4-1-2024

The Effects of Fatigue on Landing Forces in Competitive Female Irish Dancers

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Honors Thesis

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Abstract

Lower extremity injuries are highly prevalent within the Irish dance population, yet research surrounding potential determinants is scarce. Many movements, particularly jumps, in Irish dance are constituted by a one-foot landing with the ankle in a plantarflexed position and the knee fully extended. This unique landing technique is contrary to other forms of dance, such as ballet, where landings typically allow for some knee flexion in a plie-like position. Subsequently, this aesthetic constraint requires large amounts of strength and balance, in addition to forcing the structures of the foot and ankle to absorb the entire shock of the landing. This study aims to determine the effect that fatigue has on landing forces following the 360 spin move, which is characterized by the dancer jumping off the ground from their lead foot, making a full 360° turn in the air before landing on the opposite foot. Since fatigue has been shown to play a role in ground reaction force, in addition to overall center of pressure, this study focuses on establishing how the lower extremities react when trying to stop the turning motion following this jump. Through having competitive female Irish dancers perform the 360 spin under both fatigued and non-fatigued trials with all landings taking place on a force plate, it was found that fatigue causes a significantly higher downward force on the left foot, indicating that this side may be more greatly affected by fatigue. The results from this study can direct future research in establishing additional injury risks associated with the Irish dance technique in order to correctly aim injury prevention measures.

Acknowledgements

I would like to extend an immense gratitude toward my thesis advisor, Dr. Bigelow, for her belief in this project and continued guidance throughout the ups and downs of the process. Special thanks also go out to the University of Dayton Irish Dance Club, in addition to the University of Dayton Honors Program, for trusting me and being so supportive of my project. I would like to extend an additional thanks to my wonderful friends and family for encouraging me and always letting me turn to them when I needed support. Finally, I would like to thank Mary Laffey-Beemsterboer and all of those at the Celtic Academy of Irish Dance for instilling such a deep love for this community. I would not be here without any of you; go raibh maith agat!

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Table of Contents

Table of Figures and Tables

Introduction

Introduction to Irish Dance

History of Irish Dance

Irish dance has a rich cultural history that stretches back to the 17th century. Similar to the oral tradition of passing down music and storytelling, many aspects of traditional Irish step dancing are attributable to the different events that have occurred in Ireland throughout history (Brennan, 1999). For example, the rigid upper body that makes Irish dance distinct from other dance forms can be related back to the colonial time and shown to be an act of resistance against English influence (Wulff, 2005). During the nationalist cultural revival in Ireland within the late 19th century, the Gaelic League decided to reinvigorate numerous aspects of the Irish culture, including language and dance. An Coimisiún Le Rincí Gaelacha, also referred to as the Irish Dancing League or CLRG, was established in 1929 as a governing body responsible for the regulation of all aspects of Irish dance, including costume, dance style, and the certification process for teachers (Wulff, 2005). Irish dance continued to increase in traction before reaching a burst of popularity in the 1990s when the professional show, Riverdance, began to first appear, thus bringing a taste of the Irish culture to those worldwide (Farrell-Wortman, 2010). Currently, CLRG continues to be the primary and fastest growing governing body within the Irish dance community, with schools in over 30 countries worldwide being certified under their rule (Cahalan et al., 2018).

Irish Dance Footwear

Traditionally, there are two types of shoes utilized within Irish dance: soft and hard shoes. Soft shoes, also known as ghillies, are a leather slipper with a poron cushion sole ranging from 2 to 4 mm at the toe and heel, shown in Figure 1 (Trégouët & Merland, 2013). With a lack of structural support within soft shoes, it has been found that loading values of the forefoot were higher than other types of shoes utilized in Irish dance (Trégouët & Merland, 2013). Irish dancers also wear hard shoes, which are more structured than the soft shoe with a fiberglass heel and tip that are used to make specific sounds during the dance. Within competition, dancers utilize both shoes depending on the round.

Figure 1: Image of Irish dance soft shoe.

Irish Dance Biomechanics

Irish solo dancing primarily consists of quick movements of the lower extremities, with hips externally rotated in a position known as "turnout". The core and upper extremities, on the other hand, remain motionless. Additionally, all dance steps are performed on both feet, requiring a symmetry within dancers (Beasley et al., 2014). Many movements, particularly jumps, in Irish dance are constituted by a one-foot landing with the ankle in a plantarflexed position and the knee fully extended, which is contrary to other forms of dance, such as ballet, where landings allow for some knee flexion in a plie position. This aesthetic constraint requires large amounts of strength and balance, in addition to forcing the muscles of the foot and ankle to absorb the entire shock of the landing (Noon et al., 2010). Furthermore, the technique utilized, while continuing to retain the traditional aspects, has become increasingly athletic and competitive over the past two decades with faster and more exaggerated movements of the lower extremities, thus creating the potential for an increased injury risk.

Injury Prevalence within Irish Dance

A recent systematic review of injury status within Irish dancers found that the self-reported prevalence of injury was higher in Irish dance populations in comparison to other dance forms, such as professional ballet and tap (Póvoa et al., 2023). When looking solely at championship level Irish dancers, it was found that 84% of participants reported at least one injury within the prior year alone (Cahalan et al., 2018). In regard to type, stress fractures of the lower extremities account for about one-third of all Irish dance injuries, with the sesamoids, metatarsals, navicular, and first proximal phalanx comprising most of these stress fracture injuries (Noon et al., 2010). Other common injuries include tendon or muscular injuries, apophysitis, and patellofemoral pain (Stein et al., 2013). Overall, injuries appear to become more prevalent as dancers increase in both competition level and time spent practicing per week (Noon et al., 2010). Fatigue has also become an interest in regard to injury risk, with a previous study finding that fatigue creates greater loading on both the ankle and knee joints within a common jump within choreography (Wild et al., 2017).

