Effect of Fatigue on Muscle Contraction in Dancers Performing Drop Landings in Coupé

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This thesis titled
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Abstract

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Effect of Fatigue on Muscle Contraction in Dancers Performing Drop Landings in Coupé

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Background: Reports suggest that as many as 97% of dancers experience injury. Dance is very physically demanding and requires a great number of jumps with single leg landings. Dancers generally have poor fitness which can lead to fatigue. Fatigue alters movement and landing patterns and may contribute to dancers’ injuries. Purpose: The purpose of this study was to determine the effect of fatigue on lower extremity muscle activation in dancers using a dance-specific fatiguing protocol and a functional dance landing test. Methods: A total of 18 healthy Ohio University Dancers were recruited to perform a drop landing task in coupé. This task was performed prior to and after fatigue. Surface electromyography was used to evaluate muscle contraction amplitude bilaterally in the gluteus medius and peroneus longus muscles at time of peak vertical ground reaction force. Main outcome measures: Pre- and post-fatigue muscle contraction amplitudes. Results: No statistical significance was found between pre- and post-fatigue conditions. Conclusion: Muscle contraction activity in the ankle and hip may not be affected by fatigue, suggesting that jump training in dance is sufficient to reduce the negative effects of fatigue. However, dancers may not accurately judge their fatigue levels and should be monitored for fatigue.
Preface

In this thesis document, Chapter 3 serves as a prepublication manuscript. This chapter has been formatted to meet the guidelines set forth by the *Journal of Athletic Training* and the document as a whole was prepared in accordance with the guidelines of Thesis and Dissertation Services at Ohio University. The reference citation style follows the guidelines of the AMA Manual of Style (10th ed., 2007).
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Chapter 1: Introduction

Approximately 97% of dancers experience injury.\(^1\) This extremely high percentage is due, in part, to the demands placed on the performers. Professional ballet dancers typically work for 9 hours in a day, with 90% of these dancers spending less than 60 consecutive minutes resting.\(^2\) Furthermore, dancers perform over 200 jumps in a single class with half requiring a single leg landing.\(^3\) Approximately 92% of ACL injuries in dancers happen during single-leg landings.\(^3\)

Dance can be described as intermittent with moderate to high intensity and variation of intensity depending upon whether the activity is during a rehearsal or performance.\(^4\) Research has shown that dancers have low amounts of rest and highly intense activity, though variance in the demands placed on dancers does exist among different levels.\(^2\) Sparse literature about the demands of dancing agrees that, overall, the energy demand for dance is moderate to high and involves intermittent activity.\(^4\) Dancers engage in rigorous work to perfect their craft, and they suffer injuries as a result.

Lower extremity, hip, and back injuries in dance demonstrate both high prevalence and high incidence.\(^5\) The foot and ankle are the most commonly injured sites, followed by the low back and knee.\(^6\) Ankle tendinopathy and hamstring strains also are commonly reported by dancers.\(^7\)

A number of factors contribute to injury in dance; however, there is little consensus regarding particular risk factors.\(^8\) Research has suggested that psychological issues may impact injury rate and time to heal.\(^5\) Furthermore, fatigue has been correlated with injury in dance.\(^5\) Fatigue alters muscle activation in the thigh by decreasing motor
control and changing the ratio of quadriceps to hamstrings contractile strength. Fatigue in dancers also negatively impacts neuromuscular and motor control. More specifically, fatigue increases motion in the trunk and hips, increases center of mass deviation medially and laterally, decreases center of mass velocity, decreases ankle motion, reduces hamstring activity, reduces tibialis anterior activity, and increases soleus activity. Reduction in muscle activity may result in decreased muscle force and power. Without sufficient force or power, the muscles may not be able to correct flaws in movement, resulting in injury.

Fatigue is generally avoided through improvements in physical fitness; however, dancers generally have poor aerobic fitness due to a dance-only mode of activity to fulfill the demands placed on them aesthetically. Furthermore, scant literature is available regarding methods for evaluating fatigue and physical fitness in dancers, and most investigations utilize non-dance specific measures. Recent research has begun to examine more dance-specific measures. One study designed a protocol involving intervals of contemporary dance movements that was shown to reliably estimate VO2max and assess physical fitness in dancers. Another study designed a choreography-based testing procedure specific to ballet called the High Intensity Dance Performance Fitness Test (HIDPFT). While generic testing is effective in evaluating physical fitness in dancers, dance-specific testing protocols will likely be received and utilized more by the dance community.

Understanding how fatigue affects dancers is required to reduce fatigue-related dance injuries. Such knowledge may help dancers manage fatigue better and alter how
they practice dance; a reduction in fatigue may concomitantly decrease fatigue-related injuries. To our knowledge, no study has examined the effects of fatigue on dancers in a translational manner by using a dance-specific fatiguing protocol in addition to using a dance-specific movement for measurement. Research accounting for such factors would offer applicability to the dance population outside of a controlled laboratory environment. In light of this gap in knowledge, the purpose of this study was to determine the effect of fatigue on lower extremity muscle activation in dancers using a dance-specific fatiguing protocol and a dance-specific task. It was hypothesized that fatigue would result in a reduction in the amplitude of muscle contractions, which would be correlated with lower muscular force and power that makes dancers susceptible to injury.

RESEARCH QUESTION AND HYPOTHESIS

- How are muscle contraction amplitudes in the peroneus longus and gluteus medius muscles of dancers affected by fatigue during a drop landing in coupé?
  - Fatigue of the lower extremity will result in a reduction in the contraction amplitude in all tested muscles.

INDEPENDENT VARIABLE(S)

- Time
  - Pre-Fatigued
  - Post-Fatigued

DEPENDENT VARIABLE(S)

- Amplitude of muscle contraction
  - Gluteus medius right and left (% MVC)
Peroneus longus right and left (% MVC)

ASSUMPTIONS

- Surface electrode placement was consistent and accurate.
- All participants gave full effort to induce fatigue and maximally contract muscles.
- Drop landings were performed with identical form from pre-fatigue to post-fatigue condition.

LIMITATIONS

- Participants may have varying levels of physical fitness and dance training.
- Adipose tissue and sweat may impact EMG signal.
- There will be no momentum involved in the landing task.

