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Comparison of body composition, neuromuscular characteristics and anaerobic endurance between novice, semi-professional and professional ballet dancers

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USE OF THESIS

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ABSTRACTS

Study 1 Comparison of body composition, neuromuscular characteristics and anaerobic endurance between novice, semi-professional and professional ballet dancers.

The purpose of this study was to compare selected physiological fitness parameters including: body composition, neuromuscular characteristics and aerobic endurance were significantly different between novice, semi-professional and professional ballet dancers. The secondary purpose was to establish which parameters were best discriminators between these dancers. Thirty-five classical ballet dancers (male: n =11 and female: n =24) divided into three different groups according to their dance skill level: novice (n=12) (age: 16.6 ± 1.5 y; height: 1.7 ± 0.1 m; weight: 58.0 ± 13.0 kg), semi-professional (n=13) (age: 20.0 ± 1.6 y; height: 1.7 ± 0.1 m; weight: 64.1 ± 10.5 kg), and professional (n=10) (age: 23.8 ± 3.5 y; height: 1.8 ± 1.2 m; weight: 63.3 ± 14.7 kg) completed one testing session. The testing session, examined dancer's body composition, neuromuscular characteristics and anaerobic endurance. To examine the differences between groups multivariate analysis of covariance (MANCOVA) was performed with gender and age controlled and a discriminant analysis was performed to determine which variables (grouped into body composition, jumping ability variables, or lower limb isometric strength) were the best predictors of group membership classification. MANCOVA results demonstrated significant differences between the groups in measures of: body fat percentage, lean muscle mass, bone mineral density, countermovement jump peak force, countermovement jump peak power, countermovement jump peak velocity, countermovement jump vertical displacement, drop jump peak force and drop jump vertical displacement ($p<0.05$). In addition, BMD and the displacement of CoM in a specific ballet leap were found to be the best discriminatory variables for group membership ($p= 0.011$ and $p=0.019$ respectively). These findings suggest that many variables differ between different levels of ballet dancers and the best discriminants of performance are BMD and the height achieved during a *grand jeté.* Further research is need in order to determine if greater jumping displacements in dance performance training is responsible for the higher BMD seen in the professional dancers.

Study 2: Do relationships exist between a grand jeté leap and two laboratory-based tests: countermovement jump and drop jump?

The primary purpose of this study was to investigate the relationship between a *grand jeté* leap and two laboratory based jumps, such as countermovement jump (CMJ) and drop jump (DJ). The secondary purpose was to establish if the magnitude of the relationship between three different skill levels: novice, semi-professional and professional ballet dancers. Thirty-five classical ballet dancers (male: n=11 and female: n=24) divided into three different groups according to their dance skill level: novice (n=12) (age: 16.6 ± 1.5 y; height: 1.7 ± 0.1 m; weight: 58.0 ± 13.0 kg), semi-professional (n=13) (age: 20.0 ± 1.6 y; height: 1.7 ± 0.1 m; weight: 64.1 ± 10.5 kg), and professional (n=10) (age: 23.8 ± 3.5 y; height: 1.8 ± 1.2 m; weight: 63.3 ± 14.7 kg) completed a single testing session. The participants performed three types of jumps. The first jump constituted of a specific ballet leap (*grand jeté*) and the difference between standing the centre of mass (CoM) height and displacement of CoM at the peak of the ballet jump was determined by three-dimensional motion capture. Next, the CMJ was executed standing on a force plate and the DJ was performed from a 40cm height box onto a force plate. Vertical displacement in both jumps (CMJ_{VD} and DJ_{VD}) was calculated from flight time. The relationship between the displacement of CoM and CMJ_{VD} and DJ_{VD} was assessed by Pearson product-moment correlation coefficient. Significant relationships were found between the *grand jeté* and CMJ ($r=0.77$, $p=0.001$) and DJ ($r=0.76$, $p=0.001$). Further, when the groups were analysed individually (CMJ: novice $r=0.64$, $p=0.025$; semi-professional $r=0.75$, $p=0.003$ and professionals $r=0.91$, $p=0.001$; DJ: novice $r=0.70$, $p=0.001$; semi-professional $r=0.80$, $p=0.001$; professionals $r=0.86$, $p=0.001$) the magnitude of the relationship improved with increasing skill level. In addition, results indicated that a *grand jeté* leap could be predicted utilising a regression equation from the CMJ_{VD} and DJ_{VD} ($p<0.05$). In conclusion displacement of CoM in a *grand jeté* leap showed large to very large correlations in two laboratory based tests: CMJ and DJ. Correlations became stronger as group skill level increased, suggesting that with superior specific ballet skills dancers may be better able to utilise their physical capacity to jump higher within the context of ballet specific jumping. Moreover, ballet experts and instructors may be able to predict ballet specific jump ability from faster and less costly laboratory based tests such as CMJ and DJ.

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LIST OF ABBREVIATIONS

y	-	years
m	-	meters
ht	-	height
kg	-	kilograms
TBM	-	Total body mass
DXA	-	Dual-energy x-ray absorptiometry
BMD	-	Bone mineral density
BMC	-	Bone mineral content
LMM	-	Lean muscle mass
$BF_{\%}$	-	Body fat percentage
BF_{kg}	-	Body fat in kilograms
CMJ_{PF}	-	Countermovement jump peak force
CMJ_{PVEL}	-	Countermovement jump peak velocity
CMJ_{PP}	-	Countermovement jump peak power
CMJ_{VD}	-	Countermovement jump vertical displacement
DJ_{PF}	-	Drop jump peak force
DJ_{VD}	-	Drop jump vertical displacement
VJ	-	Vertical jump
CoM	-	Centre of mass
IPF	-	Isometric peak force
rIPF	-	Relative isometric peak force
ASIPF	-	Allometrically scaled isometric peak force
RFD	-	Relative force development
CV	-	Coefficient of variation
CI	-	Confidence interval
ICC	-	Intraclass correlation coefficient
W	-	Watts
N	-	Newtons
SSC	-	Stretch shortening cycle

CHAPTER ONE INTRODUCTION

Dance is a discipline that requires high technical proficiency and quality of emotive expression. Therefore for a dancer to be successful they must possess outstanding technique as well as excellent artistry (Krasnow & Chatfield, 2009). In recent years, modern choreographies have evolved and developed to be extremely physical demanding. For this reason, dancers have to maintain a high level of physical fitness to be able to succeed in their careers and avoid or overcome injury (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2009). Recent investigations have focused on quantifying physiological fitness and thus evaluating dancers not only as artistic performers but also most importantly as athletes (Koutedakis & Jamamurtas, 2004; Rimmer, Jay, & Plowman, 1994; Twitchett, Koutedakis, & Wyon, 2009). Specifically, these investigations have attempted to measure the anthropometric parameters, neuromuscular characteristics, jumping ability and anaerobic endurance, of dancers in order to establish the effect of these variables on skill execution in modern dance (Chatfield, Byrnes, Lally, & Rowe, 1990a).

Previous studies have shown a positive relationship between physiological fitness and dance performance, suggesting that improvements in specific physiological variables such as body composition, neuromuscular characteristics, muscular power, strength and anaerobic endurance could lead to increases in dance skill execution, longevity of the performer and injury prevention (Koutedakis, Cross, & Sharp, 1996; Koutedakis et al., 2007). Angioi and colleagues (2009), correlated seven physical parameters with an aesthetic skill competence test, and established that high levels of muscle endurance were a good predictor of skill performance in modern dancers. Similarly, Chatfield et al. (1990b) performed a cross-sectional study on three different levels of modern dancers, to determine the effects of body composition, aerobic capacity, anaerobic capacity and isokinetic strength on the aesthetics of a dance specific test. Findings from this investigation suggest that semi-professional dancers who scored high ranks in the execution of the ballet test skill also showed greater differences in aerobic capacity and low body fat compared to the novice and

advanced level dancers. These results are in agreement with previous research indicating that, sustaining greater physiological fitness could improve dance performance. Nevertheless, it is important to highlight that these findings were obtained with methods not specifically designed for ballet performers. On this premise, it would be appropriate to evaluate ballet dancers' physiological fitness with specifically designed dancing tests to obtain a more representative measure of their performances.

Since classical ballet is a discipline that requires a specific physical thinness in order to achieve a specific aesthetic appearance, (particularly in females) (Yannakoulia et al. 2000) a dancers' body composition becomes an important factor to consider when evaluating selected physiological fitness parameters. Unfortunately, most female ballet dancers encounter the pressure from artistic directors to achieve a slender elongated body in order to become competent and thus successful in their work place (Wilmerding, McKinnon, & Mermier, 2005; Yannakoulia, Keramopoulos, & Matalas, 2004). In addition, it has been established that novice dancers are seven times more likely to develop anorexia nervosa than high school students who do not participate in dance training (Anshel, 2004). Hence it is common for females dancers to start reducing their caloric intake from very early years of their dancing career, to achieve the slim body associated with being a "ballerina", even though the long hours of training that they undertake would require significant caloric intake in order to maintain performance. This tendency is supported by a study from Dotti et al., (2000) whom investigated eating habits in a group of 160 young female novice ballet dancers between the ages of 11 to 20 years. These authors reported that 38% of participants in their study exhibited evidence of having an eating disorder. Furthermore, it seems that caloric restriction is also common in professional ballerinas and is found not only in female adolescents ballerinas but also in female adult ballerinas. For instance, Hergenroecher et al., (1991) found that 43% of the dancers in a professional ballet company in America suffered from anorexia nervosa. These findings provide evidence to suggest that caloric restriction occurs from an early age in dancers and this practice could negatively affect the dancers' body composition, placing them at a greater risk for injury, bone health and the occurrence of the female athlete triad (Kuennen, 2007).

The relationship between body composition and injury occurrence in ballet dancers, has been previously studied by Twitchet et al., (2008). This study establishes that some female dancers suffering from the female athlete triad are at a greater risk for the occurrence of injury. The female athlete triad is a disorder caused by the combination of undergoing prolonged hours of training and low muscle mass measures, as well as experiencing menstrual disturbances caused by reduction in hormonal levels (Doyle-Lucas, Akers, & Davy, 2010). The female athlete triad has been associated with a low bone mineral content (BMC) and a low bone mineral density (BMD) that can develop into osteopenia later in life. In addition, osteopenia can then develop into osteoporosis after menopause in female dancers (Tournis et al., 2010). Therefore, to improve bone health in young ballet dancers, body composition scans, such as: dual energy x-ray absorptiometry scan (DXA), could be useful to examine: BMD, BMC, total lean muscle mass (LMM) and body fat percentage (BF%) which are know as good predictors of bone status (Yannakoulia et al., 2004).

The literature supports the observation that total LMM of young athletes is positively correlated with muscular strength and force production (Wyon, Allen, Angioi, Nevill, & Twitchett, 2006). It has also been proposed that athletes involved in activities such as rhythmic gymnastics and weight training, characterised by high strains and high mechanical loading could benefit from an osteogenic effect, thus resulting in increases in LMM (Bemben, et al. 2004). Since ballet training is an activity that is similar to rhythmic gymnastics, which also shows greater ground reactions forces particularly when landing on pointe, it has been suggested that dancers could benefit from greater muscular strength in order to improve their specific skill execution (Kuennen, 2007). Moreover, augmentations in LMM and muscular strength could significantly influence jump ability (Van Langendonck, Claessens, Lysens, Koninckx, & Beunen, 2004). Such an augmentation in LMM and potentially greater jump ability may subsequently elicit improvements in BMD. However, the association of BMD and BMC with dancers' jumping ability has not been evaluated rigorously. The combination of body composition measurements, neuromuscular characteristics and anaerobic capacity measured in a single study would allow for a discriminant analysis to be performed in order to determine the variables that

best predict membership to a dance specific skill level group, specifically, a professional dance group.

Finally, an essential element to discuss in ballet dancers is their ability to perform jumps. Jumping is considered a very important component of the ballet curriculum. Wyon et al., (2011) performed a match comparison of discrete skills such as plies, jumps, support, assisted lifts and lifts between professional ballet dancers and professional modern dancers. The results from this study establish that ballet dancers performed at higher intensities with significantly longer rest periods than the modern dancers. This could be caused by the increased number of power movements such as jumps in their choreographies used by ballet dancer. Therefore, it appears that both dance forms, tax completely different energy systems (ballet: anaerobic system and modern: aerobic system). Furthermore, dancers that are able to accomplish the highest jumps (greater vertical displacement of the centre of mass) and complex ballet leaps are considered high achievers in dance skills (Wilson & Kwon, 2008). Leaping ability is a technical element that requires integration of neuromuscular characteristics such as explosive strength, muscular power, motor coordination and strength (Chockley, 2008). However, it has been determined that dancers sustain most injuries during the jumping section of their training. For instance, Nilson et al. (2001) showed that 54% of females dancers from a professional ballet company, sustained reoccurring ankle and feet injuries, mostly from their jumps carried out through their daily dance routine. These injuries may be associated with inappropriate technique during the landing portion of the jump. Therefore the evaluation of ballet jump kinematics and determination of jump height differences between skill levels, could be a valuable tool to assists in the development of strategies to prevent injuries and enhance jump performance (Koutedakis, Owolabi, & Apostolos, 2009; Russell, 2010).

Dance movements, such as jumps and leaps, have been biomechanically assessed since the 1970's. In recent years, technological developments have allowed for the three-dimensional analysis of athlete performances, comparing differences in their kinematics and movement patterns to describe efficient jump techniques (Sousa & Lebre, 1996). For instance, in rhythm gymnastics, Di

Cagno et al., (2008) performed a comparison between male and female, elite and sub-elite rhythmic gymnasts, assessing their leaping ability and correlating it with their squat jump (SJ). These researchers found no correlation between SJ height and three technical leaps indicating that SJ is not a good predictor of a gymnast's technical leaping ability. Nevertheless similar investigations in ballet dancers have been limited. McNitt et al., (1992) described the differences in executions of a leap step or in ballet terms a "*grand jeté*" leap, between professional, semi-professionals and novice dancers. This investigation reported significant differences in jumping patterns and approaches to the jump between the different levels of dancers (McNitt-Gray, Koff, & Hall, 1992). However, to the author's knowledge there has been no investigations relating neuromuscular characteristics, such as lower body isometric strength or jumping power to jumping kinematics of a specific ballet leap across different levels of classical dancers. Moreover, no previous laboratory tests such as a counter-movement jump (CMJ) or a drop jump (DJ) have been compared to jumping ability during an actual ballet jump. In contrast, there has been sufficient attention to neuromuscular characteristics such muscular power in ballet dancers during the VJ. For instance, Wyon, et al. (2006) examined muscle strength and VJ height, between corps of ballet, first soloist, soloist and principal dancers in an international ballet company. In this study, soloists possessed higher lower limb strength scores than the corps of ballet and principals, and also demonstrated higher VJ heights and more powerful jumps. These outcomes suggests that younger dancers who dance in the corps of the ballet may need additional training to increase muscular strength and power levels that will enable overall greater jump height.

Even though there are a few studies in the literature that examine physiological fitness parameters and their effect to dance performance in dancers (Angioi, Metsios, Twitchett, et al., 2009; Chatfield et al., 1990b), there seems to be a paucity of research comparing specific elements of physiological fitness such as body composition, neuromuscular characteristics and anaerobic endurance between different levels of classical ballet dancers (See Figure 1.1 for selected physiological fitness parameters). Therefore the main purpose of this investigation was to determine if there is a difference between physiological

fitness parameters such as body composition, neurological characteristics including: jumping ability, lower limb explosive power, lower limb isometric strength and anaerobic endurance, between novice, semi-professional and professional ballet dancers. Furthermore, this comparison was designed to establish which variables best discriminate between novice, semi-professionals and professional ballet dancers. The second aim of the thesis was to investigate the relationships between the displacement of CoM in a *grand jeté* leap and two laboratory-based jumps tests (i.e. CMJ and DJ). The purpose of this comparison was to determine the magnitude of the relationships between the jumping activities (ballet specific and laboratory based) in order to determine if the ability to utilise a dancers physical capacity to jump during a specific ballet jump varied between skill levels.
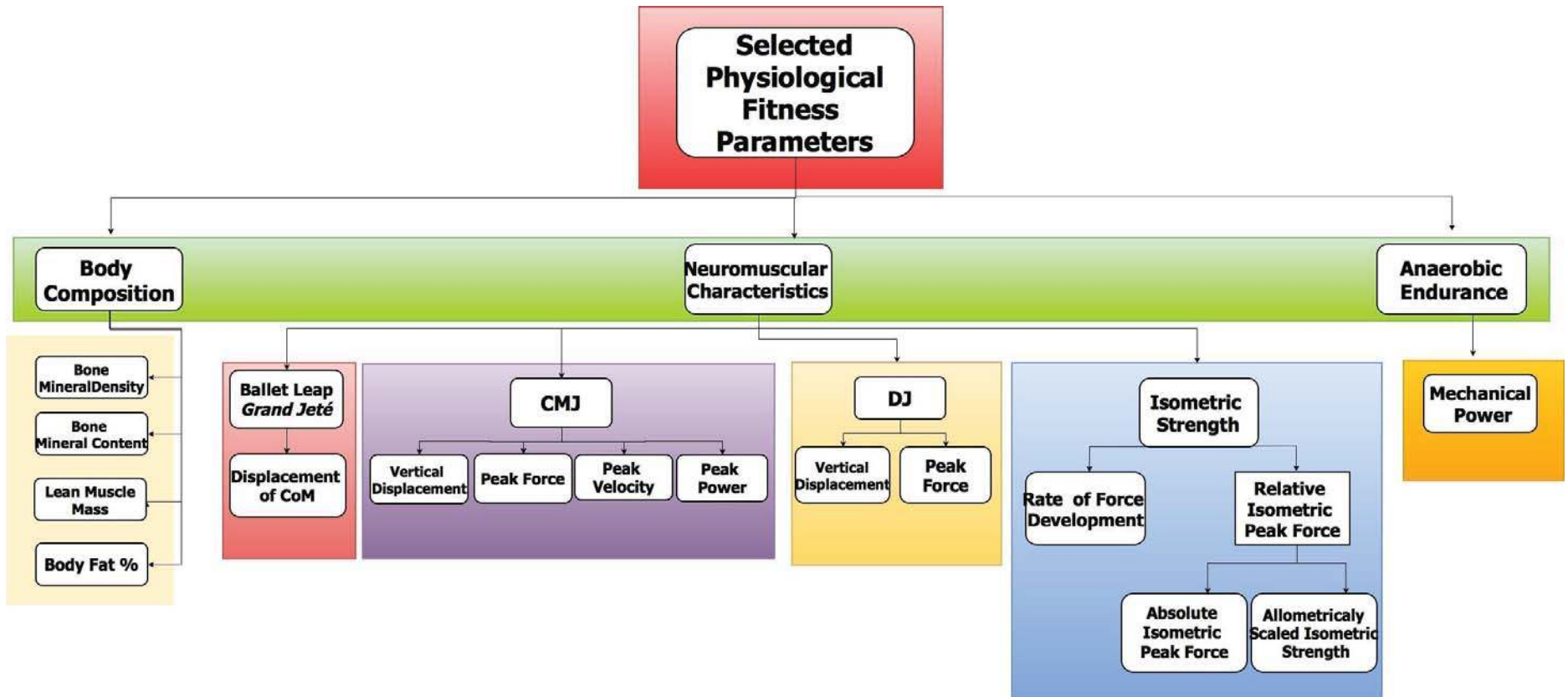
Figure 1. 1 Selected physiological fitness parameters assessed between three different skill level groups of dancers: body composition, neuromuscular characteristics and anaerobic endurance

1.1 Purpose of Research

The primary purpose of this research was to provide a cross-sectional evaluation of selected physiological fitness parameters, where intra-group comparison was performed at three different levels of skill in ballet dancers: novice, semi-professional and professional dancers. Specifically, body composition variables including: body fat percentage (BF%), lean muscle mass (LMM), bone mineral density (BMD) and bone mineral content (BMC); followed by neuromuscular characteristics comprising: displacement of the centre of mass (CoM) during a *grand jeté* leap, countermovement jump peak force (CMJ$_{PF}$), countermovement jump peak velocity (CMJ$_{VEL}$), countermovement jump peak power (CMJ$_{PP}$), countermovement jump vertical displacement (CMJ$_{VD}$), drop jump peak force (DJ$_{PF}$), drop jump vertical displacement (DJ$_{VD}$), lower limb isometric strength variables: isometric peak force (IPF), relative isometric peak force (rIPF), allometrically scaled peak force (ASPF) and rate of force development (RFD); and lastly anaerobic endurance were compared. Furthermore, it was important to determine the significant variables that act as best discriminators between the different skill levels of dancers in order to establish group membership. The secondary purpose of this research was to investigate the relationship between a specific ballet jump (*grand jeté* leap) and two laboratory based jumps, CMJ and DJ. Additionally, the magnitude of the relationship was examined to determine if the ability to utilise dancers neuromuscular characteristics, such as expressing lower body power in a *grand jeté* leap, varied between skill levels.

