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Ground Reaction Forces for Irish Dance Landings in Hard and Soft Shoes

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ABSTRACT

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Introduction: Irish dance has evolved to become more athletically demanding, thus making the art form very hard on dancers' bodies. Irish dancers must land from difficult moves without letting their knees bend or heels touch the ground, causing large amounts of force to be absorbed by the body. Past studies have found dancers landing with a range of 4.5–6 times body weight, potentially causing high amounts of overuse injury. The majority of injuries incurred by Irish dancers are due to overuse (79.6%). The landings that occur in Irish dance have been minimally evaluated in current literature. Obtaining values of vertical ground reaction forces (GRFs) produced by Irish dancers will assist in understanding the causes of overuse injuries, fill significant gaps in the current literature, and identify which Irish dance moves should be used less frequently to possibly reduce the chance for overuse injury.

Purpose: To determine vertical GRFs produced by female Irish dancers in hard and soft shoes during common movements. The purpose of this study was to determine peak force, rise rate of force, and impulse in selected Irish hard shoe and soft shoe dance movements.

Materials and Methods: Sixteen female Irish dancers between 14 and 25 years of age were recruited from the 3 highest competitive levels. Each performed a warm-up, reviewed 8 common Irish dance moves, and then performed each move 3 times upon a force plate. Four moves each were performed in soft and hard shoes. GRFs were measured using a 3-dimensional force plate running at 1000 Hz. Peak force, rise rate, and vertical impulse were all calculated. It was hypothesized that the 8 moves would produce different GRFs.

Results: Peak forces normalized by each dancer's body weight were significantly different across moves ($F = 65.4$, $p < 0.01$; $F = 65.0$, $p < 0.01$; and $F = 67.4$, $p < 0.01$ respectively). Years of experience was not correlated with peak force, rise rate, or impulse ($p > 0.40$).

Conclusion: There is a large range in peak forces created by Irish dancers. Moves that have high average peak forces may have a higher risk in causing overuse injuries. All dancers should take care to limit the use of these moves in their choreography to prevent such injury.

Keywords: Irish dance, ground reaction forces, overuse injury

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INTRODUCTION

Irish dance has speedily evolved over the past 20 years, becoming more competitive, athletic, and intricate, with dancers beginning training in advanced levels of technique as early as 9 years old in order to compete at the international level.[1,2,3,4,5] This has elevated the levels of musculoskeletal injury due to the increasingly challenging choreography and unprecedented physical demand.[2]

Irish dancing is performed in two styles of shoes, soft and hard (Figure 1), both with little to no cushioning.[3] Soft shoes are made of flexible leather and hard shoes are leather shoes with fiberglass tips on the toe and heel. Dancing in soft shoes shows some similarities to ballet in movement style; dancers must be high on their toes and perform large, athletic leaps. Unlike ballet, Irish dancers must land these leaps with no bend (plié) in the knee and without heel strike (en relevé).[2] Dancing in hard shoes has more similarity to tap dance and clogging, where creating unique rhythms with the feet is required. The main objective is to be "loud, powerful, and rhythmical while standing upright, much like in soft shoes."[1] Unlike tap and clogging, Irish dancers emphasize strength and power with large lower leg motions at high velocities to produce loud and explosive effects.[3] Dancers wearing hard shoes, just as in soft shoes, must also land en relevé with no plié. Landing by touching the toes and the heels as well as allowing the knee to plié, as in ballet, helps dissipate the ground reaction forces (GRFs).[2] The high and poorly dispersed GRFs created in the joints of the lower extremity of the Irish dancer have not been evaluated in current literature.[2]

Even though the two kinds of shoes encourage different styling and choreography, they have many similarities. The arms must be held to the sides, with the upper body completely immobile relative to the lower body.[6,7] The legs move generally in the sagittal plane with near constant hip external rotation, little to no hip abduction, and maximal adduction over the midline of the body (Figure 2).[2,7] The weight of the body must be balanced on the metatarsophalangeal joints, with maximum ankle plantarflexion and metatarsophalangeal dorsiflexion.[7] The movements must be in exact rhythm to the accompanying music, timing every foot placement to the provided beat.[6] The dancer must be "aggressive yet graceful, expressive yet controlled, and perform exhaustingly difficult material with a sense of ease."[7] These expected aesthetics were developed with no consideration for longevity and overall health of the dancers and are causing high levels of injury.