DELIMITATIONS

- Participants were healthy dancers in the Ohio University dance program.
- Participants were compared against themselves.
Chapter 2: Review of Literature

INTRODUCTION

Approximately 97% of dancers experience injury.\(^1\) This high injury rate is due, in part, to the demands placed on the performers. Professional ballet dancers typically work for 9 hours a day, with 90% of these dancers spending less than 60 consecutive minutes resting.\(^2\) Dancers engage in rigorous amounts of practice to perfect their craft, and they suffer injuries as a result.

Muscle activation under fatigue conditions is generally understood in non-dancer populations.\(^10\) In dancers, studies have shown that fatigue alters muscle activation in the thigh by decreasing motor control and changing the ratio of quadriceps to hamstrings contractile strength.\(^9,10\) Another study examined the effect of rest days on injury rates in a performing arts population and suggested that performers do not obtain sufficient rest to avoid injury.\(^16\) Fatigue also constrains postural control in dancers.\(^17\)

Understanding how fatigue affects dancers is required to reduce fatigue-related dance injuries. Such knowledge may help dancers manage fatigue better and alter the how they practice dance; a reduction in fatigue may concomitantly decrease fatigue-related injuries that keep dancers out of the studio and away from the stage. A logical first step is to determine the effect of fatigue on lower extremity muscle activation in dancers. To illustrate the importance of such research, this review of the literature will examine the known effects of fatigue, the evaluation of fatigue in dancers, dance related injuries, the demands place on dancers, and the impact of fatigue and rest days on dance performance.
DANCE-RELATED INJURIES

There is consensus in the literature that higher quality evidence is needed to report injuries in dance. Reviews and meta-analyses have examined prevalence, incidence, injury risk, and long term effects of injury; all of these recommend additional and higher quality research. Knowledge of injuries in dance is essential in establishing the relationship of injury to fatigue.

Prevalence and Incidence

One study provided injury prevalence statistics that showed 47% of the dancers surveyed had chronic injuries, and 42% had sustained an injury in the last 6 months. A small sample prevalence study found that 82% of dancers had sustained at least one injury, and the rate of injury was 0.59 per 1000 hours of dance. Another study found the incidence of injury in dance to be 1.33 per 1000 hours of exposure. Further research is necessary to establish a consensus about prevalence and incidence of injury in dance.

Common Injuries

Foot and ankle injuries have been found to be the most prevalent injury site in dancers, followed by the low back and knee; however, ACL injuries in dancers occur significantly less frequently than non-dancer athletes. Other research has found lower extremity, hip, and back injuries to be prevalent with high incidence as well. The most common injuries include ankle sprains, ankle tendinopathy, hamstring strain, and low back pain. Hamstring strains were found to be located more frequently in the proximal tendon as opposed to the muscle belly.

Contributing Factors to Injury
The literature reports several factors that contribute to injury in dance; however, there is little consensus about particular risk factors. Improper training, poor technique, hazards in the environment, biomechanical deficits, and structural deformities in the foot are documented risk factors. One study showed that psychological factors may impact injury rate and time to heal. Additionally, history of lateral ankle sprain has been correlated with sprains in the opposite ankle, and fatigue has been shown to contribute to knee injury. Another study investigated the impact of functional asymmetries on injury and found asymmetries present in 11 of 16 dancers. The authors found 9 of those 11 dancers had overuse injuries to the foot and leg. Furthermore, of those 9 dancers, 8 had abnormal foot movement patterns, 7 had previously injured their foot, and 4 exhibited sacroiliac dysfunction. The author suggested that these abnormalities are common in dancers and that they may predispose the dancer to injury if not treated fully in a timely manner.

**DEMANDS PLACED ON DANCERS**

Dance can be described as intermittent with moderate-to-high intensity and variation of intensity depending upon whether the activity is during a rehearsal or performance. One study examined the demands placed upon ballet dancers in a working day. This study is unique as it investigated what dancers go through physically in a typical day. The researchers showed that dancers undergo small amounts of rest time with high intensities of activity, and that there is variance in the demands placed on different ranks of dancers.
Beck et al.\textsuperscript{4} completed a review of the literature investigating the necessary energy required of dancers and identified that there is insufficient evidence to draw conclusions about requisite energy for dance. The authors noted, however, that the sparse literature on the topic agrees that, overall, the energy demand for dance is moderate to high, and that dance is an intermittent activity.\textsuperscript{4} After warm-up for classes and during rehearsals, dancers undergo short periods of high intensity followed by long periods of rest. When dancing at a performance, dancers engage both aerobic and anaerobic systems while dancing at intermittent high to heavy intensities. This study also showed that, in general, dancers have poor aerobic fitness due to a dance-only mode of activity to fulfill the demands placed on them aesthetically.\textsuperscript{4} High quality research is needed to solidify current findings and better understand the demands placed on dancers of all genres and skill levels.

**KNOWN EFFECTS OF FATIGUE**

Research has shown that fatigue in the lower extremity can impact a number of factors including balance, motor control, joint position sense, and landing mechanics.\textsuperscript{10,24,25} Fatigue can reduce motor control in the lower extremity, which may negatively impact balance and may lead to injury.\textsuperscript{10} Many of the known effects of fatigue have centered around impact on the knee joint. Fatigue has been shown to reduce joint position sense in the knee.\textsuperscript{25} Furthermore, studies have shown that fatigue negatively impacts landing mechanics by increasing knee valgus angle during landing.\textsuperscript{24} Whereas dancers routinely perform a variety of jumps, these findings bring concern for the health of dancers. Overall, research underscores the negative impact of fatigue as it relates to
potential injury. Examining specific muscles and muscle groups may be helpful in further assessing the effects of fatigue (see Table 1).

**Hip Abductor Fatigue**

A majority of the research involving fatigue in the hip abductors centers around the gluteus medius muscle. In general, studies have shown that fatigue of the abductor muscle group results in increased postural sway, particularly medially and laterally.\(^9\) Other findings show an anterior translation of center of pressure under fatigued conditions as well as an increase in hamstring muscle activity.\(^{26}\) Investigating the specific effects of gluteus medius fatigue has shown a reduction in gluteus medius activity in addition to a reduction in postural control and movement quality.\(^{27,28}\) These findings illustrate a deleterious effect on movement under fatigued hip abductor conditions.