1.2 Significance of research

Given the paucity of dance research exploring physiological fitness parameters between different levels of classical ballet dancers, the significance of this study was the addition of comparisons of body composition, neuromuscular characteristics and anaerobic endurance across three distinctive levels of dancers. This study described selected physiological fitness parameters of both the

developing and professional ballet dancer. Knowledge of these characteristics might allow the dance novice and semi-professional, to focus on the improvements in those variables that are associated with professional ballet dance performance, thus potentially increasing the dancers likelihood of becoming a professional dancer or possibly preventing injury. Finally, this research provided the potential for use of a novel tool to monitor and establish dancers' specific jumping ability using simple, reliable laboratory based jump measures. Collectively, this research has added a unique comprehensive contribution to the research literature through the examination of the dancer's body composition, neuromuscular characteristics and anaerobic endurance.

1.3 Research questions

1. Are there significant differences in body composition, neuromuscular characteristics and anaerobic endurance between novice, semi-professional and professional ballet dancers?

2. Are there body composition, neuromuscular characteristics and anaerobic endurance variables that act as best discriminators between three levels of ballet dancers?

3. Is there a relationship between the displacement of CoM in a *grand jeté* leap and two laboratory based tests: CMJ and DJ?

4. Are there variations in the magnitude of the relationship between the displacement of CoM in a *grand jeté* leap and the laboratory based jump tests between the levels of dancers?

1.4 Hypotheses

1. There will be statistically significant differences in body composition, neuromuscular characteristics and anaerobic endurance, between the three different ballet groups.

2. There will be one or more physiological fitness characteristics variables acting as best discriminators to differentiate group membership between the three different skill levels of ballet dancers.

3. There will be a significant relationship between the displacement of CoM in a *grand jeté* leap and the two laboratory-based tests.

4. The magnitude of the relationship between the displacement of CoM in a *grand jeté* leap and laboratory based jump tests will vary by level of dancer.

1.5 Limitations

1. The applications of these findings are limited to male and female ballet dancers with similar physiological fitness parameters and ballet experience.

2. Findings of this research may lack generalizability to all dancers due to various training differences and specific physiological fitness parameters. A larger sample size would allow for greater

confidence in the means identified in the variables studied between the different skill level groups.

3. Within the classical ballet discipline, male novice ballet students are scarce; therefore there was a lack of male participants particularly in the novice group. For this reason the distribution between the numbers of participants with the same gender was not divided evenly in the novice and semi-professional groups. However, it is important to mention that gender was integrated as a covariate in the statistical analyses".

4. Menstrual status, menstrual history and eating habits are important factors influencing BMD and BMC in female ballet dancers. However determination of those variables was out of the scope of this study. Therefore future research examining the relationship between BMD, BMC, menstrual history and status, and eating habits is warranted.

5. This study investigated the relationship between a *grand jeté* leap and two laboratory based jumps. Further investigations should be performed in order to better understand the relationship between laboratory based jump tests and other specific skill ballet leaps.

CHAPTER TWO   LITERATURE REVIEW

Classical ballet is an art form that was born in the French courts of Louis XVI in the 17th century. Dancers at these courts carried out intricate movements, using their body as a tool to express rhythm and diverse emotions (Vaganova, 1969). These dancers attempted to convey stories of: honour, grace, love, riches and victory in their dances, creating an analogy to the privileged opulence in which they were submerged (Fonteyn, 1980). Ballet schools were created in this historical period, and provided the dancers a physical space to practise their routines and enhance their skills (Fonteyn, 1980). More importantly, these schools initiated the categorisation of dancers according to their physique type. Dancers who possessed short and muscular bodies most commonly performed the fast and quick movements. Conversely, dancers who possessed a tall and elongated body performed slower and more elegant routines (Fonteyn, 1980). This early division of different human physiques and their relationship to dance skill execution provided a milestone for understanding how dancers' physical characteristics could influence their performance. Sadly, since the development of this classification most of the dance community has possessed a strong belief that dance training should merely focus on dance skill acquisition and aesthetics without emphasis on overall athleticism. It was not until recently with new research in dance science, that dance experts began to understand that enhancements of physical factors, which underpin performance, could benefit the art form of dance (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2012; Poggini, Losasso, Cerreto, & Cesari, 1997; Rafferty, 2010).

This point of view is completely opposite in sports, where physiological fitness has been studied extensively for many years (Claessens, Lefevre, Beunen, & Malina, 1999; Hutchinson, Tremain, Christiansen, & Beitzel, 1998; Pearson & Gehlsen, 1998). For instance, sports researchers have acquired extensive knowledge about developing athletic performance and preventing injury. These researchers have attempted to enhance the athlete's physiological fitness by applying additional conditioning programs and monitoring athletes' responses to overload principles (Noakes, 2000; Sands & McNeal, 2000). Unfortunately, there

are very few dance studies exploring the physiological fitness of dancers and the relationships with dance skill execution (Koff, 1998). Particularly, the literature provides indication of dancers aerobic capacity (Cohen, Segal, Witriol, & McArdle, 1982; Wyon, Head, Sharp, & Redding, 2002; Wyon, Abt, Redding, Head, & Sharp, 2004; Wyon & Redding, 2005). However, knowledge about body composition, neuromuscular characteristics and anaerobic endurance that could significantly influence ballet performance in different levels of ballet has yet to be determined.

Hence, this literature review focuses primarily on exploring these less investigated dance physiological fitness parameters, which include aerobic and anaerobic endurance, neuromuscular characteristics, muscular strength, and body composition with the purpose to establish the foundation of the dance research within those variables and also to provide some direction where new investigation should be focus.

2.1 Aerobic and anaerobic endurance

In the first relevant study Chmelar (1988) undertook physiological parameters and compared them across different levels of dancers (semi-professional and professionals), as well as different styles of dance (modern and ballet dancers). This study revealed that dancers share the same underlying physical factors that affect other athletes, especially rhythmic gymnasts, namely factors such as strength, muscular endurance and body composition. Thus enhancing these attributes could potentially improve dance execution and possibly prevent injury or reduce injury rates (Angioi, Metsios, Twitchett, et al., 2009; Malkogeorgos, Zaggelidou, Zaggelidis, & Christos, 2013; Rimmer et al., 1994). Notably, professional ballet dancers have shown lower aerobic capacities (42.2 $\pm$ 2.9 ml-kg $^{-1}$-min $^{-1}$) than modern dancers (49.1 $\pm$ 5.9 ml-kg $^{-1}$-min $^{-1}$) and for this attribute, resemble sedentary individuals (Chmelar, 1988). When examining VO_2 max values professional ballet dancers were substantially lower than endurance athletes (Chmelar, 1988). However, these findings should be interpreted with

caution because a treadmill protocol was used to assess maximal aerobic endurance and running is an unusual activity for ballet dancers. In addition, the same study investigated, dancer's anaerobic endurance. Findings of this study indicate that professionals dancers expressed lower blood lactate levels than their modern dance colleagues during a Wingate power test (6.0 ± 1.5 mmol$\cdot$L^{-1} vs. 9.7 ± 1.4 mmol$\cdot$L^{-1} respectively). Based upon these results in appears that ballet dancers are not trained to sustain intense anaerobic activities. While ballet training is an intermittent activity it appears to lack sufficient intensity to stress the anaerobic system (Chmelar, 1988). Similarly, Shantz and Astrand (1984) investigated anaerobic and aerobic endurance during ballet classes, rehearsals and performances in a professional ballet company and reported significantly lower blood lactate values during the dancers daily classes compared to their rehearsals (3 mM vs. 11 mM respectively). In addition, these researchers also compared maximal oxygen uptake between ballet classes and rehearsals and found a 35-45% increases in maximal oxygen uptake during rehearsals. Collectively, the literature suggests that dance practice or training does not provide sufficient muscular overload to produce an appropriate training effect that would magnify aerobic and anaerobic performance capacities. In addition, there are significant differences in intensity demands between the various components of a dancers training routine.

Rimmer et al. (1994) profiled the physiological characteristics of dancers during daily routine training, and with intensity levels being assessed with the use of heart rate monitors during their dance class work and rehearsals. Their results suggest that during class work, ballet dancers only spend 52% of their time in the heart rate training zone, which corresponds to 60-90% of maximum heart rate necessary for aerobic training (Pate et al., 1995). It could be that dancers usually commence jumping in the last minutes of the class, thus preventing cardiovascular adaptation. Similarly, Rimmer et al. (1994) also reported that dancers during their performance rehearsals spent only 56% of time in the max heart rate training zone. Hence, ballet activity during class and rehearsals could be classified as an intermittent activity, which does not produce a high aerobic or anaerobic training effect that would enhance the dancers' aerobic or anaerobic endurance. These results suggest that dancers do not have the physiological capacity to tolerate prolonged moderate exercise or short-term high intensity bouts of exercise in their

routines. This may place them at an increased risk for injury when compared to the modern dancer. In support of this view, Wyon et al., (2005) suggest that there is a significant difference between aerobic and anaerobic demands between rehearsals and stage performances in modern dancers. They conducted a specific aerobic test in pre-rehearsals and post-performance training periods. These periods would be equivalent in sports to pre-season and post-season. Results demonstrated that in the post-performance period dancers showed a significant decrease in heart rates and blood lactate levels, allowing for a training adaptation (mean HR pre-rehearsal: 167 ± 10.7 vs. post-performance: 155 ± 12.9 b$\cdot$min^{-1}; Blood lactate pre-rehearsal: 2.2 ± 0.92 mmol$\cdot$L^{-1} vs. post-performance: 1.5 ± 0.77 mmol$\cdot$L^{-1}). It may be that during the preparation or pre-rehearsals period, there are longer rest intervals due to skill guidance to the dancers from the choreographers. In contrast, following the pre-performances period, the work to rest ratio decreases rapidly causing an overload to be placed on the dancers aerobic and anaerobic capabilities, thus inducing a training effect. Unfortunately, this rapid transition between the rehearsals and performances could put the dancer at an increased risk for sustaining an injury in response to their training regime.

Baldari and Guidetti (2001) compared the aerobic and anaerobic endurances of rhythmic gymnastics and dancers. These two disciplines share artistic qualities that could benefit from enhanced aerobic endurance and neuromuscular characteristics such as power and strength (Angioi, Metsios, Twitchett, et al., 2009). There was a significant difference in the parameters studied between the two disciplines, even though they endure similar training schedules and perform similar aesthetic leaps. For instance, rhythmic gymnasts possessed significantly higher VO$_{2 \ max}$ values when compared to dancers, when assessed with a running test. Additionally, according to their blood lactate levels gymnasts were able to tolerate higher levels of intensity. These findings suggest that gymnasts have superior aerobic and anaerobic endurance when compared to dancers. One explanation is that most gymnasts undergo additional strength and conditioning training in order to optimise their performance, as opposed to dancers who tend to only use dancing as their training method. Based upon these findings dance training alone does not appear to provide a sufficient stimulus for improving a dancers physiological fitness, thus dancers should consider additional training methods to improve these essential parameters (Koutedakis et al., 2007).

More recently Twitchett et al., (2009) rigorously examined the major physiological fitness demands of classical ballet including the impact of cardiorespiratory fitness, muscular strength, muscular power, muscular endurance, and body composition. The authors agreed that professional ballet dancers during the ballet bar and some of the centre work of a dance class are performing anaerobic work, as a result of the intermittent nature of these training practices. Moreover, during the "allegro" or jumping session of the class, intensity levels increase resulting in HR elevating to 85-95% of maximum capacities for short periods. While these short periods of training are very intense they do not appear to exert a sufficient stimulus to enhance the aerobic and anaerobic fitness. Interestingly, Twitchett et al., (2009) suggest that the main focus of dance science should be the investigation of the aerobic capacities of dancers. This unidimensional focus highlight the lack of research being conducted on other important physical fitness characteristics relevant to ballet dance performance. Additional research exploring the muscular strength, muscular power, speed and agility and more importantly the relationship of these variables and dance performance is warranted.

2.2 Jump ability

Traditionally, ballet training mainly focuses on the artistic skills components such as: grace, flexibility and coordination, essential for the art form (Clarkson, Freedson, Keller, Carney, & Skrinar, 1985; Cohen et al., 1982). However, the literature suggests that dance instructors do not pay enough attention to the development of physiological fitness characteristics. For instance it appears that there is not enough intensity in dance training to stimulate the cardiovascular system or strength training to improve lean muscle mass and thus improve strength and power in their specific jumps. Specifically, jump ability is a vital requirement in the development of the dancer. A key factor related to the ability to execute higher jumps is the overall LMM or greater muscle cross sectional area of the lower body, as this muscle mass exerts a significant influence

on maximal voluntary force outputs (Seeman et al., 1996). However, force production capacity is not the only factor exerting an influence on jump height. Bosco and collegues (1982) suggested that neuromuscular contractile capabilities and the utilisation of elastic energy also contribute to powerful jumps. In agreement with this notion is a study by Ciacci and Bianchi (2011), whom performed a biomechanical assessment of a specific ballet leap or "*grand jeté* leap" and found that female jumps were lower than the males (centre of mass height Female: 1.34 m vs. Male: 1.55 m). A reason for this difference in jump height could be that males possess higher LMM than women, thus allowing them to generate higher forces during jumping tasks. Also these performances could be attributed to a lower capacity to utilize the elastic energy in soft tissues. Nevertheless, one of the limitations of the Bosco et al., (1982) study was that it had a very small sample size and these results have not been reproduced with a larger sample of dancers.

Although there has been relatively little research on the jumping ability and displacement of centre of mass in specific ballet jumping tasks of dancers, it has been previously established that this population does not jump higher than age matched control groups, or demonstrate higher peak force outputs in the CMJ, VJ and DJ (Harley, Gibson, Lambert, Vaughan, & Noakes, 2002). An explanation for these lower power outputs and jump heights in a specific skill could be attributed to a greater emphasis being placed on the aesthetic component of the dance specific jumps during training. Specifically, dancers typically try to achieve alignment and control during take off and landing, thus sacrificing jump elevation. In agreement with this finding are the studies by Kenne and Unnithan (2008) who performed a comparison between ballet dancers and basketball players. In this study it was proposed that ballet dancers endure many explosive power jumps similar to the basketball players, however it was found that dancers do not undergo traditional weight training programs to increment their strength and power. Hence the ballet dancers demonstrated significant lower levels of mean and peak power compared with the basket-ballers. This reduction in muscular power levels could indicate that continuous repetition of ballet movements for many years does not produce sufficient muscular strength and power levels, thus

dancers do not develop the ability to produce high level of force or high vertical displacements during jumping activities when compared to other athletes.

2.2 Strength

Muscular strength is the ability to produce a maximal amount of force rapidly in a single voluntary joint contraction (Koutedakis, Khaloula, Pacy, Murphy, & Dunbar, 1997). Lower limb strength is a requisite attribute needed for dancers to subsequently achieve the necessary jump height whilst performing a dance specific routine (Golomer, Keller, Féry, & Testa, 2004). An increase in a dancer's jump height augments the spectator's illusion of effortless and higher leaps as a result of exerting force rapidly through the lower limbs (Brown, Wells, Schade, Smith, & Fehling, 2007). This may suggest that increasing muscular strength in dancers, could lead to improvements in jumping ability and overall performance.

Recently Koudetakis et al. (2007) demonstrated significant increases in isometric knee extensor strength of dancers following a resistance training intervention. The dancers undertook a twelve-week resistance and aerobic training program resulting in an increase in maximal isometric strength (90.6 ± 16.0 vs. 102.0 ± 17.4 kg pre and post training respectively) and muscle cross-sectional area. These findings suggest that enhancements in strength are associated with augmentations in cross-sectional area, resulting in an increased capability to generate force effectively, ultimately resulting in enhanced jumping capacity. Even though this data suggests that resistance training may be beneficial for dancers, many dance experts have been reluctant to incorporate resistance training into their weekly training routines because of two main reasons. Firstly, there is a fear that supplementary resistance training could diminish artistic qualities as well as their body aesthetics. Secondly, there is a belief that gains in strength could diminish flexibility and thus negatively impact dance artistry. (Koutedakis & Jamamurtas, 2004). However, current research has disputed both of these commonly held beliefs. For instance, Stalder and colleagues (1990) reported that

increases in the isometric strength of the adductors could occur without increments in calf or thigh circumference, suggesting that increases in strength are not necessarily associated with increases in muscle hypertrophy. This view is supported by Koutedakis et al., (2007), who performed a twelve-week lower limb resistance training intervention that resulted in no changes in the thigh circumferences of dancers after the 12-week training period. A secondary finding from this study was that the control groups displayed a reduction in strength across the duration of the study (94.1 ± 15.8 vs. 83.1 ± 11.2 kg control group pre and post training respectively). It is possible that this decrease in strength occurred in response to only performing dance training. Based upon this finding it may be hypothesised that dance training does not exert enough training stimulus to maintain strength and potentially may not maintain muscle mass. While this data is interesting, strength was only assessed by the determination of isometric peak force. Further analyses of force generating capacities of dancers should consider examining other force-time dependent variables such as the rate of force development or amount of impulse during isometric muscle actions in order to get a more complete picture of the dancer force generating capacities.

While previous research have established the benefits of increased dance performance capacity after undergoing a twelve week strength training program that resulted in increases of isometric strength (Koutedakis et al., 2007; Brown et al., 2007), it has also been demonstrated that increases in the lower body strength of dancers could potentially decrease the risk for lower limb injuries (Koutedakis et al., 1997). Specifically, it can be noted that the greater the lower body strength possessed by the dancer there is a lower risk of injury and if injury does occur they generally tend to be less serve. These data suggest that it may be beneficial to integrate dance specific resistance training into the preparation of dancers as it can positively impact dance performance and reduce overall injury risks (Koutedakis et al., 1997).

Resistance training has been traditionally used in sports to gain increases in lean muscle mass, reduction in body fat and increasing metabolic rate (Brown et al., 2007). In addition resistance training it is also know for enhancing neuromuscular characteristics such as enhancing firing of motor unit recruitment

(Kirkendall et al., 1984). Therefore, comparisons of strength outputs between different ballet skill levels could assist in the determination of the strength requirements for higher-level ballet performances.

2.3 Body Composition

There has been a general increase in the number of methods that can be used for the assessment of body composition in athletes as a result of technological advances that have facilitated these types of evaluations. For example, hydrodensitometry, or under water weighting, has historically been a widely used method for estimating BF% in athletes (Withers et al. 1987). However, this method has been demonstrated to possess an error rate of 2-3% under the best conditions (Fornetti et al, 1999). For this reason, scientists have attempted to develop more valid and precise methods to determine body composition, such as the dual-energy X ray absorptiometry (DXA). This method was designed with the purpose of establishing BMD and BMC and currently is consider a reliable and valid method of assessing BF% (Fornetti et al, 1999). Consequently, body composition in classical ballet, has been previously examined by several authors (Chmelar, 1988; Kuno, Fukunaga, Hirano, & Miyashita, 1996; Wilmerding et al., 2005). Even though, methods for assessing body composition in these studies have not been reported (for instance Chmelar, 1988) or improved from older methods (e.g. under water weighing and skin folds), these studies have agreed that ballet dancers, particularly female professionals, have low body fat percentages. Specifically, dancers possessed body fat percentages ranging from 12.9% to 17.4%, which are below the general populations normal standard values and lower than other athletes involved in sports such as: figure skating and rhythmic gymnastics (Chmelar, 1988). Interestedly even though dancers demonstrate lower percentages of body fat, it is established that ballet training alone does not provide high values in energy expenditure, thus female ballerinas usually decrease their energy intake to achieve their ideal body type (Twitchett et al., 2009). These eating disturbances in addition to: prolonged training hours and low hormonal levels could lead female ballerinas to be at risk for the female

athlete triad. The female athlete triad is a disorder caused by the combination of undergoing prolonged hours of training as well as experiencing menstrual disturbances caused by: low body mass indices, low body fat percentages, low total muscle mass and low estrogen levels (Doyle-Lucas et al., 2010; Kuennen, 2007). The female athlete triad in female athletes has been reported to been associated with low bone mineral content and low mineral densities, which can later in life develop into bone diseases such as osteoporosis (Tournis et al., 2010).