Studies conducted on injuries in Irish dancers found high levels of lower extremity injury and overuse injury. A recent study of Irish dancers,[1] found the majority of injuries incurred were in the lower extremity (94.9%), with the most common categorized as overuse (79.6%). The majority of dancers (79.7%) had multiple injuries, with a mean of 3.1 injuries per dancer. As the competitive level and thus the skill level of the dancer increased, so did the dancer's number of injuries.[1] Another article[2] cites that 33.7% of subjects often or always danced in pain. These injuries are caused by the extreme demands of Irish dance technique. It has been hypothesized that the high percentage of overuse injuries in Irish dancers is due to the repetitive stomping, high-impact landings en relevé with no plié, forced turn-out at the ankle and the metatarsaophalangeal joint,[1] lack of cushioning in the forefoot causing the structures up the musculoskeletal chain to absorb the shock[3], and weak hip abductors due to the overcrossed position and lack of hip abduction within the movement vocabulary.[8,9,10]

In addition to having high amounts of impact, Irish dancers also practice the same routine for months at a time to perfect it for competitions.[7,11,12] Injury caused by repetitive tasks can contribute to overall structural fatigue.[11,12] The primary risk factor for overuse injuries in the lower extremity across all forms of dance is repetitive impact; these impacts increase the likelihood of injuries such as stress fractures, shin splints, plantar fasciitis, and Achilles tendon strains.[13,14]

To the researchers' knowledge, only two studies have analyzed GRFs produced by Irish dancers. Shippen et al. analyzed GRFs during a common Irish dance move called a "rock step" and found that the maximum GRF was 4.5 times the dancer's body weight, and the maximal load supported by the ankle joint was 14 times the dancer's body weight.[15] One study[3] measured peak force, maximum pressure, and impulse differences between hard shoes, soft shoes, and practice shoes with the dancers performing the same routine in each shoe. They found significant differences in the location of maximum pressure during landings and impulse; the forefoot received the most pressure and soft shoe landings received the highest levels for impulse. Maximum GRFs may be linked to an increase in injury rates,[16,17] and thus a study that records peak Irish dance GRFs would be a significant contribution to the literature.

The purpose of this study was to evaluate the high and poorly dispersed GRFs created in the joints of the lower extremity of the Irish dancer, since they have been minimally evaluated to date.[2] Even with the growth of Irish dance to a global phenomenon, there is a large deficit of research on the burgeoning dance form with very few studies concerning vertical GRFs created by the Irish dancer. Obtaining values of vertical GRFs produced by Irish dancers will assist in understanding the causes of overuse injuries.

We hypothesized that there would be a difference between the peak force, rise rate of force, and impulse recorded during selected hard-shoe moves and soft-shoe moves. There are few similar moves between soft and hard shoes, so comparisons between shoes would have little meaning. Thus, comparisons were made between moves rather than shoes. We hypothesized that the peak force will rank the 4 soft-shoe and 4 hard-shoe moves in this order:

Soft:

1. Leap: flexing the front leg's hip while flexing the back leg's knee followed by landing on the front foot (Figure 3)
2. Birdie: flexing the front leg's hip while flexing the back leg's knee followed by landing on the back foot (Figure 4)
3. Bicycle: maximally flexing both knees alternately (Figure 5)
4. Skip: three walks followed by one hop (Figure 6)

Hard:

1. Stomp: landing a flat foot on the floor with full force (Figure 7)
2. Double toe: jumping onto the distal ends of the phalanges of one foot repeatedly (Figure 8)
3. Click: hitting the heels together while maximally flexing both hips alternately (Figure 9)
4. Saute en pointe: jumping onto the distal ends of the phalanges of both feet simultaneously (Figure 10)

MATERIALS AND METHODS

Participants

This study examined 16 female nonprofessional Irish dancers that have reached the top 3 competitive levels, Open Prizewinner, Preliminary Championships, and Open Championships. The age of the participants was 14–25 years. The study was delimited to dancers who had been training consistently over the past 6 months who were rehearsing without debilitating injury.

Data was collected after the training for a major competition was complete and before the training for the next major competition began, so it was easier to find dancers that fit this category. Only dancers trained exclusively in Irish dance were included as landing mechanics might be influenced by other forms of dance technique. Participants were recruited from local dance studios through flyers and word of mouth. Subjects read and signed a Brigham Young University Institutional Review Board-approved consent form. Subjects recorded number of years of Irish dance training, competitive level, hours per week of training, height, and weight.