**Quadriceps and Hamstrings Fatigue**

A rise in interest over anterior cruciate ligament injury prevention has resulted in many studies examining fatigue in the quadriceps and hamstrings. The hamstring muscle group exhibits delayed reaction compared to the quadriceps when the muscles are fatigued and moving the limb into extension.\(^{22}\) During rapid stopping, quadriceps and medial hamstrings show delayed activation.\(^{30}\) Hamstring fatigue reduced hamstring strength and altered landing kinematics.\(^{31}\) Furthermore, quadriceps and hamstring fatigue alters both knee and hip landing mechanics.\(^{32}\) These findings indicate that quadriceps and hamstring muscle fatigue can cause changes in typical movement patterns at the knee joint.

**Peroneal Fatigue**
There is minimal research investigating the impact of peroneal fatigue at the ankle joint. The literature that does exist reports that peroneal muscle fatigue reduces ankle neuromuscular control; however, peroneal fatigue has not been found to alter joint position sense. More specifically, the peak torque of the peroneal muscles and the median frequency of contraction have been shown to decrease under fatigued conditions, particularly during plantar flexion. More research needs to be conducted to further examine the effects of peroneal fatigue on the body.

Table 1. Implications of Muscular Fatigue

<table>
<thead>
<tr>
<th>Peroneus longus</th>
<th>Quadriceps and hamstrings</th>
</tr>
</thead>
<tbody>
<tr>
<td>• ↓ ankle neuromuscular control&lt;sup&gt;33&lt;/sup&gt;</td>
<td>• ↓ HS activity compared to quadriceps&lt;sup&gt;29&lt;/sup&gt;</td>
</tr>
<tr>
<td>• peroneal peak torque&lt;sup&gt;35&lt;/sup&gt;</td>
<td>• ↓ quadriceps activity with rapid stopping&lt;sup&gt;30&lt;/sup&gt;</td>
</tr>
<tr>
<td>• ↓ median frequency of contraction&lt;sup&gt;35&lt;/sup&gt;</td>
<td>• Altered landing mechanics&lt;sup&gt;31&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Hip abductors

• Increased postural sway<sup>6</sup>

• Anterior CoP<sup>26</sup>

• Poor posture control and movement quality<sup>27</sup>

• ↓ gluteus medius activity<sup>27</sup>
EFFECTS OF FATIGUE ON DANCERS

Published findings examining fatigue in dancers has corroborated findings in non-dancer populations that have found fatigue to alter normal movement patterns.\(^1\) Evidence has also shown that fatigue is multifaceted and should be treated as such.\(^{11}\)

**Physiological and Biomechanical Effects**

Fatigue in dancers has been shown to negatively impact neuromuscular control.\(^{11}\) One study found that fatigue increased motion in the trunk and hips and increased center of mass deviation medially and laterally.\(^{12}\) Decreased center of mass velocity, decreased ankle motion, reduced hamstring activity, reduced tibialis anterior activity, and increased soleus activity were also reported. These findings corroborate other reports of a reduction in hamstring activity in dancers\(^9\) and non-dancers.\(^{29}\) Furthermore, dancers were also found to have reduced knee joint loading; this impacts protective mechanisms in the ankle musculature and the dispersion of forces in the lower extremity.\(^{36}\) These internal physical effects negatively influence movement patterns, thus making it logical to assume that injury may result.

**Psychological Effects of Fatigue**

Additional studies examined the psychological impact of fatigue. One found that injured dancers displayed higher levels of body dissatisfaction, disordered eating tendencies, and perfectionism than did uninjured dancers.\(^{37}\) The same study concluded that dancer reports of fatigue, prolonged work exposure, highly intense and repetitive work, and mood or diet changes may provide insight to increased injury vulnerability.\(^{37}\)

**Fatigue and Injury**
Numerous studies suggest that fatigue influences injury.\textsuperscript{1,11,38-40} Fatigue places dancers in jeopardy of injury, particularly in activities like jumping, as it alters landing patterns and causes the knee to absorb a majority of the landing impact.\textsuperscript{11} Dancers may perform over 200 jumps in a single 90 minute technique class, and 50\% of those jumps involve a single leg landing.\textsuperscript{3} Furthermore, 92\% of ACL injuries in dancers occurred during a single-leg landing task.\textsuperscript{3} One study compared a dance company that performed a great number of jumps to a company that performed few jumps; the authors found that 100\% of the anterior cruciate ligament tears between the two companies occurred in the company that performed more jumps.\textsuperscript{38} Relationships also have been found between timing and the occurrence of injury in relation to fatigue. The majority of dance injuries occur in the final stages of rehearsal and performance seasons.\textsuperscript{1,3,39,40} One study found that 67\% of injuries happened late in the day and 75\% happened late in the performing season.\textsuperscript{1} The prevalence of injuries late in the day or season can be attributed to the breakdown in movement mechanics\textsuperscript{39} and overtraining.\textsuperscript{40}

**IMPACT OF FATIGUE ON LANDING MECHANICS**

Whereas dancers perform numerous jumps and land on one leg approximately half of the time, it is important to consider the impact fatigue may have specifically on landing mechanics. Many studies have examined single- and double-leg landing mechanics in dancers and non-dancers. In non-dancers, landing mechanics are dependent upon the specific landing task: forefoot, rearfoot, single-leg, double-leg, etc.\textsuperscript{41} Non-dancers with ACL injuries develop poor single-leg landing mechanics in their affected leg compared to the non-affected leg.\textsuperscript{42} Non-dancers with acute lateral ankle sprains also
display altered landing mechanics and use compensatory strategies to reduce landing forces during single-leg landings on the affected leg. During landing, males and females in both dancer and non-dancer populations have shown similar landing mechanics. In dancers, females show greater time to stability during landing, and inclined stages cause dancers to alter their landing mechanics. Also, dancers show greater trunk stability and less knee valgus than non-dancer athletes.

Fatigued landings have been examined repeatedly in non-dancer populations. When comparing fatigued landings to non-fatigued landings, no difference in shock attenuation has been observed. Fatigued landings in non-dancers may also result in greater knee and ankle motion, greater ground reaction force, and increased time to stabilization in both sexes.

