SELF-DESCRIBED DIFFERENCES BETWEEN LEGS IN BALLET DANCERS: DO THEY RELATE TO POSTURAL STABILITY AND GROUND REACTION FORCE MEASURES?

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DEDICATION

I dedicate the publication of this manuscript to my "support system" who helped me fight through the ups and downs I experienced during researching, writing, editing, and testing. To Mom, Dad, Landon, and '09-'11 "IUBTers": Thank you so much for your support, encouragement, patience, and understanding while I worked on (and occasionally struggled with) this endeavor.

I want to especially thank "my" dancers for being so willing to help me in the conception, development, and execution of this project. Without you, this thesis quite literally would not exist!

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SELF-DESCRIBED DIFFERENCES BETWEEN LEGS IN BALLET DANCERS: DO THEY RELATE TO POSTURAL STABILITY AND GROUND REACTION FORCE MEASURES?

Ballet technique classes are designed to train dancers symmetrically but they may actually create a lateral bias. It is unknown if dancers are functionally asymmetrical or how dancer's perceived imbalances between legs manifest themselves. The purpose of this study was to examine ballet dancers' lateral preference through analyzing their postural stability and ground reaction forces in fifth position when landing from dance-specific jumps. Thirty ballet majors volunteered to participate in this study. Each subject wore ballet technique shoes and performed fundamental ballet jumps out of fifth position on a force plate. The force plate recorded center of pressure (COP) and ground reaction force (GRF) data. Each subject completed a laterality questionnaire that determined the dancer's (1) preferred landing leg for ballet, (2) self-identified stronger leg, and (3) self-identified leg with better balance. All statistical comparisons were made between the leg indicated on the post-test questionnaire and the other leg. No significant differences were identified between the limbs in any of the analyses conducted ($p > .05$). The results of this study indicate that a dancer's preferential use of one limb over the other has no bearing on the GRFs or balance ability after landing jumps in ballet. Similarly, dancers' opinions of their leg characteristics (such as one leg being stronger than the other) seem to be separate from the dancers' actual ability to absorb GRFs or to balance while landing from ballet jumps. Although we found no functional asymmetry in the measures studied here, the things that could contribute to a lateral bias in ballet technique class and to functional differences associated with this lateral bias are multi-faceted. The results of this study cannot, by themselves, definitively say that ballet technique class develops the dancer equally bilaterally or that ballet dancers are without any functional asymmetry.

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INTRODUCTION

Generally, the legs of healthy athletes are not equal in use,[1-5] functional abilities,[1-4,6] or muscle characteristics.[2,5,7-9] However, in ballet, the dancer is expected to use each leg equally.[10-12] In theory, ballet technique classes should train both limbs equally, since the same exercises and movements are performed by each leg.[10,12] However, it has been suggested that the way technique class is taught can contribute to functional or physical differences between the legs.[12] This asymmetry may be due to more repetitions being performed with the right leg than the left or the frequent use of the right leg as the working leg during the initiation of barre and centre combinations.[12] Dancers are aware of this possible asymmetry and oftentimes claim to be able to sense differences between their legs in strength, flexibility, and functionality. However, little is known about how, or if, these perceived imbalances manifest themselves when the performer is dancing. The presence of a lateral bias, or overdevelopment of one leg compared to the other, in ballet technique class could have several consequences for the dancer, including injury and chronic pain.[12]

Possessing good postural control is important to the athlete and dancer alike because heightened balance abilities are associated with a decreased risk of injury.[13,14] Dancers are frequently studied in association with postural control[15-20] since ballet requires controlled movements mixed with brief periods of standing still,[16,21] which demands superior postural control for success.[22] Most studies have compared dancers to non-dancers, finding that dancers maintain their postural control more efficiently.[15-17,20] However, since these studies included subjects that were not ballet dancers, the tasks performed were rather non-specific, with the most dance-specific task being standing on one leg with the eyes open. The improved postural control associated with dance training is only demonstrated when a dancer performs tasks that are similar to the fundamental tasks associated with dance.[16,18,20]

Poor postural control is not the only thing that can lead to injuries. Another factor related to the incidence of injury is the ground reaction force (GRF) acting on the feet and legs, especially when landing from a jump.[23-25] Jumps are frequent in ballet repertoire, with one study reporting over 200 jumps per one and a half hour technique class.[26] Of these observed jumps, 56% of them were one-footed landings,[26] causing the landing leg to absorb higher forces than it has to absorb during two-footed landings. Ground reaction forces are of particular importance to the dance science community due to their relationship with stress fractures in the foot and lower leg.[25] These injuries often plague a dancer's career and can even end it. Surprisingly, there are very few studies analyzing GRFs in dancers.

Movement in ballet is founded on five positions of the feet,[27,28] known as first, second, third, fourth, and fifth positions.[28-30] All movements in ballet start, end, or move through at least one of these foot positions.[29] Although it would make sense to examine dancers in several functional postures, there is a paucity of literature examining anything related to ballet dancers in any foot position other than first position. First position joins fifth position as the most common starting positions for dance movements in ballet training and performance.[31] Yet, fifth position is not as prominently featured in the dance science literature. In the literature examining balance and ballet dancers, functional tasks are also scarce. For example, balance has been studied in static postures,[15-20] but dynamic ballet movements have seemingly been left out.

As more dance-specific, functional tasks are investigated in published literature, a greater number of studies can examine more complex topics within the field of dance science. The results and conclusions from such studies can lead to improvements in healthcare for the dancer or in a dancer's performance. However, many of these studies require a broader base of scientifically-supported knowledge than currently exists. Presently, studies examining dancers have not investigated balance or GRFs in any fundamental foot position with a focus on laterality. Therefore, the purpose of this study was to examine ballet dancers' lateral preference through analyzing their postural stability and ground reaction forces in fifth position when landing from dance-specific jumps.

METHODS

Subjects

Thirty ballet dancers (23 females, 7 males; age: 19.6 ± 1.1 yrs.; height: 169.7 ± 8.7 cm; weight: 55.2 ± 8.7 kg) volunteered to participate in this study. All subjects were public university students majoring in ballet and were participating in ballet class and rehearsals five days per week. All subjects completed a medical screening questionnaire to determine eligibility for participation in the study. No potential subjects were disqualified due to pre-existing conditions or injuries that would interfere with jumping or balancing ability. The amount of ballet training averaged 12.8 (± 4.0) years of experience, with the females having 8.2 (± 1.6) years of experience dancing en Pointe. Prior to participation, all subjects read and signed an informed consent form. Both the form and the study were approved by the university's Institutional Review Board for the Protection of Human Subjects.

Procedures

Each subject performed three trials of four different tasks, for a total of 12 trials. All trials were performed in fifth position with the subjects wearing ballet technique shoes (Figure 1). The four tasks performed were (Figures 2-5): (1) changement landing with the left foot in front, (2) changement landing with the right foot in front, (3) entrechat trois landing on the right foot, and (4) entrechat trois landing on the left foot. The order in which the tasks were performed was randomized in an attempt to avoid any possible order effect. After completing all of the jumping tasks, each subject filled out a laterality questionnaire (Figure 6).

To begin each testing period, the subjects were instructed to step onto the force plate and stand in fifth position, centering themselves on an 'X' on the center of the force plate. The subjects were instructed to hold their arms in classical first position and to look straight ahead to a small black square on the wall throughout the trials. These instructions were designed to minimize any possible negative effects on balance that might occur as a result of arm, head, or eye movements during a trial. When the subject was ready to begin, he or she was instructed to perform a jump. The jump was either a changement or an entrechat trois. A changement is a jumping step beginning in fifth position. The dancer changes foot position in the air and lands in fifth position with the opposite foot in front. The foot that begins in front of the other foot finishes the jump in back of the other foot. An entrechat trois (frequently shortened to "trois") is similar to a changement in that the feet cross each other while the dancer is in the air. Each crossing is counted as two movements, since each leg makes one movement during a crossing, and an entrechat trois has three crossings. However, unlike a changement, a trois is landed on one foot.