Procedure

Each dancer was weighed and measured with their shoes and exercise attire on. Each subject performed a 5-minute treadmill walking warm-up at a self-selected speed followed by practice trials of all the moves to ensure all dance motion occurred on the force plate (AMTI, Watertown, MA), followed by the recorded trial. The 5-minute warm-up was done to simulate conditions of a dance class warm-up. Five retro-reflective markers were used. Two were placed on the left heel and forefoot and 3 markers were placed on the right heel, toe, and ankle to determine which foot is in contact with the ground during the force collections. Vicon Nexus 2.3 (Vicon, Oxford, UK) was used to synchronize force and motion measures between feet.

Dancers performed 4 common moves for soft-shoe and hard-shoe styles for a total of 8 different moves. Soft-shoe moves included a leap, bicycle, skip, and birdie. Hard-shoe moves included a click, stomp, saute en pointe, and a double toe. Descriptions and pictures of each move are included in Figures 3-10. These moves were chosen because they are common worldwide for high-level competitors and typify the required stiff landing. Each dance move was performed to a metronome to control for speed. The dancer performed 3 trials; all measurements were included in data collection. Dancers were able to perform each move on their preferred side to allow the dancer to perform the move with their best possible technique. Dancers were cued to produce a good trial; the researcher told the dancer that the trial would only count when the dancer landed on the force plate, demonstrated correct technique and footwork, and performed on time with the metronome. Dancers practiced each sequence prior to data collection to synchronize movements to the metronome and ensure landing on the force plate.

Instrumentation

Vertical GRFs were collected with the Vicon Nexus 2.3 for each dance movement. Vertical GRFs were collected at a sampling rate of 1000 Hz, standardized to the dancer's weight, and filtered with a low-pass 50 Hz filter.

Statistical Analysis

Kinetics were analyzed by Statistical Analysis Software (Cary, NC, USA). A mixed model analysis of variance with dance condition as the independent variable and peak force, rise rate of force, and impulse as dependent variables determined differences. The slope of force over time ranged from 10–90% of peak force. Potential covariates in this study were years of experience, hours spent in dance each week, competitive level, weight, height, and age; these covariates were entered in a stepwise fashion. Significant variables ($\alpha < 0.05$) were further analyzed using post hoc comparisons.

RESULTS

The data collected supported the hypotheses, including the ranking order of the hard-shoe and soft-shoe dance moves from greatest to least peak force. Also, peak forces, rise rates, and impulses were significantly different across moves ($F = 65.4$, $p < 0.01$; $F = 65.0$, $p < 0.01$; and $F = 67.4$, $p < 0.01$, respectively). Pairwise comparisons showing which moves were specifically different from each other are shown in Tables 1–3 and Figures 11–13. The move with the highest peak force was the stomp while the lowest was the skip. The move with the highest rise rate was the double toe while the lowest was the skip. The move with the highest impulse was the leap while the lowest was the skip. Individual peak forces ranged from 0.67–9.86 times body weight. Individual rise rates ranged from 10–147 body weights per second. Individual impulses ranged from −0.12 to 0.32 body weight seconds. Years of experience, number of years of Irish dance training, competitive level, hours per week of training, and height were not correlated with peak force, rise rate, or impulse ($p > 0.40$).

DISCUSSION

The main purpose of this study was to increase knowledge and awareness of what choreographic moves might be damaging to Irish dancers' bodies. The primary finding was that moves such as the stomp can yield vertical peak forces as high as 9 times body weight. Advanced dancers could practice stomps perhaps 100 or more times in a class and this would obviously cause stress to the joints of the dancers.

A secondary purpose of the study was to increase general knowledge of the biomechanics of Irish dance. Very few studies have been conducted that have included peak force, impulse, or rise rate as a measurement for Irish dance moves. Impulse is a measure of force applied for a specific amount of time, essentially measuring how long the dancer is pushing against the floor to produce her movement, like a measure for momentum change. Impulse is the best way to quantify cumulative loading, making it a potentially important measurement due to the repetitive nature of Irish dance movements. It has also been shown that increased impulses increase risk for pain in runners, so measuring impulse could add to the knowledge base of Irish dance injury risk. Rise rate is a measure of how quickly a dancer can develop force, and a higher rise rate generally means more explosive strength. Both are important measurements that could impact a dancer's performance ability as well as injury rate. We chose to measure these to formulate a basis for Irish dance biomechanical information.