Studies, which have examined the BMD of female adolescents dancers, have received considerable attention in the scientific literature (Kuennen, 2007; Burckhardt, 20011; Hincapie et al, 2010). However, the results of these investigations have resulted in conflicting findings in regard to BMD parameters. For instance, some authors (Tsai et al. 2001; To and Wong 2011a) argue that dancing is a physical activity that involves high strain rates and high ground reaction forces that stimulate an increase in bone specific parameters, especially in the trunk and lower extremities. More specifically, Friesen et al., (2011) performed a comparison of BMD between semi-professional modern dancers and aged match controls. In addition, these authors also investigated strength levels in the upper and lower extremities in order to relate them to bone specific parameters. While the dancers in this investigation showed lower body fat percentages and higher incidence of eating disorders, they also exhibited higher BMDs and strength levels when compared to the control group. These findings suggest that modern dance training, due to its repetitive mechanical loading, could be beneficial for dancer's bone health. Conversely, Buckhardt et al., (2011) studied the effects of diet on BMD in adolescent ballet dancers, determining that from a sample of 127 female dancers only 42.5% had normal BMD values. In addition, 15.7% from the same sample, suffered from severe thinness caused by poor eating habits. Based on this data, these authors demonstrate that a dancers caloric restriction could negate improvements in their bone parameters; placing them at a greater risk for BMD disturbances that potentially could lead to the development bone related diseases. Specifically, late menarche and amenorrhoea, produced by low caloric intake, are significant factors that influence BMD at puberty. A comparative study by Keay and colleagues (1997) established that dancers, suffering from amenorrhoea due to low body fat, sustain significant lower

standardised of BMD compared with eumenorrhoeic dancers. Based upon these findings it appears that a low body fat and alterations to menarche have the potential to stimulate negative affects on BMD, which could possibly lead to the development of early osteoporosis later in life. Therefore, to prevent osteoporosis, low BMD and the female athlete triad it is recommended that young dancers have their body composition assessed. Body composition could be investigated by administrating full body scans, that could verify body fat percentage, total muscle mass, BMD and BMC in order to give a complete picture of the dancers overall body composition. Moreover, measures of total muscle mass in young athletes have been positively correlated with muscular strength and force production, which has been shown to positively influence vertical jump ability and lead to improvements in sports performance (Van Langendonck et al., 2004). Based upon these findings it is likely that a similar relationship exists between the muscle mass and performance capacity of dancers, but this has not received much attention in the scientific literature.

2.4 Relationships between selected physiological fitness parameters and dance performance.

The literature defines dance as an art form, which comprises technical proficiency and qualitative emotive expression. However, it seems that dance science has placed extra emphasis on the quantification of the dancers physiological fitness, rather than investigating their overall dance performance abilities (Krasnow & Chatfield, 2009). Accordingly, an early study by Chmelar (1988), explained that: "there is a lack of investigation addressing the communion of the dancer's physiological capabilities with the dancer's performance", suggesting that more research in this area could illuminate whether increases in selected physiological parameters could also improve the overall quality of movement and proficiency of ballet skills. Fortunately, dance science researchers have improved their scientific knowledge around this topic with the development of a reliable and valid tool to assess technique and skill as well as dance artistry and aesthetics. For instance, in 1990, Chatfield and Byrnes performed a cross-

sectional analysis of three different levels of modern dancers compared to non-dancers. In this study a qualitative assessment was completed examining technical execution, use of space, time and energy, phrasing movement and performance presence. However, a correlation between the dance competence test and other physiological fitness parameters was not undertaken. Nearly two decades later Krasnow and Chatfield (2009) established a performance competence evaluation measure (PCEM) with the goal of determining qualitative aspects of dance performance. This test comprised of four different levels of ability: 1) Full body involvement; 2) Body integration and connectedness; 3) Articulation of body segments; and 4) movement skills. The system was developed with the idea of relating the dancers body to the qualities of perceived images and transmitting them through dance expression. In addition, this study was developed with the intention of examining changes in the previous mention abilities, and their effect in the dancer's physiological fitness components such as flexibility, strength and body composition. However, this method of qualitative assessment used a very small spectrum of scoring points (Likert scale only from 1 to 3 points), which does not provide a sufficient proficiency rating system. This small rating system could negatively affect the scores for a dance sequence from the judges (Krasnow & Chatfield, 2009).

Similarly to the PCEM assessment, Angioi et al., (2009), proposed another reliable qualitative tool, which contained criteria that focused on several aspects of dance performance such as control movements, spatial skills, accuracy of movements, technique, dynamics as well as performance qualities and overall performance. These authors also investigated which physiological fitness components of modern dancers were the most associated with their aesthetic competence. Based upon this work, the best predictors for aesthetic competence were push ups and jump ability, which are measures of muscular strength and power. Specifically, these results suggested that increases in muscular strength and power of the upper and lower body, could have a significant benefit to the aesthetics of dance specific jumps. In addition, a later study from the same group of investigators performed a six-week circuit training and whole body vibration intervention, which resulted in significant increases in specific physiological parameters. More specifically, increases in neuromuscular characteristics and

aerobic endurance capacities in the dancers {vertical jump (cm) pre: 29.9 ± 5.81 vs. post: 33.6 ± 3.38; press ups (n/min) pre: 29 ± 7.24 vs. post: 37 ± 12.34; and aerobic fitness (beats/min at 46 mL.kg^{-1}.min^{-1}) pre: 196 ± 9.71 vs. 177 ±15.5} as well as increases in aesthetic competence scores (pre: 38 ± 12.92. vs. 43 ± 6.34)} were reported. These results confirm that enhancements in neuromuscular capacities and aerobic endurance can positively influence aesthetic competency in modern dancers (Angioi et al., 2012). However, these investigations were design exclusively for modern dancers, and to the authors knowledge no studies like this have been conducted with classical ballet dancers. As an expansion of the work of Angioi et al., (2012) it would be very interesting to determine differences between skill levels of ballet dancers using specific ballet pieces from the classical repertoire, rather than an unspecified random ballet sequences. Set choreograph of ballet pieces taken from the classical repertoire are fundamental stepping-stones for the development and growth of ballet students. Additionally, the classical repertoire accurate execution could assist in the discrimination between novice, semi-professional and professional dancers. For instance, a previous study by Twitchett et al., (2009) analysed the physiological demands of classical ballet performance using video analysis. These authors examined work intensity, body movement, partner work and transitory movements between ranks in a professional ballet company (artists, soloist and principals), during live video performances. The analysis determined significant differences between the ranks, which performed at different intensities with the principals spending the greatest time working at moderate (17.3%) to high intensity (14%), with the least amount of rest (53%), compared to the soloist who performed a greater amount of jumps per minute, but demonstrated a larger work to rest difference. These results suggested that ballet is an intermittent activity that requires specific physiological fitness characteristics depending on company ranking. Therefore, pre-performance training should be tailored to meet these demands in order to ensure that dancers can handle these demands and minimise injury risks.

In summary based on this literature review dance studies have been more abundant in the last two decades mainly focusing on the optimisation of physiological fitness parameters and their effect on dance aestheitic competence. Particularly, body composition, anaerobic endurance and neuromuscular

characteristics such as jumping ability, muscular strength and muscular power and have been examined. All of these variables appear to play an important role underpinning dance performance. It is possible that interventions that target the enhancements of these factors in dance populations could extend a dancer's career and reduce injury risk. However the specificity of the dancers training and their unique aesthetic in their body types causes a series of complications that could interfere with their wellbeing. Firstly previous findings suggested that dancers possess lower aerobic and anaerobic capacities especially in their preparation period due to the stop and start nature of their training practices as they attempt to maximise the artistic aspect of dance performance. Secondly, it has been found that dancers do not possess greater neuromuscular characteristics when compared to other athletes with similar muscle cross-sectional area. One rationale for this finding may be attributed to the specific aesthetics of the dancer's jumps, which tend to result in lower jump heights and ground reaction forces when compared to other athletes. Thirdly the dance population in general tend to avoid resistance training due to a fear that excessive hypertrophy could negatively affect their physical aesthetic. This lack of resistance training may result in a reduced capacity to generate muscular forces during their dance movements and could also increase overall injury risk. Finally the reviewed literature presents conflicting evidence about the impact of ballet training on overall bone health status. Therefore, more research is needed that explores the body composition, neuromuscular characteristics and anaerobic endurance ability of dancers in order to understand how these variables differ between various levels of expertise.

While there is sufficient research investigating modern dancers, studies comparing novice, semi-professional and professional ballet dancer's physiological fitness parameters are scarce. Therefore the aim of this thesis was to extend the knowledge in two particular areas. Firstly to compare ballet dancers individual selected physiological fitness parameters between three different levels of ballet dancers, with the purpose of establishing which variables best discriminates between the different levels of dancers. Secondly to assesses the relationship between a specific ballet jump skill (the *grand jeté* leap*)* and two laboratory based jumping tests (CMJ and DJ) in order to investigate whether the magnitude of the relationship vary between the three levels of dancers.

CHAPTER THREE
EXPERIMENTAL STUDY 1

Comparison of body composition, neuromuscular characteristics and anaerobic endurance between novice, semi-professional and professional ballet dancers.

3.1 Introduction

Classical ballet is an art form that entails emotivism and expressiveness, as well as demanding specific physiological fitness parameters and aesthetics from individuals pursuing it. Previous cross-sectional studies have investigated selected physiological fitness parameters of various types of dancers, with the purpose of improving training and decreasing injury rates (Chatfield et al., 1990a; Chmelar, 1988; Wyon et al., 2002). Based upon these studies, it can be concluded that enhancing selected physiological fitness parameters such as aerobic and anaerobic endurance, neuromuscular characteristics and body composition could positively impact dance specific skills and dance performance in ballet dancers (Oreb et al., 2006). Unfortunately, there is a paucity of studies establishing selected physiological fitness parameters in different skill level groups of classical ballet dancers. Specifically, very few studies have quantified the specific contribution of these variables to different skill levels of ballet dancers. For instance, Chmelar et al., (1988) examined the physiological fitness profile between semi-professional and professional ballet dancers and established significant differences between aerobic, anaerobic endurance and isokinetic strength between the groups. Furthermore, results from the discriminant analysis in this study, demonstrated that blood lactate and maximal oxygen uptake were the two physiological fitness parameters that best differentiate professional ballet dancers from semi-professionals ($F_{6,30}$ = 7.86, $p < 0.001$) (Chmelar, 1988). Based upon these data, it appears that ballet dancers share the same under lying parameters that affect other athletes. Specifically variables of: neuromuscular characteristics including jump ability, muscular power, muscular strength, muscular endurance, anaerobic endurance, and body composition have been determined to play an important influential role on dance performance. Thus, determination of these parameters, could lead to improved execution of dance manoeuvres and also serve as a means of injury prevention (Angioi, Metsios, Koutedakis, & Wyon, 2009; Malkogeorgos et al., 2013; Rimmer et al., 1994).

The scientific literature largely supports the notion that dancers are performing athletes (Koutedakis & Jamamurtas, 2004). This argument can be

explained based upon the fact that dancers, just like athletes, undergo long training hours to improve their skills and also, endure demanding physical movements whilst at rehearsals and theatre performances. While, studies in the dance science literature have focused on investigating dancer's aerobic endurance, other physiological fitness components such as body composition, neuromuscular characteristics and anaerobic endurance have received less detailed attention (Harley et al., 2002; Twitchett et al., 2009). For instance, neuromuscular characteristics particularly jumping ability is an essential skill previously investigated in classical ballet (Pekkarimen, Litmanen, & Mahlamaki, 1989; Laws & Petrie, 1999). In addition, jump proficiency is often used as a criterion by dance experts in dance auditions, hence an important determinant of a dancer employment opportunity. Several studies have been conducted investigating biomechanical aspects of ballet jumps (Krasnow, Wilmerding, Stecyk, Wyon, & Koutedakis, 2011; Murgia, 1995; Poggini et al., 1997). However, there have been relatively few studies specifically comparing the displacement of the centre of mass (CoM) achieved during specific ballet leaps, or between jumps executed by different skilled ballet groups. Moreover, Harley et al., (2002) performed a comparison of neuromuscular characteristics in countermovement jumps (CMJ) and drop jumps (DJ) between dancers and an age matched control group. These investigators established that dancers did not generate significantly higher power outputs in their jumps, when compared to the age control group ($p<0.05$). In agreement with these findings, Kenne and Unnithan (2008) report that even though ballet dancers possessed similar lower limb muscle torques values during isokinetic tests to basketball players, they generate significantly lower levels of relative peak power during the Wingate Anaerobic Test (basketballers= 9.1 ± 1.3 vs. ballet dancers= 8.1 ± 1.0 W·kg^{-1}, $p < 0.05$). However, the methods used to assess anaerobic peak power, did no take into account the specificity of ballet training and were not develop specifically for dancers, therefore these results must be interpreted with caution.

In contrast, Kirkendall and Street (1986) investigated anaerobic capacities in several athletes including professional dancers, by utilizing a specific jump test, which required participants to perform maximal rebound vertical jumps for a minute in order to calculate mechanical jumping power from cumulative flight

time. This method of evaluating muscular mechanical power could be suitable for dancers, because it possesses an eccentric component which entails a deceleration phase, where elastic energy is stored in the connective tissues, and thus may be better suited for stretch-shortening cycle activities such as ballet. Moreover, these researchers established that a group of mixed gender professional ballet dancers possessed the lowest power outputs when compared to wrestlers, soccer players, bobsledders and basketball players. Thus, further investigation exploring strength and rate of force development, which could influence the underlying expression of power within various levels of dancers, is warranted in order to establish which aspects of power development significantly influence ballet performance.

Muscular strength is defined as the maximal force that is produced in a single muscular contraction (Koutedakis et al., 1997). Investigations by Chatfield and Barnes (1990a) compared isokinetic strength, body composition and a dance competency test between modern dancers and an age matched control group. These authors reported no significant difference between the isokinetic strength measurements attained within each tested group, suggesting that modern dance is not a sufficiently demanding activity to increase muscle strength and power. Nevertheless, isokinetic strength, which is a velocity dependent test, may not be the most appropriate test for dancers because it does not produce high rates of force development (RFD) like those seen in isometric strength assessments (Stone et al., 2004). In addition, isometric measures of neuromuscular characteristics including the RFD and isometric peak force (IPF) have large to very large correlations ($r = 0.71$ and $r = 0.53$ respectively) with explosive movements such as the CMJ and SJ. Based upon these relationships the determination of specific neuromuscular characteristics could be very advantageous to determine within ballet dancers population (Marcora & Miller, 2010). Furthermore, in agreement with these findings Koutedakis et al., (2007) reported significant increases in the isometric strength values of dancers after the completion of three months of strength training (Lower limb isomeric strength pre=90.6 ± 16.0 vs. post= 102.0 ± 17.4), Additionally, it was noted that after this training period there were also improvements in a dance specific performance test as a result of an increase in overall explosiveness".

In sports, body composition has been characterised as the distinct components of the body, which are usually divided in variables such as: lean muscle mass (LMM), body fat percentage (BF%), total bone mineral density (BMD) and bone mineral content (BMC) (Andreoli et al., 2001). The quantification of these variables by means of Dual-energy X-ray absorptiometry (DXA) scans, has been proven to be an effective method to enhance sports performance and prevent injury. Similarly, body composition has been previously investigated in semi professional and professional ballet dancers (Twitchett et al., 2008; Van Marken Lichtenbelt, Fogelholm, Ottenheijm, & Westerterp, 1995; Wilmerding et al., 2005). However, careful inspection of the available scientific literature reveals contentious results regarding the body composition of ballet dancers. For instance, Van Marken Lichtenbelt et al. (1995) demonstrated significant differences in BF% and BMD between professional female ballet dancers and an age-matched control group. Specifically, dancers displayed lower BF% ranging from 10.0 to 24.1% compared to a control group ranging from 15.6 to 32.8% and demonstrated a six percent higher total BMD than the control group. These results could be attributed to the fact that dance is a weight bearing activity, thus creating a positive osteogenic effect. In contrast, other studies have reported that dancers, particularly professionals, are at risk for the female athlete triad as a result of a sustained lower caloric intake (Benson, Engelbert-Fenton, & Eisenman, 1996; Hoch et al., 2011). For instance, Doyle-Lucas et al. (2010) compared BMD, menstrual irregularities and eating disorders between professional ballet dancers and an age matched control group. Results from this study reported that six out of fifteen professional ballet dancers assessed, met the criteria for the female athlete triad, which includes having low BMD, menstrual irregularities due to hormonal alterations and possessing eating disorders. Therefore, the monitoring of body composition, particularly the BMD, BMC, LMM and BF% across different levels of female ballet dancers could be beneficial to examine the risk or occurrence of the female athlete triad.

In summary, a critical analysis of the current body of scientific knowledge reveals that there is limited research exploring selected physiological fitness parameters (i.e. body composition) and neuromuscular characteristics (i.e. jump ability in a specific skill, muscular power, muscular strength and anaerobic

endurance) between different levels of ballet dancers. Therefore, the primary aim of the present study was to compare the selected physiological fitness parameters of novice, semi-professional and professional ballet dancers. The secondary aim was to determine which of the selected physiological fitness parameters were best discriminators of skill level.

