KINETIC ANALYSIS OF LANDING A GRAND JETÉ BETWEEN BAREFOOT AND POINTE SHOE FOOTWEAR FOR DOMINANT AND NON-DOMINANT LEGS

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The purpose of this study was to examine the vertical ground reaction force in the skill of a Grand Jeté between barefoot and pointe shoes for both dominant and non-dominant legs. Seven female college dancers participated in the the study, and the results showed that there were no statistically significant differences between the landing legs or footwear conditions. However, there was an observable difference between the landing forces of the dominant and non-dominant legs, indicating that the dancers may be able to dissipate landing forces more effectively when landing on their dominant leg. This study provides a preliminary understanding on the effects of footwear between dominant and non-dominant legs. Future studies are warranted to evaluate the kinematics of lower body extremity to acquire a comprehensive understanding on the skill of Grand Jeté.

KEYWORDS: dance, ground reaction forces, injury prevention, landing

INTRODUCTION: A dance skill movement that is primarily common in ballet and contemporary dance is called a Grand Jeté. A Grand Jeté is a jump in which a dancer springs from one foot to land on the other with one leg forward of their body and the other stretched backward while in the air. The goal of the movement is to create the illusion that the dancer is floating through the air. Unfortunately, there is an injury incidence of 40-80% depending on the level of participation in dance, with a lifetime incidence of up to 90% for all dancers (Joy & Macintyre, 2000). Joy and Macintyre (2000) further identified injury patterns, with the lower leg, foot, and ankle making up roughly 40% and the knee and hip each about 20% of the injuries. The strength of the landing forces may also predispose the dancer to a higher susceptibility of injury. Previous research studies have shown that the ground reaction force upon landing a jump or leap can be as much as 3.5-8.0 times a person's original body weight (Ferris et. al., 1997; McNitt-Gray 1993). Additionally, Fietzer, Kulig, and Popovich Jr. (2010) examined the ground reaction forces and knee mechanics in the weight acceptance phase of a dance leap take-off and landing, and the authors found that peak ground reaction forces were 26% greater during the landing phase. This high amount of force severely taxes the joints and causes joints that lack adequate muscle strength and support to be more prone to injury. Wyon, Harris, Brown, and Clark (2013) conducted a Grand Jeté study and found there was a significant difference in the forces of landing a Grand Jeté between the dominant (BW: 4.11 ± 0.69) and non-dominant leg (BW: 4.21 ± 0.98) throughout the course of performing the movement multiple times; however, the study did not examine the impact of footwear that may contribute to this difference in the forces of landing to prevent injury. Ballet dancers commonly wear pointe shoes footwear when performing a Grand Jeté, and these shoes have a wooden block inserted into the tip of the shoe to help dancers reach full extension of the ankle joint while on their toes. While wearing pointe shoes, the dancer's foot is required to absorb a significant amount of force in a small area on the toes, which may lead to structural changes causing them to be more prone to injury. However, the question of how pointe shoes would affect the landing of a Grand Jeté remained to be answered. Therefore, the purpose of this study was to examine the kinetic of vertical ground reaction forces of landing from leaping while performing a Grand Jeté in both barefoot and pointe shoe footwear between the dominant versus non-dominant side in order to identify which variable predisposes the dancers to the highest risk of injury due to a higher landing force.