Years of experience or competition level were nonsignificant for the data measured, which means that beginning level students can be exposed to as much injury risk as champion dancers when controlling for number of hours practiced. Beginning dancers are at risk because when a dancer begins training, their tissues are not yet adapted to the level of force placed upon them. It was also found that one of the most common Irish dance moves, and one that is learned quite early in the training process, the stomp, had the highest peak force. This move is learned early on because it is easy to put into choreography and does not take much experience to learn. This means dancers do not have the chance to adapt to these high GRFs through years of training and also have not yet developed good technique, thus increasing their injury risk. Obviously, advanced dancers are at risk of injury as well; years of dance will impact a dancer's joints greatly because overuse injuries are cumulative in nature. Even though their tissues have had more time to adapt, their joints have also had more time to be stressed and potentially damaged.

Bicycles, birdies, and leaps are fairly similar; they all involve leaving the ground with the intent to leap high and stay in the air as long as possible, so it is no surprise that they were not significantly different from each other in almost all measurements. Skips, on the other hand, are more focused on traveling far than spending a great deal of time in the air. They are most often used to increase speed before performing large leaps. This difference in purpose explains why skips were significantly different from the other 3 soft-shoe moves.

Clicks, double toes, sautes en pointe, and stomps all serve different purposes within choreography, but still have a high focus on creating sound. A well-performed click will bring both legs into maximal hip flexion followed by 0 degrees hip flexion with a great deal of sharpness and speed, and the quickness with which this must be performed adds to the vertical GRFs. A double toe focuses on creating many sounds in quick succession, leaping onto the phalanges while forcefully extending the knee; this knee extension is the main cause for the measured vertical GRFs. A saute en pointe must create sound, but its focus is to impress the audience with the dancer's balance on the extremity of their phalanges rather than creating loud beats, which is the main reason why this move was significantly different from the other hard-shoe moves. A stomp is intended to draw attention through sheer volume; its sole purpose is to create a loud, distinct sound, more so than any other Irish dance move including those not chosen for this study. This may be the cause for its statistically significant differences in peak force from every other chosen move.

We must be cautious with the comparisons of hard-shoe moves vs soft-shoe moves. This is due to two main factors: the purposes of each shoe within Irish dance are different (soft to demonstrate grace and athleticism through large movements that travel great distances; hard to demonstrate strength and power while creating clear, intricate sounds) and the shoes themselves (soft having a sole of soft, flexible leather and hard having 2 solid pieces of fiberglass attached to the sole). It is not common for dancers to compete hard-shoe moves in soft shoes or soft-shoe moves in hard shoes, so care must be taken when comparing movements in each shoe type.

Irish dance, in hard shoes especially, is unique in that, unlike most other forms of dance, the dancer wants to create loud sounds and thus must land with great force.[2] These large forces lead to an increased risk of injury,[7,18] which leaves Irish dancers and teachers with the task to design training to increase volume but keep injury prevention in mind. According to Wolff's Law, greater forces also can lead to increased tissue strength if teachers incorporate gradual adaptation to the required loads.

The measurement of impulse is comparably high to impulse in other forms of movement because of the lack of knee flexion and ankle dorsiflexion, making the landing very rigid. Another potential cause for the high impulse rates is the dancers have comparably short times when their feet are on the ground, which increases the force of impact. High rigidity could potentially lead to increased injury risk, especially with more repetitions.

Correct technique stipulates certain moves to be landed with no knee flexion or ankle dorsiflexion,[2] so some moves are difficult to modify to decrease injury risk. In the opinion of the primary researcher, dance moves that involve landing on the ball of the foot, however, may incorporate one modification. These moves can utilize toe eccentric extension. If a dancer allows the distal phalanges to land followed by the ball of the foot, the toes and distal ends of the metatarsals may act as a spring that can accept more force than if a dancer were to land first on the ball of the foot. This technique modification could be further amplified by strengthening the intrinsic muscles of the foot to increase the deceleration during landing. This modification applies to leaps, bicycles, birdies, skips, and clicks. It could potentially be beneficial for dancers to also give the illusion of having a straight leg but utilize an inconspicuous amount of knee flexion while landing. This will allow the dancer to meet technique standards but without as much potential damage to the knee joints. A further recommendation would be to dance on sprung surfaces, limit the amount of repetitions of dance moves that have higher injury risk within a practice session, and rehearse in practice shoes that have more shock absorption.

