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Comparison of Ground Reaction Forces between Novice and Experienced Ballet Dancers Performing a Second Position Jump Landing

Dayun Jeon

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by

Dayun Jeon

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Approved:

Eadric Bressel Major Professor	Edward M. Heath Committee Member
Brennan Thompson Committee Member	

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Abstract

Ballet dancers are exposed to the high likelihood of lower extremity injury due to repeated high-impact jumps under stringent ballet rules. According to the claims of current literature, excessive vertical ground reaction force (VGRF) and the rate of force development (RFD) during the landing phase of a jump are highly associated with the incidence of lower extremity injuries. Experience level of the dancer may provide insight into the etiology of such injuries; however, this contention has not been formally tested. The aim of this study was to compare the VGRF and RFD between novice and experienced ballet dancers during a ballet second-position jump landing task. Twelve novice ballet dancers and 10 experienced dancers performed second-position jumps on a force platform that was set flush to the floor. The peak VGRF (N) during the landing phase of the second-position jump in the novice group (369.3 ± 96.8 N) was 60% greater ($p = 0.001$) than the experienced group (150 ± 63.7 N). Additionally, the RFD (N/s) during the landing phase of the second-position jump in the novice group (4412.6 ± 1.3 N/s) was 67% greater ($p = 0.001$) than the experienced group (1467 ± 718 N/s). However, there were no significant differences between groups in secondary measures such as peak take off force, flight time, and jump height (p = 0.71, 0.18, 0.20, respectively). The results of this study indicate the need to provide specific instruction, or other countermeasures, on landing technique for novice dancers, which may minimize impact force followed by preventing potential injury.

Introduction

Ballet is one of the most popular genres of dance in the world, and the ballet dancer is characterized by being classical and full of grace. Ballet is generally known for increasing balance abilities, flexibility, and improving posture.[1] However, professional ballet dancers tend to suffer from mental and physical stress as competitive sport athletes because ballet is a combination of an art and a high-performance sport.[1] Although ballet as a recreational or physical activity becomes more popular from young to older generations, it is known that nearly 86% of professional dancers experience injuries to the lower extremities such as acute ankle sprains, anterior cruciate ligament injury, or musculotendinous injury throughout their dancing careers.[2] Leanderson et al.[3] reported that the rate of total injury incidence is 0.8 per 1,000 hours of dancing in both female and male dancers, and the most common diagnoses were ankle sprain and tendinosis pedis.

Due to the characteristics of ballet, there are multiple factors that may hinder a dancer's vertical jump including unskilled technique, inadequate instruction, hard floor surfaces, and ballet footwear.[2] The other vital elements of ballet are *en pointe*, *flex*, and *turn out*. Extreme plantar flexion and dorsiflexion of the foot, called *pointe* and *flex* respectively, are fundamental movements in ballet dancers. Ritter and Moore[4] suggested that lateral ankle sprains and ankle tendinitis are the most common reported injuries in ballet dancers as a result of those unusual positions. It can also negatively affect their jumping ability, since dancers must constantly keep their feet either plantar flexed or dorsiflexed. *Turnout* is placing the lower extremities rotated 90° externally, and is known for causing anterior cruciate ligament injury in ballet dancers. Lee et al.[5] investigated the influence of *Sissonne Fermee*, a ballet jump-landing task with turnout, on lower extremity joint angles. The results supported that muscle activation, foot movement, and landing strategy affect these ankle injuries during *Sissonne Fermee* with turnout.[5]

Ground reaction force (GRF) is formulated as the product of mass and acceleration (F = ma). GRF occurs when the foot contacts the ground and reflects the duration and intensity of stress placed on the body during foot contact with the ground by using a force platform.[6] Rate of force development (RFD) is defined as the change in force over the change in time, and it is associated with the mechanical stress on the body, and it can be explained by how fast the impact force is developed in jump landing tasks. Bressel and Cronin[6] suggested excessive vertical ground reaction force (VGRF) and RFD are potential contributing factors to injuries, and in particular, the peak impact force appears to be highly associated with lower extremity injuries. Proper landing techniques and strategies under stringent ballet rules are important not only for the sake of esthetic appearance but also for the injury prevention for ballet dancers. Thus, it is important to gain a better understanding of the landing phase of jumps to promote not only effective injury prevention strategies but also suitable rehabilitation programs for each dancer.

