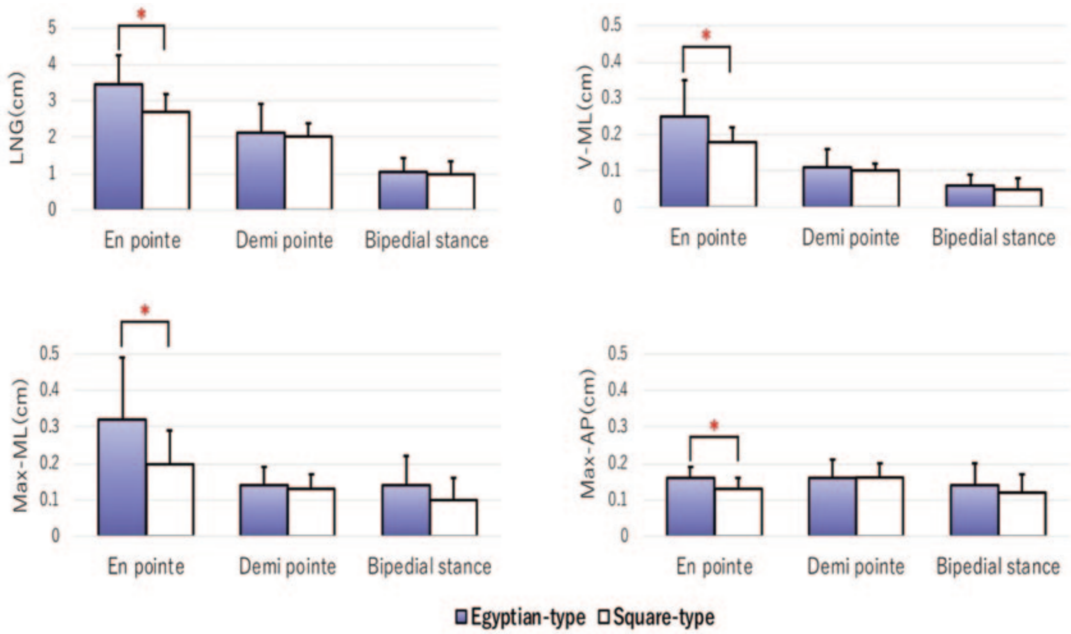

FIGURE 4. Comparison of COP between two types of toes during *en pointe* and *demi pointe*, bipedal stance. Asterisks indicate significant differences between two types of toes. (p<0.05).

causing pain to the dancer during *en-pointe*.[8] In the present study, the dancers with Egyptian-type toes showed greater maximal displacement in medial-lateral and anterior-posterior during *en-pointe* than those with square-type toes. In the dancers with square-type toes, the more similar toe length allows more simultaneous loading of the toe-tips and creates a large surface area to support the body and load. This transmits balance ground reaction forces evenly through the two tips of the toes, resulting in smaller COP displacement than that of Egyptian-type toes. This result might be because dancers with a prominent hallux as in Egyptian-type toes cannot shorten their hallux appropriately inside the toe shoes, creating less floor contact and affecting the postural stability during pointe work. Therefore, dancers with square-type toes were more stable in pointe work than dancers with Egyptian-type toes.

The afferent information transmitted to the central nervous system from the plantar receptors of the somatosensory system influences balance and postural control. Several external factors, such as footwear, type of contact surface, and proprioceptive insole, have been reported as plantar sensitive and change the abilities to rebalance and manage movement.[17–20] However, previous researchers did not investigate quantitatively the relationship between postural stability and toe types. In our study, COP parameters in dancers with two types of toes (Egyptian-type, square-type) were compared in three tasks involving two ballet postures, and dancers with Egyptian-type toes had significantly greater maximal medial-lateral and anterior-posterior displacement than those with square-type toes during *en-pointe*. Some researchers have suggested that increased contact area leads to tactile stimulation and proprioception feedback under the foot and improvement of static balance.[31] We believe that two toe lengths in Egyptian-type toes might induce different strengths of stimulation on plantar receptors and result in greater COP displacement.

With respect to the postural stability of ballet dancers, several reports claim that dancers with a history of ankle sprain demonstrated higher maximum medial-lateral displacement than healthy controls.[12] In addition, the duration of ballet training has been found to have an association with postural stability in the eyes-closed condition.[32] Therefore, we excluded dancers with injured ankles in the present study, and all measurements were conducted with the eyes open. Furthermore, the longitudinal arch reportedly has an effect on postural stability, so we excluded dancers with obvious low and high longitudinal arches.[33,34]

Ballet dancers with Egyptian-type toes were found to showed greater displacement during *en-pointe*, which is an essential position for dancers. Previous literature recommended that ballet dancers utilize toe padding in pointe shoes to avoid pain and deformities.[8,11,20] Our results suggest that they should also consider customized toe padding to correct toe-length imbalances or deviations and perform rehabilitation such as trunk or foot intrinsic muscle training to improve their balance control. Future studies are needed to examine the contribution of toe padding for the different toe types and evaluate its utility in improving balance control during ballet postures and movements.

Our study has some limitations. The main limitation is the small sample size and lack of control group. However, we excluded potential confounding factors and were able to demonstrate statistically significant differences between two types of toes. The second limitation was about pointe shoes conditions: the size of the base of support or the toe box was not measured and we did not control for pointe shoe design and make. Pointe shoe design and toe box size may have affected balance control. However, there were no significant differences in foot width and length in both groups. The last limitation is that dancers with Greek-type feet were excluded in this study because of their small sample size. Some researchers have stated they are not uncommon in dancers even though this foot is not biomechanically ideal for the pointe position[9]; however, we did not include them.

Conclusion

Ballet dancers with Egyptian-type toes demonstrated greater displacement in the medial-lateral and anterior-posterior directions during *en-pointe* compared to ballet dancers with square-type toes. For ballet dancers, it is important to be aware of their types of toe and their character of sway to optimize ballet training and balance.

Authors' Contributions. Momoko kizawa designed the review, developed the search strategy, performed the initial searches, and wrote the first draft of the manuscript. Toshito Yasuda is lead doctoral supervisor and supported the development of the protocol. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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