CONCLUSION

Irish dancers demonstrated a wide range of peak forces, rise rate of force, and impulse between the 8 selected moves. Some moves, such as skips, clicks, bicycles, and sautes en pointe, may be included in choreography with less consideration for their potential for overuse injury because of their comparably lower peak forces. Other moves such as stomps, double toes, leaps, and birdies should be limited within choreography due to their higher peak forces and thus greater potential for overuse injury. Teachers, judges, dancers, and dancers' parents should change their expectations for moves used in class drills, performances, and competition choreography to increase the longevity of dancers' careers and decrease the potential for overuse injury. A dancer's well-being is more important than impressing a panel of judges.

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Table 1. Mean Differences Between Moves for Peak Force Normalized by Body Weight ($p > 0.05$)

Peak Force (BW)	Leap (A)	Birdie (B)	Bicycle (C)	Skip (D)	Stomp (E)	Double Toe (F)	Click (G)	Saute en Pointe (H)
Leap (A)		0.027	0.150	1.285	−1.614*	−0.293	0.407	1.014*
Birdie (B)	−0.027		0.124	1.259*	−1.641*	−0.320	0.380	0.988*
Bicycle (C)	−0.150	−0.124		1.135*	−1.764*	−0.443*	0.257	0.864*
Skip (D)	−1.285*	−1.259*	−1.135*		−2.900*	−1.579*	−0.879*	−0.271
Stomp (E)	1.614*	1.641*	1.764*	2.900*		1.321*	2.021*	2.628*
Double Toe (F)	0.293	0.320	0.443*	1.579*	−1.321*		0.700*	1.307*
Click (G)	−0.407	−0.380	−0.257	0.879*	−2.021*	−0.700*		0.607*
Saute en Pointe (H)	−1.014*	−0.988*	−0.864*	0.271	−2.628*	−1.307*	−0.607*	

White: soft vs soft
Light Gray: soft vs hard
Dark Gray: hard vs hard
*Statistically significant

Table 2. Mean Differences Between Moves for Rise Rate Normalized by Body Weight (p > 0.05)

Rise Rate (BW/s)	Leap (A)	Birdie (B)	Bicycle (C)	Skip (D)	Stomp (E)	Double Toe (F)	Click (G)	Saute en Pointe (H)
Leap (A)		0.394	2.231	19.550*	−24.096*	−4.360	6.079	15.140*
Birdie (B)	−0.394		1.838	19.156*	−24.490*	−4.754	5.685	14.746*
Bicycle (C)	−2.231	−1.838		17.319*	−26.327*	−6.592*	3.848	12.908*
Skip (D)	−19.550*	−19.156*	−17.319*		−43.646*	−23.910*	−13.471*	−4.410
Stomp (E)	24.096*	24.490*	26.327*	43.646*		19.735*	30.175*	39.235*
Double Toe (F)	4.360	4.754	6.592*	23.910*	−19.735*		10.440*	19.500*
Click (G)	−6.079	−5.685	−3.848	13.471*	−30.175*	−10.440*		9.060*
Saute en Pointe (H)	−15.140*	−14.746*	−12.908*	4.410	−39.235*	−19.500*	−9.060*	

White: soft vs soft
Light Gray: soft vs hard
Dark Gray: hard vs hard
*Statistically significant

Table 3. Mean Differences Between Moves for Impulse Normalized by Body Weight (p > 0.05)

Impulse (BWs)	Leap (A)	Birdie (B)	Bicycle (C)	Skip (D)	Stomp (E)	Double Toe (F)	Click (G)	Saute en Pointe (H)
Leap (A)		0.030*	0.017	0.151*	0.072*	0.062*	0.065*	0.110*
Birdie (B)	−0.030*		−0.013	0.121*	0.042*	0.032*	0.035*	0.080*
Bicycle (C)	−0.017	0.013		0.134*	0.055*	0.045*	0.048*	0.093*
Skip (D)	−0.151*	−0.121*	−0.134*		−0.079*	−0.089*	−0.086*	−0.041*
Stomp (E)	−0.072*	−0.042*	−0.055*	0.079*		−0.010	−0.008	0.038*
Double Toe (F)	−0.062*	−0.032*	−0.045*	0.089*	0.010		0.003	0.048*
Click (G)	−0.065*	−0.035*	−0.048*	0.086*	0.008	−0.003		0.045*
Saute en Pointe (H)	−0.110*	−0.080*	−0.093*	0.041*	−0.038*	−0.048*	−0.045*	