Although there is a myriad of literature about how to make athletes jump higher or farther in biomechanical aspects, there is a paucity of research examining the impact forces of the landing phase of jumps in dancers. Chockely[7] mainly focused on the comparison of shoe condition during jumps between barefoot and pointe shoes. It was reported that jump landing in pointe shoes was 72% (531.14 ± 82.28 N) of the maximum VGRF (735.93 ± 95.79 N) in barefoot. Walter et al.[2] compared VGRF between landing in flat shoes and landing in pointe shoes. They observed a significant decrease in VGRF when subjects landed wearing pointe shoes. Pointe shoes that are made of multiple layers are thought to absorb and disperse some of the reaction forces.[2] They concluded it was beneficial for ballet dancers to have technique classes in pointe shoes to help prevent potential injuries through minimizing VGRF applied to the body.

However, in terms of decreasing potential injuries, Pearson and Whitaker[8] suggested that wearing demi pointe shoes as a transitional stage between flat shoes and pointe shoes is crucial in preventing ankle injuries in terms of gradational training in changes of pressure on a dancer's feet. Wearing pointe shoes when considering dancer's ankle injuries has its merits and faults. Even though wearing pointe shoes decreases VGRF during jumps, it is advantageous for dancers to train from flat shoes to demi pointe shoes to pointe shoes gradually to help them minimize their potential injuries. Lin et al.[9] compared performance of ballet turns (*Pirouette*) between novice and experienced ballet dancers. They observed that novice dancers exerted a greater propulsive GRF during the turn initiation than experienced dancers. In terms of comparing VGRF, there were no group differences for impact VGRF during the landing phase of turns, and RFD was not examined in their study.[9]

Therefore, one may argue that it would be more relevant to quantify the impact VGRF and RFD during the landing phase of basic ballet jumps, such as the second-position jump, rather than turns. Second-position jump is a basic jumping skill in ballet, dancers are required to practice and perform this jump from beginners to professional dancers. Presumably, the impact VGRF and the RFD are greater during the landing phase of a jump than turn. however, this conjecture has not been clearly elucidated in the literature.

Accordingly, the purpose of this study was to compare impact VGRF and RFD during ballet second-position jump-landing tasks between novice and experienced ballet dancers. It was the first attempt to investigate impact VGRF during the landing phase of jumps in two groups of ballet dancers of various skill levels. The results of this study could provide guidelines on developing useful strategies to prevent potential injuries and for rehabilitation programs in different skill levels of dancers. It could also be a useful reference material for dance instructors or dancers themselves to be aware of the importance of mastering jump skills through appropriate practice and provide insight on how to avoid potential injuries from jumps in ballet. The alternative hypothesis of this study was that there are differences in the rate and magnitude of the VGRF among ballet dancers with different skill levels.

Research Question

1. What is the rate and magnitude of the VGRF among ballet dancers for a second-position jump landing?
2. Do novice and experienced dancers display different impact VGRF and RFD during a second-position jump landing?
3. Do novice and experienced dancers display different peak take off force, time in the air, and jump height during a second-position jump landing?

Methods

Participants

Twenty-two dancers 18 to 24 years were volunteered for this study. Twelve female students from the Ballet I class, which is the class for novice ballet dancers, and 10 experienced female ballet dancers from Cache Valley Civic Ballet Company were asked to volunteer to participate in this study. Two groups were scheduled on the same day at different times. They signed a consent form approved by the Institutional Review Board of Utah State University. A short questionnaire was handed out to collect self-reported information on age, height, weight, dominant leg, years of ballet experience, practice hours per week, and any orthopedic injury experience in the past 6-months. Dancing experience level was defined as less than 2 years for novice dancers, and more than 6 years for professional dancers as the previous research determined the years of dancing experience for professional dancers.[9,10] Volunteering participants were screened out if they reported any orthopedic injuries in the past 6 months or had a high chance of pregnancy.[2] After the questionnaire was completed, all participants had 10 minutes to warm-up with their personal preference style such as stretching or prior jump practice to become familiar with the selected jump. The sample size of this study was determined by power analysis in G*Power under the following conditions: a) effect size d = 0.25, b) an alpha level of 0.05, and c) power level of 0.80.[11] Table 1 shows the basic physical characteristics of novice and experienced dancers who participated in this study. Because all participants' dominant leg was their right leg, their dominant leg as a factor in the table below was excluded. Also, none of the participants had any orthopedic injuries in the past 6 months and the chance of pregnancy.

Table 1. Subject Characteristics

	Novice Dancers (*N* = 12)		Experienced Dancers (*N* = 10)		
	M	(SD)	M	(SD)	*p*-value
Age (yr)	19.9	(1.88)	18.8	(1.23)	0.12
Height (cm)	167	(4.73)	165	(7.12)	0.40
Weight (N)	648	(97.2)	557	(33.5)	< 0.05*
Ballet experience (yr)	0.88	(0.23)	11	(3.09)	< 0.01*
Practice per week (hr)	2.38	(0.74)	12	(4.40)	< 0.01*

Note. M = mean, SD = standard deviation.
*Statistical significant difference between groups ($p < 0.05$).