METHODS: Seven right leg dominant female college dancers with a mean age of 20.4 ± 1.5 years old, a mean height of 1.63 ± 0.06 meters, a mean mass of 62.8 ± 4.5 kilograms, a mean dance experience of 17.6 ± 2 years in a variety of disciplines, such as ballet, contemporary, and jazz, and 1-2 years of pointe experience were recruited to participate in this study. Leg dominance was determined by asking the dancers which leg they naturally choose to practice and perform movements on and then confirmed by having dancers fall forward and determine which leg they bring forward to catch themselves. A pair of new Capezio pointe shoes was provided for each dancer, and Capezio Ouch Pouches were provided for the dancers to cushion their toes to allow the dancers to perform the movement with full intensity without experiencing significant toe pain. Participants had minimal experience with Capezio pointe shoes and were allotted five to ten minutes to warm-up and feel comfortable with the shoes. Each participant was allowed 2-3 practice trials to mark where they needed to begin the movement to land directly on an AMTI force plate that was operated at 1,000 Hz. All participants were instructed to perform a Grand Jeté at maximal effort, landing on one foot on the force plate. Maximal effort of the movement would indicate that the dancers reach their individual maximum height and split in the air before they land, and this effort was monitored and confirmed with the use of a Casio high speed video camera (Model: EX-FH25) that was positioned to capture the sagittal view of the Grand Jeté at 120 Hz. Each participant performed the movements three times in each condition: landing on the dominant foot, landing on the non-dominant foot, landing on the dominant foot wearing the pointe shoes, and landing on the non-dominant foot wearing the pointe shoes. A total of 12 trials were collected for each participant and a total of 84 trials was collected in the study. The force plate information was collected through Vicon Nexus (v. 1.8). The ground reaction force of the three phases of landing the Grand Jeté was analysed to determine the force of the first moment of impact on the force plate (initial/maximum force), the minimum force (maximum dorsiflexion when landing to stabilize oneself), and the toe-off force (the force of the toes pushing on the force plate when stepping off the plate). A two-way (2 sides of the body x 2 landing footwear conditions) repeated measure ANOVA was conducted at $\alpha = 0.05$, utilizing the mean of the three trials for each condition per participant. A t-test with a Bonferroni adjustment was also conducted at $\alpha = 0.013$ for a more extensive analysis. Ground reaction force data were analysed for both raw and normalized body weight (BW). Statistical analyses were conducted using SPSS (v. 25). Since the landing motion of the Grand Jeté primarily occurred in the sagittal plane of motion, the focus of this preliminary study was on the vertical ground reaction force. Follow up studies will be conducted to examine additional variables such as rate of loading, additional directional forces, and kinematic measurements for a comprehensive understanding of a Grand Jeté.

RESULTS: The results of this study yielded no statistically significant difference in three phases (initial/maximum, minimum, or toe-off) of vertical ground reaction forces when completing a Grand Jeté at maximum effort/intensity between the barefoot and pointe shoe conditions, as well as between the dominant and non-dominant legs. From the two-way ANOVA repeated measure test, the main effect of side, dominant vs. non-dominant, was approaching significance ($p = 0.078$) at the first phase of landing the Grand Jeté. This observable difference indicates that the initial landing forces of the dominant (right) leg were consistently less than the initial landing forces of the non-dominant (left) leg in both barefoot and shoe conditions, Table 1 & 2.

Table 1. Initial/maximum vertical ground reaction force between footwear and side conditions

Max GRF (N)	**Barefoot Mean ± SD**	**Shoe Mean ± SD**	***p***
Dominant (Right)	1837 ± 584	1895 ± 394	0.819
Non-Dominant (Left)	2033 ± 588	2227 ± 504	0.353
p value	*0.388*	*0.135*	

Statistically significant at p < 0.013

Table 2. Normalized body weight for maximum ground reaction force between footwear and side conditions

Max GRF of BW	Barefoot Mean ± SD	Shoe Mean ± SD	*p*
Dominant (Right)	3.01 ± 1.03	3.07 ± .61	0.877
Non-Dominant (Left)	3.35 ± 1.11	3.66 ± 1.01	0.321
p value	*0.353*	*0.113*	

Statistically significant at p < 0.013

With regards to the minimum forces/maximum dorsiflexion in the second phase of landing a Grand Jeté, no significant differences were found in forces of landing for the dominant leg between barefoot (1149 ± 265 N or BW: 1.86 ± .38) and pointe shoe (1100 ± 297 N or BW: 1.77 ± .39) conditions. Similar findings were observed in the forces of landing for the non-dominant leg between barefoot (1190 ± 290 N or BW: 1.95 ± .56) and pointe shoes (1208 ± 175 N or BW: 1.96 ± .28). For the last phase (toe-off) of completing a Grand Jeté, no significant differences were found in forces of landing for the dominant leg between barefoot (1405 ± 342 N or BW: 2.66 ± .48) and pointe shoe (1342 ± 232 N or BW: 2.17 ± .32) conditions. Similar findings were observed in the forces of landing for the non-dominant leg between barefoot (1451 ± 317 N or BW: 2.37 ± .54) and pointe shoes (1355 ± 210 N or BW: 2.21 ± .40).