The force plate recorded GRF and center of pressure (COP) measures. The GRF measures included maximal vertical GRF equalized to body weight (N/kg) and time to maximal vertical GRF (sec). The COP measures were anterior-posterior (AP) sway (cm), medial-lateral (ML) sway (cm), total COP excursion (measured through COP path length) (cm), and average COP velocity (cm/s).

Two of the questions on the questionnaire were examined using data collected during the trois conditions and one was analyzed using both changement and trois data. Since two of the three questions analyzed were yes/no questions followed by a question asking the dancer to indicate the right leg or the left leg only if they indicated yes, not all dancers provided a response to every question. Additionally, two dancers did not indicate a preferred landing leg on the questionnaire. This is why the *n* values (the number of respondents) for each question are different from each other and are less than the overall number of participants in this study (30). Reliability testing was performed on the questionnaire by having subjects fill out the questionnaire on two separate days, several months apart. The overall intraclass correlation coefficient ($ICC_{(2,1)}$) was 0.79 (SEM = 0.65).

To minimize the risk of injury from participating in this study, the subjects were scheduled to participate after ballet class or rehearsal, offered the opportunity to warm-up before participating, and given 30-second rest intervals between tasks. Since all of the tasks are fundamental ballet jumps and all subjects were university ballet majors, familiarization with the jump technique was not necessary. One practice trial of each task was allowed for each subject to become familiar with the surface of the force plate. This study used the AccuGait force plate (Advanced Mechanical Technology Inc. [AMTI], Watertown, MA). Data were acquired and processed using NetForce (AMTI, Watertown, MA, version 2.4.0) and BioAnalysis software (AMTI, Watertown, MA, BioSoft, version 2.3.0), respectively. Acceptable trials were defined as trials in which the participant completed the task without moving out of fifth position, moving arms out of first position, landing with any part of the foot off of the force plate, or making any head movements.

Statistical Analysis

The mean of the three trials for each task was used for statistical analysis. All data were grouped according to the responses provided in the post-test questionnaire and all comparisons were made between the leg indicated on the post-test questionnaire and the other leg (labeled "preferred leg" and "non-preferred leg," respectively). For each of these comparisons, the GRF measures and the COP measures were analyzed separately. Every comparison was performed using a multivariate repeated measures Analysis of Variance (ANOVA). Alpha level was set at $p < .05$.

RESULTS

No significant differences were found in any of the multivariate repeated measures ANOVA. The Wilks' Lambda values and p values are listed in Table 1. The means and standard deviations are in Table 2.

DISCUSSION

It is a common belief among dancers and dance educators that ballet technique classes may teach or enforce a preferential use of one leg over the other. This unequal training and asymmetrical development is known as lateral bias. It has been suggested that lateral bias in ballet training may cause or contribute to habits that negatively influence a dancer's body and dance technique in the form of injuries or plateaus in development as an artist.[12] However, very little research has been performed to determine if a lateral bias actually exists in ballet technique classes[12] or what, if any, detrimental effects a lateral bias may have on the dancer's body or development.

Since most of the tasks performed in life require the use of both limbs in different capacities (in ballet, this is represented in the form of the support leg and the working leg), it is expected that the legs would be developed and used differently.[32] However, the preferential use of one limb over the other for a specific function may change depending on the task to be performed.[32] This concept has an implication for research examining single-leg tasks. Researchers often ask subjects to identify their preferred leg for kicking a ball and then label this leg as the dominant leg.[1,33-36] However, kicking a ball is not a very functional task for ballet, and dancers, in theory, do not have a dominant leg.[10-12] Therefore, examining the preferred leg for a given ballet-specific task may be more useful to the researcher than determining a dominant limb. Perhaps researchers should attempt to identify leg preference through the use of a questionnaire specific to dance tasks, allowing the researcher a more complete look at the dancer's "laterality profile," ideally providing insight into the complexity of lateral bias in ballet.[32] We developed and used such a questionnaire for this very purpose. Responses on the questionnaire provided a framework for examining our data.

No differences between the preferred leg and the non-preferred leg were found for any of the tasks analyzed. The lack of differences in our study may be due to the fact that the subjects participating in this study are elite ballet dancers who are highly skilled and technically proficient. In fact, the apparent symmetry demonstrated in this study could be part of the reason that the dancers in this study have been successful enough in ballet to progress to such a high level. It could be argued that functionally-asymmetric dancers do not possess the ballet-specific skill set needed to succeed at this level. No matter what may have contributed to our findings, the results support the idea that the preferential use of one leg over the other for specific dance tasks is not directly related to the proficient performance of that task.[32] In general, it seems that a dancer's preferential use of one limb over the other has no bearing on the GRFs or balance ability associated with landing jumps in ballet. Similarly, dancers' opinions of their leg characteristics (such as one leg being stronger than the other) seem to be separate from the dancers' actual ability to absorb GRFs or to balance while landing from ballet jumps. The following paragraphs will specifically look at the data related to each limb preference question.

"Which leg do you prefer to use when landing from a jump in ballet?" – Trois Condition

The dancer's preferred landing leg was examined using the trois data. This analysis allowed us to determine if there were any physical manifestations of landing leg preference in GRF absorption or balance ability after landing a one-footed ballet jump. Interpretation of results indicates that a dancer's preferred landing leg does not differ from the other leg in the maximum vertical GRF incurred during the landing of the trois or in the time from initial contact with the ground to the maximum GRF. In terms of GRF absorption, ballet dancers do not land differently (or "better") on their preferred landing leg as compared to their non-preferred leg. Additionally, the dancers' preferred landing leg did not demonstrate different balance capabilities than their non-preferred landing leg. It appears that a landing leg preference does not translate to better balance ability on that leg. These findings are consistent with the idea that limb preference does not have any relevance to the performance of a given task for the ballet dancer.[32] Therefore, the clinical dance medicine professional may be able to extrapolate that landing leg preference may not have any bearing on the way dancers (1) absorb the potential injury-causing GRFs associated with landing jumps or (2) maintain balance after landing single-leg jumps in ballet.

"Do you feel that one of your legs is stronger than the other one? If so, which one?" – Trois Condition

We chose to examine the dancer's self-identified stronger leg since this information is often volunteered during clinical injury evaluations and strength is frequently associated with better function or control.[37,38] We chose to analyze this question in the trois condition because we felt that the discovery of a difference in landing forces and/or balance ability after landing a one-footed jump on the dancer's "stronger leg" as opposed to landing on the "weaker leg" could provide some insight into how certain dance injuries develop. Strength differences between muscle groups are thought to lead to injury, but to date, it is unclear what correlation, if any, muscular imbalance has with injury risk or rate.[32]

It would make sense for the dancer's identified stronger leg to demonstrate its supposed superior strength through absorbing GRFs over a longer period of time, indicating that the dancer's muscles, and not the bones, are absorbing these forces.[24,25] Strength can be associated with balance ability, too. The body's postural control system uses small muscular contractions to maintain balance.[15,39-42] It could be conceived that a "stronger" leg would demonstrate better balance through the muscular contractions needed to control the body's natural sway. However, we found no difference between the "stronger leg" and the other leg in time to maximal ground reaction force or any of the COP measures. While not directly measured in this study, we hypothesize that both heightened balance ability and the ability to absorb GRFs in a controlled fashion may be more a function of enhanced neuromuscular control as opposed to sheer muscular strength alone.[25] For the clinical dance medicine professional, it is helpful to know that when a patient states that their currently injured leg “is weaker than the other one,” it has little to do with the GRFs associated with landing from vertical jumps or with single-leg balance capabilities, two factors often credited with heightening injury risk.[13,14,23-25]

“Do you feel that you balance better on one leg compared to the other? If so, which one?” – Changement Condition, Trois Condition

The self-identified leg with better balance was chosen to be analyzed in both the changement and trois conditions since the design of this study examined the dancer’s balance ability after landing a ballet-specific jump and we wanted to determine if the dancers balanced better on the leg they felt had better balance. If there was a difference, we also wanted to ascertain if this difference would manifest itself in both single-leg and double-leg tasks.