However, fatigued landings have received minimal attention in dancer populations. One study reported that dancers and non-dancers both exhibit altered landing mechanics when fatigued. Both groups showed increases in knee valgus and trunk motion post-fatigue. Further research is warranted to investigate functional landing mechanics in fatigued dancers.

EVALUATING FATIGUE IN DANCERS

There is much debate in the literature regarding the use of non-dance activities to provide a measure of physical fitness in dancers. Clearly, one’s level of physical fitness can impact fatigability. To understand the relationship between physical fitness and fatigue in dancers, it is important to understand general physical fitness levels of dancers, as well as the current evaluation methods available.
Physical Fitness and Fatigue in Dance

Many studies have established that a dance-only training regimen is insufficient for the level of fitness necessary for dancing.\textsuperscript{4,13,52,53} Researchers speculate that omitting external training could be the cause of overall low aerobic fitness in dancers as well as the anaerobic nature of dance class and rehearsal.\textsuperscript{4} There has been concern regarding non-dance-specific training for fear that dancers will lose their desired aesthetic appearance;\textsuperscript{52} however, it has been shown that improvements in aerobic capacity and leg strength are not deleterious to dance performance.\textsuperscript{13} Unfortunately, the dance community tends to side with tradition and generally believes that the ideal dancer body is achieved with dance-only activity.

Physical fitness has been linked to enhanced dance performance,\textsuperscript{54} with strength training and aerobic fitness programs proving beneficial to dancers.\textsuperscript{4,13} One study found that dancers that increased their dance training load to achieve physical fitness did not improve their VO2max as much as dancers that used a non-dance exercise program.\textsuperscript{4} Another study evaluated physical fitness between dancer skill levels, finding that professional dancers have better physical fitness than their pre-professional counterparts.\textsuperscript{55} Overall, there is much agreement in the literature that dancers need to incorporate general fitness training into their dance programs.

Methods of Evaluating Fatigue

Scant literature identifies methods for evaluating fatigue and physical fitness in dancers. Most investigations utilize non-dance-specific measures. One study used flexibility assessment, a treadmill test, and strength testing to evaluate physical fitness.\textsuperscript{13}
However, recent research has examined dance-specific measures of aerobic capacity.\textsuperscript{14,15} For example, one study designed a protocol involving intervals of contemporary dance movements that were shown to reliably evaluate VO2max and physical fitness in dancers.\textsuperscript{14} Another designed a choreography-based testing procedure specific to ballet.\textsuperscript{15} While generic testing is effective in evaluating physical fitness in dancers, dance-specific testing protocols will likely have a greater chance of being utilized in the dance community.

**REST AND INJURY**

The effects of rest on dancers or other performing artists is minimally reported in the literature. One investigation examined the effects of rest days using an acrobatic circus company and found that every 4 to 6 weeks, a 2-day break may be helpful in avoiding fatigue-related increases in injury rate.\textsuperscript{16} Other research has shown that rest periods or periods of reduced activity may reduce the incidence of illness, thus preventing illness from hampering performance.\textsuperscript{56} Although little evidence supports how long rest periods should be for dancers, the current literature suggests that recovery periods should be 3 to 5 weeks in length after the close of a dance concert series.\textsuperscript{56,57} One study examined a number of factors related to fatigue in dancers both before and after a 6-week break in performing.\textsuperscript{58} The researchers showed increases in dancers’ flexibility, anaerobic power, leg strength, and VO2max immediately after the break. Furthermore, 2 to 3 months after the break had ended, even greater increases in leg strength and VO2max were detected. The authors suggested that these results show that burnout is present at the
end of a dancing season, thus hampering fitness and conditioning. However, a 6-week break may aid in restoration.

CONCLUSION

Only a small amount of evidence shows how fatigue affects dancers. In general, the available evidence is of low quality, and few conclusions can be drawn. No study has established the effects of fatigue on dancers in a fully clinically applicable manner, nor has one used a dance-specific fatiguing protocol in addition to using a dance-specific movement for measurement. Examining fatigue in this way would be more useful to the dance population outside of a controlled laboratory environment. Many factors, like the effect of fatigue on performance, injury rate, and movement patterns, need to be investigated to help prevent fatigue-related injuries in dance.
Chapter 3: Effect of Fatigue on Muscle Contraction in Dancers Performing Drop Landings in Coupé

Context: Reports suggest that as many as 97% of dancers experience injury. Dance is very physically demanding and requires a great number of jumps with single leg landings. Dancers often exhibit suboptimal fitness levels that can lead to fatigue. Fatigue alters movement and landing patterns and may contribute to dancers’ injuries. Objective: The purpose of this study was to determine the effect of fatigue on lower extremity muscle activation in dancers using a dance-specific fatiguing protocol and a functional dance-specific drop landing test. Design: Within-subjects repeated-measures. Setting: University laboratory setting. Participants: Eighteen male (n = 1) and female (n = 17) healthy Ohio University dance students (age = 19 ± 0.84 years, dance experience = 14.72 ± 2.24 years) were recruited to participate. None had a history of musculoskeletal injury in the last 6 months that caused discontinuation of dance activity for one or more days. Data Collection: Participants were asked to perform drop landings in coupé prior to and after fatigue. Surface electromyography was used to evaluate muscle contraction amplitude bilaterally in the gluteus medius and peroneus longus muscles at time of peak vertical ground reaction force. Data Analysis: A multivariate repeated measures ANOVA was conducted for the independent variable time (pre- and post-fatigue) for the

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1 This chapter represents a prepublication manuscript to be submitted to the Journal of Athletic Training (May 2018). Authors are: Alexandra E. Bryan, AT (School of Applied Health Sciences and Wellness, Ohio University, Athens); Dustin R. Grooms, PhD, AT, CSCS (School of Applied Health Sciences and Wellness, Ohio University, Athens); Jae Yom, PhD (School of Applied Health Sciences and Wellness, Ohio University, Athens); and Jeffrey A. Russell, PhD, AT, FIADMS (School of Applied Health Sciences and Wellness, Ohio University, Athens).
dependent variables (gluteus medius right, peroneus longus right, gluteus medius left, and peroneus longus left). Alpha level was set at \( p < 0.05 \) for all analyses. **Results:** No statistical significance was found between pre- and post-fatigue conditions \( [F_{(4,14)} = 0.567, p = 0.69, \omega^2 = 0.14] \). **Conclusions:** Muscle contraction activity in the ankle and hip may not be affected by fatigue, suggesting that jump training in dance is sufficient to reduce the negative effects of fatigue. However, dancers may not accurately judge their fatigue levels and should be monitored for fatigue.

