GROUND REACTION FORCE AND KINEMATIC CHARACTERISTICS OF PIROUETTE IN BALLET IN FLAT SHOES VERSUS POINTE SHOES

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The purpose of this study was to investigate the ground reaction force and kinematic variables in the ballet single turn called pirouette in both flat shoes and pointe shoes by skilled professional ballet dancers. Kinematic parameters of both legs and ground reaction force were obtained from eight skilled ballet dancers through a three-dimensional motion analysis. We found significant increased ground reaction force and significant increased range of motion for both legs only for hip joint in pointe shoes, while angular velocity of hip, knee and ankle joint in pointe shoes were significantly greater in pointe shoes than those in flat shoes. From the results of this study, it is indicated that performing a single pirouette in pointe shoes would increase in ground reaction force associated with greater joint range of motion and angular velocity of lower extremity.

KEY WORDS: ballet, ground reaction force, joint kinematic characteristics, pointe shoes.

INTRODUCTION: Pointe shoes are unique footwear for female ballet dancers. After initial couple of years of ballet training in flat shoes made from soft fabric or leather, young female dancers can start their dance training in pointe shoes. They have to perform every dance movement in pointe shoes on the stage. So it is beneficial for dancers or teachers to know biomechanical characteristics of this turn both in flat and pointe shoes. In ballet, turns called pirouette is one of the essential movements to be advanced dancers, while similar movements are performed by rhythmic sports gymnasts. Few previous studies have investigated this turn by biomechanical analysis (Kim, Wilson, Singhal, Gamblin & Kwon, 2014, Lin, Su, Wu & Lin, 2013, Lin, Chen, Su, Wu & Lin, 2014), although the movements examined in those studies were only in flat shoes. So the purpose of this study was to investigate differences in ground reaction force and leg joint kinematic variables during single pirouette in ballet by skilled dancers in flat shoes versus pointe shoes.

METHODS: Subjects were eight skilled professional ballet dancers including three principle dancers and three soloists of major ballet company in Tokyo, Japan. Their average age was 27 years old and their average dance experience was 23 years. All participants provided informed consent for the study after receiving a detailed explanation of the study purpose, potential benefits, and risks involved. The experimental procedures used for this study conformed to the Declaration of Helsinki and approved by the Institutional Review Board. Each participant was instrumented with 67 reflective markers. The trajectories of the markers were captured by a motion analysis system (VICON) comprising eight digital cameras with an acquisition speed of 250 frames per second. A link segment model was constructed comprising pelvises, thighs, shanks and feet. The joint angles of the leg were calculated using 3D software (KWON3D). Participants stand on two separate force platform (Kistler). Ground reaction force was recorded at 1000Hz simultaneously with video images. Each participant performed three successful single pirouettes in flat shoes and in pointe shoes respectively in randomized order. Subjects wore their own shoes for both flat shoes and pointe shoes conditions. Regardless of their limb preference, all participants were asked to turn right using right leg as gesture leg and left leg as stance leg.

RESULTS: Figure 1 shows the motion sequence in single pirouette. Figure 2 shows a typical example of vertical component of ground reaction force (Fz) and joint angle of hip, knee and ankle for both gesture leg and support leg during single pirouette in flat shoes and in pointe shoes. Vertical component of ground reaction decrease with flexion of both knee joint called "plie" in ballet and two peak Fz appeared during rotation. The first peak corresponds to upward movements of COM from plie and the second peak corresponds to heel-raise movement with rotation. Peak Fz showed significant increase in pointe shoes compared with in flat shoes (Figure 3). For support leg, significant increased range of motion in hip flexion, external rotation and abduction and significant decreased ankle dorsi-flexion were observed in pointe shoes. For gesture leg, we found significant increased range of hip flexion in pointe shoes. For support leg, peak angular velocity of hip flexion, extension, and adduction significantly increased and that of hip internal rotation, knee extension, and ankle dorsi-flexion significantly decreased in pointe shoes. For gesture leg, peak angular velocity of hip flexion, extension, adduction, knee flexion, extension, and ankle plantar flexion significantly increased and that of hip internal rotation significantly decreased in pointe shoes (Table 1).