In this study, AP sway and ML sway represent slightly different motions *within the foot* than these measures typically represent in non-ballet research, but they still represent *movement of the center of pressure* in the anterior-posterior and medial-lateral directions, respectively. The different motions within the foot are due to the position of the foot during turnout. Due to this external rotation of the leg, AP sway primarily reflects the dancers shifting their weight across the foot, from one side of the foot to the other. ML sway predominantly describes the body weight being shifted between the heel and the toes because of the position of the foot in turnout. COP length and COP velocity are not changed by turnout, because both measures describe the total movement of the center of pressure. These measures are closely related to each other, since COP velocity is simply the COP length divided by the length of time studied.

We found no differences in the dancers' postural control in the anterior-posterior direction (AP sway), the medial-lateral direction (ML sway), the total path traveled by the dancer's center of pressure (COP length), or the speed of movement of the center of pressure (COP velocity). These results indicate that a dancer's self-identified leg with better balance does not demonstrate superior balance ability as compared with the other leg. Furthermore, just as the preferred landing leg did not demonstrate heightened balance ability, the dancers' identified "leg with better balance" did not demonstrate enhanced GRF absorption capabilities while landing.

As discussed previously, dancers are often studied with regard to balance ability.[15-20] However, no studies have compared perceived balance ability and actual balance ability to determine if there is a relationship. The results of this study indicate that *perceived* heightened balance ability on one leg over the other does not manifest itself in *actual* heightened balance ability for either a two-legged stance with one foot in front of the other or a one-legged stance. This lack of association could substantiate the decision to arbitrarily choose a single limb to test for research examining balance tasks for ballet dancers instead of testing the preferred balancing leg.

Limitations of the Study

The study sample was limited to university ballet dancers. Therefore, the results may not necessarily be the same for other types of dancers (modern, jazz, tap, etc.). Additionally, the audition and admission process for obtaining entry into this particular university ballet program is rather vigorous, so this study's subject pool consisted of elite-level dancers. This high level of talent may be why no differences were found in any of the comparisons; it is possible that differences would be found in younger, less-experienced, or less-talented ballet dancers.

Suggestions for Future Research

There are several studies that could be designed to examine the physical and functional manifestations of perceived lateral bias in the dancer. Building off of the concepts in this study, it would be interesting to examine dancers' perceived differences in strength from one leg to the other using dynamometry (for multiple muscle groups) and electromyography (during multiple functional ballet tasks). This study design would allow the researchers to determine if the described differences between legs are present in force production or muscular recruitment. As mentioned previously, imbalance in muscular force production could lead to injury. "Correct" or superior patterns of muscular recruitment could help the body safely absorb higher GRFs.[25] Another study that could provide great insight into the laterality question presented here would be one using biomechanical markers on the body to examine the landing mechanics of double- and single-leg landings in the context of the dancer's self-identified "stronger leg" and "preferred landing leg." Such a study could show that the side-to-side differences described by dancers are reflected in the body's mechanics, rather than in the ability to land or balance. Authors examining landing mechanics of ballet dancers during single-leg drop landings have concluded that the dancers did not tend to land with mechanics often associated with an elevated risk of injury, but this study only tested dancers on their dominant leg.[24] It would be interesting to see if these findings would change once lateral preference and perceived strength were taken into account. If it could be shown that dancers can accurately predict which leg will land with faulty mechanics, predisposing them to injury, then these specific laterality questions could be incorporated into dance injury prevention screenings.

Conclusion

Ballet technique classes are designed to train both legs equally, but may actually contribute to functional differences in the legs. However, little is known about whether this asymmetrical training exists or if any functional differences are present in ballet dancers. The results of this study indicate that a dancer's preferential use of one limb over the other has no bearing on the GRFs or balance ability after landing jumps in ballet. Similarly, dancers' opinions of their leg characteristics (such as one leg being stronger than the other) seem to be separate from the dancers' actual ability to absorb GRFs or to balance while landing from ballet jumps. However, the factors that could contribute to a lateral bias in technique class and to functional differences associated with this lateral bias are multi-faceted. The results of this study cannot, by themselves, definitively conclude that ballet technique class develops the dancer's legs symmetrically or that ballet dancers are without any functional asymmetry.

Clinically, it appears that GRF absorption and balance ability in dancers are not influenced by: (1) which leg the dancer prefers to land with, (2) which leg the dancer feels is stronger, or (3) which leg the dancer feels has better balance. However, there may be a psychological aspect of the dancer's belief that one leg is "worse" than the other that is not yet known.

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Table 1: Wilks' Lambda values and p values for statistical analyses.

	Wilks' Lambda Value	p Value
Landing Leg – Trois		
GRF Measures	0.25	.78
COP Measures	1.37	.27
Stronger Leg – Trois		
GRF Measures	0.60	.56
COP Measures	1.59	.23
Leg with Better Balance – Changement		
GRF Measures	0.01	.99
COP Measures	1.55	.23
Leg with Better Balance - Trois		
GRF Measures	0.41	.67
COP Measures	1.78	.18

GRF measures were maximum vertical ground reaction force equalized to body weight and time to maximum vertical ground reaction force. COP measures were anterior-posterior sway, medial-lateral sway, center of pressure length, and center of pressure velocity.

Table 2: Means and standard deviations for statistical analyses.

	Max. Fz (N/kg)	Time to Max. Fz (s)	AP Sway (cm)	ML Sway (cm)	COP Length (cm)	COP Velocity (cm/s)
Landing Leg – Trois (N=28)						
Preferred Leg	2.29 ± 0.33	0.12 ± 0.02	8.98 ± 2.25	13.43 ± 1.90	92.55 ± 13.94	9.80 ± 1.46
Non-Preferred Leg	2.30 ± 0.39	0.13 ± 0.02	9.84 ± 2.91	14.78 ± 4.07	92.74 ± 22.46	9.81 ± 2.30
Stronger Leg – Trois (N=19)						
Preferred Leg	2.32 ± 0.31	0.13 ± 0.02	8.33 ± 2.11	13.32 ± 2.11	91.99 ± 15.31	9.78 ± 1.59
Non-Preferred Leg	2.26 ± 0.38	0.12 ± 0.02	10.04 ± 3.11	14.75 ± 4.15	92.79 ± 22.47	9.84 ± 2.32
Leg with Better Balance – Changement (N=23)						
Preferred Leg	2.19 ± 0.31	0.12 ± 0.03	9.46 ± 2.67	11.52 ± 4.16	61.93 ± 9.02	6.55 ± 0.89
Non-Preferred Leg	2.19 ± 0.31	0.12 ± 0.03	8.28 ± 2.84	12.06 ± 4.47	63.48 ± 10.13	6.77 ± 0.99
Leg with Better Balance – Trois (N=23)						
Preferred Leg	2.29 ± 0.30	0.12 ± 0.02	9.91 ± 3.52	13.75 ± 2.84	93.23 ± 14.98	9.95 ± 1.58
Non-Preferred Leg	2.35 ± 0.39	0.12 ± 0.02	9.17 ± 2.61	15.13 ± 3.89	96.22 ± 20.59	10.27 ± 2.14

LIST OF FIGURES

Figure 1: Fifth Position. This picture shows the feet in fifth position, with the right foot in front. This picture also shows ballet technique shoes and the force plate.