**Key Words:** dance, biomechanics, electromyography, fatigue, vertical ground reaction force, high intensity dance performance fitness test

**Key Points**

- No significant differences were found in muscle activation between pre-fatigue and fatigued conditions.
- Dancers did not perceive themselves to be fatigued after completing the fatiguing protocol.

Approximately 97% of dancers experience injury.\(^1\) This high percentage is due, in part, to the demands placed on the performers. Professional ballet dancers typically work for 9 hours in a day, with 90% of these dancers spending less than 60 consecutive minutes resting.\(^2\) Furthermore, dancers perform over 200 jumps in a single class with half requiring a single leg landing.\(^3\) Approximately 92% of ACL injuries in dancers happen during single-leg landings.\(^3\)

A number of factors contribute to injury in dance; however, there is little consensus regarding particular risk factors.\(^4\) Research has suggested that psychological
issues may impact injury rate and time to heal. Furthermore, fatigue has been correlated with injury in dance. Fatigue alters muscle activation and negatively impacts neuromuscular control, which may result in decreased muscle activity. Without sufficient force or power, the muscles may not be able to support the biomechanics required in dance movements, thus resulting in injury.

Fatigue is generally avoided through improvements in physical fitness; however, dancers generally have poor aerobic fitness due to a dance-only mode of activity to fulfill the demands placed on them aesthetically. Furthermore, scant literature is available regarding methods for evaluating fatigue and physical fitness in dancers, and most investigations utilize non-dance specific measures. Recent research has begun to examine more dance-specific measures, including the High Intensity Dance Performance Fitness Test (HIDPFT). Dance-specific testing protocols will likely be received and utilized more by the dance community.

Understanding how fatigue affects dancers is required to reduce fatigue-related dance injuries. Such knowledge may help dancers manage fatigue better and alter how they practice dance; a reduction in fatigue may concomitantly decrease fatigue-related injuries. To our knowledge, no study has examined the effects of fatigue on dancers in a translational manner by using a dance-specific fatiguing protocol in addition to using a dance-specific movement for measurement. Research accounting for such factors would offer applicability to the dance population outside of a controlled laboratory environment. In light of this gap in knowledge, the purpose of this study was to determine the effect of fatigue on lower extremity muscle activation in dancers using a dance-specific fatiguing
protocol and a functional dance-specific drop landing test. It was hypothesized that fatigue would result in a reduction in the amplitude of muscle contractions, which would be correlated with lower muscular force and power that makes dancers susceptible to injury.

**METHODS**

**Participants**

A total of 18 dancers (1 male, 17 female, mean age = 19 ± 0.84) were recruited using a convenience sample of university-level dancers enrolled as dance majors or minors at Ohio University. The participants had 14.72 ± 2.24 years of dance experience. The study was approved by the university’s Institutional Review Board.

All participants were healthy dancers with no history of musculoskeletal injury in the last 6 months that caused discontinuation of dance activity for one or more days. Dancers were asked to refrain from strenuous activity and caffeine use for the 24 hours preceding testing. Participants were excluded based on their responses in a screening questionnaire, including injury history and certain medical conditions or medications that may inhibit or be problematic for reaching full exertion.

**Procedures**

**Questionnaires.** After enrollment, all participants gave their informed consent. All participants also completed a demographics form and the Physical Activity Readiness Questionnaire (PAR-Q). No participants were excluded based on PAR-Q scores.

**Equipment.** A university biomechanics lab was used for all testing procedures. A Bertec 600 x 1200 mm force plate (Bertec, Inc., Columbus, Ohio) was used for collecting
ground reaction forces. A Noraxon surface electromyography (EMG) system operated by Noraxon MR 3.10 software (Noraxon, Inc., Scottsdale, Arizona) was used to record EMG signals. Noraxon dual Ag-AgCl electrodes were used; the sEMG signals were transmitted wirelessly to the system’s computer by surface transmitters attached to nearby electrodes.

**Warm Up and Maximal Voluntary Contraction Testing.** Participants performed 10 minutes on a stationary bicycle to warm up with a goal of reaching 3/10 on the category-ratio perceived exertion scale, and were instructed to stretch for 5 minutes after cycling.

After the warm up, electrodes were placed and maximal voluntary contraction (MVC) testing was done. The skin areas that received the EMG electrodes were prepared by abrading them with 220 grit extra fine sandpaper, following by wiping vigorously with an isopropyl alcohol-soaked pad.

EMG electrodes were placed over the gluteus medius approximately 33% of the distance between the greater trochanter and the iliac crest, beginning at the greater trochanter (see Figure 2a). Participants were instructed to lay on their side, and to medially rotate the thigh and pull the thigh into abduction. Resistance was provided by a non-elastic band wrapped around the knee at the lateral femoral condyle and secured to a fixed point. The participant was instructed to perform a maximum contraction against resistance for 5 seconds. Two trials were completed for each side.

For the peroneus longus, electrodes were placed over the belly of the peroneus longus muscle approximately 17% of the distance between the fibular head and the lateral malleolus, beginning at the fibular head (see Figure 2b). Participants were in a seated
position with the knees extended and a non-elastic band around the midfoot and a fixed point. Participants were instructed to maximally evert for 5 seconds. Two trials were completed for each side.

Figure 1. (a) Electrode placement for gluteus medius. (b) Electrode placement for peroneus longus.