The 360 Spin Move

The 360 spin is characterized by the dancer jumping off the ground from their lead foot, making a full 360° turn in the air before landing on the opposite foot. During the spin, both knees remain fully extended with the legs in line with the torso. The lead foot that was utilized for the takeoff remains in the front during the entire movement, with the thighs crossed over each other and feet pointed. When the spin is complete, the dancer lands on their back foot, opposite of the foot that initiated the takeoff. Additionally, during the entire movement, arms remain by the sides of the dancer and their head stays in line with the rest of the body during rotation, which differs from other dance techniques, such as ballet, where dancers use visual spotting to aid in postural stability (Lin et al., 2014). Figure 2 depicts both the run leading up to the spin and the 360 spin itself. It is important to indicate that the participants within this study kept their arms down by their sides during the entire movement, unlike what is shown within the images, to coincide with proper technique utilized in competitions.

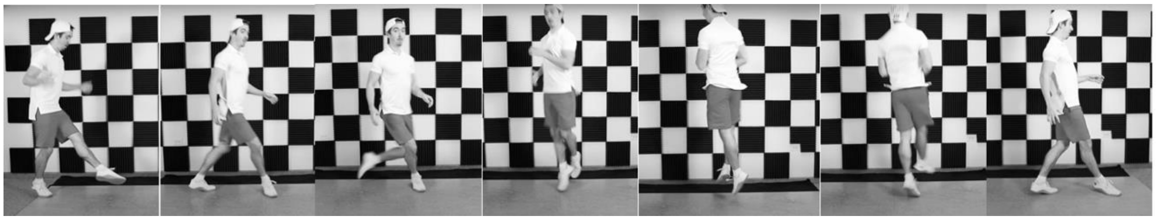


Figure 2: Depiction of run and 360 spin.

Ground Reaction Force and Center of Pressure

In regard to other types of dance, increased ground reaction force has been identified as a potential risk factor for overuse injury (McPherson et al., 2019). Whenever an individual exerts any sort of pressure onto the ground, whether during walking, running, or dancing, the ground exerts the same force back onto them, known as ground reaction force (GRF). This idea is based on Newton's third law, the Law of Action-Reaction, which states that if one object exerts a force on a second object, the second object exerts an equal and opposite force back onto the first object. Vertical GRF, also known as downward force (Fz), that reaches a high magnitude for a reduced period of time, such as during landings of jumps, is often referred to as impulsive load. Tissue responses to this type of load are often believed to be responsible for injury patterns seen within athletes (McGinnis, 2013). Furthermore, there are a number of factors that have the potential to increase GRF, including poor technique, footwear utilized, and ground conditions.

Ground reaction force, just like other forces, has components in the X, Y, and Z-axes, which refer to the force acting between the foot and ground in the transverse, anteroposterior, and vertical directions, respectively. It is important to note, however, that these axes may be different depending on how the coordinate system is defined by a particular data collection tool. Center of pressure (COP) refers to the point of application of GRF within the vertical direction and is often used to determine postural control within dynamic situations, such as walking (Jamshidi et al., 2010). Within this study, COP was used to determine how efficiently an individual was able to stop the turning motion within the landing of the 360 before moving on to the subsequent run since altered COP within the foot can potentially lead to adverse outcomes, such as the rolling of an ankle. In order to determine both the ground reaction force and center of pressure measurements during the landing of the 360, a force plate was utilized. When a participant landed on the force plate, ground reaction force and moments in the X, Y, and Z-axes were recorded, in addition to a computation of the center of pressure throughout the entire duration of the landing.

Study Purpose

The overall objective of this study was to determine the effects of total body fatigue on landing forces within the 360 spin. Since fatigue often results in improper technique within the dance context, this implies that this variable has the potential to be linked to increased ground reaction force and overall injury rates. Therefore, this study aims to establish how the lower extremities react when trying to stop the turning motion following the 360 under fatigued conditions. It was hypothesized that fatigue would cause a greater ground reaction force during the landing. It was also hypothesized that the overall sway area, indicated by center of pressure displacements, would be larger due to a lack of postural stability when fatigued.

Materials and Methods

Participants

Eight healthy, competitive Irish dancers were recruited from one Dayton-area CLRG school, Celtic Academy of Irish Dance, in addition to the University of Dayton Irish Dance Club. In order to eliminate skewed results due to differences in center of gravity and postural control between males and females, only female dancers were invited to participate in the study (Steindl et al., 2006). Additionally, all participants were required to be within the open championship level within the CLRG organization, which is the highest level a dancer can reach within competition, and be able to perform the 360 spin move on both feet to ensure consistency in technique. Dancers were excluded from the study if they had a current lower extremity injury that affected how they landed Irish dance jumps, were currently going through any physical rehabilitation for lower extremity injuries, had to utilize tape and/or a brace in order to perform the move without injury, or had any balance or vestibular problems.

Study Design and Measurements

Each participant completed the study in one 45–60-minute session. Upon entry into the lab, participants filled out appropriate paperwork, consisting of a form containing inclusion criteria and a consent form, as included within the appendix. If the participant was under the age of 18, they completed a respective assent form, while their parent/guardian completed a parental consent form, also included within the appendix.

The entire study procedure was described to the participants thoroughly, in addition to providing an explanation of the Borg's scale to prevent confusion. The Borg's scale that was utilized ranges from 6-20, with 6 representing no exertion at all and 20 representing maximal exertion (Center for Disease Control and Prevention) (Figure 3). Furthermore, participants were cautioned of the potential risks of slipping and falling, in addition to feelings of discomfort due to fatigue.

6	No exertion
7	
8	
9	
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	
20	Maximal exertion

Figure 3: Borg's scale (6-20).