Starting Position **Ending Position**

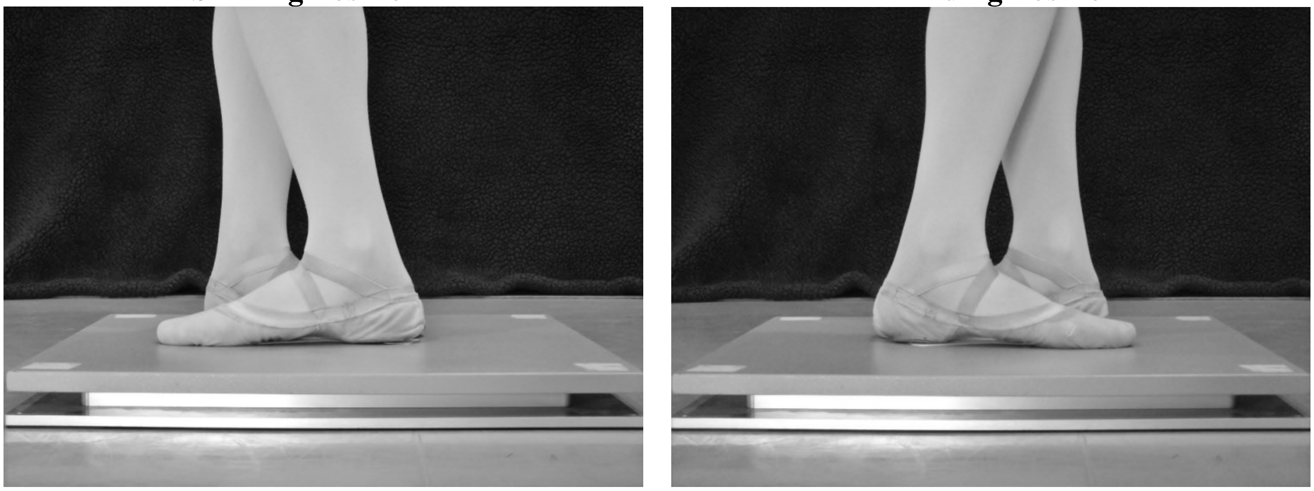

Figure 2: Changement Left. This jump starts in fifth position with the right foot in front, shown on the left. The dancer jumps into the air, switches foot position, and lands in fifth position with the left foot in front, shown on the right.

Starting Position **Ending Position**

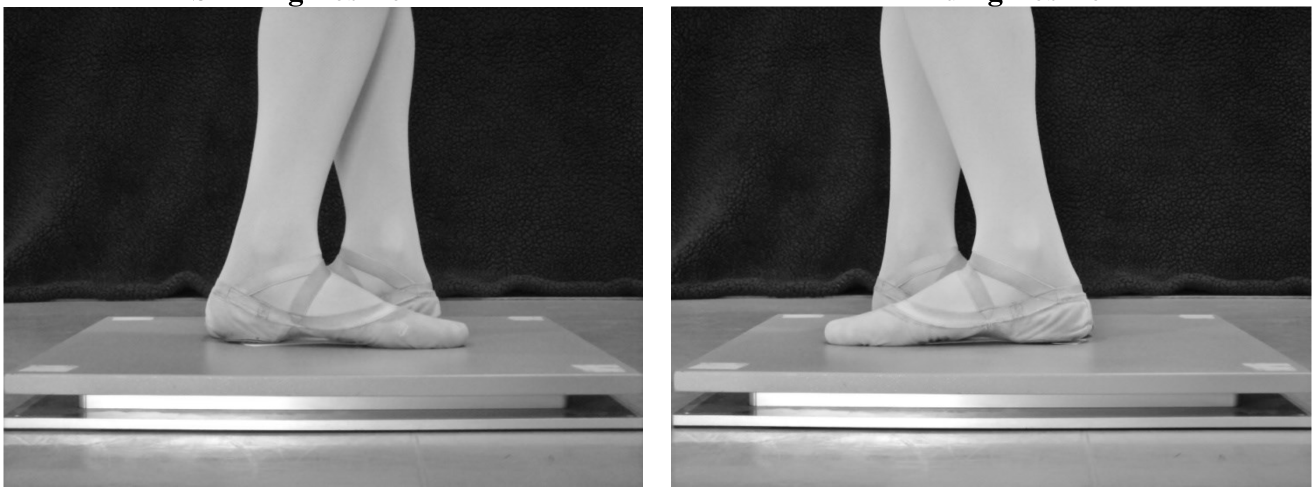

Figure 3: Changement Right. This jump starts in fifth position with the left foot in front, shown on the left. The dancer jumps into the air, switches foot position, and lands in fifth position with the right foot in front, shown on the right.

Starting Position

Ending Position

Figure 4: Trois Right. This jump starts in fifth position with the left foot in front, shown on the left. The dancer jumps into the air, switches foot position twice, and lands on the right foot with the left foot near the lower half of the right leg, shown on the right.

Starting Position

Ending Position

Figure 5: Trois Left. This jump starts in fifth position with the right foot in front, shown on the left. The dancer jumps into the air, switches foot position twice, and lands on the left foot with the right foot near the lower half of the left leg, shown on the right.

* Which leg do you prefer to use when landing from a jump in ballet? ☐ Right ☐ Left

* Do you feel that one of your legs is stronger than the other one? ☐ Yes ☐ No
If so, which one? ☐ Right ☐ Left

*†Do you feel that you balance better on one leg compared to the other? ☐ Yes ☐ No
If so, which one? ☐ Right ☐ Left

Figure 6: Post-test Questionnaire. The subjects answered these questions after they completed all of the jumping tasks.
* Indicates that the trois data were analyzed according to the responses to this question.
† Indicates that the changement data were analyzed according to the responses to this question.

APPENDICES

APPENDIX A

Operational Definitions

Assumptions

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Statement of the Problem

Independent Variables

Dependent Variables

Hypotheses

References

Operational Definitions

1. Acceptable trial: An acceptable trial was a trial in which the participant completed the task without moving out of fifth position, moving arms out of first position, landing with any part of the foot off of the force plate, or making any head movements.
2. Anterior-Posterior sway: Anterior-posterior sway is the movement of the center of pressure in the anterior-posterior direction as recorded by the force plate.
3. Center of pressure (COP) length: The COP Length is the length of the total distance traveled by the center of pressure as recorded by the force plate.
4. Center of pressure (COP) velocity: For this study, we examined the average velocity traveled by the center of pressure as recorded by the force plate.
5. Changement: Changement is an abbreviated version of the ballet term "changement de pieds", a French phrase that means "change of feet." Changements are jumping steps, beginning in fifth position. The dancer changes foot position in the air and lands in fifth position with the opposite foot in front. The foot that begins in front of the other foot finishes the jump in back of the other foot. A changement is also an entrechat deux.
6. Entrechat trois, commonly shortened to "trois": Entrechats are jumping steps in which the dancer takes off with both feet and quickly crosses the legs, according to the number of the entrechat, before landing. The number of the entrechat is indicated by the number following it (deux, trios, quatre, etc.) and defines the number of crossings. Each crossing is counted as two movements, since each leg makes one movement during a crossing. Odd-numbered entrechats, such as the trois, land on one foot. For this study, the trois will begin in fifth position and will be landed on the foot that starts the jump behind the other foot.

