MOTION OF CENTRE OF PRESSURE DURING STANDING ON TIP TOE ON ONE LEG: ASSOCIATION WITH FOREFOOT SHAPE OF CLASSIC BALLET DANCERS

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This study clarified how the centre of pressure (COP) is kept in the forefoot area during standing on tip toe on one leg by classical ballet dancers. During standing on tip toe on one leg with ballet shoes, the weight is distributed around the first and second toes and at the distal point of the second metatarsal bone ideally. Thus, the supporting surface during standing on tip toe on one leg would be affected by alignment of the metatarsal bones. Motions of the COP during standing on tip toe on one leg were investigated for ten female recreational dancers and six female professional dancers in classical ballet. The results suggested that balance holding time tended to be longer as the distal points of the metatarsal bones aligned more like a straight line in recreational dancers.

KEYWORDS: ballet, standing, tip toe, balance, centre of pressure.

INTRODUCTION: Keeping balance is an essential technique in classical ballet dancing especially when standing on tip toe on one leg. Classical ballet dancers stand on tip toe in ballet shoes, with weight is distributed around the first and second toes and at the distal point of the second metatarsal bone ideally (Warren, 1989). When rising on tip toe, dancers stand on the ball of the foot (Clippinger, 2007). The alignment of the metatarsal bones possibly varies by individual (Figure 1). If lengths of the first and second metatarsal bones are different, the distal points of the first, second, and fifth metatarsal bones would not align (Figure 1). This would make keeping balance difficult (Clippinger, 2007).

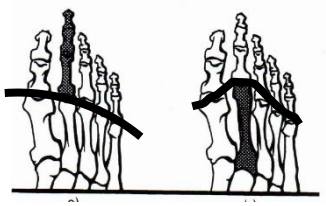

Figure 1: Examples of alignments of the distal points of metatarsal bones. The illustration was adapted from Huwyler, J.S. (2002) with addition of the lines of distal points of metatarsal bones.

Training of classic ballet dancers would develop a better balance control strategy during standing on tip toe on one leg even if the alignment of the metatarsal bones was lined. The purpose of this study was to clarify how the centre of pressure (COP) was kept in the forefoot area during standing on tip toe on one leg by classical ballet dancers. In this study, we investigated an association between the alignment of the metatarsal bones and balance holding time and the COP distribution in the fore foot. The hypotheses were that a balance holding time would be associated with an angle defined by the distal points of the first, second, and fifth metatarsal bones and that COP controls would be different between the professional and recreational dancers.

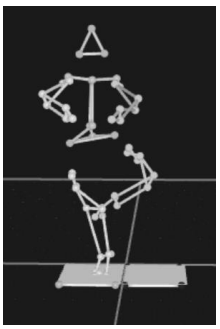

Figure 2: Standing on tiptoe on one leg from the ballet first position

METHODS: Ten female recreational dancers, most of whom have trained classic ballet dancing once or twice per week, and six female professional dancers in classical ballet were recruited in this study. They had no injuries at the time of the experiment. Professional dancers identified that the left leg was often trained as a supporting leg when turning in ballet lessons, though the dominant leg was different amongst the dancers. Dancers performed standing on tip toe on one leg from the first position of ballet without using ballet bars and kept balance aesthetically as long as they could (Figure 2). The successful performances were captured three times for each supporting leg using a twelve-camera motion capture system and a force platform. The reflective markers were attached on the distal end of the second toe,

sides of the distal points of the first and fifth metatarsal bones and at the distal point of the second metatarsal bones on the dorsum of foot. The angle between a line connecting the distal points of the first and second metatarsal bones and a line connecting the distal points of the fifth and second metatarsal bones was measured (defined as the angle of the metatarsal bones).
The balance holding time was defined as the period when the plantar flexion of the supporting ankle joint was kept with minimal movement of the other leg in the air. Dancers, who could not keep a balance more than one second twice out of three trials were eliminated from the analyses of the corresponding supporting leg. Locations of the COP were determined in the forefoot frame, whose origin was defined by an intersection of a vector connecting the markers on the first and fifth metatarsal bones with a vector connecting the markers on the second metatarsal bone and toe. The periods when COPs were in the medial or lateral of the second metatarsal bone were evaluated by dividing the periods with the balance holding time. The correlation between the alignment of the metatarsal bones and balance holding time were evaluated using the paired t-test. Periods when COPs were in the medial or lateral of the second metatarsal bone was compared between the recreational and professional dancers using the unpaired t-test.