All participants performed the 360 spin move under both rested and fatigued conditions, with every trial occurring on a 20’ x 16’ wooden platform, similar to the stages utilized within competition. This wooden platform was constructed with plywood sheathing that was 23/32” in height. Additionally, a force plate was embedded in the center of the platform to be used for data collection by constructing the wooden boards around the plate shown within Figure 4. In order to make the force plate flush with the wooden platform, interlocking EVA foam mats were stacked underneath the plywood sheathing and held together utilizing non-slip rug strips. A sticky mat was also provided within the lab to allow dancers to remove any dust or dirt from the bottom of their shoes that may increase slipperiness and subsequently the risk of falling.

Figure 4: Wooden platform setup in lab.

Participants wore their own Irish dance soft shoes that are used for practice during the entirety of the study. Additionally, the shoe brand worn by each participant was noted within the data collection sheet to account for potential obscurities within data collection due to slight differences in structure. At the beginning of the session, each participant was given a 5-minute warmup time to stretch and warm up as they saw fit in order to prevent injury. Participants were not permitted to go over a rate of perceived exertion of 9 during this time to ensure that they were adequately rested for the non-fatigued trials. Participants then performed a total of 4 non-fatigued tests of the 360 spin, with 2 tests on each foot. The order of these tests was randomized through a computerized random number generator to reduce potential fatigue effects within the non-fatigued trials. During these force tests, each participant performed a specific run on the wooden platform, which precedes all major jumps in Irish dance, leading up to the 360 spin, where the landing occurred on the force plate. Following the landing of the jump, participants were instructed to repeat the run out of the jump to keep the momentum moving forward, like what occurs during a dancer's actual routine, and to prevent any additional steps on the force plate.

After completing the non-fatigued force tests for baseline data, participants went through an Irish dance-specific fatigue protocol on the wooden platform, similar to the one utilized and deemed appropriate during the study by Wild et al. During this protocol, participants performed 16 bars of "skips" and 16 bars of "sevens" to music that is used for both practice and competitions at 113 beats per minute. This exercise was repeated continuously with no breaks in between the different steps until each participant attained a rating of perceived exertion (RPE) of at least 17 on Borg's scale. An RPE of 17 corresponds to a "very hard" exertion rate but is able to be sustained for a short period of time. This exertion level is roughly equivalent to a heart rate of 170 beats per minute and relates to how a dancer feels after their dance in competition (Dishman et al., 1987). Overall, the fatigue protocol only lasted for about 2-3 minutes for each participant, which is similar to the duration of dances within competition. During the "sevens" portion of the protocol, the researcher held up a sign containing Borg's scale for the participant to identify their current level. Additionally, fatigue was noted through a significant decrease in technique as seen by the primary investigator, who has a background in Irish dance. If any participant showed signs of extreme fatigue or increased risk of injury (pale complexion, extreme panting, unsteady balance), they were asked to stop and take a break. This, however, was not observed in any participant for any trial. Once the correct fatigue level had been reached, the participant immediately performed the run before initiating into the 360 spin. If the participant missed landing on the force plate during any of the trials, they would skip back around and immediately go into the run again to ensure the intended RPE was maintained. Each participant performed a total of 4 tests of the 360 spin while fatigued, with two tests on each foot. The order of these tests was randomized through a computerized random number generator and the fatigue protocol was initiated between each landing data collection. Additionally, between each fatigued force test, the participants were allowed a two-minute water break. At the halfway mark of the fatigued trials, participants were given a 15-minute break before resuming the tests to prevent overexertion.

Data Acquisition

Data collected from a force plate (Bertec, Columbus, OH, USA) was used to perform descriptive statistics to help determine the effect of fatigue on plantar forces. The collected data of interest included the ground reaction force for the vertical (Fz) direction. Figure 5 represents the force plate with the coordinate axis in order to highlight this measurement. Additionally, the COPx and COPy or the center of pressure in both the x-direction (medial-lateral) and the y-direction (anterior-posterior) were established. All of these values were computed and recorded through the force plate connected to a laptop for acquisition. An example of collected data is shown in Figure 6.

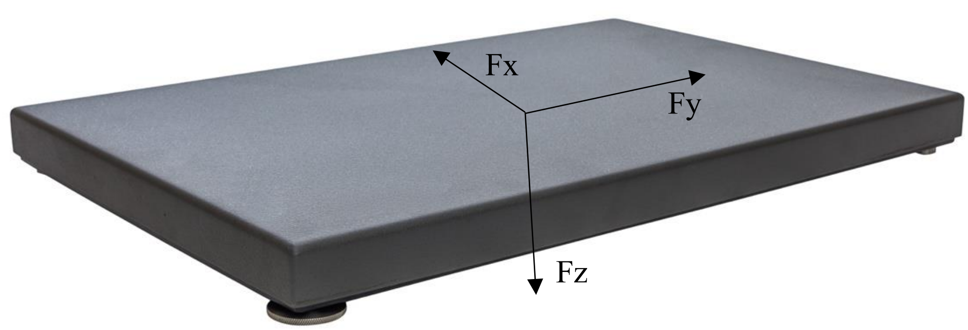


Figure 5: Force plate with coordinate axis.