7. Fifth position: Fifth position is a functional ballet foot position obtained by the heel of the front foot contacting the great toe of the rear foot, with both legs in the dancer's maximal turnout.
8. Ground reaction force (GRF): Ground reaction force is the force that a support surface (the force plate) exerts on the body when the body is in contact with the support surface. These forces are equal in magnitude, but opposite in direction, to the forces the body exerts on the support surface. This study will examine the maximum ground reaction force exerted on the body during two different ballet jumps, each landing in two different foot positions.
9. Healthy subject: A healthy subject was defined as not having a significant injury to the lower extremity within the last two weeks. A significant injury was defined as an injury that caused the dancer to miss more than three consecutive days of ballet class and/or rehearsal.
10. Maximal turnout: A dancer achieves maximal turnout through maximal external rotation of the lower extremity. Theoretically, maximal turnout is not achieved through forcing turnout, and it is the amount of turnout that a dancer uses while dancing. To avoid inadvertently influencing the balance measurements, measurements of turnout were not made.
11. Medial-Lateral sway: Medial-lateral sway is the movement of the center of pressure in the medial-lateral direction as recorded by the force plate.
12. Technique shoes: Technique shoes are flat ballet shoes (not pointe shoes). Technique shoes are typically worn by both men and women during technique class and by men during rehearsal and performance.
13. Time to maximum GRF: The time to maximum ground reaction force is the time, measured in seconds, from the initial contact with the force plate upon landing until the maximum ground reaction force value is reached.

Assumptions

The following assumptions will apply to this study:

1. Subjects followed directions completely and correctly.
2. Subjects provided uniform effort in all trials.
3. Subjects applied appropriate dance technique at all times.
4. The force plate is a reliable and accurate way to evaluate COP and GRF measures.
5. Answers on the questionnaire were honest and accurate.
6. The time of day did not have an effect on the results.

Delimitations

The following delimitations apply to this study:

1. Subjects were ballet majors at a large Midwestern public university.
2. There were 30 subjects participating in this study.
3. Subjects were between 18 and 22 years old.
4. Subjects were considered "healthy," meaning that they were free of significant lower extremity injuries (defined as an injury causing the dancer to miss more than three consecutive days of ballet) during the two weeks prior to participating in the study.
5. Subjects wore technique shoes during testing.
6. Subjects were tested landing from entrechats, specifically changement (deux) and trois.

Limitations

The following limitations applied to this study:

1. The surface of the force plate may have been slicker than the typical floor surface of the dance studio or stage, making it more difficult for dancers to achieve and maintain turnout.
2. The amount of turnout and how turnout was achieved may have differed among subjects.

Statement of the Problem

Ballet technique class is designed to develop both legs equally, but may, in fact, contribute to greater development of one leg over the other.[1,2] Dancers are aware of this possible asymmetry and oftentimes claim to be able to sense differences between their legs in strength, flexibility, and functionality. However, little is known about how, or if, these perceived imbalances manifest themselves when the dancer is dancing. The presence of a lateral bias, or overdevelopment of one leg compared to the other, can have several consequences for the dancer, including injury and chronic pain.[2] Another factor that can contribute to the incidence of injury is the ground reaction force (GRF) acting on the feet and legs, especially when landing from a jump. Ground reaction forces are of particular importance to the dance science community due to their relationship with stress fractures in the foot and lower leg – injuries that can plague, or even end, a dancer's career. Surprisingly, there are very few studies analyzing GRFs in dancers. In dance medicine literature focusing on ballet dancers, studies examining balance while performing functional tasks are scarce. For example, balance has been studied in static ballet postures,[3-8] but dynamic ballet movements have seemingly been left out. Increased balance capabilities can reduce the risk of injury.[9,10] Therefore, examining balance in functional postures and tasks could have implications for developing and critiquing injury prevention programs. Currently, studies examining dancers have not investigated balance or GRFs in any fundamental foot position with a focus on laterality. The purpose of my study is to analyze dancers' postural stability and GRFs in fifth position, landing from dance-specific jumps, in the context of lateral preference.

Independent Variables

For each of the jump conditions (double-leg landing [changement] and single-leg landing [entrechat trois]), one independent variable was evaluated in this study:

Limb at two levels

a. Preferred leg
b. Non-preferred leg

Dependent Variables

Six dependent variables were evaluated in this study:

1. Maximum ground reaction force (GRF) equalized to body weight
2. Time to maximum GRF (s)
3. Anterior-posterior (AP) sway (cm)
4. Medial-lateral (ML) sway (cm)
5. COP length (cm)
6. COP velocity (cm/s)

Research Hypotheses

For both the changement and trois jump conditions, the following research hypotheses applied:

1. There will be a significant difference in the maximum GRF equalized to body weight between the preferred leg and non-preferred leg landings.
2. There will be a significant difference in the time to maximum GRF between the preferred leg and non-preferred leg landings.
3. There will be a significant difference in AP sway between the preferred leg and non-preferred leg landings.
4. There will be a significant difference in ML sway between the preferred leg and non-preferred leg landings.
5. There will be a significant difference in the COP length between the preferred leg and non-preferred leg landings.
6. There will be a significant difference in the COP velocity between the preferred leg and non-preferred leg landings.

Statistical Hypothesis

For both the changement and trois jump conditions the following statistical hypotheses applied:

1. Maximum GRF equalized to body weight $H_A: \mu_P \neq \mu_{NP}$
2. Time to maximum GRF $H_A: \mu_P \neq \mu_{NP}$
3. AP sway $H_A: \mu_P \neq \mu_{NP}$
4. ML sway $H_A: \mu_P \neq \mu_{NP}$
5. COP length $H_A: \mu_P \neq \mu_{NP}$
6. COP velocity $H_A: \mu_P \neq \mu_{NP}$

Null Hypothesis

For both the changement and trois jump conditions the following null hypotheses applied:

1. Maximum GRF equalized to body weight $H_0: \mu_P = \mu_{NP}$
2. Time to maximum GRF $H_0: \mu_P = \mu_{NP}$
3. AP sway $H_0: \mu_P = \mu_{NP}$
4. ML sway $H_0: \mu_P = \mu_{NP}$
5. COP length $H_0: \mu_P = \mu_{NP}$
6. COP velocity $H_0: \mu_P = \mu_{NP}$

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APPENDIX B

Literature Review

REVIEW OF LITERATURE

This review of literature will discuss the technical foundations of ballet and how improper execution of the basic mechanics of ballet can put the body out of alignment, possibly leading to an elevated risk of injury. Limb dominance and preference in athletics and ballet will be examined. The definition of postural stability will be reviewed, followed by a discussion of the various measures that have been used to assess it in human subjects. A similar discussion about ground reaction forces will follow a definition of these forces. Lastly, balance and ground reaction force studies in dancers will be examined.

Ballet

The technical basis of ballet includes the five fundamental positions of the feet.[1,2] All movements in ballet start, end, or move through one or more of these positions.[3] These positions are distinct from other athletic positions due to turnout, which is created primarily from external rotation of the hips.[1,3-7] Ballet foot positions are known as first, second, third, fourth, and fifth positions.[2-4] The foot positions were developed in an effort to appear more open to the audience and to allow the dancer to move more efficiently through balletic movements.[1] The foot positions are also thought to provide the dancer with a "precise" base of support.[1]

Each of the foot positions are achieved with the hips externally rotated in the dancer's "maximal turnout".[1,2,4,5] The heels touch in first position.[2,4] Second position abducts the legs so that the feet are pelvis-width apart.[4] Third, fourth, and fifth positions are referred to as the crossed positions since one foot is placed in front of the other.[4] Third position places the feet with the heels in line with the middle of the other foot.[2,4] In fourth and fifth positions, the legs are adducted further than in third position, to the point that the heel of one foot is in line with the toes of the other foot.[4] In fourth position, the feet do not touch – they are separated by about the length of a foot.[4] In fifth position, the heel of the front foot is in contact with the great toe of the rear foot.[2,4]