3.2 Methods

3.2.1 Experimental approach to the problem

This cross-sectional investigation compared selected physiological fitness parameters of thirty-five cross gender ballet dancers (male: n =11 and female: n =24), whom were novice ballet students (n=12: 2 males and 10 females), semi-professional (n=13: 4 males and 9 females) or professional ballet dancers (n=10: 5 males and 5 females). Inclusion criteria for each group consisted of: professional dancers needing to have five years of professional training, semi-professionals needing to be in their third year of a dance degree and novice students needing to be at least 6 months into their dance training. All testing was conducted at the dance laboratory, strength laboratory and the Institute of Health Research at Edith Cowan University. Data collection was performed in accordance with the standards approved by the ECU ethics committee (See Appendix A) and all participants provided informed consent prior to participation (See Appendix B) The study was completed over one testing session (See Figure 3.1 for testing sequence), were body composition was assessed first (BF%, LMM, BMD, and BMC) followed by the evaluation of the dancer's neuromuscular performance characteristics including: displacement of centre of mass (CoM) during a *grand jeté* leap, countermovement jump peak force (CMJ_{PF}), countermovement jump peak velocity (CMJ_{VEL}), countermovement jump peak power (CMJ_{PP}), countermovement jump vertical displacement (CMJ_{VD}), drop jump peak force (DJ_{PF}), drop jump vertical displacement (DJ_{VD}), lower limb isometric strength variables: isometric peak force (IPF), relative isometric peak force (rIPF),

allometrically scaled peak force (ASPF) and rate of force development (RFD) and anaerobic endurance were compared.
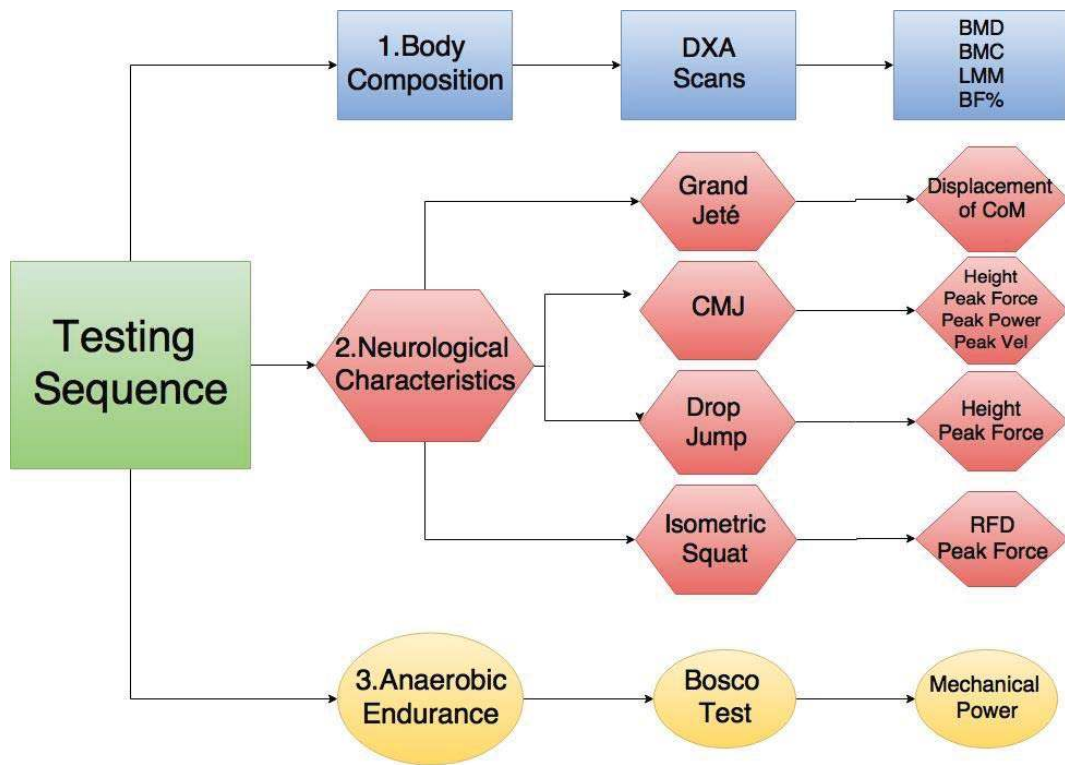
Figure 3. 1 Testing sequence order.
Note: Participant's first completed the body composition scans; followed by the neuromuscular tests and finalise with the anaerobic endurance test.

3.2.2 Participants

A total of thirty-five classical ballet dancers (male: n =11 and female: n =24) participated in this study, which involved 3 groups: professional ballet dancers from a prestigious ballet company in Western Australia, final year dance semi-professional dancers from the Western Australia Academy of Performing Arts, and novice ballet students from the Western Australian Conservatoire of Classical ballet. All participants were training more than ten hours per week, and their descriptive characteristics are presented in table 3.1. In addition, a medical history questionnaire was provided to screened and confirmed participants good health (See Appendix D). Dancers were excluded from this study if they had any injuries that would preclude them from completing any of the testing procedures required in this investigation. Furthermore, participants received an information sheet with the benefits and risks of the study (See Appendix C), and an informed consent was obtained from the participants and assent was obtained from their parent or guardian if they were under the age of 18. These procedures were undertaken in accordance with the Edith Cowan University Ethics procedures (See appendix B).

Following a power analysis (G*power 3.0.10), it was indicated that mixed gender sample size need it a minimum of 7 participants per group, was required to achieve a statistical power of 0.80 and alpha = 0.05 (Faul, Erdfelder, Buchner &Land, 2009). In addition, female participants were strictly recruited beyond their first menarche, therefore past the age of puberty, in which large skeletal maturity occurs (Lai et al., 2008).

Table 3. 1 Participant's descriptive characteristics

	Novice			Semi-professionals			Professionals			*p*-value	Effect size
	Totals $n=12$	Male n=2	Female n=10	Totals n=13	Male n=4	Female n=9	Totals n=10	Male n=5	Female n=5		
Age (y)	16.6± 1.5	16.5±2.1	16.7± 1.5	20.0±1.6	20.8±1.5	20.2±1.6	23.8±3.5	24.6±4.4	23.0±2.4	0.001[*]	0.60
Total body mass (kg)	58.0±13.0	81.2±4.6	53.4±7.9	64.1±10.5	75.6±8.6	58.6±6.1	63.3±14.7	77.1±2.2	49.6±2.5	0.226	0.09
Height (m)	1.7±0.1	1.8±2.6	164.3±5.7	1.7±0.1	183.1±7.0	168.2±6.1	1.8±1.2	185.8±7.4	165.9±6.1	0.471	0.05
Years of training (y)	1.3±0.9	0.6±0.1	1.47±1.0	3.4±1.4	3.0±0.1	3.6±1.6	7.2±2.4	8.0±4.5	7.0±2.2	0.001[*]	0.56

Note: (*) Significantly different at $p \leq 0.05$.

3.2.3 Body composition assessment

All participants underwent body composition assessments with the use of dual energy x-ray absorptiometry scan (DXA) (DXA; Hologic Discovery A, Waltham, MA) (Clasey et al., 1997; Mattila, Tallroth, Marttinen, & Pihlajamki, 2007). Prior to undertaking the DXA scans, participants were required to refrain from any physical activity for 48 hours prior to undergoing the body scan. A complete body scan was performed and analysed by the same qualified technician in order to, measure the participant's total body mass (TBM), BF%, LMM, BMD and BMC. The DXA was calibrated prior the each testing session as per manufacturer guidelines in order to control for possible baseline drift. These physical assessment methods have been previously validated and are have shown high reliability in our lab (CV < 2.4%; ICC > 0.98) (Hart, Nimphius, Spiteri, Cochrane, & Newton, 2015)

3.2.4 Neuromuscular assessments

3.2.4.1 Kinematic assessment of a *Grand Jeté* Leap

Following the DXA scans, the participants performed a *grand jeté* leap to determine displacement of centre of mass (CoM). Participants were fitted with a full body inertial sensor suit and underwent anthropometric measures and calibration (See Appendix E, for specific landmarks measurements), (Xsens Technology, Enschede, The Netherlands) to allow for the determination of the displacement of the CoM based on a previously validated camera-less inertial sensors full body model (Roetenberg, Luinge, & Slycke, 2009). Participants performed five trials with one minute rest between each "*Gran jeté*" leap, taking off with their preferred leg and extending the opposite limb to achieve a 180° degree angle in the air. After completion of the *grand jeté* leap assessment, data was exported from the Xsens MVN Studio 3.4 software to a excel spread sheet (Microsoft Office Excel, Microsoft Office for Mac, Microsoft Corporation 2010)

for calculation of changes in CoM displacement. This calculation was determined by taking the difference between the participant's CoM height whilst standing and their displacement of CoM at the peak height of the *gran jeté* leap. Test-retest reliability for changes in displacement of CoM between five trials was conducted with a coefficient of variation (CV) =1.9 with 95% Confidence Interval (95%CI) = (1.7-2.1) and intraclass correlation coefficient (ICC) (ICC = 0.96, 95%CI = 0.94-0.97), as described in Table 3.5.

Figure 3. 2 Illustration of the participant during the static calibration with the MVN Xsens suit

Figure 3. 3 Illustrating a participant performing a specific ballet leap

3.2.4.3 Jump ability in two laboratory tests

All laboratory based jump tests (CMJ and DJ) were conducted on a force platform sampling at 600 Hz (Ballistic Measurement System; Fitness Technology, Adelaide, Australia) and followed the kinematic assessment as suggested by Baechle and Earle (2008). The CMJ was the first jump test performed. The participants were instructed to hold a carbon fibre pole (as previously described by Nimphius et al., (2010) in order to restrict arm movement. All subjects performed three CMJs to a self-selected depth for three trials, with one minute of recovery between each jump in accordance with previously published methods (Nimphius et al., 2010). Following the CMJs and three minutes of recovery, DJs were performed from a 40 cm box with one-minute rest between each trial. Participants were instructed to "step out" and "away" from the box and to "jump as high and as fast as possible" upon landing (Markwick et al. 2015).

All force data for the jumping tests were filtered using a fourth order Butterworth digital filter with a cut-off frequency of 50 Hz. The Ballistic Measurement System software (Ballistic Measurement System; Fitness Technology, Adelaide, Australia) was used to calculate CMJ and DJ vertical displacement (CMJ_{VD} and DJ_{VD} respectively), using the flight time achieved during each of the jumping motions. The following equation was used to convert the flight time into CMJ_{VD} and DJ_{VD}. Where g represents gravity and flight time is measured in seconds (Bosco, Luhtanen & Komi, 1990).

$$vertical\ displacement = \frac{g\ x\ (flight\ time\ ^2)}{8}$$

When the vertical jump measures were assessed for reliability with the use of the ICC and CV all variables met the minimum standards of ICC > 0.70 and CV < 15% (Tran et al., 2015). Specifically, the reliability for the variables measured were as follows: CMJ_{VD} : CV= 4.2%, 95% CI= 3.6-5, ICC=0.97, 95% CI= 0.95-0.98; DJ_{VD}: CV= 3.1%, 95% CI=2.7-3.7, ICC=0.94, 95%CI=0.91-0.97.

3.2.4.2 Lower limb Isometric Strength Test

Following the jumping ability tests, the participants performed an isometric squat test in order to determine lower body strength. The isometric squat was performed on a force platform (400 Series Performance Plate; Fitness technologies, Adelaide, South Australia, Australia) that sampled at 600 Hz and was placed inside an isometric rack that utilises pins to fix a metal bar to a desired height. The participants were instructed to assume a standard squat position, in accordance with previously published methods (McBride et al. 2006). This position required the participant's to assume a squat position that was standardised at a knee angle of 140° degrees, which was determine using a goniometer. The dancers were instructed to push against the fixed bar with maximal effort as fast and as hard as possible for three seconds, while the investigator gave verbal encouragement. Following a familiarization protocol, the testing protocol was repeated three times in order to ensure that reliable data was collected. In between each trial two minutes of recovery were allowed in order to ensure full recovery between tests. Data was then analysed with standard computer software (Ballistic Measurement System; Fitness Technology Adelaide, South Australia, Australia) in order to assess the lower limb dancers IPF, RIPF, ASPF and RFD in the squat. The peak rate of force development was determined by assessing 20 ms intervals across the force time curve.

3.2.4.4 Anaerobic Endurance test

The last test consisted of a jumping test to determine the anaerobic endurance of the dancers. In this anaerobic test the participants performed a series of continuous CMJs for a minute, on a contact mat in conjunction with the kinematic measuring system (KMS) (Fitness Technologies, Adelaide, Australia) to determine the flight time of each jump. The depth of countermovement was standardised with a goniometer to determine the knee angle (120°) and a rubber band was placed to mark the required countermovement depth. The participants were instructed to slightly touch the rubber band on each jump prior to jumping as

high as possible. Verbal encouragement was given throughout the duration of trial. Calculation of mechanical power of each trial was achieved by entering values of total flight time of all jumps and number of jumps during sixty seconds on a spread sheet (Microsoft Office Excel, Microsoft Office Professional Edition, Microsoft Corporation, 2007) into the following equation described by Bosco et al., (1983).

$$Mechanical\ Power\ (W.kg^{-1}) = \frac{g^2\ x\ Tf\ x\ 60}{4\ x\ n\ x\ (60 - Tf)}$$

Where g= 9.81 m. s^{-2}, Tf= total flight time, and n= number of jumps.

The reliability of this test has been previously established and demonstrated to produce high reproducibility r =0.95 (Bosco et al., 1983).

3.2.5 Statistical Analysis

For statistical analysis all variables were categorized into three different dependant variables groups. First group, comprised of body composition variables such as: TBM, BF%, BFkg BMD, BMC and TLM; Second group, included the dancer's neuromuscular performance characteristics variables (displacement of CoM in a *gran jeté*, CMJ$_{VEL}$, CMJ$_{PF}$, CMJ$_{PP}$, CMJ$_{VD}$, DJ$_{PF}$, DJ$_{VD}$ and anaerobic endurance); and the third group, entailed lower body isometric strength measurements (IPF, rIPF, ASIPF and RFD). Three different skill levels groups were used as independent variables. Normality in the data set was assessed and ensured by the use of Levene's normality test. Furthermore, prior the main analysis a Pearson product moment correlation analysis was conducted in order to examine the strength and direction of all the dependent variables within each group. This analysis was then used to exclude the most highly correlated variables in order to avoid redundancy during the Multivariate Analysis of Covariance (MANCOVA). Coefficient values (r) were interpreted as follows: r=0.0 to 0.10 considered trivial, r =0.11 to 0.30 was considered small, r=0.31 to 0.50 was considered to moderate, r=0.51 to 0.70 was considered large, r=0.71 to 0.90 was

considered very large and, $r=0.91$ to 1.0 was considered nearly perfect (Hopkins, 2010). In addition, the excluded variables from the MANCOVA were subsequently examined using a univariate analysis ANCOVA to determine if they were significant different between the three ballet groups.

Each of the three grouping variables were analysed performing three-separate MANCOVAs, with the use of the Roy Largest Root test with a significance level set at $p\leq0.05$ to establish if there was a significant differences between the dependant variables groups. Age and gender were included as covariates, to account for skeletal maturation and sex differences in the corrected model. In addition, partial eta squared effect sizes (ES) were calculated as $\eta^2=$ sum of squares effect divided by the sum of squares total (The magnitudes of ESs were considered trivial, <0.2; small, 0.2-0.6; moderate, 0.6 to 1.2; and large, 1.2-2.0; very large, 2.0 to 4.0 (Hopkins, 2010).

Follow-up univariate analysis of covariance (ANCOVA) and stepwise discriminant analyses were performed within each group, to establish which dependent variables were the best set of predictors to establish differences between the different skill ballet groups. Data was examined using SPSS Version 22.0 (SPSS Inc., Chicago, IL, USA) for statistical analysis and to ensure all underlying assumptions from the multivariate analysis were met. All results (showed as adjusted means followed the MANCOVA analysis ± SD) are summarized in Table 3.2-3.5.

3.3 Results

Variables are presented within the three different variable groups: body composition (Table 3.3.1), neuromuscular characteristics variables (Table 3.3.2) and lower limb isometric strength variables (Table 3.3.3). Reliability of all the variables are presented in table 3.3.4

3.3.1 Body composition variables

Results from the MANCOVA analysis indicated significant differences between the three ballet levels in the body composition variables group. More specific, combined measurements of: BF%, BMD and LMM variables showed differences between the groups when controlling for gender effect ($F_{4, 29}$ =4.34, p=0.007, η^2 =0.37). In addition, this group results showed no statistical age effect in the analysis, thus age was removed as a covariate from the model (p =0.246).

A follow up univariate analysis ANCOVA, revealed significant differences between the groups in: BMD, BF% and LMM (p=0.012, p=0.013, p=0.027 respectively). Lastly LMM also was significant different between the professional and semi-professional group p= 0.010 with the professional demonstrating the lowest values mean= 45.36 kg against semi-professional = 50.98 kg and novice = 47.32 kg (See Table 3.2). Two variables were excluded from the MANCOVA in this group (Total body mass and BMC) do to the large correlations with LMM (LMM: r=0.98 and BMC: r=0.94), thus they were analysed individually performing a univariate analysis ANCOVA. The analysis showed, that BMC and total body mass were not significantly different between the groups ($F_{2,30}$ = 2.70, p=0.084, η^2 =0.15; $F_{2,30}$ =1.48, p=0.243, η^2 =0.09 respectively).

Discriminant analysis, for the body composition group of variables demonstrated two discriminant functions. The first explained 64.7% of the variance, canonical r^2 = 0.37, whereas the second explained only 35.3%, canonical r^2 = 0.25. In combination these discriminant functions significantly differentiated the three ballet levels, Λ=0.47, χ^2_4=22.47, p=0.013. The correlations between outcomes and discriminant functions revealed that BMD and BMC were the variables that most contributed 61% to the discriminant function (BMD= 61% and BMC= 51%). In addition a stepwise discriminant analysis revealed that BMD was the best predictor for group membership, in the body compositions variables group (p= 0.011). It is important to stress that BMD as the best discriminant variable could be a limitation in this study due to age being largely related to age

as confirm through a correlational analysis ($r= 0.55$). However, when the covariate age (described above) was included in the MANCOVA there was no significant age effect difference between the groups ($p= 0.234$)

3.3.2 Neuromuscular characteristics variables

The MANCOVA demonstrated a significant difference between the neuromuscular characteristics variables, between the three different ballet groups ($F_{7,26} =4.99$, $p=0.001$, $\eta^2 =0.57$) when gender and age were integrating as covariates. However no age effect was noted in the model $p=0.234$, therefore age was removed from the analysis as a covariate.

The follow-up univariate analysis ANCOVA showed significant differences between the groups in the following variables: CMJ_{PF} ($F_{2,31} =4.17$, $p=0.025$, $\eta^2 =0.21$), CMJ_{PP} ($F_{2,31} =4.71$, $p=0.016$, $\eta^2 =0.23$) and CMJ_{VD} ($F_{2,31} = 3.50$, $p=0.043$, $\eta^2 =0.18$) when controlling for gender. In addition, displacement of CoM in a *grand jeté* leap was found not significantly different in the model ($F_{2,31} =2.91$, $p=0.069$, $\eta^2 =0.16$) see figure 3.4. Furthermore the pairwise comparison demonstrated significant differences between the professionals and the semi-professional and novice group in CMJ_{PF} (professional vs. students $p=0.018$ and professionals vs. semi-professional ($p=0.014$) with the professional group carrying out the lowest mean value between when compared to the other two groups (professional $CMJ_{PF} =1341.94$ N vs. semi-professional $= 1560.48$ N and novice 1560.13 N). Similarly, for the CMJ_{PP} a significant difference was noted between the professionals and the semi-professional group $p=0.005$. The professional group exhibited the lowest peak force values during the CMJ (professionals $CMJ_{PP} = 2670.69$ W vs. semi-professional $=3216.96$ W). Lastly, the semi-professional group achieved the highest CMJ_{VD} displacement when compared to the other groups (Semi-professional $CMJ_{VD} =0.32$m vs. professionals $CMJ_{VD} = 0.30$m; and novice $CMJ_{VD} = 0.28$m). Additionally, there was significant statistical difference between the semi-professional group and the novice group

p=0.013 for vertical displacement during the CMJ. In contrast, no statistical difference was found between the novice and the professional groups in CMJ_{VD} (p=0.166). Moreover, a univariate ANCOVA analysis was performed separately on DJ_{VD} to determine differences between the three groups. Results showed that there was significant difference in DJ_{VD} between the groups ($F_{2,30}$ =4.57, p=0.019, η^2 =0.23) when gender and age was accounted as covariates. Moreover, a post hoc Bonferroni test demonstrated that a significant difference was found between the professionals and semi-professional groups p=0.048 with the professionals possessing the lowest values between the groups (Professional: DJ_{VD}= 0.47 m; Semi-professional: DJ_{VD} = 0.51 m; Novice: DJ_{VD}= 0.49 m). No significant differences were observed between the different skill levels of dancers in the anaerobic endurance variable.

Consequently, discriminant analysis for the neuromuscular characteristics variables group established two discriminant functions. The first explained 69.8% changes in the variance, canonical correlation r^2=0.56, while the second one explained 30.2% with a canonical correlation of r^2=0.35. The first discriminant function was found to significantly differentiate between the three ballet groups Λ =0.29, χ^2_4= 35.36, p=0.004. The correlation matrix for the first function revealed that the displacement of CoM in a *grand jeté* leap loaded the highest in the first function r=0.47 with CMJ_{VD} and DJ_{VD} loading second best equally (CMJ_{VD} r=0.35 and DJ_{VD} r=0.35). Therefore, the stepwise discriminant analysis showed that displacement of CoM in a *grand jeté* leap was the best discriminator to establish group membership p=0.019. See Figure 3.4 for canonical discriminant functions.