White: soft vs soft
Light Gray: soft vs hard
Dark Gray: hard vs hard
*Statistically significant

Figure 1. Soft and hard Irish dance shoes. Soft-shoe dancing focuses on showcasing large, athletic moves while traveling around the stage. Hard-shoe dancing focuses on creating loud and complex rhythms.

Figure 2. Irish technique. Irish dancers need an extreme amount of external rotation, knee extension, plantarflexion, and hip adduction.

Figure 3. Leap. The dancer lifts one leg to at least 90 degrees hip flexion, pushes off the standing leg and lands onto the leg initially lifted. We are interested in the landing of the initial lifted leg.

Figure 4. Birdie. The dancer lifts one leg to at least 90 degrees hip flexion, pushes off the standing leg and lands onto the original standing leg. We are interested in the landing of the original standing leg.

Figure 5. Bicycle. The dancer brings one leg into maximal knee flexion, pushes off the standing leg to bring knee to maximal flexion while fully extending the initial leg, and then lands on the original standing leg while returning the initial leg to maximal knee flexion. We are interested in the landing of the initial standing leg.

Figure 6. Skip. The dancer places one foot in front, closes with the back foot, replaces the first foot in the front, and then hops on that same foot. We are interested in the landing of the foot placed in the front the second time.

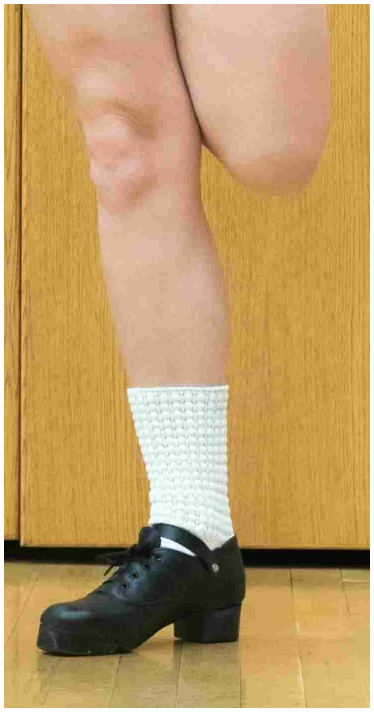

Figure 7. Stomp. The dancer pushes off one leg and brings the other foot onto the ground with full force.

Figure 8. Double Toe. The dancer stands on one leg and hits the distal end of the opposite foot on the ground, leaps onto the toe of the same foot, and replaces the original standing leg on the ground. We are interested in the landing of the leap onto the toe.

Figure 9. Click. The dancer lifts one leg, pushes off the standing leg while bringing the opposite leg past to click the heels together, then lands on the first leg while bringing the initial standing leg back to the ground. We are interested in the landing of the initial standing leg.

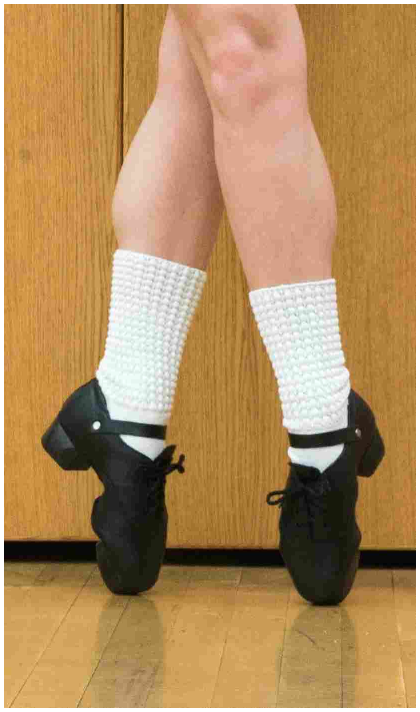

Figure 10. Saute en Pointe. The dancer pushes off with both feet and lands on the distal portion of their phalanges. We are interested in the landing of both feet at the same time.