Timestamp	Sync	Aux	Fx	Fy	Fz	Mx	My	Mz	COPx	COPy
690582	0	0	5.629843	6.318291	41.499023	7.292969	-0.107483	-2.152282	0.00259	0.175738
690583	0	0	7.167171	8.231376	57.036621	9.078674	-0.615234	-2.635784	0.010787	0.159173
690584	0	0	9.302921	9.417667	76.520508	11.675354	-1.384888	-3.41499	0.018098	0.152578
690585	0	0	12.348818	10.813906	99.75	15.092651	-2.637451	-4.240698	0.026441	0.151305
690586	0	0	17.224726	11.467388	127.266113	19.735474	-4.357849	-5.380455	0.034242	0.155072
690587	0	0	23.883455	12.323618	160.398682	26.036011	-6.83548	-7.002162	0.042616	0.162321
690588	0	0	33.277836	13.844804	196.104736	34.081665	-9.631622	-8.872608	0.049115	0.173793
690589	0	0	44.191727	15.571171	230.624023	42.954956	-12.480042	-10.816122	0.054114	0.186255
690590	0	0	54.510612	18.283443	257.775146	51.644531	-14.721954	-12.958782	0.057112	0.200347
690591	0	0	61.791924	21.260677	273.244141	59.09137	-15.922516	-14.807034	0.058272	0.216259
690592	0	0	66.637001	24.017338	278.194092	64.790222	-15.726105	-16.089525	0.056529	0.232896
690593	0	0	69.058517	25.14348	276.38208	68.897461	-14.799469	-17.136467	0.053547	0.249283
690594	0	0	70.579567	25.849033	273.505859	71.453613	-13.463257	-18.075661	0.049225	0.261251
690595	0	0	71.497932	25.818638	272.344971	73.143005	-12.202911	-18.438349	0.044807	0.268568
690596	0	0	71.832626	26.260015	274.051514	73.593811	-11.354126	-18.099764	0.041431	0.26854
690597	0	0	71.902924	27.412664	276.348145	72.376648	-11.178192	-16.85294	0.04045	0.261904
690598	0	0	68.304901	28.243826	277.715576	69.542358	-11.300598	-14.076851	0.040691	0.250409
690599	0	0	57.007584	27.6394	276.614014	65.457764	-11.381714	-8.457954	0.041147	0.236639
690600	0	0	35.49424	24.574003	275.300293	61.327454	-11.391388	0.037023	0.041378	0.222766
690601	0	0	11.472729	17.350061	275.641113	58.482727	-10.744904	8.70397	0.038981	0.21217
690602	0	0	-8.24165	5.990568	280.473145	57.918091	-9.331299	14.621092	0.03327	0.206501
690603	0	0	-21.462698	-7.527191	291.696289	59.539856	-7.578156	17.332438	0.02598	0.204116
690604	0	0	-33.450974	-21.324829	308.411865	62.592224	-6.160156	17.378025	0.019974	0.20295
690605	0	0	-46.011482	-33.58934	328.888672	66.622437	-5.679749	16.117638	0.01727	0.202568
690606	0	0	-58.554291	-40.578312	351.298584	70.207458	-6.124908	15.084888	0.017435	0.199851
690607	0	0	-69.888069	-42.602333	372.990234	72.942139	-7.318573	15.095234	0.019621	0.19556
690608	0	0	-78.807838	-41.322533	392.435547	75.430298	-8.934845	15.683273	0.022768	0.192211
690609	0	0	-86.208496	-39.567802	408.290283	77.957153	-10.111664	16.251329	0.024766	0.190936
690610	0	0	-91.792999	-36.933163	422.228027	81.39325	-10.799713	17.228077	0.025578	0.192771
690611	0	0	-96.508102	-35.116547	435.174561	86.285706	-10.937744	18.500834	0.025134	0.198278
690612	0	0	-99.415466	-34.289589	450.350342	92.370972	-10.84433	19.510052	0.02408	0.205109
690613	0	0	-100.20617	-35.850143	467.364502	99.183167	-10.843658	20.004309	0.023202	0.212218
690614	0	0	-99.133781	-38.774384	485.669434	106.310669	-11.386139	19.630533	0.023444	0.218895

Figure 6: Sample data collected from Bertec force plate.

Data Analysis

The maximum ground reaction force for the vertical direction (Fz_{max}) was evaluated during the time that the landing foot was in contact with the force plate following the 360. In order to accurately compare this value between participants, all Fz_{max} values were normalized to bodyweight by simply dividing the Fz_{max} value by each participant's respective bodyweight in kilograms (N/kg). Average values were then found for both non-fatigued and fatigued trials of the right and left foot within each participant. Once all participant averages were found, total averages were determined between all participants for all four trial types. To determine the statistical significance of the averages between the trial types, a paired-samples t-test ($p<0.05$) was performed in SPSS statistical software.

Similarly to the Fz_{max} values, the center of pressure (COP) data was evaluated only during the time that the landing foot was in contact with the force plate. Using a specific code within MATLAB (Natick, Massachusetts, USA), the COPx and COPy data were kept at 1000 Hz with no down-sampling. This data was then filtered using a fourth-order low-pass Butterworth filter with 5 Hz. cutoff. The code was then calculated to quantify the total area of an ellipse enclosing the COP data points, fit with 95% confidence, to determine stability during landing. After determining the 95% confidence ellipse for each individual trial that was conducted throughout the entirety of the study, averages were found for non-fatigued and fatigued trials of the right and left foot. The statistical significance was then determined between the averages for each trial type using a paired-samples t-test ($p<0.05$) test in SPSS statistical software. Furthermore, for both the Fz_{max} and COP values, the left and right side of each trial type were compared to each other to ensure similarity due to the symmetric nature of Irish dancing.

Results

Mean and standard deviations for the normalized average Fz_{max} values for all trials are shown in both Table 1 and Figure 7. The Fz_{max} values between the non-fatigued and fatigued trials on the right foot were deemed not statistically significant ($p=0.201$), but the fatigued trials on the left foot showed a significantly greater downward force when compared to the non-fatigued trials of the same foot ($p=0.004$). Furthermore, when comparing the left and right side of each trial type, no statistical differences were found (non-fatigued, $p=0.169$; fatigued, $p=0.879$).

Table 1: Fz_{max} average and ± standard deviation values for all trials.