The phrase "ideal turnout" is often used to describe the angle of turnout needed to be considered aesthetically pleasing in ballet. A dancer achieves ideal turnout through 90° of external rotation of each lower extremity, so that the feet form a 180° angle when measured in first position.[7] While most dancers cannot achieve ideal turnout, the angle of turnout used by dancers has been shown to be consistently greater than a dancer's passive external rotation of the hip.[3,4,7] Some experts believe that the extra degrees of turnout can be achieved healthily through external rotation of both the tibia and foot.[4,7] In weight-bearing, a dancer can achieve additional rotation in the lower extremity below the hip by using friction from contact with the floor to achieve greater turnout.[7] Other experts believe that a dancer's turnout should not exceed the external rotation capabilities of the hip.[3] Proponents of this belief feel that the additional degrees of turnout (the difference between passive external rotation and the amount of turnout) are only reached through compensatory motions throughout the leg that force turnout.[3,6]

The amount of turnout present in fifth position has been shown to be greater than the amount of turnout present in first position.[5,7] In fact, one study comparing turnout angles in first and fifth positions found that fifth position functional turnout angles were greater than those in first position for both static and dynamic positions.[7] The static position examined was an assumed position and the dynamic position was examined when the dancers were landing from a jump.[7] This study also found that compensated turnout, defined as the difference between functional turnout and hip external rotation, was greater in fifth position than in first position.[7]

There have been several possible explanations offered with regard to this phenomenon. This greater amount of turnout present in fifth position may be due to the dancer's ability to force turnout at the knee and ankle by bracing one foot against the other in this position.[5] Another possible explanation could be the emphasis in ballet technique on fully crossing the feet while in fifth position; this motion would necessarily need an increased external rotation of the legs.[7] Yet another explanation for finding increased turnout in fifth position is that fifth position is the most frequently practiced position during both ballet training and performance.[7]

Forcing turnout can lead to several misalignments in the lower extremity, especially at the foot and knee.[3,5] Many dance teachers and dance medicine professionals believe that forced turnout, and the improper alignment that it causes, places the dancer at an elevated risk of injury.[3,6] It is thought that forcing turnout directly leads to chronic injuries through overload of the involved tissue.[7] However, the few studies[3,6,7] that have examined potential relationships between incidence of injury and turnout, hip range of motion, or postural alignment have had mixed results.

One study administered an injury history questionnaire to dancers and compared the results with postural alignment findings previously published by the same authors.[6] This study did not find significant relationships between poor alignment and elevated incidence of injury.[6] These findings, or, rather, lack of findings, may be due to the study's cross-sectional design.[6] In a cross-sectional study, the possible correlation between poor alignment and injury may be difficult to find.[6] Previous or recurrent injuries may force dancers to correct alignment faults during their dance career or to retire from dancing entirely.[6] Such instances may not be apparent in a cross-sectional study.[6] A longitudinal study may be a more appropriate design.[6]

In a study examining dancers with injuries and dancers without injuries, the investigator found that there was not a significant difference in hip range of motion between the two groups.[3] However, a significant difference did exist between the two groups of dancers for both functional turnout angle, measured in first position, and compensated turnout.[3] Compensated turnout referred to the calculated difference between the dancer's turnout in first position and his or her external rotation range of motion at the hip.[3] These results imply a link connecting forced turnout and chronic injuries in dance, without implying a similar link between hip external rotation and injury.[3]

One study found that the incidence of chronic injuries in dance are more related to functional turnout angles or dynamic control of the turnout angle than to hip external rotation capabilities alone.[7] The authors suggest that it is not enough to simply measure hip external rotation during an assessment of a ballet dancer's turnout.[7] Both the number and severity of non-traumatic injuries were found to be related to reduced functional turnout.[7] The number of non-traumatic injuries was positively correlated with both compensated turnout and the difference between the static and dynamic turnout angles for all three foot positions examined: first position, fifth position with right foot front, and fifth position with left foot front.[7] The severity of non-traumatic injuries was positively correlated with the difference between the static and dynamic turnout angles.[7] Prior to beginning their study, the investigators expected to find that dancers with a greater difference between the turnout angles exhibited during static and dynamic postures (those dancers who land in a less turned-out position than the starting/static position) had more, or more severe, injuries; their results support this belief.[7] Based on their findings, the investigators recommend that dancers achieve turnout angles that are based upon available range of motion and postural alignment.[7] Dancers should be realistic about the angle of turnout that they can actually achieve.[7] By following these recommendations, the authors suggest that the dancer would be able to decrease the need to compensate or force turnout, thereby decreasing the associated chronic tissue overload.[7] There are a number of potential risk factors for developing chronic injuries in dance; exhibiting a lowered dynamic control of turnout and attempting to attain turnout angles that exceed anatomical and physiological limits of range of motion are two such risk factors.[7]

Limb Dominance and Preference

In athletes, relying on one leg more than the other is normal and often desired. Generally, in the healthy athlete, the legs are not equal in use,[8-12] functional abilities,[8-13] or muscle characteristics.[9,12,14-16] The unequal use of the limbs in the athlete can lead to a larger difference in muscle thickness between the dominant and non-dominant legs, when compared to healthy, non-athletic individuals.[15] Some athletes, such as soccer players, may need to have equal limb capabilities to excel in their sport.[8] However, even the best of these athletes frequently exhibit differences between the limbs, resulting in a reduced playing ability when forced to use the non-preferred limb.[8] Skilled soccer players have demonstrated faster foot velocities resulting in higher ball velocities when using their preferred leg as compared to the non-preferred leg.[10,13] The faster leg-swinging speed may be related to a greater ability to generate larger muscle force during kicking on the preferred side.[10]

A study comparing the preferred and non-preferred legs of soccer players with respect to balance ability and muscle response found better stability in the non-preferred (non-kicking) leg, but this difference was not statistically significant.[8] The parameters examined within the study had such low power that the number of subjects required to produce statistically significant results was tremendously impractical.[8] Differences in muscle characteristics have been found in middle-aged individuals involved in sports, too; muscles in the dominant lower leg have been found to be significantly stronger than those on the non-dominant side.[16] There are even differences in knee laxity between the dominant and non-dominant legs of athletes.[17,18]

In ballet, the dancer is expected to use each leg equally.[19,20] In theory, ballet technique classes should train both limbs equally, since the same exercises and movements are performed by each leg.[19,21] However, it has been suggested that the way ballet technique class is taught can contribute to differences between the legs.[21] This asymmetry may be due to more repetitions being performed with the right leg than the left or the frequent use of the right leg as the working leg during the initiation of barre and centre combinations.[21] The presence of a lateral bias, or overdevelopment of one leg compared to the other, in ballet technique class can have several consequences for the dancer.[21] The development of technical skills can plateau and the dancer may be limited in the choreography he or she is able to perform.[21] Lateral bias in ballet can also lead to injury or the development of chronic pain.[21] One author even speculated that laterality in technique class can contribute to the development of unilateral stress fractures throughout a dancer's career.[22]

Studies examining functional differences between the lower limbs in ballet dancers have produced mixed results.[7,19,23] Unilateral maximal vertical jump height and mechanics have been shown to be equal bilaterally in female professional ballet dancers.[19] It was suggested that this limb symmetry is developed through ballet technique class.[19] Symmetrical training in ballet technique class may develop the neurophysiological components of unilateral jumping, such as muscular strength and coordination, equally.[19] A study comparing the turnout angle maintained after landing from a jump with the turnout angle achieved prior to jumping found a larger difference between the angles when the left foot was in front (as compared to the right foot in front) in fifth position.[7] The larger difference seen with the left foot in front indicates that the dancers landed in a less-turned out position than the starting position.[7] The larger post-jump turnout angle present with the right foot in front indicates a greater control of turnout during dynamic activity on the right side than the left.[7] This asymmetry could be a result of any limb imbalance that may be present in ballet training and choreography.[7] A different study examining a group of dancers found significant intra-subject differences in postural stability between the left foot and the right foot.[23] These authors felt that their results could be a reflection of the tendency for ballet dancers to rotate while standing on the left foot, potentially providing them with better balance on the left leg.[23]