RESULTS: The COP was located in the trigonal area, which the distal points of the first and fifth metatarsal bones and the endpoint of the second toe made during keeping a balance on tip toe on one leg (Figure 3). Balance holding time was longer in the professional dancers than in the recreational dancers in both legs (Table 1). The angles of the metatarsal bones were not different between the groups (Table 2). The balance holding time tended to be correlated with angles of the metatarsal bones in the left supporting leg of recreational dancers ($p=0.05$, $r=0.71$) whereas the correlation was not observed in each supporting leg of the professional dancers (Figure 4). In the recreational dancers, the holding time when the COP was in the medial side of the second metatarsal bone was as much as the time when the COP was in the lateral side of the bone in the in the left supporting leg (Table 3). The holding time when the COP was in the medial side of the second metatarsal bone was longer than the time when the COP was in the lateral side of the bone of the right supporting leg (Table 3). In the professional dancers, the holding time when the COP was in the medial side of the second metatarsal bone was as much as the time when the COP was in the lateral side of the bone of the left supporting leg in both groups (Table 3). The holding time when the COP was in the lateral side of the second metatarsal bone was longer than the time when the COP was in the medial side of the bone of the right supporting leg in the professional dancers not in the recreational dancers (Table 3: $p<0.01$). There were no correlations between the angles of the metatarsal bones and the holding times whether the COP was in the medial or lateral sides of the second metatarsal bone.

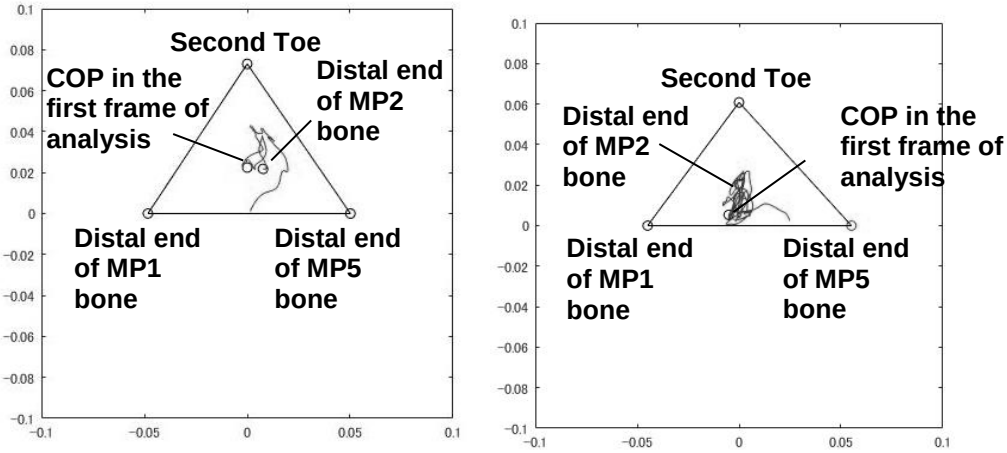

Figure 3: COP trajectory in the right leg support (Left: a recreational dancer; Right: a professional dancer)

Table 1: Balance holding time.

Group	Left support leg (s)	Right support leg (s)
Recreational	3.49 ± 2.41 (n = 8)	3.83 ± 3.47 (n = 10)
Professional	8.78 ± 3.48 (n = 6)	9.48 ± 3.13 (n = 6)

Table 2: Angles of metatarsal bones.

Group	Left support leg (deg)	Right support leg (deg)
Recreational	135.5 ± 21.4 (n = 8)	151.0 ± 24.1 (n = 10)
Professional	150.4 ± 9.73 (n = 6)	151.9 ± 18.6 (n = 6)

Table 3: COP holding time in medial/ lateral sides of MP2 bone.

Group	Left support leg (%)		Right support leg (%)	
	MP1 side	MP5 side	MP1 side	MP5 side
Recreational	50.1 ± 25.2	50.0 ± 24.7	60.3 ± 25.1	39.7 ± 25.1
Professional	46.4 ± 33.1	53.6 ± 33.1	78.8 ± 11.9*	21.1 ± 11.8*