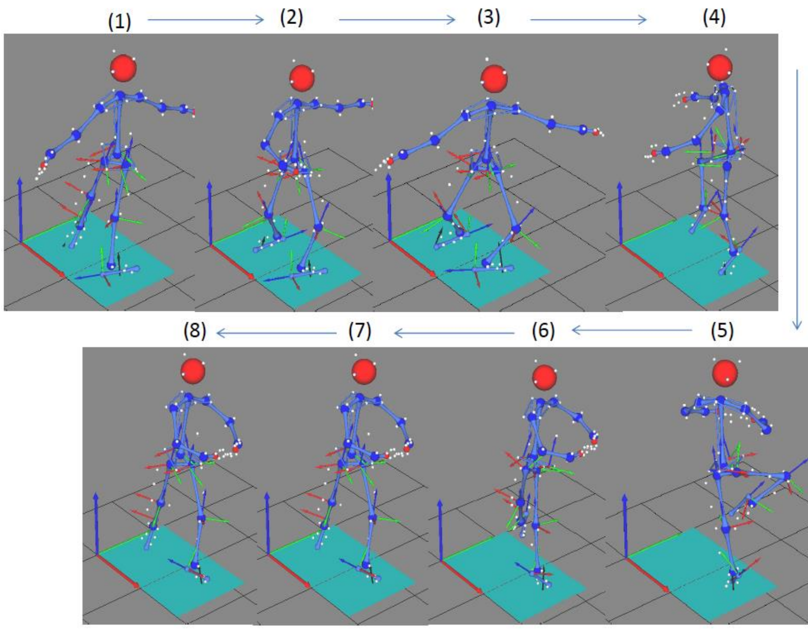

Figure 1: Motion sequence of a single pirouette en dehor in this study

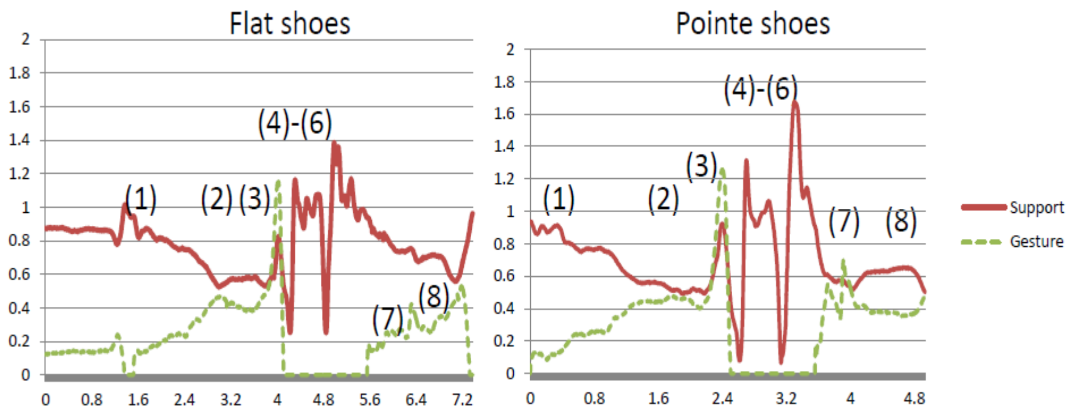

Figure 2: Vertical component of ground reaction force during single pirouette in flat shoes (Left) and pointe shoes (Right)
(Numbers correspond to each phase in the movement sequence presented in Figure 1.)

Table 1: Peak joint angle of the hip, the knee and the ankle in stance leg and gesture leg

	Stance leg (Left)	Flat shoes (deg.) Mean	Sd	Pointe shoes (deg.) mean	Sd	
Hip	Flexion	55.9	3.6	57.4	4.0	***
	EX-rotation	35.2	10.1	36.2	13.2	***
	Abduction	22.9	3.3	23.5	4.2	***
	Adduction	3.2	4.1	4.1	3.4	
Knee	Flexion	53.9	13.5	57.7	9.5	
Ankle	Plantar flexion	123.4	5.7	123.7	13.3	
	Dorsi flexion	48.2	5.5	22.4	4.4	***