The age and height between novice and experienced groups were not significantly different, but the weight, the years of ballet experience, and practice hours per week between the two groups were significantly different ($p < 0.05$).

Procedures

The testing procedures took place in a controlled environment (Biomechanics Laboratory, Room 203, Utah State University). After participants completed their warm-up, they performed four consecutive ballet second-position jumps on a force platform wearing ballet flat shoes. Only the dominant leg of each participant was placed on the force plate due to the size of the force plate.

Figure 1. Second-position Figure 2. Second-position jump

During each trial, the participant was instructed to perform a maximal effort vertical jump and attempt to make technically correct second-position jumps. Auditory cues were given from the researchers to begin the jump. Ballet second-position jumps (Figure 2) are a vertical jump beginning in the ballet second-position (Figure 1). The second-position involves placing the lower extremities rotated externally with turnout, and the knees should be aligned straightly in this position. It facilitated the comparison of VGRF and RFD during the landing phase of the jump following the ballet second-position jump between novice and experienced ballet dancers.

Data Analysis

Kinetic data for all second-position jumps were obtained via a tri-axial force platform (Model FP4080, Bertec Corporation, Columbus, OH, USA) mounted flush with the ground. Technical specifications for the force platform contain: 1) dimensions: width = 40 cm, height = 15 cm, length = 80 cm, 2) mass: 28 kg, 3) max vertical load: 10,000 N, 4) max horizontal load: 5,000 N, 5) natural frequency (vertical): 740 Hz, 6) natural frequency (horizontal): 570 Hz, 7) static resolution: ± 1 N, 8) resolution: 0.19 N per least significant bit, 9) linearity: 0.2 percent of full scale output.

Kinetic data were collected and analyzed with Acknowledge software (BIOPAC Systems Inc., Goleta, CA, USA). Kinetic data sampling (1000 Hz; 25 N threshold) was manually-initiated when the instructor gave verbal cues to each participant. Data collection was set for a 10 s time period and was manually terminated once the clear and desired second-position jump had been performed. Kinetic data were filtered with a 4th order, recursive, low-pass Butterworth filter using cut-off frequency of 20 Hz. Approximately 3 out of 4 jumps from each participants' data were analyzed to compute the mean of each dependent measure after eliminating unrepresentative data. Unrepresentative data were either mistakes in the jump execution or incorrect foot placement over the force plate during the landing phase of the jump. The principle investigator used visual observation to determine representative data.

The following dependent measures were computed from the filtered force data: Impact VGRF and RFD as primary dependent measures; peak take off force, time in the air, and jump height as secondary measures. Impact VGRF (N) was defined as the first peak force value recorded during the landing phase of the jump and RFD (N/s) was the slope that indicated the first peak impact force divided by the time to peak. Both VGRF and RFD were also normalized to body weight to reflect units in BW and BW/s, respectively. Peak take-off force was the highest force recorded during the take-off phase of the jump, and time in the air is the flight time between the instant of take off and land. Jump height was calculated based on the time in the air by using the equation $d = v_i t + \frac{1}{2} a t^2$.[12] Where d = distance, v_i = initial velocity, t = time interval, and a = acceleration.

<u>Statistical Analysis</u>

After the dependent measures were screened for outliers and normality, independent t tests for each dependent measure (impact VGRF, RFD, peak take off force, time in the air, and jump height) were conducted to compare two independent groups (i.e., novice and professional groups). Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS, Inc., Chicago, IL; Version 24). The level of significance was set at $p < 0.05$. A Holm's correction to the 0.05 level was made for kinetic comparisons because of the large number of comparisons and the risk this poses on misinterpreting a true Type I error.[13,14] To help appreciate clinical differences, effect sizes (ES) were quantified to appreciate the meaningfulness of any statistical differences and Cohen's convention for effect size interpretation was used (< 0.41 = small, 0.41 – 0.7 = medium, and > 0.7 = large).