Postural Stability

Postural stability is demonstrated when the body restores itself to an "equilibrium point" after being subjected to a disturbance.[24,25] An intrinsic balance system, or postural control system, is needed to stabilize the human body, as it is inherently unstable.[24,26-29] This postural control system, in stabilizing the body, results in slight movement of the location of the center of pressure.[24-26,28] Center of pressure has been defined in relation to the plantar surface of the foot as the starting point of the ground reaction force vector, or the center of the external forces acting on the foot.[26,30] The movement of the center of pressure is referred to as body sway and takes place primarily in the horizontal plane of motion.[24-26,28,31]

The amount of body sway that can take place without a person losing balance is circumscribed by the limits of stability.[32] The size of the area within these limits changes depending on the size of the support base, among other factors.[32] A small base of support results in a small area within the limits of stability.[32] With a small base of support, the distance between the center of gravity and the limits of stability is small.[32] The dynamic quality of the limits of stability is key to balance control during activities such as ballet that require small bases of support for success.[32]

The human body has been shown to oscillate as a functionally rigid unit.[28,31] Examining these oscillations involves measuring and studying the ground reaction forces applied to the body as well as the forces generated by the muscular contractions (a part of the postural control system) regulating the oscillations.[28,31] Postural control, or stability, has been assessed through examining the movement of the center of gravity, which is calculated from the analysis of body sway.[24,28,31,33]

Specifically analyzing ground reaction forces or body sway to examine balance requires the use of electronic laboratory equipment. However, balance can be assessed many different ways, ranging from clinically-applicable techniques to highly specific research methods. Balance has been studied in static[24,27,31,32,34-41] and dynamic[24,28,30,35,42] postures, with single-leg[27,31,33,35,37-40,42-44] and double-leg[28,31,32,34,38,39] support, on stable[27,34-36,38,39] and unstable[27,34-38] surfaces, and with varying degrees of visual impairment.[27,31,34-37,41] Multiple clinical assessments of balance have been studied,[27,34,36-38,42] as have various methods that are more equipment intensive and better suited for laboratory use.[24,26,28-31,33,35,36,38-40,43,44]

One piece of equipment often used in the research laboratory, the force plate, has distinguished itself as the gold standard both for measuring ground reaction forces and for calculating body sway from center of pressure measures. Force plates measure the vertical ground reaction force and present a way to calculate center of pressure data from this force, among others.[39] A force plate measures the point of force application through three or four load cells that are located within the plate.[26,31,38,39] Most force plates measure the anterior-posterior and medial-lateral components of the horizontal ground reaction force in addition to the standard measures of vertical ground reaction force, anterior-posterior sway of the center of pressure, and medial lateral sway of the center of pressure.[39] Force plates can also measure torque about the horizontal axes of the plate.[39] A subject stands on the plate and the resulting forces recorded by each load cell are changed into an electrical signal that is analyzed to determine the point of force application.[26,31,39] A force plate accurately measures the body's center of pressure[26,39] and is often used to assess the validity and accuracy of other measures of balance.[30,38] Both the center of pressure and force measures are sensitive to changes in stance difficulty.[39]

There are some common aspects of postural control that are frequently examined with force plates. Some of these aspects are steadiness, symmetry, and dynamic stability.[39] Although each study defines its own specific terminology, basic definitions of these terms do exist. Steadiness often refers to the ability of the subject to keep his or her body as still as possible.[39] Frequently, symmetry is defined as the capability of the subject to evenly distribute his or her weight between both feet while in an upright position.[39] Dynamic stability oftentimes refers to the capacity to transfer the vertical component of the center of gravity throughout the area of the base of support.[39] Force platform measures can be used to define both symmetry and dynamic stability. Symmetry is quantified when the force platform is used to measure the location of the center of pressure during a sampling period as the subject stands in a specific stance.[39] Dynamic stability is quantified through the vertical component of the center of gravity.[39] As long as the sampling period is long enough, the average position of this measure mirrors the average position of the center of pressure.[39]

Good balance is important to a physically active population for several reasons, including easier performance of activities of daily living and greater success in sport performance. Perhaps the most important reason for a physically active individual to possess good postural control is the apparent relationship between heightened balance abilities and decreased injury risk.[40,45] Balance training, performed on a foam stability pad, has been shown to eliminate the increased risk of inversion ankle sprains associated with elevated body mass indices and a history of ankle sprains.[45] Similarly, decreased postural control has been suggested to predispose individuals to ankle injuries, including sprains.[40]

Ground Reaction Forces

Ground reaction forces are intrinsically linked to center of pressure measures through the definition of the body's center of pressure[26,30] as well as the method of measuring postural sway[24,28,31,33] discussed previously. Additionally, ground reaction forces are studied through the same pieces of laboratory equipment used to calculate and assess body sway. The most frequently used piece of equipment is the force plate. As mentioned previously, the force plate is regarded as the gold standard for measuring ground reaction forces.[39]

The ground reaction force is the force exerted on the body by a support surface, such as the ground or a force plate. These forces are equal in magnitude, but opposite in direction, to the forces the body exerts on the support surface. Ground reaction forces are also called impact forces, since they are studied with regard to the amount of force exerted on the body following a step, drop, or jump. Ground reaction forces are often studied with respect to the gait cycle.[46] Impact forces have also been studied in association with two-footed landings,[46-49] one-footed landings,[19,50-52] and cutting activities.[47]

Ground reaction forces resulting from a jump landing are absorbed throughout the lower extremity, starting at the point of contact with the ground and traveling up the leg.[46] The impact on the lower extremity resulting from running produces significantly higher forces than the impact normally experienced during walking. The ground reaction forces resulting from jumping and landing from jumps are significantly higher than those present in running.[46] The human body has physiological shock absorbers that attenuate the ground reaction forces acting on the body.

Possessing good control over the rate the body diffuses ground reaction forces may prevent lower extremity injuries.[51] It has been suggested that, after injury, reducing the stresses or forces placed on the lower extremity, especially at the site of injury, may assist in the healing process.[46] However, the forces applied to the body in the first 50 milliseconds after landing from a jump cannot be attenuated through reactive muscular contraction, since the body needs that much time to react to the force application.[53] High forces applied to the body during this period of time may contribute to the development of overuse injuries, including stress fractures and shin splints.[53] Since the neurological system cannot respond quickly enough to dissipate forces in the first 50 milliseconds of force application, the athlete must land in a balanced position and with proper technique to prevent injury. In fact, training in landing technique and balance, beginning early in a female's athletic career could offset the potentially injurious landing mechanics adopted after reaching developmental maturity.[51]

Balance in Dancers

Dancers are often thought to have a heightened awareness of their body movements and positions.[35] Dance movements are frequently associated with postural control, since they involve combinations of controlled movements mixed with brief periods of standing still, or balancing, often on one leg.[35,42] Ballet requires superior balance and coordination for successful performance.[23] Oftentimes, the choreography of classical ballet requires the dancer to perform movements at the extreme ends of range of motion and to maintain postures that place the center of gravity on or beyond the boundaries of stability.[23] These requirements demand superior postural control.[23]