3.3.3 Lower limb isometric strength variables

Results from multivariate analysis MANCOVA showed no significant differences in lower limb isometric strength variables between the three different ballet groups. ($F_{3,29}$ =2.12, p= 0.120, η^2 = 0.18) (See Table 3.4). In addition, ASIPF was not included in the MANCOVA analysis, due to a very large correlation with rIPF (r=0.93). Therefore results from the univariate ANCOVA analysis demonstrated no significant differences in allometrically scaled isometric peak force (ASIPF) between the groups ($F_{2,30}$ =0.90, p=0.418, η^2 =0.05) Similarly, stepwise discriminant analysis found no significant contribution from the strength measurements to the discriminant function, indicating that strength variables were not a good predictor in the model to differentiate between the ballet groups (IPF: p=0.889; rIPF: p=0.912; ASIPF: p=0.882; RFD: p=0.839) respectively.

Table 3. 2 Body composition measurements between three levels of ballet dancers

Variables	Novice		Semi-professional		Professional		*p*-value	η^2
	Adjusted Means ± SD	95% CI	Adjusted Means ± SD	95% CI	Adjusted Means ± SD	95% CI		
Total Body Fat (%)	20.00± 3.91*	18.43-21.57	17.06± 4.77*	15.58-18.54	19.91±3.85*	18.18-21.64	0.013*	0.25
Total body fat (kg)	11.86 ± 2.54	10.41-13.30	10.73 ± 2.66	9.36-12.09	11.60±1.79	10.02-13.20	0.479	0.05
Total lean muscle mass (kg)	47.32 ± 11.71*	44.44-50.20	50.98±10.45*	48.26-53.70	45.36±13.15*	42.19-48.54	0.027*	0.21
Bone mineral density (g.cm $^{-2}$)	1.10± 0.08*	1.07-1.14	1.18±0.07*	1.15-1.22	1.17±0.12*	1.13-1.21	0.012*	0.25
Bone mineral content (g)	2296.6±448.4	2109.6-2483.6	2547.7±412.2	2415.8-2679.5	2458.2±653.2	2253.9-2662.5	0.084	0.15

Note: (*) Significant p-value ≤ 0.05.

Table 3. 3 Neuromuscular characteristics variables between three different levels of ballet dancers

Variables	Novice		Semi-professional		Professional		p-value	η^2
	Adjusted Means ± SD	95% CI	Adjusted Means ± SD	95% CI	Adjusted Means ± SD	95% CI		
Displacement of CoM in a *grand jeté* leap (m)	0.52 ± 0.07	0.48-0.56	0.53 ± 0.08	0.50-0.57	0.59 ± 0.11	0.54-0.63	0.069	0.16
CMJ peak velocity (s)	2.46 ± 0.27	2.32-2.61	2.54 ± 0.31	2.40-2.68	2.52 ± 0.31	2.36-2.68	0.717	0.02
CMJ peak force (N)	1560.1 ± 297.1*	1442.8-1677.4	1560.5 ± 356.5*	1449.8-1671.1	1341.9 ± 405.3*	1212.7-1471.2	0.025*	0.21
CMJ peak power (W)	2926.9 ± 886.9*	2674.0-3179.7	3217.0 ± 963.2*	2978.5-3455.5	2670.7 ± 1148.6*	2392.1-2949.3	0.016*	0.23
CMJ vertical displacement (m)	0.28 ± 0.07*	0.26-0.30	0.32 ± 0.06*	0.30-0.34	0.30 ± 0.08*	0.28-0.33	0.043*	0.18
DJ peak force (N)	2107.1± 438.0	1620.3-2594.0	1915.4 ± 490.2	1456.2-2374.6	2273.7 ± 1583.5	1737.3-2810.1	0.584	0.03
DJ vertical displacement (m)	0.49± 0.06*	0.46-0.51	0.51±0.05*	0.50-0.53	0.47± 0.06*	0.45-0.50	0.019*	0.23
Anaerobic capacity (W. kg $^{-1}$)	12.92 ± 5.06	10.48-15.36	15.14 ± 3.25	12.84-17.44	14.31 ± 3.74	11.62-17.00	0.410	0.06

Note: (*) Significant p-value ≤ 0.05.

Table 3. 4 Lower limb isometric strength measurements between three different levels of ballet dancers

Variables	Novice		Semi-professional		Professional		*p*-value	η^2
	Adjusted Means ± SD	95% CI	Adjusted Means± SD	95% CI	Adjusted Means ± SD	95% CI		
Isometric peak force (N)	1612.3 ± 523.3	1357.7 -1866.9	1806.1 ± 318.8	1626.7-1985.6	1803.3 ±537.4	1525.1-2081.4	0.473	0.05
Relative isometric peak force (N.kg^{-1})	25.60 ± 5.62	21.52- 29.67	28.36 ± 4.21	25.49-31.23	30.50 ±4.98	26.05-34.95	0.394	0.06
Rate of force development (N.s $^{-1}$)	4602.9 ± 3334.1	2924.4 -6281.4	6747.3 ±1838.5	5564.2-7930.5	5473.9 ±2681.4	3640.3-7307.6	0.069	0.16
Allometric scaled isometric peak force (N.kg$^{-2/3}$)	101.19 ± 23.83	85.82-116.56	112.80 ± 15.72	101.96-123.63	117.993 ± 21.42	101.20- 134.79	0.418	0.06

Note: (*) Significant p-value ≤ 0.05.

Table 3. 5 Results for Intra-Reliability in Neuromuscular Variables

	CV %	LOWER LIMIT	UPPER LIMIT	ICC	LOWER CONFIDENT LIMIT	UPPER CONFIDENT LIMIT
Displacement of CoM in a *Grand Jeté* **leap (m)**	1.9	1.7	2.1	0.96	0.94	0.97
CMJ Peak Velocity	2.7	2.4	3.3	0.95	0.92	0.97
CMJ Peak Force	4.6	3.9	5.5	0.97	0.94	0.98
CMJ Peak Power	9.3	8	11.2	0.93	0.88	0.96
CMJ Vertical Displacement	4.2	3.6	5	0.97	0.95	0.98
DJ Peak Force	12.8	11	15.4	0.87	0.80	0.92
DJ Vertical Displacement	3.1	2.7	3.7	0.94	0.91	0.97
Isometric Squat Rate of Force Development	22.2	18.9	27	0.86	0.79	0.92
Isometric Peak Force	7.0	6.0	8.4	0.95	0.91	0.97
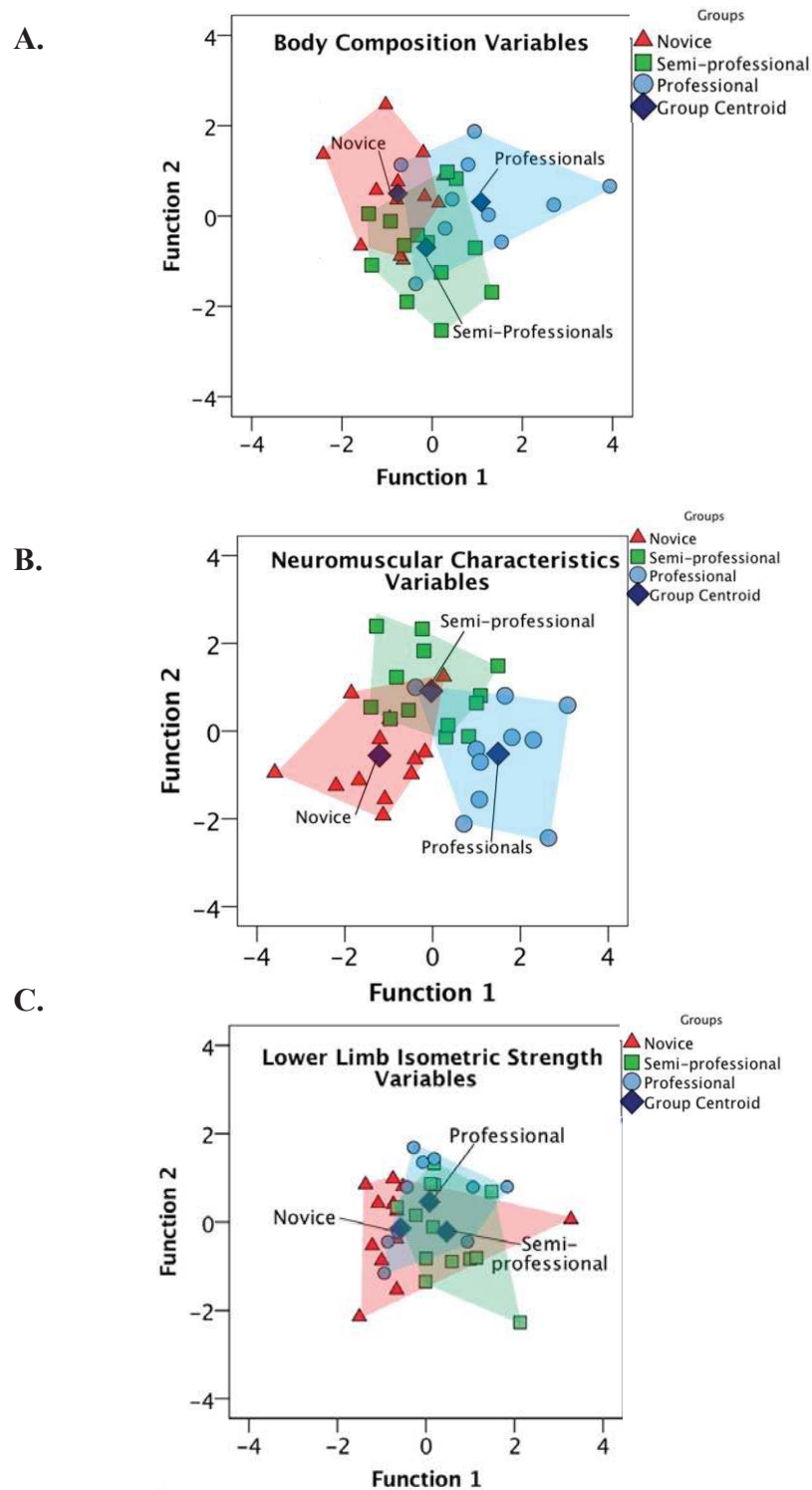
Figure 3.4 Canonical discriminant functions (DF) for three different groups of variables

A) Body composition variables DF =0.61 BMD+ 0.52 BMC – 0.27 BF% + 0.24 TLM + 0.22 TBM - 0.08 BFkg. B) Neuromuscular characteristics variables: DF =0.47 Specific ballet leap + 0.35 CMJ_{VD} + 0.35 DJ_{VD}, 0.23 CMJ_{PVEL} + 0.20 DJ_{PF} + 0.17 Anaerobic capacity + 0.14 CMJ_{PP} – 0.01 CMJ_{PF} . C). Lower limb isometric strength DF= 0.94 RFD + 0.61 IPF + 0.58 ASIPF+ 0.46 rIPF.

3.4 Discussion

The aim of this study was two fold. The first aim was to compare selected physiological fitness parameters between novice, semi-professional and professional ballet dancers. Specifically, the differences between body composition, neuromuscular characteristics and aerobic endurance variables were compared between each group. The second aim was to determine which of the selected variables were the best predictors for group membership classification. Based upon these goals three groups of variables were analysed, resulting in three major findings within each group.

In the first group of body composition variables including BMD, BF%, and LMM were found to be significantly different between the three levels of ballet performance ($p < 0.05$ and $\eta^2 = 0.25$, 0.25 and 0.21 respectively). Specifically, the novice group showed the lowest BMD (BMD= $1.10 \pm 0.08 \text{g.cm}^{-2}$) when compared to both the semi-professional and professional ballet groups. These results are in agreement with Young et al., (1994) who reported similar total body BMDs in elite ballet students (BMD= $1.09 \pm 0.01 \text{g.cm}^2$) possessing a very similar age to the novice students in the present study (17 ± 0.2 y). Furthermore, it was reported that BMD is significantly different between young adult female ballet students at weight bearing sites compared to an under weight sedentary control group. Therefore, these data suggests that dance training could be a beneficial activity to increase bone peak mass in this age group, especially at weight bearing sites such as the greater trochanter and lumbar spine.

The greater total body BMD observed in the semi-professional and professional group in the present study could represent a direct outcome of prolonged years of dance training endure by these two groups of dancers. This assumption is closely link to the work of Van-Marken-Lichtenbelt et al., (1995). These researchers also suggested that over time professional ballet dancers sustained significantly greater BMD adaptations at weight bearing sites, when compared to an age matched control group, demonstrating that weight-bearing exercise provides a positive osteogenic effect in dancers. Additionally, results of the present study show a rise in

BMD in the semi-professional and professional groups, which could suggest that BMD increases as young adults mature. Hence, this augmentation in BMD in the older groups could be an outcome of those dancers approaching their peak bone mass, which approximately occurs at 25 years of age (Heaney et al., 2000). Interestingly, it was observed in our study that semi-professional dancers possessed the greatest BMD ($1.18 \pm 0.07\,\text{g}\cdot\text{cm}^{-2}$) when compared to professional ($1.17 \pm 0.12\,\text{g}\cdot\text{cm}^{-2}$) and novice ($1.10 \pm 0.08\,\text{g}\cdot\text{cm}^{-2}$) dancers. While these findings may be surprising, it is possible that this group of dancers is exposed to a greater range of dance disciplines in their education curriculum. Specifically, it is common for semi-professionals to complete a minimum of 7.5 hours of modern classes per week, in comparison with the novice or professional dancers (Students = 3 hours per week and professionals = 0). Additionally, modern dance entails a larger mechanical loading than classical ballet (Friesen et al., 2011), thus this increase in mechanical loading experienced by the semi-professional may offer an osteogenic stimulus that positively influences their total BMD (Friesen et al., 2011). Therefore, differences in BMD between these specific ballet groups could be influenced by their training regimes, which are dictated by the level of their dance career. Specifically, it is expected that the training practices for both novice and semi-professionals will contain a greater diversity of dance methods when compared to professional ballet dancers. Furthermore, it is important to mention that other factors that could potentially influence BMD can include age of menarche, eating habits and type of physical activity undertaken during pre-pubertal years. While these factors can impact BMD they were not included in this study and were considered outside the scope of this thesis, therefore further investigation in this topic is warranted.

An additional factor that is often considered when examining ballet dancers is their overall body composition (Friesen et al., 2011; Malkogeorgos et al., 2013; Wilmerding et al., 2005; Yannakoulia, Keramopoulos, Tsakalakos, & Antonia-Leda, 2000); Therefore, when all groups were analysed together, BF% means ranged between 17.1 ± 4.8 to $20.0 \pm 3.9\%$, which falls into the optimum BF% levels for adult university female ballet dancers as described by Twitchett, Koutedakis and Wyon, (2009). In contrast, Van Marken Lichtenbelt et al., (1994) reported factors that affected BMD such as BF% in a cohort of professional female ballet dancers from a ballet company, ranging in ages similar to our study (17-34 y). These researchers

demonstrated BF% results from underwater weighing ranging from 10.0 to 24.1%, which are lower than the results determined in the present study. However, it has been establish that DXA scans, possess a much lower error measure, compared to underwater water weighing. Therefore DXA is considered a much more accurate method of assessing body composition (Salamone, et al. 2000) and may produce more realistic body composition assessments. Additionally, BF% was determined to be significantly different between the groups investigated, with the semi-professional group possessing the lowest BF% (See table 3.2).

This outcome was not expected, as ballet is a stylized art form that requires a low level of BF% to maintain specific aesthetics appeal, particularly at an elite level. In contrast to the findings of the present study, Wilmerding et al., (2005) report that professional ballet dancers were significantly leaner when compared to their modern dance counterparts, dance students and semi-professional dancers. Similarly, BF% in dancers has been described by a few authors (Clarkson et al., 1985; Van Marken Lichtenbelt et al., 1995), who also suggest that professional ballet dancers possess lower BF% ranging from 16.0-18.0% in females and 5.0-15.0% in males which is different than the levels found in the present study (See table 3.2). Moreover, it has been previously suggested by Koutedakis and Jamurtas (2004) and Stokic, Srdic and Barak (2005), that female dancers with BF% bellow 17% are most likely to be at risk for amenorrhea and hence may suffer from the female athlete triad. Additionally, other studies have established that extremely lean dancers are more prone to injury when compared to dancers who are above the normal ranges (Benson, Gillien, Bourdet, & Loosli, 1985).

A second important component of body composition is LMM. In our study LMM was found to be significantly different between the three different ballet groups (p-value< 0.005, η^2 = 0.21). Surprisingly, the semi-professional group exhibited the highest LMM values (LMM= 51.0 ± 10.5kg) when compared to the novice (LMM= 47.3 ± 11.7kg) and professional (LMM= 45.36 ± 13.15kg) dancers. Supporting our findings, previous studies have established that LMM is impacted by physical activity and directly correlated with muscular strength, which is related to jump ability. Therefore the high LMM observed in the semi-professionals group, could partially

explain their higher performance in the CMJ_{VD}, DJ_{VD} and isometric squat. Furthermore, when looking at the present data the professional dancers unexpectedly demonstrated the lowest LMM values when compared to the novice and semi-professional dancers. One possible explanation for these results could be related to the training undertaken by the recruited dancers as they all were recruited from the same professional ballet company. In support of this contention, Wyon et al., (2007) have established that the degree of VJ utilised by dancers in their performances may be related to the hierarchy of the dance company or the dancers position within the company. When comparing VJ performance capacity between soloists and the corps for the ballet company it was noted that soloists demonstrated significantly better VJ capacities. In addition, the rank of the dancers within the company can also impact the overall performance workload within the company. While it may be expected that higher workloads would influence VJ performance via increased workloads positively impacting LMM, the contemporary body of scientific knowledge suggests that within this population that this relationship does not always exist (Seeman et al., 1996; Wyon et al., 2007).

Another possible reason that could affect the low measurements in LMM in the professional groups, is the fact that professional ballet dancers have been shown to sustain low TBM, low BF% and low to waist-to hip and waist to thigh ratios, as a requirement for ballet imposed aesthetics (Twitchett, Koutedakis & Wyon, 2009). Additionally, both female and male professional dancers are often required to achieve an ultra ballerina body type, which may partially explain the lower LMM observed in this study (Hamilton, Hamilton, Marshall, & Molnar, 1992). Moreover, female dancers who have a low caloric intake have exhibited a negative association with alterations in the hormonal mechanisms that underpin muscle growth and those that are related to menstrual disturbances or other medical problems (To & Wong, 2011b). The results of the present study are similar to those reported by Kaufman et al., (2002) where no significant differences in LMM were noted when comparing elite professional dancers and an age-weight matched controls. Collectively these data indicates that professional dancers may not possess greater LMM when compared to healthy active populations, which could potentially exert a negative impact on their dance skill performance capacity.

In order to further explore which specific body composition variables underlie dance performance, a discriminant analysis was conducted in the present study. Specifically, this analysis revealed that total BMD was the best predictor of dance group membership in the first group of variables. However, these findings could be considered a potential limitation in our study due to the close relationship between age and BMD, as described by Khan et al., (1998). Although Khan et al., (1998) suggests that postmenopausal BMD status is intrinsically related to peak bone mass (achieved approximately around 25 years old), which is dependent on the accrual of bone and physical activity during pre-pubescent years, our study only demonstrated a moderate correlation between BMD and age ($r= 0.50$). Furthermore, Khan et al., (1988) also report that postmenopausal ex ballet dancers sustained higher scores of BMD compared with an aged match control groups, suggesting that childhood ballet training may positively influence BMD after menopause. Additionally, it is important to note that all female participants in the present study were past the age of menarche and therefore considered beyond the point at which large changes in skeletal maturity is expected to occur in response to pubertal growth (Lai et al., 2008).

Findings from the discriminant analysis with the body composition variables, including BF%, LMM, BMD, and BMC demonstrated that the professional group sustained a larger separation from the groups centroids when compared with the other two groups centroids. However, the centroids of the other two groups were closely aligned with each other (See Figure 3.4).