Participants performed vertical jumps prior to completing the pre-fatigued drop landings and after the post-fatigued drop landings to evaluate if, from a functional perspective, fatigue was sufficiently induced. They were instructed to jump as high as they possibly could on the force plate. Each participant was allowed 2 trials for the jump; the average height of the 2 trials was the participant’s jump height score. Jump height was calculated from time in the air:

\[ h = \frac{1}{2} a (t/2)^2 \]
**Drop Landings in Coupé.** To perform this maneuver, a participant dropped from a box individualized according to his or her vertical jump height, landing on the designated leading leg in coupé (see Figure 3). Box height was set at the individual’s maximum vertical jump height, rounded to the nearest 1 cm. A 10 cm box was used with 1 cm platforms added to it as needed to achieve the correct height. Participants were instructed to drop from the box without stepping down or jumping from the box and to land their drop in coupé and hold for 3 seconds. The dancers were allowed enough practice trials for them to become accustomed to the drop landing.

Participants landed on a force plate and muscle contraction amplitude for the landing leg at time of peak vertical ground reaction force (vGRF) was recorded. Participants performed two drop landings on the right leg, and two drop landings on the left leg; average muscle contraction amplitude was calculated for each leg. Participant drop landings were recorded using 2D video cameras from the frontal and sagittal planes.
This drop landing procedure was performed prior to and after completing the fatiguing protocol.

**Fatiguing Protocol.** The High Intensity Dance Performance Fitness Test (HIDPFT)\(^1\) was used to induce fatigue. The HIDPFT has been validated for fatigue induction and has been used in other studies to induce fatigue\(^6,11\) (see Table 1). The protocol uses a series of dance movements involving first and second position jumps, floor rolls, transferring of weight from feet to hands and back, circular springs with an arm pattern, and a parallel jump with an arm swing (see Table 2).\(^11\) This series is repeated 3 times in 1 minute at a pace of 106 beats per minutes, followed by 2 minutes of rest.\(^11\) This process is repeated 3 more times.

The EMG electrodes were held in place during the HIDPFT with Velcro straps to help ensure the equipment stayed in place. The test was administered via DVD for
consistency of executing the moves, and category-ratio perceived exertion ratings were collected during the 2-minute rest periods to help ensure participants were maintaining vigorous to maximal effort. Participants were asked to maintain 7 to 10 on the scale.

**Table 2.** HIDPFT Protocol

<table>
<thead>
<tr>
<th>1 minute dance sequence of moves*</th>
<th>2 minutes rest / Exertion Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 minute dance sequence of moves*</td>
<td>2 minutes rest / Exertion Rating</td>
</tr>
<tr>
<td>1 minute dance sequence of moves*</td>
<td>2 minutes rest / Exertion Rating</td>
</tr>
<tr>
<td>1 minute dance sequence of moves*</td>
<td>2 minutes rest / Exertion Rating</td>
</tr>
</tbody>
</table>

*Tempo at 106 bpm.

**Table 3.** Sequence of Dance Moves

1. Jumps in first and second position
2. Rolls to the floor
3. Weight transfer from feet to hands
4. Circular springs with arm pattern
5. Parallel jump forward using arm swing

Repeat 3 times

**Data Analysis.** All EMG data were analyzed using Noraxon MR 3.10 software. Full-wave rectification was performed first for all EMG channels. Following
rectification, smoothing was performed using the root mean square algorithm set at a duration of 20 ms. Amplitudes were normalized to the average MVC values. Filtering was not done secondary to the manufacturer’s recommendation against it. The point of peak vGRF was the reference point to analyze contraction amplitudes. Processing was performed for each trial and averages were calculated for each muscle (right gluteus medius, left gluteus medius, right peroneus longus, left peroneus longus).

**Statistical Analysis**

A multivariate repeated measures ANOVA was conducted for the independent variable time (pre- and post-fatigue) for the dependent variables (gluteus medius right, peroneus longus right, gluteus medius left, and peroneus longus left). Alpha level was set at $p < 0.05$ for all analyses.

**RESULTS**

The overall multivariate repeated measures ANOVA did not reveal significant differences for time [$F_{(4,14)} = 0.567$, $p = 0.69$, $\omega^2 = 0.14$]. Therefore, no additional follow-up tests were conducted. Two outliers were identified and determined to have minimal effect; these were included in the analysis. Descriptive statistics are located in Table 3. The values shown indicate muscle activity of the indicated leading leg during landing.

<table>
<thead>
<tr>
<th></th>
<th>Pre-fatigue</th>
<th>Post-fatigue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gluteus medius right</td>
<td>79.80 ± 61.41</td>
<td>74.86 ± 64.49</td>
</tr>
<tr>
<td>Peroneus longus right</td>
<td>63.88 ± 31.17</td>
<td>87.95 ± 99.61</td>
</tr>
</tbody>
</table>
Subjective fatigue ratings during the HIDPFT and jump height pre- and post-fatigue were recorded. The participants’ reports of fatigue were greatest at the end of the test with a rating of 6.50 ± 2.01 on a scale of 1 – 10. Jump height was not different between pre- and post-fatigue.

**DISCUSSION**

The purpose of this study was to determine the effect of fatigue on lower extremity muscle activation in dancers using a dance-specific fatiguing protocol and a functional dance-specific drop landing test. We hypothesized that fatigue would result in a reduction in the amplitude of muscle contractions. Our results suggested there was no significant change in muscle contraction amplitude during the pre- and post-fatigued conditions.

**Muscle Contraction Activity**

These findings do not corroborate the results of previous research. McEldowney et al.\(^6\) used a similar methodology and found that the ratio of quadriceps to hamstring activity was altered post-fatigue. Lin et al.\(^17\) also found a reduction in hamstring activity post-fatigue, as well as reduction in tibialis anterior activity and an increase in soleus activity. These studies did not specifically examine muscle contraction amplitude changes in the gluteus medius or peroneus longus muscles, though both examined hamstring activity. These three muscles have varying cross-sectional areas and are
primary stabilizers at different joints throughout the lower extremity. The cross-sectional area of the hamstring muscles is larger than that of the gluteus medius and peroneus longus. Perhaps fatigue has a greater impact on muscles with a larger cross-sectional area, explaining the discrepancy in results between the present study and its predecessors. Furthermore, the findings from preceding studies plus our own suggest that fatigue may impact the amplitude of contraction of muscles that cross and stabilize the knee joint and have no effect on those muscles that primarily act at and stabilize the hip and ankle.