		Average Fz_{max} (N/kg)	**Standard Deviation (N/kg)**
Non-Fatigued	**Left**	**25.95**	2.4
	Right	27.11	2.6
Fatigued	**Left**	**29.10**	2.5
	Right	28.92	2.8

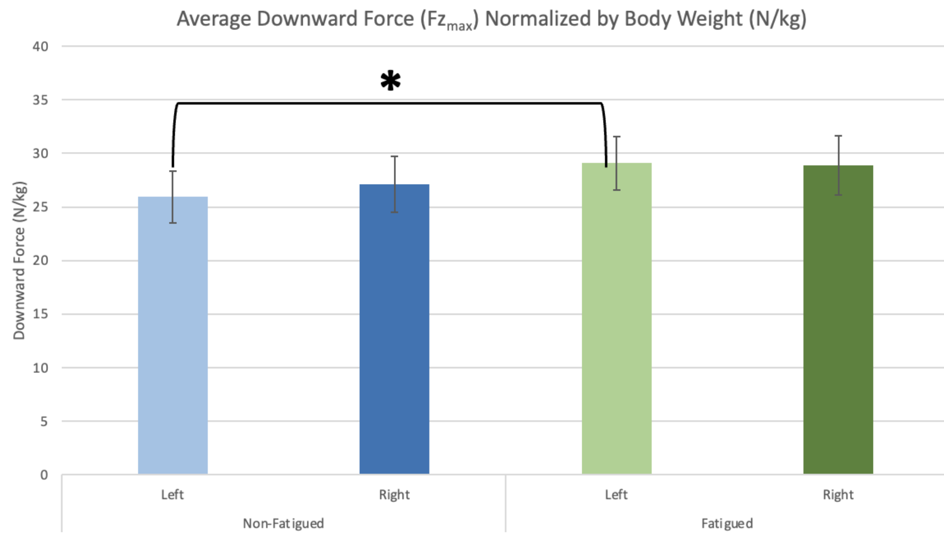


Figure 7: Bar chart of Fz_{max} average and ± standard deviation values for all trials.

For the 95% confidence interval ellipse sway area data, there were no statistically significant differences between fatigued and non-fatigued trials on either foot, but the data for the left foot appeared to be trending toward significance (left, p=0.103; right, 0.488). Furthermore, it is important to note that the average sway area values appear to be higher for the non-fatigued trials than the fatigued trials, despite no significance.

Table 2: Average sway area values and ± standard deviation values for all trials.

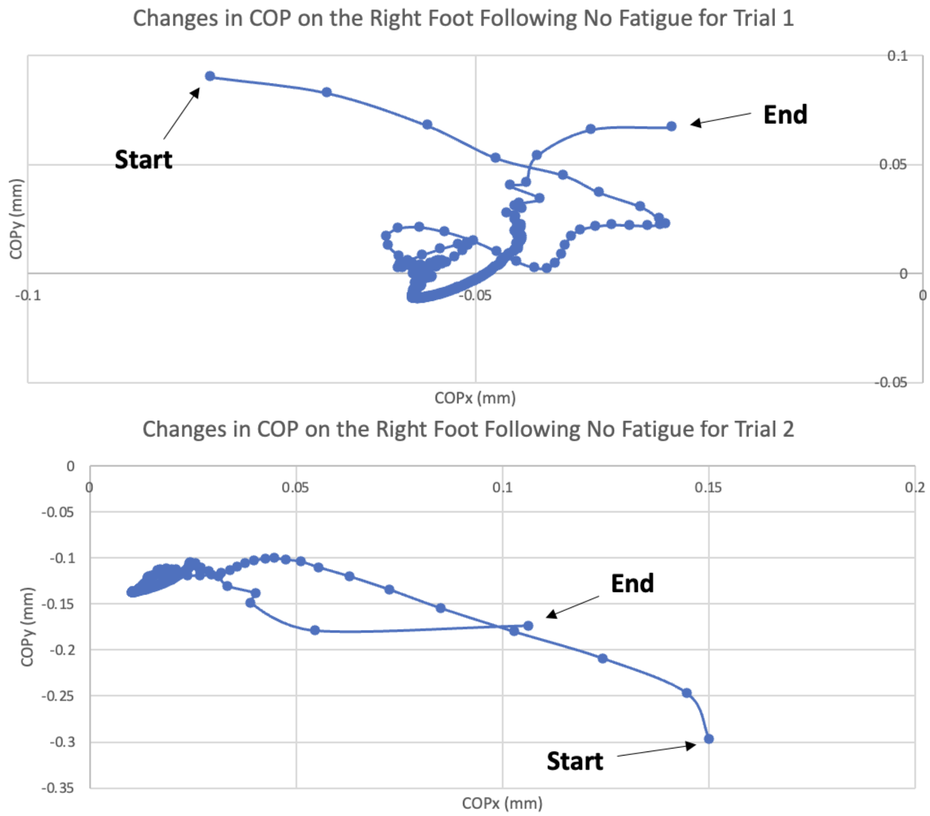
		Average 95% Confidence Ellipse Sway Area (mm^2)
Non-Fatigued	**Left**	2434.04 ± 1511.5
	Right	2045.92 ± 1086.8
Fatigued	**Left**	1387.58 ± 647.3
	Right	1605.42 ± 1056.9