Several studies have investigated the balance capabilities of dancers. Most have compared dancers to non-dancers,[27,32,35,37,41] while others have simply expanded their results to conceivably apply to dancers, due to the immense similarities between the elite gymnasts studied and dancers.[31] These studies suggest that the training a dancer or gymnast receives assists him or her in maintaining postural control better than someone who has not had this training.[27,31,32,35] In fact, dancers demonstrated different postural control strategies,[27,41] faster long-latency responses in the postural muscles used to regain balance,[32] and greater consistency in muscle activation than non-dancers.[32] These findings are of particular interest when a dancer requires rehabilitation for an injury.[27,32] It is important for the clinician directing the dancer's rehabilitation to note that special training may be needed to help a dancer regain his or her postural control capabilities to their pre-injury levels.[27] Additionally, these findings may be the reasons dancers are able to maintain static postural control over a very small base of support.[32]

However, it is worth stating that the effect of the balance training associated with activities such as gymnastics or dance seems to enhance the participant's ability to balance only when tested under conditions similar to this training (i.e. standing on one leg with the eyes open).[31,35] Ballet accustoms dancers to standing on one foot or balancing in a posture that is difficult to maintain.[23] Postures that are more common to normal human activity, such as standing on two feet with the weight evenly distributed, are easy to maintain and are equally familiar to dancers and non-dancers.[41] Therefore, these postures reveal no differences in balance abilities between dancers and non-dancer controls.[41] In more challenging postures, the different postural control strategies and advanced balance abilities of dancers are demonstrated.[41]

Although it would make sense to examine dancers in several functional postures, there is a paucity of literature examining anything related to ballet dancers, especially their balance capabilities, in any foot position other than first position. Examining first position is logical due to its prominence in ballet technique,[7] but first position is not the only position featured so heavily in ballet. First position joins fifth position as the most common starting positions for dance movements in ballet training and performance.[7] Yet, fifth position is not as prominently featured in the dance science literature. Functional tasks are also scarce in the literature examining balance and ballet dancers. Balance has been studied in static ballet postures, but dynamic ballet movements have seemingly been left out. No studies have examined postural control in ballet dancers in both static and dynamic dance positions.

Ground Reaction Forces and Dancers

Dancers rely upon the health and sturdiness of their bodies, especially their legs, throughout their career.[48] Ballet is a very physically-demanding activity, and it requires the dancer to perform jumps frequently.[54] One study reported over 200 jumps performed per one and a half hour technique class with 56% of these jumps landing on one foot.[55] It has been suggested that dancers are at risk for injury to the lower extremity, especially the anterior cruciate ligament (ACL) of the knee, due to their repetitive jumping and landing on one outstretched leg, combined with the high ground reaction forces that result from such jumps.[51,53]

So, to avoid injuries, dancers need to be able to perform several jump landings with correct mechanics.[51]

A few studies have investigated the ground reaction forces acting on ballet dancers. One such study examined male and female modern and ballet dancers in a single-leg drop landing.[51] These investigators found no difference between genders in either maximum vertical ground reaction force or “loading rate from initial contact to maximum ground reaction force”.[51] The authors concluded that, compared to pre-existing data of ground reaction forces in recreational athletes, dancers do not experience lower maximum ground reaction forces.[51] However, the authors did find that dancers tend to attenuate the ground reaction force from landing over a longer period of time.[51] The investigators suggested that dancers may be able to avoid serious injury to the lower extremities through their ability to control the rate at which ground reaction forces resulting from jumps are absorbed.[51] When ground reaction forces are absorbed over a longer period of time, they are absorbed by the muscles rather than the bones of the feet and lower legs. This longer shock attenuation lowers the magnitude of the forces absorbed by the body in the critical first 50 milliseconds following a jump landing.[53] The high forces applied during this time contribute to skeletal injuries, most notably stress fractures of the foot and lower leg.[53]

One study investigating potential differences between the ground reaction forces acting on the body while landing from a jump en pointe, or on the toes, as compared to landing with the entire foot.[48] The findings from this study identified distinct phases of landing when rolling through the foot that assist in absorbing ground reaction forces while landing.[48] These phases do not occur when landing en pointe, indicating that a much smaller area of the foot is able to absorb ground reaction forces. Therefore, if the force from landing was the same for both landing en pointe and landing with the whole foot, there would be a higher risk of injury associated with the landing performed en pointe.[48] This elevated risk of injury is due to the inability of the lower extremity to diffuse the force from landing through the elastic properties of soft tissue, such as the muscles that are used to control the motion of the foot when rolling through a landing.[48] Also, the force attenuation that occurs while landing en pointe must take place in half the time of the attenuation during a full-footed landing.[48]

Another study examining the ground reaction forces in dancers had professional dancers perform single-leg jumps for maximum height.[19] The investigators found no difference in jump height between the right and left legs.[19] This would tend to imply that the forces resulting from maximal single-leg jumps would be similar, as well, although this was not the primary focus of this particular study. In a study comparing the ground reaction forces absorbed by dancers in pointe shoes and in flat ballet shoes, the investigators found a significantly higher maximal ground reaction force in the ballet jump landings performed in flat shoes.[56] The authors suggested that the construction of the types of shoes may have influenced these findings; they theorized that the extra material, toe box, and shank of the pointe shoe may have absorbed more ground reaction forces than the thin, sole-less flat shoe.[56]

Examining the ground reaction forces experienced while landing from a jump in ballet can have several implications on improving dance technique and injury prevention.[48] Better understanding the external forces placed on ballet dancers while jumping will foster a safer environment for the dancer to develop athletically and artistically.[48] The ground reaction forces acting on the feet and legs, especially when landing from a jump, have not received much attention from dance science professionals. These forces are of particular importance to the dance medicine community due to their relationship with stress fractures in the foot and lower leg – injuries that can plague, or even end, a dancer's career.

Summary

Ballet technique is centered around five foot positions, which require the dancer's maximal turnout.[1,2] Turnout is achieved by external rotation of the lower extremity, primarily occurring at the hip.[1,3-7] In an attempt to achieve ideal turnout, dancers often force turnout by over-rotating their legs and using the ground to maintain this position.[3,6,7] The turnout angle present in fifth position is greater than the angle present in first position.[5,7] This difference is associated with a greater amount of forced turnout.[5] When a dancer tries to force turnout, the dancer's body alignment can be altered, possibly placing the dancer at an elevated risk of injury.[3,5-7]

Athletics generally results in the preferential use of one limb over the other, leading to muscular and functional differences between the preferred and non-preferred limb.[8-16] Ballet dancers are expected to be able to use each leg equally.[19,20] Ballet technique class is designed to develop both legs equally, but may, in fact, contribute to greater development of one leg over the other.[19,21] Asymmetry resulting from technique class may lead to pain and injury.[21,22]

The human body uses an intrinsic balance system to steady the body, demonstrating postural stability.[24-29] Possessing good postural stability, or balance, seems to decrease a person's risk of lower extremity injuries.[40,45] Controlling the rate of force absorption can decrease a person's risk of lower extremity injuries, as well.[51] Postural stability can be measured through examining the forces exerted by the body through the foot to control normal body oscillations.[24,28,31,33] These forces, as well as ground reaction forces, are recorded through the use of a force plate.[39]

Balance abilities in dancers have been examined through many different techniques, including the use of a force plate. Dance requires advanced balance capabilities,[23] so it is not surprising that these studies have found that dancers maintain their postural control better than non-dancers.[27,31,32,35] The enhanced postural control associated with dance training is only present in postures similar to the tasks frequently performed in dance.[31,35] However, no studies have been found that examine a dancer's balance in any fundamental foot position other than first position, nor have any studies examined a dancer's postural stability when landing from a dance-specific jump.

Ground reaction forces are important to the dance medicine professional due to their association with injuries to the lower extremity.[48,51,53] In dancers, ground reaction forces have been studied in several different contexts, with most of the results providing insight into the improvement of dance technique and dance medicine.[48,51,53] Future studies examining ballet dancers and ground reaction forces can continue to develop dance injury prevention programs, as well as dance training philosophies.[48]

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