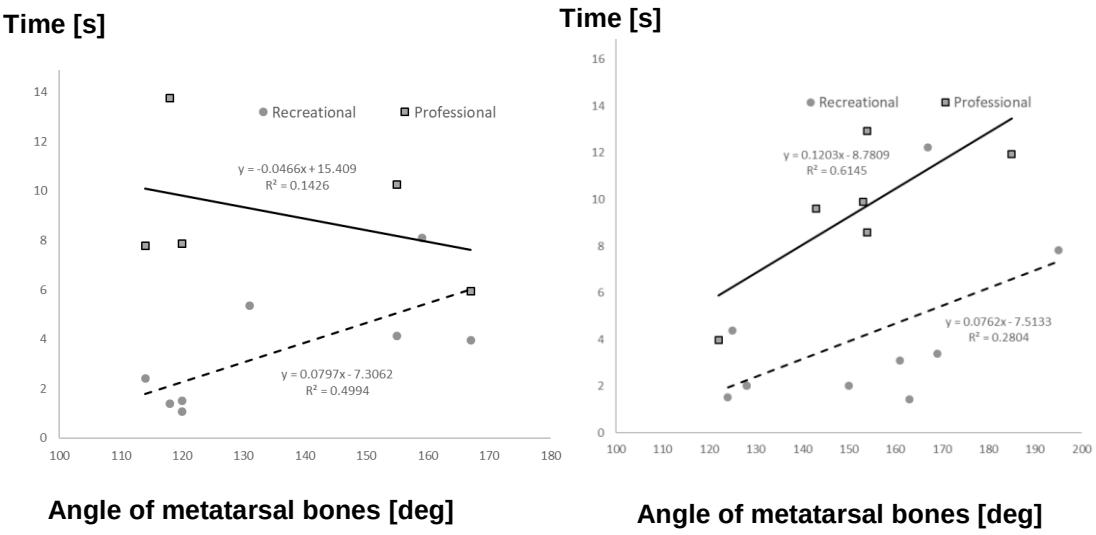

Figure 4: Correlation between balance holding time and angle of metatarsal bones (Left: left supporting leg; Right: right supporting leg)

DISCUSSION: The purpose of this study was to clarify how the centre of pressure (COP) was kept in the forefoot area during standing on tip toe on one leg by classical ballet dancers. The hypotheses were that a balance holding time would be associated with an angle defined by the distal points of the first, second, and fifth metatarsal bones, and that COP controls would be different between the professional and recreational dancers. The first hypothesis tended to be supported in the left supporting leg. The second hypothesis was supported in the right supporting leg in view of distribution of the COP, either medial or lateral side of the second metatarsal bone. The distal points of the metatarsal bones were not aligned in a line at least for the first, second, and fifth metatarsal bones (Table 2). Thus, the dancers in the present study would have possibility to locate the COPs either on the medial or lateral sides of the second metatarsal bone disproportionately.

The balance holding time may be associated with the angle of the metatarsal bones in the recreational dancers not in the professional dancers in the present study (Figure 4). The angle of the metatarsal bones in the recreational dancers was not significantly different between both feet. Thus, the control of the COPs would be different between both legs in the recreational dancers. The difference between the groups may result from the difference of ballet training opportunity.

Distribution of the COP, either medial or lateral side of the second metatarsal bone was different between the groups only in the right supporting leg (Table 3). Though the ballet

instruction book mentions that weight is distributed around the first and second toes and at the distal point of the second metatarsal bone ideally, the professional dancers in the present study held the COPs toward the fifth metatarsal bone longer than toward the first metatarsal bone when standing on the right leg. The right leg is not used as a supporting leg in classical ballet dancing compared to the left leg. Thus, professional dancers might have understood that they had to change the balancing strategy when standing on the right leg. Because the distal points of the metatarsal bones were not aligned in a line, the professional dancers might try to keep the COPs within the larger area in the side of the fifth metatarsal bone than the narrower area in the side of the first metatarsal bone. The recreational dancers might not have changed the strategy between both legs because they have thought to train both legs almost equally through the ballet lessons.
In the present study, the supporting legs were not classified in view of dominance. Because the motion task in the present study is not performed ordinarily, we assumed that effects of ballet training rather than the leg dominance would affect to the performance.

CONCLUSION: In this study, we investigated how classical ballet dancers keep a balance on tip toe on one leg, focusing on an association between the alignment of the metatarsal bones and balance holding time. The balance holding time may be associated with the angle of the metatarsal bones in the recreational dancers not in the professional dancers. The professional dancers in the present study held the COPs toward the fifth metatarsal bone longer than toward the first metatarsal bone when standing on the right leg. This was not observed in the recreational dancers. Difference of ballet training opportunity might have changed the strategy for balancing on tip toe on one leg.

REFERENCES

Warren, G.W. (1989). Classical ballet technique, pp.20 Florida: The University of South Florida Press.

Huwyler, J.S. (2002). THE DANCER'S BODY, pp.108. Nottingham; Russel Press

Clippinger, K.S. (2007). Dance anatomy and kinesiology, pp.329. Champaign; Human kinetics.