Results

Impact VGRF in N and BW both were significantly different between novice and experienced groups ($p < 0.01$, ES = 2.7 and $p < 0.01$, ES = 2.4, respectively). The mean of impact VGRF (N) during the landing phase of a second-position jump in the novice group was 60% greater than the experienced group. The mean of impact VGRF normalized to body weight (BW) in novice group was also 53% greater than the experienced group. In addition, the RFD in N/s and BW/s were both significantly different between novice and experienced group ($p < 0.01$, ES = 2.7 and $p < 0.01$, ES = 2.8, respectively). The mean of RFD in N/s and BW/s in the novice group was 67% and 62% greater than the experienced group, respectively. However, there were no significant differences in peak take off force, time in the air, and jump height between the novice and experienced group ($p = 0.71$, $p = 0.18$, $p = 0.20$, respectively). Table 2 displays the numerical results of VGRF during the ballet second position jump. The numerical value of impact VGRF between the two groups is shown in Figure 3.

Table 2. GRF during Ballet Second-Position Jump in the Two Groups

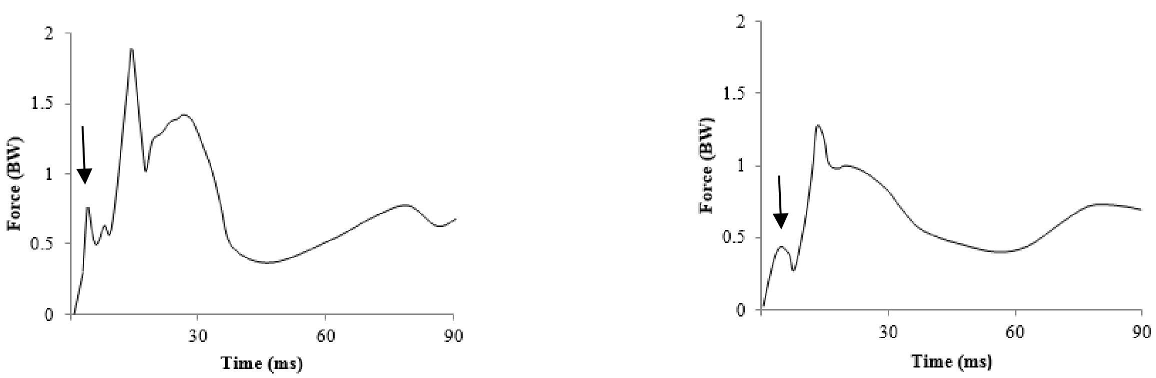
	Novice	Experienced			
	M (SD)	M (SD)	T	*P* value	ES
Impact VGRF (N)	369 (96.8)	150 (63.7)	-6.1	< 0.01*	2.7
Impact VGRF (BW)	0.57 (0.15)	0.27 (0.10)	-5.6	< 0.01*	2.4
RFD (N/s)	4412 (1.3)	1467 (718)	-6.2	< 0.01*	2.7

RFD (BW/s)	6.80 (1.79)	2.59 (1.13)	-6.4	< 0.01*	2.8
Peak take off force (N)	946 (282)	902 (255)	-0.4	0.71	0.2
Time in the air (s)	0.33 (0.03)	0.35 (0.03)	1.4	0.18	0.7
Jump height (m)	0.13 (0.03)	0.15 (0.02)	1.3	0.20	0.8

Note. M = mean; SD = standard deviation; t = t-test; ES = effect size (Cohen's d).
*Statistically significant difference between two groups ($p < 0.001$)

Figure 3. Ground reaction force (GRF) value for the jump landing demonstrated by one representative novice dancer (A. 21N) and one experienced dancer (B. 2E). The arrow indicates impact forces (F1) that measured in two dancers' second-position jump landing.

A. B.



Discussion

The primary aim of this study was to compare impact VGRF and RFD during ballet second-position jump landing tasks between novice and experienced ballet dancers. The results of this study supported the hypothesis that there is a significant difference in impact VGRF between the two groups, but there were no significant differences in peak take off force, time in the air, and jump height. The findings indicated that the difference in impact VGRF between the groups is mainly due to the different skill levels of landing, which is significantly different between the two groups, because no significant differences were found in the force during the take-off and flight phase as well as the jump height. The novice group tended to have a greater impact VGRF and RFD than the experienced group, which could lead to a greater possibility of injury in terms of the landing phase of ballet jumps in novice dancers than experienced dancers. This result contrasts with the previous study that there was no significant difference in the impact force between novice and experienced ballet dancers although they investigated dancers' turning, not jump landing.[9] The means of VGRF for each of the two groups in this study were both lower than the results of VGRF in Lin et al.'s study.[9] Lin et al.[9] had dancers lift their gesture leg up and down during the turns (*Pirouette*) in their study. The differences in other dance movements (turning vs. jumping) could elicit different results making it difficult to compare VGRF between studies.