**Fatigue Induction**

Based on prior findings, the results of this study were unexpected. The present study used the High Intensity Dance Performance Fitness Test (HIDPFT) which was shown previously to induce fatigue in dancers. The present study measured fatigue subjectively with perceived exertion ratings and functionally with vertical jump testing, rather than assessing fatigue objectively like the other studies. Based on the subjective exertion ratings, dancers did not perceive themselves to be fatigued by the end of the testing protocol.

McEldowney et al. and Redding et al. both established that the High Intensity Dance Performance Fitness Test, the fatiguing protocol for the present study, induces fatigue as measured by blood lactate levels and heart rate. McEldowney et al. suggested that further research confirm the induction of fatigue by measuring a functional variable like jump height. The results of vertical jump testing in the present study suggest the participants were not fatigued sufficiently to impact jump height. These findings may have resulted from a lack of effort on some participants’ part or a lack of familiarity with
the choreography. Alternatively, the HIDPFT may not induce central fatigue, meaning the participants do not perceive that they are fatigued. Furthermore, Leiderbach and colleagues\(^3\) examined the effects of fatigue on dancers and concluded that the majority of injuries in dance occur late in the day or at the end of a performance season. The HIDPFT may not be long enough to induce the same level of fatigue experienced after a full dance class or day of classes.

**Limitations**

The present study has several limitations, including a small sample size. In addition, the use of surface EMG is convenient, though we experienced connectivity issues due to the participants sweating and the nature of the modern dance choreography that required rolling on the floor. Adipose tissue and sweat negatively impacted the EMG signals of some participants. Sweat caused electrodes to become displaced and new ones had to be attached. This may have created variations in signals and, further, when electrodes had to be replaced after the fatiguing protocol, participants were able to recover more while the electrode was replaced.

Subjective exertion ratings may also have impacted results. Each participant was shown the same scale, though participants may perceive their fatigue differently. A 3 out of 10 to one participant may be a 6 out of 10 to another. Regardless of interpretation, participants were asked to maintain a 7 out of 10 or higher. Most were unable to do so. This suggests the fatiguing protocol was insufficient, or the dancers were not exerting themselves fully.
The testing procedures used in the present study were not fully clinically applicable. Though a landing in coupé is functional for a dancer, the speed and force direction from landing from a full out leap is quite different from a simple drop. Also, dancers rarely land stationary from a leap or jump. Typically, the choreography flows from the landing into another dance move. The present testing procedure did not allow for these aspects of true dance landings.

**Clinical Implications and Future Research**

The results of this study suggest that current jump training practices in dance enable a dancer to land without change in muscle activity in the gluteus medius and peroneus longus, the primary hip and ankle stabilizers. The low reported measures of exertion are of concern as they may suggest that dancers do not sense their fatigue accurately, or that the HIDPFT does not induce fatigue. Ensuring dancers have enough rest is still crucial to their optimal performance.

Future research should investigate the impact of fatigue on other dance genres as the dancers used in the present study were primarily modern dancers. Additionally, further investigation is warranted as to the effectiveness of the HIDPFT’s ability to induce fatigue. Examination of objective, functional, and subjective measures of fatigue to determine if central, peripheral, or both forms fatigue are achieved represent areas needing research attention. Alternatively, a different fatiguing protocol may yield more accurate results. Should another fatiguing protocol be used, it should be dance-specific like the HIDPFT to create similar fatigue as when a dancer is in class. Furthermore, investigating kinematic variables like joint angles or displacement may yield more
clinically applicable results. EMG does not account for these variables and is limited as such.

CONCLUSION

This study aimed to determine the effect of fatigue on lower extremity muscle activation in dancers using a dance-specific fatiguing protocol and a dance-specific drop landing task. No significant differences were found between muscle contraction activity pre- and post-fatigue. This is contrary to similar literature regarding muscle contraction activity in dancers when fatigued. The lack of congruency between the present study and those before it may be due to a failure to induce fatigue in the participants. The results of this study suggest that dance jumping and landing training is sufficient, though instructors and healthcare professionals should take care to monitor dancers for fatigue as the dancers themselves may not accurately judge their levels of fatigue. Future research should investigate other dance forms and fatiguing protocols, and the effect of fatigue on kinematic variables.

REFERENCES


Chapter 4: Conclusion

This study aimed to determine the effect of fatigue on lower extremity muscle activation in dancers using a dance-specific fatiguing protocol and a dance-specific task. No significance was found between muscle contraction activity pre- and post-fatigue. This is contrary to similar literature regarding muscle contraction activity in dancers when fatigued. The lack of congruency between the present study and those before it may be due to a failure to induce fatigue in the participants or technological issues with the EMG. Additionally, the lack of congruency could indicate that fatigue impacts the contraction activity of select muscles only.

The results of this study suggest that dance jumping and landing training is sufficient, though instructors and healthcare professionals should take care to monitor dancers for fatigue as the dancers themselves may not accurately judge their levels of fatigue. The HIDPFT requires further investigation to be encouraged to use for the induction of fatigue outside of a laboratory setting. Future research should investigate other dance forms and fatiguing protocols as well as the effect of fatigue on kinematic variables.
References


53. Mistiaen W, Roussel NA, Vissers D, Daenen L, Truijen S, Nijs J. Effects of aerobic endurance, muscle strength, and motor control exercise on physical fitness and


Appendix A: Specific Aims

Approximately 97% of dancers experience injury.¹ This absurdly high percentage is due, in part, to the demands placed on the performers. Professional ballet dancers typically work for 9 hours in a day, with 90% of these dancers spending less than 60 consecutive minutes resting.² Furthermore, dancers perform over 200 jumps in a single class with half requiring a single leg landing.³ Approximately 92% of ACL injuries in dancers happen during single-leg landings.³ Dancers engage in rigorous amounts of work to perfect their craft, and they suffer injuries as a result.

Muscle activation under fatigue conditions is generally understood in non-dancer populations.⁴ Studies have shown that fatigue alters muscle activation in the thigh of dancers by decreasing motor control and changing the ratio of quadriceps to hamstrings contractile strength.⁵ We also have some understanding of the effect of rest days on injury rates in a performing arts population which suggests that performers do not obtain sufficient rest to avoid injury.⁶ We also know that fatigue reduces postural control in dancers,⁷ and that a number of factors contribute to dancer fatigue, but little research has been conducted to show the effects of resultant fatigue,⁶ specifically during landing which dancers do so frequently. In order to reduce fatigue-related injuries in dancers, we must know how fatigue affects the dancer. Such knowledge may help dancers reduce fatigue. My research is intended to examine one piece of how fatigue affects the dancer.