Discussion

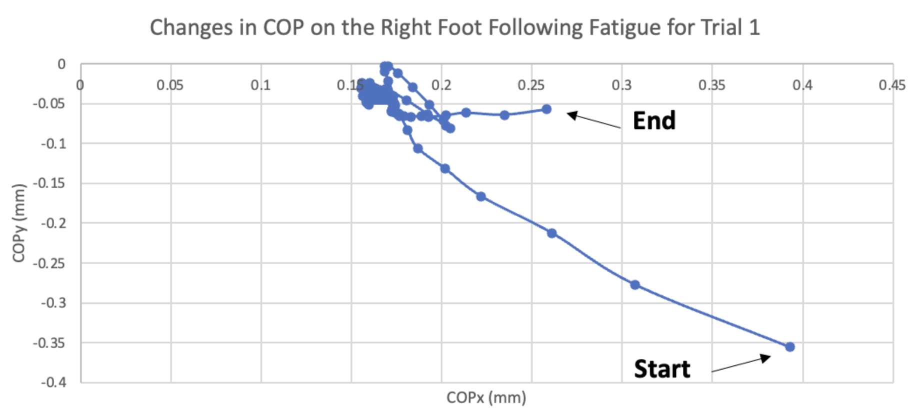
The main purpose of this study was to determine the effects of fatigue on landing forces within the 360 spin move, including changes in Fz_{max} and COP data. Despite dancers being expected to have a symmetry between lower limbs due to performing all steps and movements on both the right and left foot, it appears that fatigue had a greater effect on left foot landings through an increased downward force. This could be due to a plethora of reasons, such as the dancer having a dominant foot or prioritizing practice on one foot compared to the other. Future research should be conducted in order to determine potential determinants. Another aspect to note within the Fz_{max} data was the consistency between standard deviation in all trials, which was around 2.6 N/kg. This indicates that the variability of Fz_{max} remained similar between all trials, despite the differing conditions.

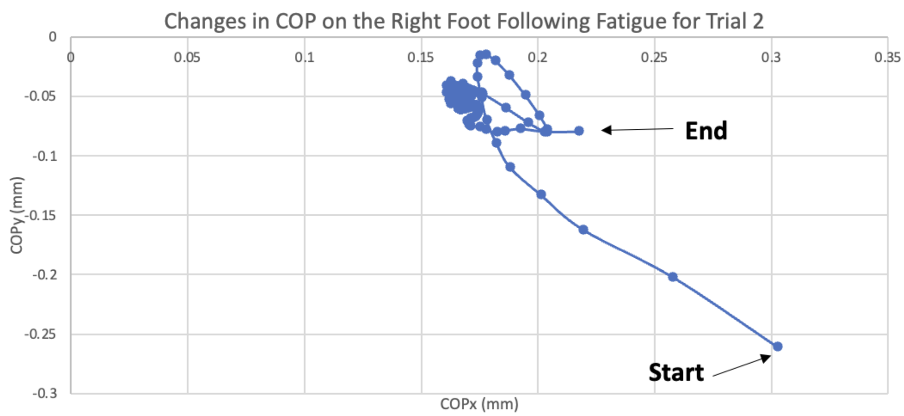
Despite having no statistical significance, there were a few factors to the COP data of potential interest. First, the difference in sway area between fatigued and non-fatigued trials on the left foot was trending toward significance, which coincides with the Fz_{max} data, and could imply that fatigue is affecting the left foot in ways more than just a greater downward force. Another interesting aspect to the COP data was the fact that the average sway area values tend to be greater within the non-fatigued trials than the fatigued trials, despite having no significance. In general, larger sway areas indicate larger shifts in COP and subsequently less postural control. One potential reason for this could be that dancers are usually encouraged to prioritize aesthetics within their technique, resulting in larger, but often less controlled, movements. When a dancer is less fatigued, they are more likely to focus on the aesthetic factors of the movement, resulting in the large but uncontrolled movement, as seen within the COP data during the landing. Furthermore, during competition, dancers are more inclined to continue this pattern, unlike in research settings where they are not being judged on their technique.

Figures 8a-b and 9a-b depict a birds-eye view of one participant's landings on the force plate for all non-fatigued and fatigued trials on the force plate, respectively. From this individual, it appears that the general center of pressure throughout the landing can be described as an initial shift in any particular direction (either anteroposterior, mediolateral, or a combination of the two) before a relatively stationary moment before the final shift prior to continuing out of the landing and off the force plate. Within the non-fatigued trials, there appears to be a smaller shift in COP within the anterior-posterior direction between the start and end of the landing in comparison to the fatigued trials. This could potentially be due to the dancer being unable to control the landing of the 360 when fatigued and falling out of it, rather than finishing the entirety of the movement before continuing onto the next move.



Figures 8a-b: One participant's COP data on the right foot following no fatigue.





Figures 9a-b: One participant's COP data on the right foot following fatigue.

There were a few limitations to this study, most notably the small sample size. By only having eight participants, the discussed results may not depict the entirety of effects that fatigue has on landing forces within the general Irish dance population. Having a greater sample size could also more accurately represent the effect of fatigue on sway area, especially since all conditions had a relatively high standard deviation. Furthermore, there were other variables that were not analyzed that could have shown additional indications of the effects of fatigue. For example, the moment about the z-axis (Mz) would have shown any turning motion experienced by the foot throughout the landing, which may have additional implications.

Overall, it was shown that fatigue does play a role within landing forces, more specifically on the left foot. As a precaution, dance instructors can alter choreography to have the 360 spin move occur at the beginning of a dancer's routine, prior to when fatigue sets in, to prevent any injury that may occur due to the increased force experienced. Instead, the final steps could have jumps that produce a lower Fz_{max} or prioritize more stationary footwork. Additionally, dancers should implement cross-training within their exercise regimen to increase both cardiovascular and muscular endurance, therefore decreasing, or delaying, the effects that fatigue may have.

Future Research

Future research should attempt to analyze data from a larger pool of participants to be able to more accurately extrapolate results out to the general population. Furthermore, additional variables could be analyzed, including Mz, to further quantify the effects that fatigue has on landing forces. Research could also be expanded to include male dancers or those within lower competitive levels to see if there are any differences present in the way that fatigue affects these additional subpopulations. Additionally, research could be done to determine the effects of fatigue that the 360 plays when dancers are wearing their hard shoes, rather than their soft shoes, to identify any potential differences.