The array of results for the neuromuscular characteristics group of variables indicated that in laboratory based jumps, such as: CMJ and DJ, there were significant differences ($p< 0.05$, $\eta^2 = 0.18$ and 0.23 respectively) between the dance groups. Specifically, the analysis showed a difference in variables such as: CMJ_{PF}, CMJ_{PP}, CMJ_{VD} and DJ_{VD}. As expected, the results for the differences between the neuromuscular characteristics for the tested groups, was aligned with the results presented for the body composition. In this regard, the semi-professionals tended to generate higher vertical displacement values in both, the CMJ and DJ when compared to the professional and novice groups (See Table 3.3). Additionally, the semi-professionals also demonstrated greater CMJ_{PF} and CMJ_{PP} values when compared to

the other two groups. One possible explanation for these findings may be related to the greater LMM found in this group when compared to both the professional and novice group. It is possible that a higher LMM exhibit in the semi-professionals group, could be related to an improved ability to generate force rapidly from a specific muscle group (Twitchett et al., 2009), which may be found in the force-time curve variables determined in the isometric squat test performed in the current study (See Table 3.4). When examining these variables, the semi-professionals produced the greatest RFD. Moreover, it was found that LMM in the present investigation was very largely correlated with RFD in the ballet dancers ($r=$ 0.71; $\eta^2=$ 0.21 and 0,16 respectively). Therefore, it is fair to suggest that LMM and RFD are intrinsically connected with the dancers CMJ_{PF}, CMJ_{PP} and also CMJ_{VD} and DJ_{VD}. This assumption is closely linked to Kuno et al., (1996), who established a relationship between muscle cross-sectional and isometric strength between Japanese professional dancers and a sedentary control group. More specifically, the investigated dancers demonstrated greater isometric strength in knee flexors and in dorsiflexors, compared to a sedentary match control group. These data suggests that the larger the cross-sectional area the greater the ability to produce force, which was observed in the analysis when examining the semi-professional group.

Whilst the results of the CMJ and DJ tests performed in the present study would seem to suggest that the semi-professional dancers possessed superior jumping ability whilst performing a CMJ and a DJ, compared to the novice and professional group, it appears that these capacities did not translate directly into their specific skill "the *grand jeté* leap". Unexpectedly, the semi-professional group was not able to elevate their CoM displacement during the *gran jeté*, to a greater extent when compared to the other two groups. In contrast the professional group showed a greater displacement of the CoM in their *grand jeté* leap, even though they possess the smallest LMM values. Similarly to our findings, Golomer and Fery (2001) reported a very large negative correlation between LMM and maximal jump height in a single leg vertical jump in adult professional dancers ($r=$ -0.82, $p >$ 0.05). Based upon the work of Golomer et al., (2001) and the present study it appears that the lower the LMM the higher displacement of CoM, during a dance specific jump performance. It is possible that dancers with lower LMM preferentially use neural control strategies

when performing dance specific jumps developed by many years of experience performing a specific skill. In addition, ballet dancers have been found to sacrifice jump height for aesthetics and style in their leaps (Harley et al., 2002). This could be an explanation of why the semi-professionals did not show a greater displacement of the CoM in the *grand jeté* leap, nonetheless this group showed greater vertical displacement elevation in CMJ and DJ.

A follow up discriminant analysis was performed to establish which of the neuromuscular characteristics variables was best able to differentiate between the three different levels of ballet dancers. Results from this analysis showed that displacement of CoM from a *grand jeté* leap was the best predictor of group membership. Even though semi-professionals showed the largest CMJ and DJ vertical displacement in the laboratory tests, this group did not achieve the highest values in the *gran jeté*. One potential reason for these differences could be that professionals had more years of training, thus possessing greater opportunity to develop and practice the *gran jeté* leap. The greater values observed in the professional group in the specific ballet jump, could be a result of other factors influencing the *grand jeté* leap. Factors such as coordination, balance, flexibility and elasticity could all influence the outcome of the ballet skill. In contrast the laboratory jumps by design did not required any higher level skill and are a specific representation of muscle capability, therefore the semi-professionals could demonstrate higher jumps, just by following the simple instructions and performed the jumps.

Previously studies have shown that the ability to express high levels of strength is an important component of the performance ability in dancers (Koutedakis et al., 1997; Koutedakis, Stavropoulos-Kalinoglou, & Metsios, 2005). Surprisingly, the discriminant analysis done in the present study indicates that there are no significant differences in lower limb isometric strength measurements between the three-ballet groups examined. Furthermore, plots from the discriminant analysis (See Figure 3.5 C), showed that in the strength variables group, the group centroids were close together, indicating no large differences in lower limb isometric strength between the different levels of dancer. These results could be an outcome of the high variance specifically observed in the RFD scores. Consequently the discriminant

analysis revealed that muscular strength is not a major determinant for group membership in professional dancers.

3.5   Conclusions

Based on results of the present study, semi-professionals ballet dancers showed overall greater LLM and neuromuscular performance characteristics scores when compared to novice and professional ballet dancers. Specifically, this group demonstrated higher values in BMDs, lower BF%s and greater LMMs. In addition, it was found that this group possessed larger neuromuscular characteristics that could lead to higher vertical displacements in laboratory based jump tests such as the CMJ and DJ. These dancers also demonstrated superior peak power and force generating capacities that where partially explained by their overall greater LMM. Unexpectedly, it was found that lower limb isometric strength for this cohort of dancers, was not a significant discriminant neuromuscular characteristic. Interestingly, the semi-professionals group possessed lower CoM displacements values in a *grand jeté* leap, showing deficits in their specific ballet skills manoeuvres. Overall, it seems the body composition variables of BMD and neuromuscular characteristic such as displacement of CoM during a *grand jeté* leap were the best discriminatory variables to established differences between the three different skilled levels of ballet dancers.

3.6   Practical applications

The main finding in this study was that determining BMD and displacement of the CoM in a *grand jeté* leap differentiates between skill status of novice students, semi-professional dancers and professional ballet dancers. Specifically, as ballet dancers progress from novice to professional levels there is a loss in LMM. Typically, when assessing body composition in other athletes', it has been found that decrements in LMM are associated with decreases in jumping ability, which may be noted in the

professional group of this study. In contrast, years of training and experience allowed the professional dancers to demonstrated greater displacements of CoM in a *grand jeté* leap compared to either novice or semi-professional dancers. These results suggest that the professionals possess the ability to maximise their specific ballet skill even though they may have lower LMM. Therefore, it is warranted to investigate the effects of strength training with professional ballet dancers in order to determine if increasing LMM would further improve dance specific performance capacities. Specifically, examining whether enhancements in LMM could possibly translate to increases CMJ and DJ vertical displacements in a laboratory setting.

CHAPTER FOUR

EXPERIMENTAL STUDY 2

Do relationships exist between a *grand jeté* leap and two laboratory-based tests: countermovement jump and drop jump?

4.1 Introduction

Jump height is an important determinant factor for success in sports such as: basketball, rhythmic gymnastics and soccer (Baker, 1996; Kums, Ereline, Gapeyeva, & Paasuke, 2005; Matavulj, Kukolj, Ugarkovic, Tihanyi, & Jaric, 2001; Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004). Jump height assessment is generally employed in sports science as a tool for monitoring training progress and determining an athlete's lower body muscular power (Kraska et al., 2009; Matavulj et al., 2001). Traditionally, jump performance has been assessed by means of two types of vertical jump tests known as the countermovement jump (CMJ) and a drop jump (DJ). These two laboratory based tests, have been proven to be reliable and valid predictors of sporting success, measuring explosive neuromuscular characteristics of an athlete's lower limbs during the propulsive action of jumping (Cronin & Hansen, 2005). Specifically, these two tests can evaluate peak velocity, force, power and most importantly vertical displacement during jumping movements (Behm, Wahl, Button, Power, & Anderson, 2005; McGee & Burkett, 2003; Wisloff et al., 2004). Determination of these jumping characteristics could be advantageous to distinguish athletic skill level, and hence assist in team recruitment or talent identification (Hori et al., 2009).

The CMJ consists of an explosive vertical jump that initiates with an approximately 90° knee and hip flexion, where the muscle undergoes an eccentric contraction to consequently performed a rapid ankle, knee and hip extension; Thereby allowing a fast and forceful concentric contraction of the agonist muscles of the legs, exhibiting in a upward movement (Newton & Kraemer, 1994). This pre-stretch mechanism is called the stretch-shortening cycle (SSC) and its efficiency significantly influences an athlete's jumping ability (Bobbert, Gerritsen, Litjens, & Van Soest, 1996; Hori et al., 2009; Komi, 2008). Specifically the SSC is characterized by the storage of elastic potential energy in the tendo-muscular complex during the eccentric contraction, which is consequently converted into kinetic energy during the concentric contraction (Komi, 2008). Similarly, another common test used in the sports science field to assess SSC and monitor athlete's power profile is the DJ (Young, Pryor, & Wilson, 1995). This test also entails a rapid eccentric contraction of the knee

extensors prior the concentric vertical jump. However, in contrast to the CMJ, the athlete must drop from a specific given height, where the purpose is to land and rapidly explode up, minimising ground contact time, augmenting ground reaction forces, hence increasing jump vertical displacement (Bobbert et al., 1996). Kums et al. (2005) assessed jumping performance characteristics in young female elite rhythmic gymnasts and an untrained control group. This study utilised a CMJ, a DJ and a squat jump (SJ), to described explosive force-generating capacity of the athletes. Results showed that rhythmic gymnasts possessed greater jump height than the control groups. Particularly when performing a DJ from a 40 cm platform ($p<0.001$). DJ is a complex motor task that responds to training specificity as is has been demonstrated following plyometric training (Newton, Kraemer, & Haekkinen, 1999). Rhythmic gymnasts due to their specific ballistic training maybe accustom to executing jumps with greater stretch forces in their routines, therefore explaining the higher DJ values than those seen in the CMJ and SJ in this investigation.

CMJ and the DJ are considered to be useful tests to assess leg power, thus jump ability in rhythm gymnastics (Di Cagno et al., 2008). Similarly to rhythmic gymnastics, another discipline that entails artistic aspects and requires aesthetic jumps is classical ballet. Jumping ability in classical ballet is a skill that requires intricate coordination between the upper and lower body limbs in order to develop enough muscular power to achieve an aesthetically adequate jump (Robertson, Galler, & Stanley, 2004). Laboratory based jump test such as the CMJ, have been employed in classical ballet as an evaluation of lower limb power, jump height and dancers skill levels (Twitchett et al., 2009). For instance, Wyon et al. (2006) established that jump height from a squatting position could be a determinant factor between rankings in a professional ballet company. More specifically, this study demonstrated that soloists and first artists demonstrated greater jump ability in a CMJ compared to corps of ballet ($p>0.05$). However, the relationship between the CMJ and dance specific skill performance, has yet to be defined with classical dancers.

Classical ballet training is a physical taxing discipline that requires dancers (particularly males) to execute complex dance sequences, comprising explosive demanding jumps which requires great power. These challenges could increase depending on the dancer's ranking in the hierarchy of the ballet company and may

also be related to the specific choreography being performed. Kenne and Unnithan (2008) performed a comparison between ballet dancers and basketball players' relative power. Data from this study revealed that ballet dancers demonstrated significantly less relative mean and peak power than the basketball players ($p<0.05$), even though they typically undergo substantial hours and years of training. This could infer that ballet training primarily focuses on improving technical skill rather jumping ability and as a result, may not be a sufficient stimulus to produce power adaptations (Brown et al., 2007).

While the examination of athletes' power employing the CMJ and DJ tests in many sports are extensive, the use of these two laboratory based jumps tests in classical ballet is scarce. Moreover, the dance science literature have indicated that the most common method to assess jumping ability in dancers, have been by means of biomechanical assessments (Koutedakis, Owolabi, & Apostolos, 2008; Wilson & Kwon, 2008b). In particular, scientists have examined kinematic characteristics such as the displacement of the dancer's centre of mass (CoM) through implementing three-dimensional motion capture analysis. Based on this kinematic analysis, basic jumping skills such as the ballet leap or "*grand jeté*" has been described (Lepelley, Thullier, Koral, & Lestienne, 2006). The *grand jeté* is a ballet leap that entails a travelling jump from one foot to the other, where the dancers must show a 180° hip angle at the peak of the jump following a parabolic trajectory (see Figure 4.2.) (Robertson et al., 2004). Due to its aesthetic effect, this leap has been commonly evaluated and can assist to differentiate expertise level and athleticism in dancers (Wilson & Kwon, 2008a). Kalichova (2011) performed a three-dimensional kinematic analysis of a *grand jeté* leap with the purpose of identifying the specific mechanisms that affect this jump. These researchers establish that dancers should aim to extend their legs rapidly at the same time that they reach their peak displacement of CoM in the jump, as this increases the airtime and consequently creates a floating illusion. Similarly, Thomas et al. (2004) investigated ground reaction forces in two experienced dancers whilst performing a ballet leap. Irrespective of the small sample size this investigation is in agreement with previous research recommending that dancers extend their arms and legs at the peak of the jump to enhance airtime, thus elevating their CoM for a longer period of time (Robertson et al., 2004; Kalichova 2011; Laws 2002). Additionally, biomechanical analyses of specific ballet leaps

indicate that dancers must coordinate upper and lower limb movement for maximal jump height.

Jumping performance have been assessed in a variety of sports, utilizing simple, valid and reliable tests such as the CMJ and DJ, yet have not been implemented often in classical ballet. This discipline has typically employed three-dimensional motion capture and kinematic analysis to determine jump ability in dancers. As a result the relationship between the specific ballet leaps and the two laboratory based tests it is unknown. Therefore, the aims of this study are to two fold. Firstly to investigate the relationship between a *grand jeté* leap and two laboratory based jumps test: CMJ and DJ; and secondly, to examine the magnitude of the relationship, to established whether the ability to transfer dancer's physical capacity into jump during a *grand jeté* leap varied between three different groups of skill levels This information could be beneficial for dance instructors to assess whether the dancer is fit for performance and also to differentiate between level of expertise In addition, findings of this study could have implications for the use of simple laboratory tests as a predictor of jump ability in a specific ballet skill such as the *grand jeté* leap.

4.2   Methods

4.2.1 Experimental Approach to the Problem

This cross-sectional investigation examined the relationship between the displacement of CoM in a *grand jeté* leap and two laboratory based jump tests: CMJ and DJ, by performing a Pearson product moment correlation. The testing procedures started with anthropometry, followed by a self-selected dynamic warm-up and several submaximal jumps, after this, the three different types of jumps. Each participant first performed a *grand jeté* leap followed by the two laboratory based vertical jumps. Correlations between the *grand jeté* leap displacement of CoM, a CMJ_{VD} and DJ_{VD} were determined in thirty-five ballet dancers (N=35: male n=10 and female n=25)

who were either: novice ballet students (n=12), semi-professional ballet students (n=13) or professional ballet dancers (n=10). All tests were performed on a single day, in a standardised order, were the participants perform the *grand jeté* leap and then the two laboratory based jumps (CMJ and DJ). A 10-minute rest was allotted between the *grand jeté* leap and the laboratory tests in order to ensure that fatigue did not negatively impact the dancers jumping performance. The order of testing was based upon the guidelines for athlete testing established by the National Strength and Conditioning Association (Baechle & Earle, 2008). All participants were instructed to maintain refrain from training 24 hours before the testing session.

4.2.2 Participants

Thirty five classical ballet dancers were recruited as participants in the present study. This sample size was determined based upon a power analysis (G*power 3.0.10) (Faul et al., 2009) that indicated a mix gender cohort of a minimum of 7 participants per group, which was required to achieve a statistical power of 0.80 and alpha = 0.05. Participants were comprised of three different groups: professional ballet dancers from a prestigious ballet company in Western Australia, final year dance semi-professional dancers from Western Australia Academy of Performing Arts, and novice ballet students from the Western Australian Conservatoire of Classical ballet and their characteristics are presented in table 4.1. Female participants were recruited strictly beyond age of menarche, hence past the age of puberty. Therefore, these female participants were considered beyond the point where large skeletal maturity changes occur due to pubertal growth (Lai et al., 2008). All participants were training more than ten hours a week at the time of the investigation. To participate in the study professional dancers had to have at least a two-year contract with a professional dance company, semi-professionals students were in the third year of their professional training and novice students had to possess at least six months of professional ballet training. In addition, all recruited participants were screened using a medical history questionnaire (See Appendix D), to ensure there were no contraindications to participation in the current research. All participants read an information sheet (See Appendix C) and provided informed consent (See Appendix B) and for those under the age of 18 assent was also received in

conjunction with parental consent prior to participation in the present study in accordance with the Edith Cowan University Ethics procedures (See appendix A)

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Table 4. 1 Participants descriptive characteristics (mean ± SD)

	All groups (N=35)	Novice (n=12)	Semi-Professional (n=13)	Professional (n=10)	p-value	Effect Size
Age (y)	20.1 ± 3.6	16.6 ± 1.5	20.0± 1.6	23.8 ± 3.5	0.001[*]	0.60
Weight (kg)	61.9 ± 12.5	58.0 ± 13.0	64.1 ± 10.5	63.3 ± 14.7	0.226	0.09
Height (m)	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1	1.8 ± 1.2	0.471	0.05
Body fat (%)	18.9 ± 4.5	20.0 ± 3.9	17.1 ± 4.8	19.9 ± 3.9	0.013[*]	0.05
Fat Mass (kg)	11.37 ±2.39	11.97 ±2.54	10.73 ±2.66	11.47 ±1.79	0.479	0.15
Fat Free Mass (kg)	48.12 ±11.76	47.32 ± 11.71[*]	50.98±10.45[*]	45.36±13.15[*]	0.027[*]	0.21
Years of training (y)	3.9 ± 3.2	1.3 ± 0.9	3.4 ± 1.4	7.2 ± 2.4	0.001[*]	0.05

Note: (*) Significantly different between the other two groups ($p \leq 0.05$).

4.2.3 Anthropometry

Participants underwent a full body scan to determine: total body mass, body fat percentage, body fat and lean muscle mass by dual energy x-ray absorptiometry scan (DXA) (DXA; Hologic Discovery A, Waltham, MA) (Clasey et al., 1997; Mattila, Tallroth, Marttinen, & Pihlajamki, 2007). These physical assessment methods have been previously validated and are have shown high reliability (CV < 2.4%; ICC > 0.98) (Hart, Nimphius, Spiteri, Cochrane, & Newton, 2015). See table 4.1.

4.2.4 Kinematic Assessment in a *Grand Jeté* leap

The *grand jeté* leap was performed in a dance studio were the athletes' displacement of CoM was analysed using the MVN three-dimensional motion tracking analysis system (Xsens Technology, Enschede, The Netherlands). Participants were fitted with a full body inertial sensor Xsens MVN suit that has been previously validated for full body kinematics (Roetenberg et al., 2009). It is a three-dimensional full body human motion capture system that utilises camera-less inertial sensors to determine body kinematics (see Figure 4.2). Specifically, the Xsens MVN constitutes of 17 inertial sensors that are used to track the subject's movements in real time, thus allowing a kinematic assessment to be performed. The displacement of the CoM was used for analysis. Specifically the CoM was calculated as the difference between maximum displacement of the CoM during the *grand jeté* leap and the standing CoM height of the participant. Five trials of the specific *grand jeté* leap were performed, and the participants were instructed to take off with their preferred leg and extending the opposite limb to achieve a 180° angle in the air. Participants had three minutes of rest between each trial. Test-retest reliability of displacement of CoM height over the five trials was determine high in reliability with a low coefficient of variation (CV) of 1.9% with a 95% confidence interval (95% CI) between 1.7 and 2.1% and an intraclass correlation coefficient (ICC) of 0.96 with 95% CI = 0.94-0.97.

Figure 4. 1 Illustration of the participant during the static calibration in the MVN Xsens suit

Figure 4. 2 Illustrating a participant performing a *grand jeté* leap

4.2.5 Jump Performance Tests

While the *grand jeté* leap contains vertical and horizontal displacements it is commonly considered a vertical jump within the dance specific biomechanics literature (Kalichova, 2004). Fundamentally, the *grand jeté* leap is an example of a projectile motion in which both vertical and horizontal forces are generated in order to maximize the aesthetics of the leap. However, when examining the *grand jeté* leap the vertical displacement of the manoeuvre is the most important component determining the aesthetics of the skill. In order to maximise the vertical displacement of the CoM during the leap, the vertical application of forces results in a greater vertical displacement of the dancers CoM. Additionally, when integrated into a dance routine, the *grand jeté* leap is preceded by a countermovement that engages the stretch shortening cycle. Based upon the importance of the vertical component of the jump and the pre-jump stretch-shortening cycle, two commonly used laboratory-jumping tests were selected. Specifically, a CMJ and a DJ were selected in order to evaluate the dancers jumping abilities. Therefore, all participants performed a CMJ and DJ to determine maximal vertical displacement from the flight time recorded on a force platform (400 Series Performance Plate; fitness Technologies, Adelaide, South Australia, Australia).