Ultimately, my long-term goal is to understand how fatigue impacts dancers so that the manner in which dance is practiced can be changed to reduce fatigue and concomitantly, fatigue-related injuries. My objective is to determine the effect of fatigue on lower extremity muscle activation in dancers. In order to accomplish this, I will evaluate the strength, or peak amplitude, of muscle contractions in dancers during a functional dance landing task.

Following application of surface electromyographic (sEMG) sensors, dancers will be evaluated for their maximal voluntary contraction amplitude for the gluteus medius and the quadricep, hamstring, and peroneal muscle groups. Then, they will perform a drop landing in a dance-specific manner with the sEMG instrumentation to assess peak amplitude of contraction. Following this testing, the dancers will be lead through a sequence of dance-related exercises proven to induce fatigue known as the High Intensity Dance Performance Fitness Test.⁸ Lastly, they will perform the drop landing with connected EMG devices again.

I hypothesize that fatigue will result in a reduction in the amplitude of the contraction. Evidence for this hypothesis is derived from previous research done in a controlled environment that compared muscle activation during a generic single-leg drop landing, before and after a fatiguing program; this study showed variation in muscle contraction activity.⁵ The proposed research will provide valuable information about the way muscles respond to fatigue that can be used to optimize dance performance by reducing fatigue-related injuries. I propose the following aim:
Aim 1: To determine the effect of fatigue on the peak amplitude of muscle contractions. After landing from a dance-specific drop landing, muscle contractions will be evaluated pre- and post-fatigue for the amplitude of the contraction. Comparisons will be made between the contractions occurring prior to and after fatigue induction. Lower peak amplitude is hypothesized following the fatiguing protocol.

Research has examined the effects of fatigue on muscle activation in the legs in dancer populations with generic movements. To my knowledge, my proposed research will be the first assessment of the effects of fatigue on dancers in a clinically applicable manner. I am not aware of other research that has used a dance-specific fatiguing protocol in addition to using a dance-specific movement for measurement. These factors make my research more applicable to the dance population outside of a controlled laboratory environment. Furthermore, my research will help contribute to the body of knowledge about the effect of fatigue on dancers. Many factors need to be investigated in order to help prevent fatigue-related injuries in dance; my proposed research will help us take one more step toward that goal.
References


## Appendix B: Data Procedures Checklist

<table>
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<tr>
<td>Electrode Placement Over 4 Tested Muscles</td>
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<tr>
<td>MVC Testing</td>
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<td>Vertical Jump Height Testing</td>
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Total Time: 52 min
Appendix C: Data Collection and Surveys

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<td>Exertion Rating during HIDPFT</td>
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<td>7 minutes</td>
<td>10 minutes</td>
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</table>
Participant Health History and Information Sheet

ID: _______________

Sex (circle one):  Male  Female  Prefer not to answer  Age: ________

University Level (circle one):  Freshman  Sophomore  Junior  Senior  5th Year

Have you had an injury to the foot, ankle, leg, knee, or hip in the last 6 months?  
Yes  No

If so, did the injury cause you to miss at least 1 day of dance rehearsal/performance?  
Yes  No

Have you been diagnosed with any heart and/or lung conditions? If yes, please list.  
Yes  No  __________________________________________________________

Are you currently taking any medications?  
Yes  No  _____________________  __________________

How many years of dance experience do you have?  
______________

Have you engaged in any strenuous exercise in the past 24 hours?  
Yes  No

---

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

<table>
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<tr>
<th>Questions</th>
<th>Yes</th>
<th>No</th>
</tr>
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<tbody>
<tr>
<td>1  Has your doctor ever said that you have a heart condition and that you should only perform physical activity recommended by a doctor?</td>
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<tr>
<td>2  Do you feel pain in your chest when you perform physical activity?</td>
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<td>3  In the past month, have you had chest pain when you were not performing any physical activity?</td>
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<td>4  Do you lose your balance because of dizziness or do you ever lose consciousness?</td>
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<td>5  Do you have a bone or joint problem that could be made worse by a change in your physical activity?</td>
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<td>6  Is your doctor currently prescribing any medication for your blood pressure or for a heart condition?</td>
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<td>7  Do you know of any other reason why you should not engage in physical activity?</td>
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</tbody>
</table>
Appendix D: Instrument Reliability

A study conducted by Rainoldi et al.\textsuperscript{1} shows ideal electrode placement for surface electromyography (sEMG). The researchers found that for the gluteus medius, the electrode should be placed approximately 33\% of the distance between the greater trochanter and the iliac crest, beginning at the greater trochanter. For the peroneus longues, the electrode should be placed over the belly of the muscle approximately 17\% of the distance between the fibular head and the lateral malleolus, beginning at the fibular head. For the vastus medialis obliquus, the electrode should be placed on a line oriented 50 degrees medially with respect to the anterior superior iliac spine, approximately 52 mm from the superomedial patella. For the biceps femoris, the electrode should be placed approximately 35\% of the distance between the ischial tuberosity and the lateral popliteal fossa, beginning at the ischial tuberosity. Furthermore, the sEMG instrumentation was used in a study conducted by McEldowney et al.\textsuperscript{2} for the same purpose of measuring muscle contraction amplitude in dancers.

The High Intensity Dance Performance Fitness Test (HIDPFT) was developed in a controlled study by Redding et al.\textsuperscript{3} The test was shown by McEldowney et al.\textsuperscript{2} to be a valid technique for inducing fatigue. This study examined blood lactate and heart rate levels to determine that the HIDPFT does in fact induce fatigue in addition to testing fitness levels. To further establish that fatigue was induced, the authors suggest a more functional measure.\textsuperscript{2} As such the force plate with be used to evaluate air time during a vertical jump before and after the induction of fatigue.
References


Appendix E: Power Analysis

A power analysis was conducted to determine sample size. Based on a small effect size 0.3, alpha level 0.05, power 0.80, and a correlation among repeated measure of 0.7 a sample size of 18 is needed.