Conclusion

Results of this study determined that Fz_{max} values are significantly higher during the landing of the 360 following fatigue on the left foot, indicating that this side may be more greatly affected by fatigue when compared to the right side. Despite no significant differences in sway area in regard to COP, future research should be conducted to support this finding. On a practical level, however, dance instructors can implement the 360 at the beginning of a dancer's routine, before fatigue sets in, to prevent any injury that may occur due to the increased force produced by this jump. Furthermore, cross training efforts can be utilized to maximize a dancer's cardiovascular health and aid in delaying physical symptoms of fatigue.

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Appendices

Appendix A: Inclusion Criteria Questionnaire

Yes	No	
☐	☐	Are you currently competing within the open championship level within CLRG-sanctioned competitions?
☐	☐	Are you able to complete the 360 spin move on both the right and left side?
☐	☐	Are you currently injured to the point where landings of Irish dance jumps are affected?
☐	☐	Do you need to wear tape and/or a brace to dance?
☐	☐	Are you currently in physical rehabilitation for a lower extremity injury?
☐	☐	Do you have any vestibular or balance problems?

Appendix B: Parental Consent Form for Minors

UNIVERSITY OF DAYTON

Parental Consent for Minor/Child to Participate in a Research Project

Project Title:	The Effect of Fatigue on Standing Balance Plantar Forces in Irish Dancers
Investigator(s):	Primary Investigator: Anna Robinson, robinsona24@udayton.edu Faculty Sponsor: Kimberly Bigelow, kbigelow1@udayton.edu
Description of Study:	The purpose of this study is to determine the effects of fatigue on landing forces in Irish dancers following the 360 spin move. There is a large prevalence of sesamoiditis and other lower-extremity injuries that may be caused by shifts in plantar forces toward supination or pronation after a dancer is fatigued. Study participants will come into the lab for a single 45–60-minute session to first perform 4 non-fatigued trials of the 360 on a force plate in a randomized order while wearing their own Irish dance soft shoes used within practice and competition (2 tests on each foot). Participants will then go through an Irish dance-specific fatigue protocol, characterized by the repetition of specific dance moves to music typical to practice and competition. Once fatigue is reached and the participant has a rate of perceived exertion of at least 17, which can be characterized by a decrease in form (such as kicking the butt) and inability to speak, the participant will “skip” up to the force plate and perform fatigued 360 trials on a force plate in a randomized order (2 tests on each foot). After each data collection, a two-minute water break will occur before repeating the fatigue protocol for the next data collection. Participants are also allowed to ask for breaks or stop participating at any time.
Adverse Effects and Risks:	Throughout the procedure, there is a risk of falling during the balance tests, similar to the risk present during dancing under normal conditions. There is also a risk for feelings of discomfort during and after the fatigue protocol. These feelings, however, will be similar to what each participant experiences during dance practices.
Duration of Study:	The study will take place in one session that will last about 45-60 minutes.

Confidentiality of Data:	Participants will not be audiotaped, photographed, or videotaped throughout the duration of this study. Additionally, the names of the study participants will not be associated with any of the trial data and will be protected through a numbered ID during data collection. All consent forms and pre-screening forms will be locked by key in a file cabinet within Dr. Bigelow's lab, which requires key card access for entry. All electronic data will be saved without personal identifiers and kept on a password protected computer.
Contact Person:	Parents or guardians of participants may contact: Anna Robinson, robinsona24@udayton.edu, 937-301-9440 Dr. Kimberly Bigelow, kbigelow1@udayton.edu, 937-229-2918 If you have questions about your rights as a research participant, you may also contact the University of Dayton's Institutional Review Board at (937) 229-3515 or IRB@udayton.edu.

____

Student's Full Name (please print)

____

Parent's Full Name (please print)

____

Parent or Guardian Signature   Date

Appendix C: Minor Assent Form

TITLE OF STUDY: The Effects of Fatigue on Landing Forces in Competitive Female Irish Dancers

Who is doing this research?

Primary Investigator: Anna Robinson

Faculty Sponsor: Dr. Kimberly Bigelow

Why should I do this?

The goal of this study is to determine the effect of fatigue on landing forces in Irish dancers to see if this factor can play a role in foot and ankle injuries.

How long will it last?
You will be tested in one session which will last about 45-60 minutes.

What will happen?
Throughout the entire session, you will be wearing your soft shoes. You will first have a 5-minute warm up session to stretch and warm up as you see fit. After this time is up, you will perform four tests of the 360 spin, including the run, on the force plate. For two of the tests, you will perform the move on your right foot and for the other two, you will perform on the left foot. After these tests, you will perform a fatigue protocol to reel music. For two eight-counts, you will skip around the room, followed by an eight-count of sevens on both feet (a total of two eight-counts). Between each set of sevens, you will do two "back-2-3s". You will repeat these two steps until you reach an RPE of 17, which is characterized by difficulty in maintaining proper form (like kicking your butt) and an inability to speak. You should feel a bit more tired at an RPE of 17 than you do after finishing a full round of reel. After you reach fatigue, you will perform the run up to the force plate and go into the 360 spin, just like during the non-fatigue portion. You will do a total of four fatigued tests and you will be let know which foot to do before you start the protocol. The dancing protocol will happen before each of the four fatigued force tests, and you will have a two-minute water break between each set of dancing. Additionally, you will have a 15-minute break at the halfway point of this fatigue protocol. You may ask for any additional breaks if needed and you can stop participating at any time if you feel too uncomfortable.

How will you feel?
You will feel tired and potentially uncomfortable after each of the fatigue protocols. These feelings of fatigue, however, are very similar to how you feel at dance practices and in competition.

Will anyone know I'm doing this?
You will not be audiotaped, photographed, or videotaped during your session. Additionally, your name will not be tied to any of the data we collect about you. All

forms that you will fill out will be kept under lock and key within Dr. Bigelow's lab, which also requires key card access for entry. Nobody will know that you participated within this study.

What if I have questions or am worried about something?

If you have questions, you may talk to Anna Robinson at robinsona24@udayton.edu or Dr. Kimberly Bigelow at kbigelow1@udayton.edu.