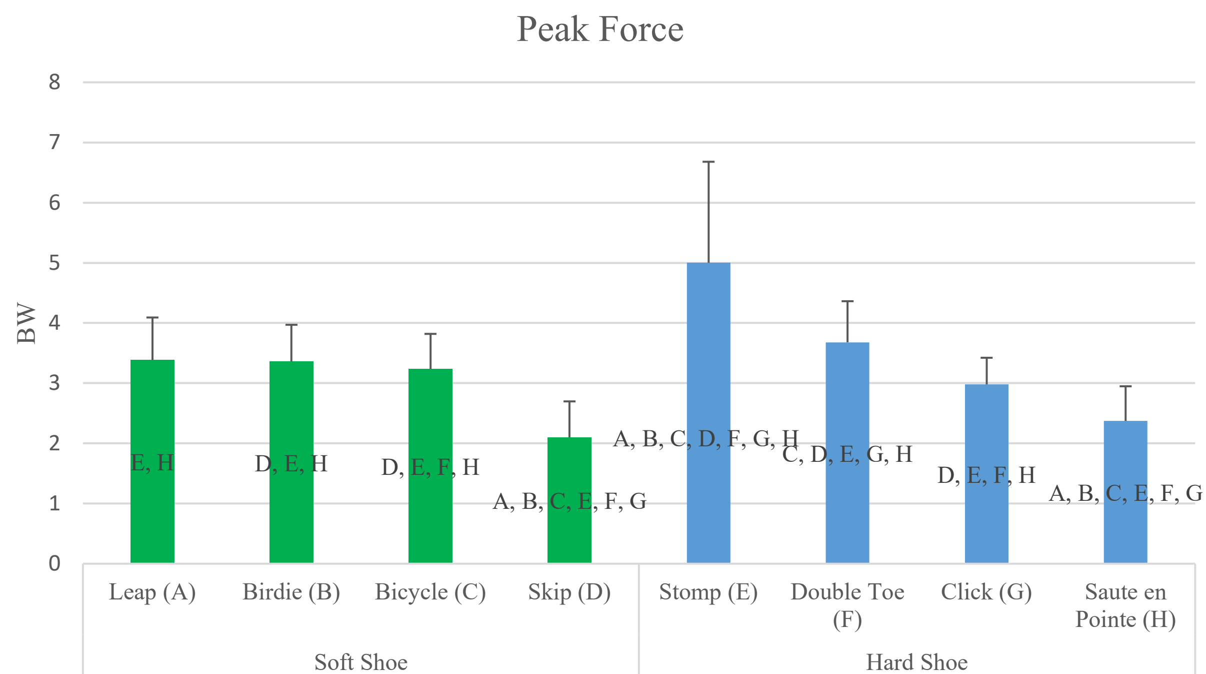

Figure 11. Peak force. Individual peak force ranged from 0.67–9.86 times body weight. Letters represent named column being significantly different from other columns. Error bars represent the standard deviations for each variable.