All laboratory based jump tests were conducted on a force platform sampling at 600 Hz. The CMJ was the first jump test performed. The participants were instructed to hold a carbon fibre pole (as previously described by Nimphius, McGuigan, & Newton, 2010) in order to restrict arm movement. Following several submaximal jumps during the familiarization period, all subjects performed three CMJs to a self-selected depth for three trials, with one minute of recovery between each jump in accordance with previously published methods (Nimphius et al., 2010). In addition, horizontal and lateral displacement were monitored and minimized to avoid alterations of measurements. Following a three minutes recovery, DJs were performed from a 40 cm box with one-minute rest between each trial. Participants were instructed to "step out" and "away" from the box and also to "jump as high and as fast as possible" upon landing (Markwick, Bird, Tufano, Seitz, & Haff, 2014).

All force time curves for the jumping tests were filtered with a cut-off frequency of 50 Hz, using a forth-order Butterworth digital filter. The Ballistic Measurement System software (Ballistic Measurement System; Fitness Technology, Adelaide, Australia) was used to calculate CMJ and DJ vertical displacement (CMJ$_{VD}$ and DJ$_{VD}$ respectively), using the flight time achieved during each of the jumping motions. The following equation was used to convert the flight time into CMJ$_{VD}$ and DJ$_{VD}$. Where g represents gravity and flight time is measured in seconds (Bosco et al. 1983).

$$vertical\ displacement = \frac{g\ x\ (flight\ time^{\ 2})}{8}$$

When the vertical jump measures were assessed for reliability with the use of the ICC and CV all variables met the minimum standards of ICC > 0.70 and CV < 15% (Young, Haff, Newton, Gabbett, & Sheppard, 2015). Specifically, the reliability for the variables measured were as follows: CMJ$_{VD}$: CV= 4.2%, 95% CI= 3.6-5, ICC=0.97, 95% CI= 0.95-0.98; DJ$_{VD}$: CV= 3.1%, 95% CI=2.7-3.7, ICC=0.94, 95% CI=0.91-0.97.

4.2.6 Statistical analysis

Means and standard deviations were calculated for all descriptive and performance variables (see Table 4.1). Significant differences between the three ballet groups (i.e. novice, semi-professional and professional dancers) were assessed with a univariate analyses of covariance (ANCOVA) where dancers' morphology and jumping ability was quantified, as well as age and gender were used as a covariate. Pearson Moment Correlation Coefficient was performed to evaluate the strength and directionality of the relationship between the displacement of CoM in a *grand jeté* leap and two laboratory based jumps such as: CMJ and DJ vertical displacement within all participants (N=35) and within each group individually. Significance for all statistical tests was set at an alpha level of p=0.05. The magnitude of effect for correlations (r) was interpreted as follows: r= 0.0 to 0.10 considered trivial, r=0.11 to 0.30 was considered small, r= 0.31 to 0.50 was considered to moderate, r= 0.51 to

0.70 was considered large, $r= 0.71$ to 0.90 was considered very large and, $r= 0.91$ to 1.0 was considered nearly perfect, according to (Hopkins, 2010). In addition, effect sizes partial eta squared were calculated (η^2 =sum of squares effect divided by the sum of squares total) as suggested by Hopkins (2010). Magnitudes of EFs were considered trivial considered trivial, <0.2; small, 0.2-0.6; moderate, 0.6 to 1.2; and large, 1.2-2.0; very large, 2.0 to 4.0 (Hopkins, 2010).

4.4 Results

A multivariate analysis ANCOVA with a Bonferroni post hoc test was used to determine between groups differences in three different skill levels of ballet dancers as shown in Table 4.2. Gender and age where introduce as covariates. Data showed that CMJ and DJ were significant different between the groups (*p*-value= 0.043 and 0.019 respectively). In addition Bonferrroni test revealed that the semi-professional group achieved the highest values in vertical displacement in CMJ and DJ (Semi-professional CMJ_{VD} =0.32 ± 0.1 vs. professionals CMJ_{VD}= 0.30 ± 0.1, and novice CMJ_{VD} =0.28 ± 0.1m; semi-professional DJ_{VD} =0.51 ± 0.1vs. professionals DJ_{VD}=0.47 ± 0.1, and novice DJ_{VD} =0.49 ± 0.1m). However, the professional group possessed the highest displacement of CoM in a *grand jeté* leap compared to the other two groups (Professionals displacement of CoM= 0.59 ± 0.1 vs semi-professional = 0.53 ± 0.1 m and novice = 0.52 ± 0.1m)

The correlations between jump height in a *grand jeté* leap (displacement of CoM) and two laboratory based jump height (CMJ_{VD} and DJ_{VD}) for all the ballet groups are shown in Figure 4.3. Consequently, correlations between the displacement of CoM in a *grand jeté* leap and the CMJ_{VD} and DJ_{VD} within the skill level group are presented in Figures 4.4-4.5. Very large correlations between the *grand jeté* leap and two laboratory tests were found (r=0.77 and r=0.76, for CMJ and DJ respectively). Furthermore, individual analysis of the groups showed an increase from large to very large correlations, as the groups augmented in skill for both the CMJ and DJ. (See Figures 4.4 A-C and 4.5 A-C respectively).

Table 4. 2 Results from the ANCOVA analysis

Variables	All groups (N=35)	Novice (n=12)	Semi-professional (n=13)	Professional (n=10)	*p*-value	η^2
Displacement of CoM in a *Grand jeté* **leap (m)**	0.54 ± 0.1	0.52 ± 0.1	0.53 ± 0.1	0.59 ± 0.1	0.069	0.16
Countermovement jump (m)	0.30 ± 0.1	0.28 ± 0.1	0.32 ± 0.1	0.30 ± 0.1	0.043[*]	0.18
Drop jump (m)	0.49 ± 0.1	0.49 ± 0.1	0.51 ± 0.1	0.47 ± 0.1	0.019[*]	0.23

Note: (*) Significantly different between the other two groups ($p \leq 0.05$).
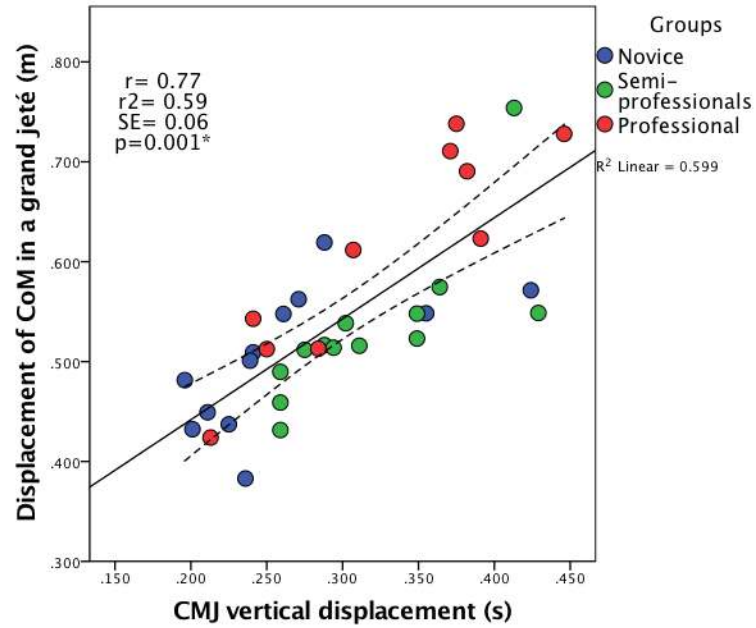
Figure 4. 3 Correlations between jump height (Displacement of CoM) during a *grand jeté* leap and vertical displacement during a (A) CMJ and (B) DJ for all participants (N=35).

Figure 4. 4 Correlations between jump height, displacements of centre of mass [CoM]) during a *jeté* leap and vertical displacement during a CMJ for each skill level group: (A) Novice, (B) Semi-professional and (C) professionals.
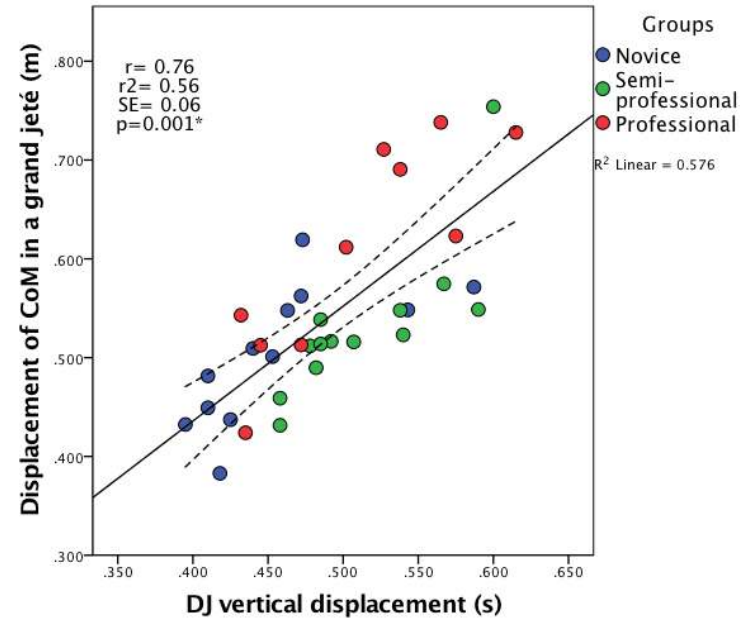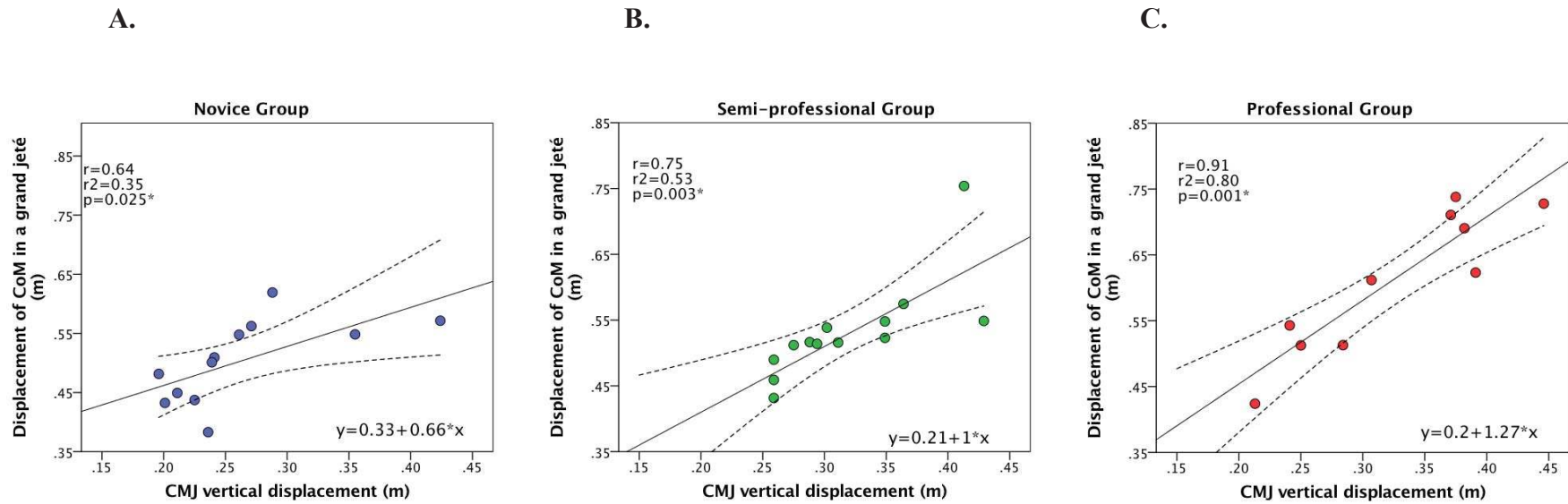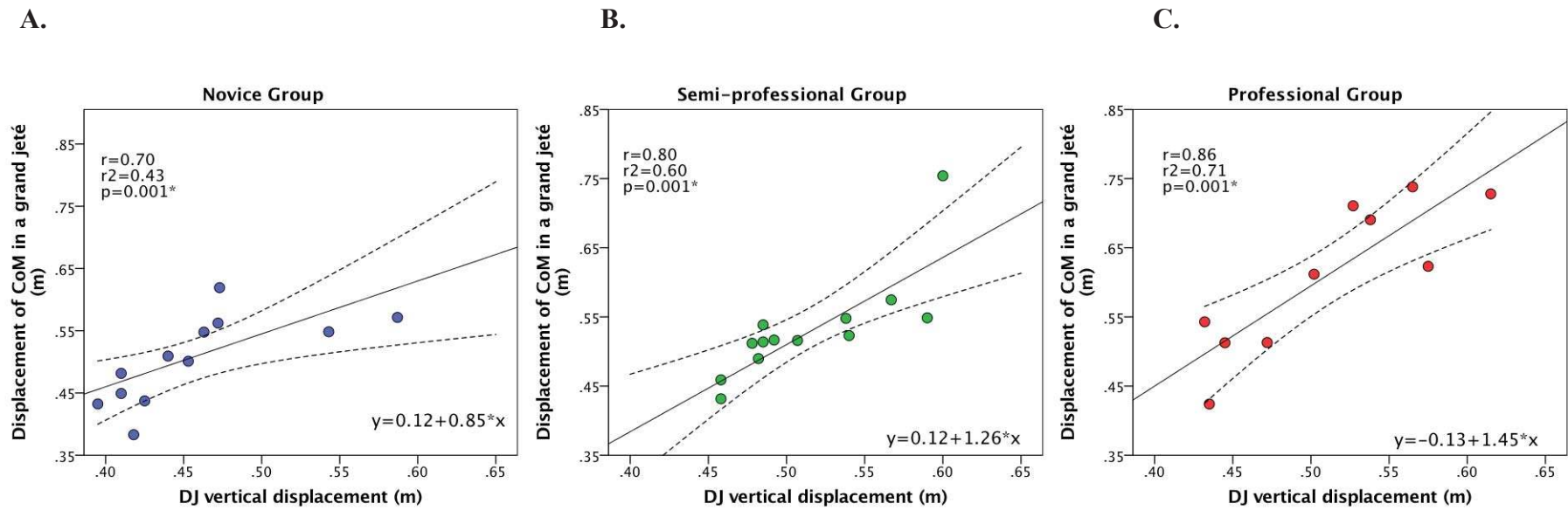
Figure 4. 5 Correlations between jump height displacement centre of mass [CoM]) during a *grand jeté* leap and vertical displacement during a DJ for each skill level group: (A) Novice, (B) Semi-professional and (C) professionals.

4.5 Discussion

This study examined the relationship between the displacement of the CoM in the *grand jeté leap* and two laboratory-based tests (CMJ and DJ). The primary findings of this investigation were that (a) CoM peak height in a *grand jeté* leap and vertical displacements in two laboratory based jumps (CMJ_{VD} and DJ_{VD}), demonstrated large to very large correlations, (b) the magnitude of the relationship between variables became stronger as the groups increased in skill level suggesting that the dancers ability to utilise their physical capacity to jump improves as the groups increase in levels..

Analysis of our results indicated significantly very large correlations ($r= 0.77$ and $r= 0.76$, $p< 0.05$ respectively) between the displacement of CoM in a specific ballet leap (*grand jeté*) and the CMJ_{VD} and DJ_{VD} across three different skill levels of ballet dancers. These very large associations between the *grand jeté* leap and the laboratory based jumps could be explained by the fact, that both procedures evaluate similar physical attributes, thus both jumping assessments could determine muscular power in dancers. Determination of muscular power in dancers could provide a quantitative insight of their jump capacity in their specific skill. Jumping ability is a fundamental skill of dance as often seen in classical and contemporary choreographies. In addition, jump ability is an integral part of dancers training which relies in lower limb muscular power for its proficiency (Walker, Nordin-Bates, & Redding, 2011). Even though there has been a paucity in studies determining lower body power by means of laboratory based jumps such as CMJ and DJ in ballet dancers, there has been previous investigations that provided evidence documenting that well trained power athletes possessing greater power outputs, greater ground reaction forces, high velocities and less contact time, consequently achieving greater vertical displacements in their jumps (Cormie, McBride, & McCaulley, 2009; Cronin & Hansen, 2005; McBride, Triplett-Mcbride, Davie, & Newton, 1999). Based upon these data it is possible that stronger more powerful dancers will exhibit a higher performance capacity in dance specific leaps such as the *grand jeté* and laboratory based vertical jump assessments.

When looking at studies performed in rhythmic gymnastics its has been shown that there are no differences in leaping and vertical jump performance between elite and sub-elite athletes (Di Cagno et al., 2008). In contrast to these data the current study suggests that there are significant differences in CMJ performance between different levels of dancers. One possible explanation for these findings may be related to the dancers fat free mass. Research by Di Cagno et al., (2009) suggests that there is a positive moderate relationship between the fat free mass of rhythmic gymnastics athletes and CMJ performance. In the present study there are significant fat free mass differences between the levels of dancers. Careful inspection of these data reveal that similar to the Di Cagno et al., (2009) study that the group that jumped the highest in the laboratory tests, also had the greatest fat free mass. Additionally, Di Cagno et al., (2009) reported a moderate relationship between fat free mass and leaping ability. However, when examining the data collected in the present study there were no significant differences and only a trivial effect between the displacements of the CoM between the groups for the *grand jeté* leap, even though there was a significant difference in fat free mass between the groups. One possible explanation for these findings may be related to the fact that elite dancers potentially posses a higher level of technical proficiency in dance specific leaping tasks and therefore are able to maximise leaping performance even though they tended to posses lower fat free-masses.

When examining the literature that has looked at CMJ and leaping tasks in rhythmic gymnasts there is no data reported which looks at the relationship between these two tasks. While Di Cagno et al., (2008, 2009) examine these measures they fail to report any data that explores how these two measures interrelate, making comparisons to the present study difficult. Furthermore, in the present study there was a large association between displacement of CoM in a g*rand jeté* leap*,* CMJ and DJ vertical displacements suggesting that these assessments possess similar movements patterns that could be transferable between tasks. These movements patterns that are ballistic in nature enable a vertical projection of the skeleton and they possess acceleration and deceleration aspects of the CMJ that closely could simulate jump movement components in a particular ballet skill such as the *grand jeté* leap (Cronin & Hansen, 2005; Lepelley et al., 2006).

While the large correlation in our data reveal that both specific and laboratory based jumps could possess similar movement patterns that could be transferable, it is also important to mention that physiological and mechanical forces could be interchangeable between two types of two jumps. For instance, the CMJ and DJ are characterized by a pre-eccentric contraction where potential energy is stored in the tendo-muscular components potentiating the jump (Komi, 2008). Similarly, in the *grand jeté* leap dancers execute a preparatory step preceding the taking off phase of the leap, hence utilizing the SSC in their specific skill to increase jump height. However, our data showed that displacements of CoM in a *grand jeté* leap were greater compared to the CMJ and DJ vertical displacement, especially in the professional group (CoM displacements in a *grand jeté* leap =0.59 ±0.1 vs. CMJ=0.30 ± 0.1 cm; DJ= 0.47±0.1 cm). It may be the case that professional dancers undergo longer hours of training and greater choreographic demands than the semi-professionals and novice groups. Therefore, performance improvements in the professional group could be a direct result of their specific training.