Consent to Participate

I agree to work with Annie and her team on this project. I understand all that is expected of me and promise to do my best. Annie has answered all my questions. I understand I may stop this activity at any time.

_______________________________	___________
Participant's Name	DATE
_____________________________________	____________________________
Participant's Signature	Researcher's Name

Appendix D: Consent Form (Over 18)

UNIVERSITY OF DAYTON - CONSENT TO PARTICIPATE IN RESEARCH

TITLE OF STUDY: The Effects of Fatigue on Standing Balance Plantar Forces in Irish Dancers

We are inviting you to be a part of a research study led by Anna Robinson and Dr. Kimberly Bigelow at the University of Dayton. Participation is not required. Please read the information below to learn more about the study. Before participating, ask questions about anything you do not understand.

PURPOSE OF THE STUDY

The purpose of this study is to determine the effects of fatigue on standing balance plantar forces in Irish dancers during flat-foot and plantarflexed stances in first position. There is a large prevalence of sesamoiditis and other lower-extremity injuries that may be caused by shifts in plantar forces toward supination or pronation after a dancer is fatigued.

PROCEDURES

This study will occur in one 45–60-minute session. You will begin by filling out appropriate paperwork, consisting of a medical form containing inclusion criteria, a demographic survey, and a consent form. If you are under the age of 18, you will need to fill out an assent form and your parent/guardian will need to fill out a parental consent form. Following completion of all paperwork, you will put on your own soft shoes, in addition to a gait belt.

You will begin the study by performing a total of four balance tests on a force plate in a randomized order. During all of these non-fatigued tests, you will be standing with your arms down at your sides and your feet turned out, while looking straight ahead at the wall in front of you. For two of the tests, you will stand flat-footed. For the other two tests, you will stand on your toes. The primary investigator will communicate with you on how you should be standing for each trial.

After completion of the four non-fatigued balance tests, you will begin the fatigue portion of the study. Before each balance test, you will perform an Irish dance specific fatigue protocol that will be danced to reel music. During this fatigue protocol, you will dance two eight-counts of skips, followed by an eight-count of sevens on each foot with a "back-2-3" between each set of sevens. After this, you will go back to the two eight-counts of skips and repeat the process. During this portion, you should focus on maintaining proper form, including kicking your butt, throughout. You will continue this fatigue protocol until you attain a rating of perceived exercise (RPE) of at least 17 on Borg's scale, which is characterized by the inability to speak while dancing, in addition to no longer being able to keep up with the music. When you reach this point, you will immediately skip up to the force plate to perform a balance test. You will be performing the same four tests as during the non-fatigued portion: two tests on your flat foot and two tests on your toes. This fatigue protocol will be done before each balance test. You will get a two-minute water break between each test during the fatigue protocol. You can ask for a break at any time if needed.

POTENTIAL RISKS AND DISCOMFORTS

Throughout the procedure, there is a risk of falling during the balance tests. You will be wearing a gait belt at all times, in addition to the primary investigator standing behind you during the balance tests to prevent falling. There is also a risk for feelings of discomfort during and after the fatigue protocol. These feelings, however, will be similar to what you experience during dance practices.

ANTICIPATED BENEFITS TO PARTICIPANTS

There are no direct benefits to you.

PAYMENT FOR PARTICIPATION

There will be no payment for participation in this study.

IN CASE OF RESEARCH RELATED INJURY

If you get sick or hurt as a result of this study you should see the doctor of your choice for treatment. You agree to tell the researcher about any illness or injury: Anna Robinson, robinsona24@udayton.edu or Dr. Kimberly Bigelow, kbigelow1@udayton.edu. **You do not give up any legal rights for personal injury by signing this form.**

CONFIDENTIALITY

We will not reveal who you are in any publications or presentations. Other people may need to see your research records. This is to confirm requirements of the study are met. They may see your name. These representatives will not reveal who you are to others. Additionally, all data will be tied to a number given to you, rather than your name. Data will be password protected. Any forms filled out, such as this consent form, will be kept under lock-and-key in Dr. Bigelow's lab, which requires key card access for entry.

PARTICIPATION AND WITHDRAWAL

You do not have to be in this study. If you do not participate, your relationship with us is not affected. You may still receive other services if applicable. You may stop participating at any time without penalty. You may be stopped from participating if the study is not good for you. You may also be stopped if study instructions are not followed.

NEW FINDINGS

During this study you will be told about any new findings (either good or bad). We will also inform you about any changes in the risks or benefits of the study. We will explain different ways to participate if the study changes. You can change your mind about staying in the study. We will ask if you wish to continue in this study if we provide new information. *If not applicable, omit this section.*

IDENTIFICATION OF INVESTIGATORS

Please contact one of the investigators listed below if you have any questions about this research.

Anna Robinson, Principal Investigator, University of Dayton, Health and Sport Science Department, 937-301-9440, robinsona24@udayton.edu.

Dr. Kimberly Bigelow, Faculty Advisor, University of Dayton, Mechanical Engineering Department, 937-229-2918, kbigelow1@udayton.edu.

RIGHTS OF RESEARCH PARTICIPANTS

You may contact the Institutional Review Board (IRB) at the University of Dayton if you have questions about your rights as a research participant: IRB@udayton.edu or (937) 229-3515.

SIGNATURE OF RESEARCH PARTICIPANT (*or legal guardian*)

I have read the information above. I have had a chance to ask questions and all of my questions have been answered to my satisfaction. I have been given a copy of this form. **I certify that I am at least 18 years of age.**

Name of Participant (please print) ____

Address ____

Signature of Participant ____________________________________ Date__________

SIGNATURE OF WITNESS

My signature as witness certifies that the Participant signed this consent form in my presence.

Name of Witness (please print) ____

Signature of Witness _____________________________________ Date __________