	Gesture leg (Right)	Flat shoes (deg.) Mean	sd	Pointe shoes (deg.) mean	Sd	
Hip	Flexion	63.9	5.4	65.9	2.1	***
	EX-rotation	23.0	11.1	20.5	10.2	
	Abduction	49.1	4.3	50.7	3.9	
	Adduction	6.7	4.0	6.4	4.4	
Knee	Flexion	132.9	17.4	137.9	7.2	
Ankle	Plantar flexion	123.9	7.1	127.8	6.2	
	Dorsi flexion	21.9	4.3	20.4	2.7	

Table 2: Peak joint angular velocity of the hip, the knee and the ankle in stance leg and gesture leg

	Stance leg (Left)	Flat shoes (deg./s) Mean	Sd	Pointe shoes (deg./s) mean	sd	
Hip	Flexion	235.2	22.1	249.9	29.5	***
	Extension	-207.1	39.5	-243.2	36.1	***
Knee	Flexion	-53.9	13.5	-57.7	9.5	
	Extension	7.7	8.6	5.0	2.5	***
Ankle	Plantar flexion	123.4	5.7	123.7	13.3	
	Dorsi flexion	48.2	5.5	22.4	4.4	***

	Gesture leg (Right)	Flat shoes (deg./s) mean	Sd	Pointe shoes mean	(deg./s) sd	
Hip	Flexion	235.2	22.1	249.9	29.5	***
	Extension	-207.1	39.5	-243.2	36.1	***
Knee	Flexion	-585.3	122.0	-638.3	146.0	***
	Extension	507.8	114.6	515.5	148.9	***
Ankle	Plantar flexion	328.5	121.4	480.1	93.6	***
	Dorsi flexion	-618.8	126.2	-712.2	101.6	*

DISCUSSION: We found significant greater peak Fz during single pirouette in pointe shoes both for support and gesture leg. It is indicated that significant increased peak Fz in pointe shoes might be caused by the increase in upward movements of COM position or by the more rigid outsole of pointe shoes compared with flat shoes condition. Previous study demonstrated that significant greater Fz on landing from ballet-specific-type of jump in flat shoes compared with pointe shoes (Walter, Docherty & Scharader, 2011). From this previous study, increased peak Fz on landing in flat shoes could have occurred partly because of the layers of material that make up pointe shoes sole which may have absorbed more forces on landing. However, in this study, we found significant greater peak Fz during single pirouette in pointe shoes that might induce risks for dance injury. In addition, for not only ankle joint but also hip and knee joint, significant increased range of motion during single pirouette in pointe shoes were obtained only for support leg. Weiss et al. (2009) have suggested that young ballet dancers with insufficient ankle and foot plantar flexion range of motion or poor lower extremity alignment or poor trunk and leg muscle strength should not be allowed to do pointe work from the point of performance enhancement and injury prevention. Since we found significant increased range of motion in knee and hip joint as well as ankle joint even during single pirouette, it is indicated that ballet dancers should strengthened leg and trunk muscle to do the same dance movements before they start pointe work.

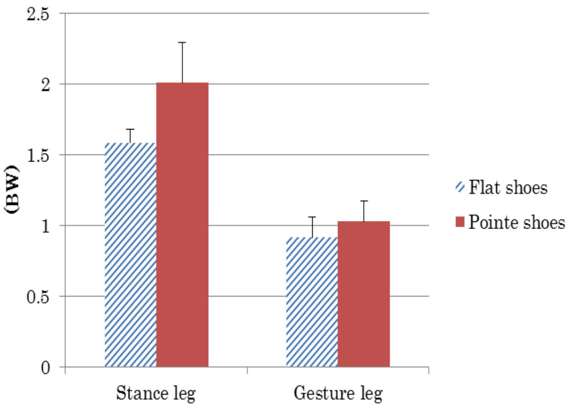

Figure 3: Peak Fz normalized by subject`s body mass during single pirouette in flat shoes (dash bars) and pointe shoes (closed bars)

CONCLUSION: From the results of this study, it is indicated that single pirouette in pointe shoes would cause increased ground reaction force and increased joint kinematics of lower extremity compared with single pirouette in flat shoes.

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