Like most athletic performances, the landing phase of a jump in ballet is mainly concerned with minimizing the impact force, which is involved in the shock absorption of the dancer's body. In terms of finding an optimal way of landing in vertical jumps, it is important to understand the impulse-momentum theorem.[6] The product of a body's mass times its velocity is called momentum ($P = m \times v$). Impulse is the product of a force and time ($J = f \times t$), and the impulse-momentum theorem is the combination of these two equations ($m \times v = f \times t$).[6] There are two types of landing that involve the relationship of this impulse-momentum theorem; hard landing and soft landing (Figure 3). Hard landing occurs when a dancer exerts a large amount of force in a short time during landing, in comparison to a soft landing which is when a small amount of force is applied over a longer time to control momentum.[6] Soft landing displays a longer impact phase and less impact forces. As Figure 3 represented, there is a clear and sharp impact force and a short period of impact phase displayed in a novice dancer and less impact forces and a long period of impact phase shown in an experienced dancer. This means experienced dancers used a longer duration in contact time to arrest their momentum for minimizing impact VGRF and RFD than novice dancers.

Chockely[7] claimed that there are three phases in landing of the jump (*rolling through the foot*) in ballet; toes' initial contacting, the ball of the foot contacting, and hill contacting.

Taking these three steps sequentially are mandatory rules for a successful second-position jump performance. To achieve the right landing phase, dancers must keep their feet with extreme plantar flexion (*en pointe*) in the flight phase to land on their toes as a first phase of landing. An extreme range of motion of forced plantar flexion is one of the main reasons for getting injuries to the ankle and foot in professional ballet dancers and it accounts for 34% to 62% of all injuries suffered by ballet dancers.[15–17] However, the strategy of landing on the toes is beneficial not only because it can decrease impact force by absorbing kinetic energy and attenuating shock with the springiness of the arch of the foot but also for the aesthetic performance of ballet jumps.[18] The average amount of experience for novice dancers recruited for this study was less than a year, and the average of practice hours per week was about 2.4 hours, which means they are still in the rudimentary stages of ballet. It would be possible that novice dancers either have less flexibility for having their toes as required extreme plantar flexion in the air, or do not clearly understand how to maintain their feet as a clear *en pointe* in the air. Thus, the lack of proficiency in jumping may negatively affect their landing phase of jump resulting in the greater impact force in novice dancers.[19]

Correct, clear, and consistent instruction from a ballet educator creates a skilled ballet dancer whose posture is correct and movement is clear. Especially when ballet teachers teach students how to jump, they frequently use external focus instruction such as ‘jump lightly as a feather and land softly without sound’ to instruct students on how to jump higher and lighter.[20] According to the literature, augmented feedback significantly decreased impact forces in jump landing, and the effect of augmented feedback for minimizing VGRF was significantly greater than sensory feedback or non-feedback.[21,22] As experienced dancers who have had those training regimens with their dance educator’s instruction, they might acquire the skills for impeccable ballet jumps as well as their own protective strategy from jumps. This gained strategy could contribute to reduce their impact force because their goal is to jump as high as possible and land as quietly as possible with what is known as *pull up*. *Pull up* is straightening the arms and legs and lifting up their body including the sternum, core, chin, and a head, while pulling down their shoulders in order for the dancers to get ready to perform any ballet movement. In addition, one of the main desirable jump techniques in ballet is ballon, which refers to the gravity defying lightness during jumps. This technique is used for a dancer to be seen suspended in the air and to land softly.[23] Thus, the proficiency and confidence gained from accumulated practice with repetitive augmented feedback in experienced dancers could definitely be one of the reasons why the impact force differs with skill levels.

There are a few limitations in this study. First, only VGRF of the second-position jump landing was examined and compared between the two groups. It could be possible that other ballet jumps with different positions may lead to different results. Also, as previously mentioned, there are more factors that can hinder a dancer's vertical jump other than a faulty technique and a lack of appropriate instruction such as ballet footwear or floor surface.[2,7,24] Second, this study did not investigate differences in the dancers' to the dancers' turnout angle. Turnout angle could possibly influence dancers' jump height and GRF also. Future study is required to identify whether the different angles of turnout between different skill levels is also a crucial factor for VGRF during ballet jump landings. Also, careful examination into the influence of the level of instruction on ballet jumps could be the next stage for future study.

Conclusion

Novice ballet dancers displayed greater impact VGRF and RFD than experienced ballet dancers during the landing phase of a second-position jump. The difference in these values does not appear to be related to take off force or jump height since these values were not significantly different between the two groups. The difference of proficiency in ballet can be considered an influential factor for dance instructors, educators, and physicians to help dancers to reduce the likelihood of potential injuries, and for dancers themselves to execute a better jump performance.

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