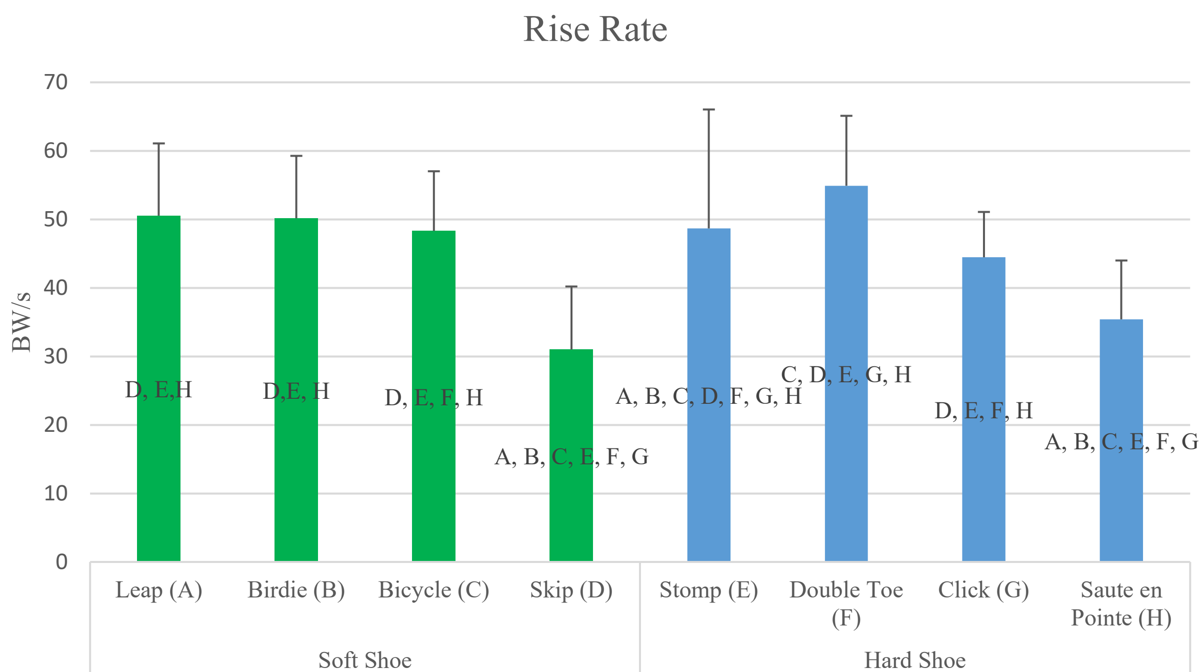

Figure 12. Rise Rate. Individual rise rates ranged from 10–147 body weights per second across all conditions. Letters represent named column being significantly different from other columns. Error bars represent the standard deviations for each variable.

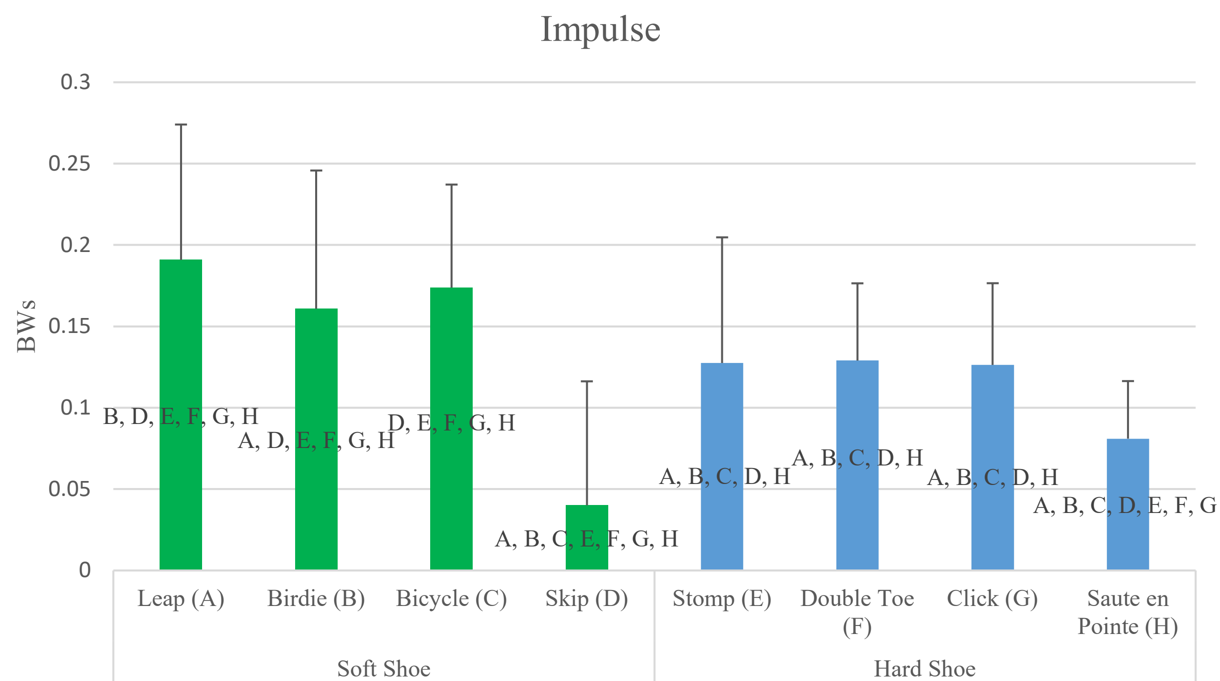

Figure 13. Impulse. Individual impulse ranged from −0.12–0.32 body weight seconds. Letters represent named column being significantly different from other columns. Error bars represent the standard deviations for each variable.