DISCUSSION: Previous research studies have shown that the ground reaction force upon landing a jump or leap can be as much as 3.5-8.0 times a person's original body weight (Ferris et. al., 1997; McNitt-Gray 1993), and this study showed between 3.0-3.7 times a person's body weight. The difference between the current study and previous literature may be due to the type of leaping and landing activity and as well as the intensity and the skill level of the participants. Also, this preliminary dance research study examined the vertical ground reaction force that occurred in the sagittal plane of the primary landing movement in three critical phases of landing a Grand Jeté at maximum effort between barefoot and pointe shoe and as well as between dominant and non-dominant legs. The effects of pointe shoe did not show any significant change in the vertical ground reaction force of landing in both dominant and non-dominant legs in all three phases. A possible explanation may be that the influence of effort/intensity of jumping and landing is greater than the influence of footwear, so there was no significant difference observed since all dancers performed a Grand Jeté at maximal effort. Another possible explanation may be that the dancers were able to change their lower limb kinematic joint angles and velocities at landing when wearing pointe shoes with toes fully extended to enable them to absorb the landing forces. This study further investigated the effects of asymmetry between dominant and non-dominant legs. Even though no significant difference was found between dominant and non-dominant legs in all three phases of landing, a lower force of landing was consistently observed in the dominant leg when compared to the non-dominant leg in all three phases of landing in both barefoot and shoe conditions. Wyon, Harris, Brown, and Clark (2013) conducted a Grand Jeté study that found a difference in landing forces between the dominant and non-dominant legs over the course of three trials. However, this preliminary study did not find a significant difference between the dominant and non-dominant legs, but the data showed it was approaching significance in the initial/maximum landing phase. The differences in findings between this current and previous studies may be due to the different skill levels of the examined populations since the previous study used 20 female dancers who were in their final year of the same pre-professional dance program at a contemporary conservatoire. Contrarily, the participants in this study were all young college dancers taught at different studios and by different instructors, which may contribute to the difference in technique and bilateral proficiency. Additionally, the results of the Wyon et al.

study (2013) were collected from the best trial, rather than as a mean of all three trials as done in this preliminary study. It was also not indicated whether the dancers in their study were allotted a warm-up, which would impact the effort/intensity of each trial because some of the trials might have possibly been performed at a lower effort/intensity while the dancers were getting used to the movement and warming up, rather than performing at the same maximum effort for each trial and each condition as done in this current study. This could contribute to the observed increase in force over the course of three trials as seen is the Wyon et al. study (2013). Some limitations should be considered in this study. This study had seven young college dancers and it demonstrated that the main effect of side (dominant vs non-dominant leg) was approaching significance. Despite the lack of statistical significance found in this study regarding the landing force exerted during the movement, there was an observed difference in initial ground reaction landing force between the dominant and non-dominant legs during both footwear conditions. With a greater sample size and lower skill level, the significance may be observed. Additionally, this study did not evaluate the level of leg strength between the dominant and non-dominant legs, so the tendency towards greater landing forces on the non-dominant leg may be a result of a higher effort/intensity of jump from the dominant leg, which may provide further understanding of the effects of jumping effort/intensity that is more critical than the footwear. Although this study focused on the kinetic analysis of landing a Grand Jeté, it is critical to examine the kinematics of a Grande Jeté during landing. Previous studies have shown that increased joint angular stiffness is associated with decreased joint angular displacement and increased moments, thereby increasing the risk of bony injury (Butler et al., 2003). Pointe shoes have a wooden block inserted into the tip of the shoe to help dancers reach full extension of the ankle joint while on their toes, and this wooden block may cause increased joint angular stiffness, resulting in a higher amount of force to be applied on joints that are prevented from displacing themselves freely to safely dissipate these high forces. Understanding the mechanics of landing in the lower extremity body joint angles and velocities will provide a comprehensive understanding of the skill of a Grande Jeté.

CONCLUSION: This preliminary study was the first to examine and quantify the effects of pointe shoes in all three phases of landing the skill of a Grand Jeté with young female college dancers. This study found no statistically significant difference between the landing legs or footwear conditions. However, the initial ground reaction force between the dominant and non-dominant legs was approaching significance. Hence, this study provides an important preliminary understanding of the effects of pointe shoes and leg dominance on landing force when performing a Grand Jeté during three phases of landing. Future studies are warranted for further investigation of additional variables, such as leg strength, kinematic measurements, 3D landing forces and internal joint stiffness, to provide a comprehensive understanding of the biomechanics of a Grand Jeté and the impact of footwear and leg dominance on injury risk.

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