The second aim in the present study, questions the magnitude of the relationships between the *grand jeté* leap and the two laboratory based jumps within the three different skill ballet groups. Interestedly, results showed positive increases in the correlations within groups. Specifically the correlations increase from large to very large as the dancers skill level augmented, for both laboratory based jumps: CMJ and DJ (CMJ: novice r= 0.64; semi-professional r= 0.75 and professional r= 0.91; DJ: novice r= 0.70; semi-professional r=0.80; professional r= 0.86). Further, it was observed that the CMJ appeared to have a greater relationship to the *grand jeté* leap than the DJ for all groups (See Figures 4.3-4.5). These findings are also supported by results of the coefficient of determination (r^2, which indicated increasing explained variance as the groups augmented in skill (novice CMJ r^2 = 0.35, semi-professional CMJ r^2 = 0.53, professional CMJ r^2= 0.80; novice DJ r^2= 0.43, semi-professional DJ r^2 = 0.60, professional DJ r^2 = 0.71). CMJ and DJ are two laboratory based jumps, that are significantly influenced by athletes high relative force application, power generation and velocity production (Peterson, Alvar, & Rhea, 2006). Moreover, this observation is further supported by Sheppard et al., (2008), who compared factors affecting vertical jump performance in the seven best elite volleyball players compared

to the seven worst players. These elite athletes displayed greater power profiles, hence showing greater measurements of relative CMJ ($r= 0.93$; $p\leq 0.01$) and also a specific volleyball performance skill such as the spike jump ($r= 0.85$; $p\leq 0.01$). These results indicate that age and expertise could have an influence in specific jump ability, thus adequate strength and power training should be employed to improve those specific physical talents in jumping performance in dancers. However, it is important to mention that the observed large to very large correlations found in this study might vary when investigating other specific ballet leaps and laboratory tests, therefore future research including other types of ballet leaps is warranted.

The present investigation determined a linear regression equation to predict displacement of CoM in a *grand jeté* leap (See Figures 4.3 A-B). Our data showed that displacement of CoM in a *grand jeté* leap could be predicted by the use of CMJ$_{VD}$ and DJ$_{VD.}$. In addition, CMJ for the entire sample and within groups was the best predictor of CoM displacement in a *grand jeté* leap (CMJ $r=0.77$ vs. DJ $r=0.76$). In contrast, other investigations have reported moderate correlations between relative CMJ height and relative squat jump height to specific skill performance in rugby players ($r= -0.43$ to -0.66) (Cronin & Hansen, 2005). Particularly the relative CMJ showed weak relationships to three speed measurements in rugby players. Similarly, Sheppard and colleagues (2008), determine DJ ability as best contributors of a specific volleyball jump in elite athletes ($r= 0.92$; $r^2=0.84$). However, these findings have to be interpreted with caution because correlation and regression analysis could be specific to that particular population.

4.6 Conclusions

In conclusion a large strong correlation between a *grand jeté* leap and two laboratory based jumps was found in the three different skill level ballet dancers, therefore potential jump height during a specific skill may be assessed or predicted using simple laboratory based tests such as the CMJ or DJ. Further, it may be hypothesised that as ballet dancers improve in skill they subsequently can better utilise their physical capacities (lower body power) during skilled jumps such as the *grand jeté* leap. The findings of this study indicated that the CMJ and DJ might be used to

potentially monitor dancer lower limb power and predict maximal height during ballet specific jumps without the demands of costly equipment and expert personnel.

4.7 Practical Applications

Explosive aesthetics leaps are an integral part of ballet performance and should be successfully implemented in daily routines and monitor by coaches and dance teacher regularly. Traditionally ballet leaps have been studied using three-dimensional motion capture assessments. However, video analytical assessments are known to be very costly, and demand sophisticated instrumentation and trained personnel. Therefore, to assess training status or talent identification it may be useful to utilised a simple CMJ or a DJ assessment that may give evidence about the capacities that underlie dance specific leaps such as: ability to store elastic energy, ground reaction forces, high velocities, less contact time and training status. The results of the present study confirm that laboratory tests such as the CMJ and DJ may be used to assess specific ballet jump skill as they both provide information of CoM vertical displacement, muscular power and rapid force development, which in turn not only could increase dancers jump capacity but also could enhance their overall performance in the *grand jeté* movement.

CHAPTER FIVE   CONCLUSIONS

The purpose of this thesis was to firstly provide a cross-sectional comparison of selected physiological fitness parameters between novice, semi-professional and professional ballet dancers. In particular, body compositions variables such as BMD, BMC, BF%, LMM and neuromuscular characteristics including displacement of CoM in a specific ballet leap, CMJ_{PF}, CMJ_{VEL}, CMJ_{PP}, CMJ_{VD}, DJ_{PF}, DJ_{VD}, as well as anaerobic endurance. In addition, lower limb isometric variables were assessed comprising of lower limb isometric strength variables including IPF, rIPF, ASPF and RFD were also compared. Additionally this study sought to define which of those variables were the best discriminators between the different levels of ballet dancers groups. A secondary aim of this study was to investigate whether a relationship exists between the displacement of a *grand jeté* leap and two laboratory based jump assessments (i.e. CMJ and DJ). In addition, the magnitude of the relationship was examined to determine whether the ability to utilise dancers physical capacities such as lower body power during a specific ballet leap varies between skill levels.

The first study sought to establish selected physiological fitness parameters between three different skill levels of ballet dancers. Results showed that body compositions variables such as: BMD, BF% and LMM were significant different between the groups ($p<0.05$). Moreover analysis of neuromuscular characteristics in several jumping tasks established that CMJ_{PF}, CMJ_{PP}, CMJ_{VD} and DJ_{VD} were significantly different between the three groups ($p<0.05$). Unexpectedly, the professional group showed the lowest values in LMM and neuromuscular performance characteristics such as CMJ_{PF}, CMJ_{PP}, and DJ_{VD} compared to the novice and semi-professional dancers. Surprisingly, the professionals group also did not show the lowest values in BF% (even though they were still within the normal ranges) compared to the other two groups. These results suggest that low LMM and higher BF% may negatively influence their laboratory based jump performance. These findings add to our understanding of the literature that greater LMM and low BF% are directly related to muscular strength, and hence these body composition variables may significantly influence jump ability in ballet dancers. However, our sample showed normal ranges in BF% (17-19%), thus further investigations with a larger sample are warranted. In

addition, a comparison of lower limb isometric strength was performed between the three different levels of ballet dancers. Although the analysis did not show significant differences in dancers lower limb isometric strength variables, and also no discriminant variables were established, we found that rate of force development was approaching significance ($p=0.069$). This outcome indicates that muscular strength in ballet dancers should be further investigated; do to the fact that lower levels of muscular strength have been related to a greater risk of injury in this population.

The purpose of the second examination was to establish whether a relationship between a *grand jeté* leap and two laboratory tests (i.e. CMJ and DJ) existed. Outcomes from a correlation analysis indicated that a large strong correlation was found between the displacement of CoM in a *grand jeté* leap and the CMJ and DJ vertical displacements ($r=0.77$ and $r=0.76$ respectively). These findings could provide valuable information in regards jumping ability of ballet dancers, thus assisting ballet experts and dance instructors, to monitor progress in training and also used for talent identification. Additionally, it was determined that the magnitude of the relationship between the *grand jeté* leap and the two laboratory based jumps vertical displacement increased with increasing dance skill level. These results indicate that as ballet dancers improve in their dance specific skills they subsequently can translate their physical capacities (lower body power) during skilled jumps such as the *grand jeté* leap.

In summary the combination of these two studies provides information of ballet dancers body composition, neuromuscular characteristics particularly in the *grand jeté* leap, best describes differences between three different skill levels groups. Discriminant analysis showed that BMD and displacement of CoM in a *grand jeté* leap classified the skill level groups. Although lower limb strength characteristic was not found to be different in the analysis, it is suggested that dancers should develop this neuromuscular characteristic that is greatly link to jump ability. Additionally no significant differences were found in anaerobic endurance between the ballet groups. Consequently a strong correlation was found between a *grand jeté* leap and two laboratory tests, which propose that lower limb muscular power could be determined in ballet dancers, employing a specific CMJ and DJ. This outcome could be very

convenient to dance experts and dance schools without the demands of costly and sophisticated equipment such as the three-dimensional motion capture assessment.

CHAPTER SIX
LIMITATIONS AND FUTURE RESEARCH

There is a paucity of research establishing the physiological fitness parameters associated with ballet performance. Therefore, this study, aimed to examine three different skill levels of ballet dancers: novice, semi-professional and professional ballet dancers in order to better understand selected parameters such as body composition, neuromuscular characteristics and anaerobic endurance. This cross-sectional study and the supporting literature review serve as a resource for dance science experts and dance instructors, to identify significant factors that contribute to the enhancement of dance performance, dance training and also may be useful for talent identification. Based on the results and limitations from this study, recommendations for future research is going to be listed as it follows:

The findings and conclusions from study one **"*Comparison of body composition, neuromuscular characteristics and anaerobic endurance between novice, semi-professional and professional ballet dancers"*** are as it follows:

Significant differences between the ballet groups in body composition and neuromuscular characteristics (excluding isometric strength) were found. Specifically, the semi-professionals group showed the greatest BMD, LMM, while exhibiting the lowest BF% when compared to the other groups. Furthermore, when looking at neuromuscular characteristics the semi-professional dancers showed the highest CMJ_{PF}, CMJ_{PP}, CMJ_{VD} and DJ_{VD}. Surprisingly the professional dancers demonstrated the highest displacement of CoM in a *Grand Jeté* leap.

BMD and displacement of CoM in a *Grand Jeté* leap resulted the best discriminators variables for group membership between the three different skill level ballet groups. These findings suggest that both BMD and displacement of CoM in a *Grand Jeté* leap should be evaluated in young dancers in order to enhance their bone health and hence improve their skill ability.

However, the following limitations could have impacted the findings of this study including: Firstly, the lack of a homogenous sample, where the number of female and male participants were not divided evenly among the groups. Therefore, an assessment of female participants' specific physiological parameters such as menstrual status was not included. Secondly, the sample size for the professional group was the lowest compared to the other two groups due to a smaller pool of potential subjects and scheduling conflicts. The sample size was found to approach significance in the isometric strength and thus more test subjects could have impacted isometric strength measurements. Thirdly, the specific displacement of CoM in a *Grand Jeté* leap and RFD was also found to approach significance between the groups. This suggests that a larger sample size could have different outcomes. Lastly, the observed large to very large correlation observed between the *grand jeté* leap and the two laboratory based jumps might vary when analysing other ballet specific jumps.

In consideration of these limitations, future research should be undertaken to investigate the following topics: 1) Comparison of selected physiological fitness parameters between genders (particularly rank with in the professional groups) in three different levels of ballet dancers. 2) Effects of ballet training on: BMD, menstrual cycle and eating habits a longitudinal study. 3) Effects of irregular menstrual cycles on BMD and specific ballet skill in three different levels of ballet dancers. 4) Effects of 12 week supplementary strength training in BMD in three different skill levels of ballet dancers. 5) The difference in injury rates between different skill level groups of ballet dancers.

The results and conclusions from study two: ***"Do relationships exists between a grand jeté leap and two laboratory based jumps tests: CMJ and DJ?"*** determine a large strong positive correlation between a displacement of CoM in a g*rand jeté* leap and two laboratory based jumps (CMJ and DJ), in the three different skill levels of ballet dancers. This study also established a large to a very large correlation between these variables as the groups increased in skill level. However, when the displacement of CoM in a *gran jeté* leap was analysed, no other kinematics variables were compared in the model. Assessments of other kinematics variables such as: hip and knee angles at the peak of the jump, could provide more insight into the dancers ability to execute a

specific ballet jump. In addition, correlations between other specific ballet leaps besides the *grand jeté* and two laboratory based jumps are warranted, in order to develop a more comprehensive understanding of these relationships.

Therefore, future research should be undertake to investigate: Fistly, a comparison of kinematics characteristics such as knee and hip angles at the peak of CoM in a g*rand jeté* leap between three different levels of ballet dancers; and further investigations should be performed to establish the relationship between other specific ballet leaps and two laboratory based jumps.

While the present study has limitations and there is great scope for future research in this area, it is important to highlight that even though classical ballet dancers are performing athletes they are also challenged by their traditional training regimes and also by their rigorous body aesthetics. In contrast, it is comforting that developments in dance science research have established strategies to reduce injury, improve training and enhance ballet performance. These strategies have been possible with the examination of the selected physiological fitness parameters (particularly body composition and neuromuscular characteristics) of ballet dancers, which can differentiate the level of performance and overall skill level of dancers. In the present investigation it was found that BMD and displacement of CoM in a *grand jeté* leap act as the best discriminators between three different levels of ballet dancers. Therefore, it is recommended that young students and dance instructors acknowledge this information and incorporate the examination of those parameters into their schedules. In addition, ballet dancers should avoid behaviours that have a negative impact on their dance performance and overall health and wellness (i.e. poor eating habits, smoking and overtraining). Specifically, behaviours that could alter a young ballet student's bone structure later in life should be avoided. Furthermore, results from this investigation also revealed that the use of CMJ and DJ could be advantageous for dance experts to determine how dancers translate their physical capacity (lower body power) into dance specific jumping skills, without the high costs of specific equipment and trained personnel needed to perform a comprehensive biomechanical analysis of dance specific skills.

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APPENDIX A: Ethics Approval

8th February 2013

Mrs Penelope BLANCO OCHOA
36c Donar Street
INNALOO WA 6018

Dear Mrs Blanco Ocho9a,

I am pleased to write on behalf of the Higher Degrees Committee to advise that your master's research proposal has been approved – **Comparison of Physiological and Kinematics Characteristics Between Professional, Full Time and University Students.**

I also wish to confirm that your proposal complies with the provisions contained in the University's policy for the conduct of ethical research, and your application for ethics has been approved. Your ethics approval number is **8256** and the period of approval is:**6 February 2013 – 22nd November 2013.**

Approval is given for your supervisory team to consist of:

Principal Supervisor: Dr Guy Haff – ECU
Co-Principal Supervisor: Dr Sophia Nimphius – ECU

The examination requirements on completion are laid down in *Part VI of The University (Admissions, Enrolment and Academic progress) Rules for Courses Requiring the Submission of Theses* available at: http://ww.ecu.edu.au/GPPS/legal_legis/uni_rules.html

Additional information and documentation relating to the examination process can be found at the Graduate Research School website: http://research.ecu.edu.au/grs/

Please note: the Research Students and Scholarship Committee has resolved to restrict Master by Research (1 year) theses to a maximum of 40,000 words or a Master by Research (2 year) theses to a maximum of 60,000 words. Under special circumstances a candidate may seek approval from the Faculty Research and Higher Degrees Committee for an extension to the word length (RSSC 33/04).

I would like to take this opportunity to offer you our best wishes for your research and the development of your thesis.

Yours sincerely

Shelley Huts
Research Assessment Coordinator
Research Assessments- SSC

Principal Supervisor: Dr Guy Huff – ECU
Co-Principal Supervisor: Dr Sophia Nimphius - ECU
HDR   FCHS Information Office

APPENDIX B: Consent form

Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
January 22nd, 2013

CONSENT FORM

By signing this consent form, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

_____

I have read the information presented in the information letter about a study being conducted by Penelope Blanco of the School of Exercise and Health Sciences, at the Edith Cowan University. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted. I am aware that I may withdraw from the study without penalty at any time by advising the researchers of this decision.

This project has been reviewed by, and received ethics clearance through, the Office of Research Ethics at the Edith Cowan University. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact Sue McDonald,Research, Ethics Support Officer, at (08) 6304 5122
Email: research.ethics@ecu.edu.au

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.

_____

Print Name

_____

Signature of Participant

_____

Dated at Joondalup, WA.

Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
January 22nd, 2013

INFORMATION LETTER

Comparison of physiological and kinematic characteristics between full time, university students and professional ballet dancers

Principal Investigator: Penelope Blanco, ECU, School of Exercise and Health Sciences.
Primary Supervisor: Dr. G. Gregory Haff. ECU, School of Exercise and Health Sciences.
Co-Primary Supervisor: Dr. Sophia Nimphius. ECU, School of Exercise and Health Sciences.

The purpose of this study is to provide a cross-sectional comparison of the physiological characteristics between three levels of ballet dancers: full time students, university students and professionals. Specifically, measurements of: body composition, isometric lower limb strength, lower body explosiveness (countermovement jump) and anaerobic mechanical power test will be examined.

These findings will provide quantitative data to determine which of the physiological and kinematics variables are most significantly different between the groups.

Thirty-six dancers will be recruited to under go a series of non-invasive physiological and kinematics tests. The subjects will be divided in three groups of twelve dancers in each group. The entire test battery will be performed at ECU Joondalup campus.

The collected data will be coded with participant numbers (not names) and will be kept in a locked area for five years after publication. After this time, all paper copies will be shredded and computer disks erased. Average data will be presented in all publications, and if an individual participant's data are presented in a figure, names or any identifying information will not be included.

You may withdraw from the study at any time without penalty by verbally indicating this to the researcher. There are no known risks associated with participating in this study.

I would like to assure you that this study has been reviewed and received ethics clearance through the Office of Research Ethics of Edith Cowan University. However, the final decision about participation is yours. Should you have any comments or concerns resulting from your involvement in this study, please contact: Sue McDonald, Research Ethics Support Officer, at (08) 6304 5122
Email: research.ethics@ecu.edu.au

If you have any questions later or require additional information about the study, please feel free to contact either of the researchers

Penelope Blanco: 61 0430075781
Email: p.blanco@ecu.edu.au

Dr. Gregory Haff: (61 8) 6304 5416
Email: g.haff@ecu.edu.au

Dr. Sophia Nimphius: (61 8) 6304 5848
Email: s.nimphius@ecu.edu.au

Medical Questionnaire

The following questionnaire is designed to establish a background of your medical history, and identify any injury and/ or illness that may influence your testing and performance. If you are under 18 then a parent or guardian should complete the questionnaire on your behalf or check your answers and then sign in the appropriate section to verify that they are satisfied the answers to all questions are correct to the best of their knowledge.

Please answer all questions as accurately as possible, and if you are unsure about any thing please ask for clarification. All information provided is strictly confidential. If you answer "yes" to any non-exercise related question that may contraindicate you from completing a testing session, a clearance from a qualified medical practitioner may be required prior to participation.

Personal Details

Name:_____

Date of Birth (DD/MM/YYYY):_____   Gender: Female/ Male

Medical History

Have you ever had, or do you currently have any of the following?

If YES, please provide details

High or abnormal blood pressure	Y	N	_____
High cholesterol	Y	N	_____
Rheumatic fever	Y	N	_____
Heart abnormalities	Y	N	_____
Asthma	Y	N	_____

Diabetes	Y	N	_____
Epilepsy	Y	N	_____
Recurring back pain	Y	N	_____

If YES, please provide details

Recurring neck pain	Y	N	_____
Severe allergies	Y	N	_____
Any infectious diseases	Y	N	_____
Any neurological disorders	Y	N	_____
Any neuromuscular disorders	Y	N	_____
Are you currently taking medications? Y		N	_____
Have you had flu in the last two weeks? Y		N	_____
Have you recently injured yourself? Y		N	_____

Do you have any recurring muscle
or joint injuries?   Y   N   _____

Is there any other condition not previously
mentioned which may affect your ability to perform exercise?

                                      Y   N   _____

Lifestyle Habits

Do you exercise regularly?   Y   N
If YES, what do you do?

_____
_____

How many hours per week?
_____

Do you smoke tobacco?   Y   N
If YES, how much per day?
_____

Do you consume alcohol?   Y   N
If YES, how much per week?
_____

Do you consume tea or coffee?   Y   N
If YES, how many cups per day?
_____

Declaration (to be signed in the presence of the researcher)

I acknowledge that the information provided on this form, is to the best of my knowledge, a true and accurate indication of my current state of health.

Participant

Name:_____ Date (DD/MM/YYYY):_____

Signature:_____

Researcher

Name:_____ Date (DD/MM/YYYY):_____

Signature:_____

_____

Parent/ Guardian (only if applicable)

I, _____, as parent / guardian of Mr/ Ms _____, acknowledge that I have checked the answers provided to all questions in the medical questionnaire and verify that they are correct to the best of my knowledge.

Signature: _____

Date (DD/MM/YYYY): _____

Practitioner (only if applicable)

I, Dr _____ have read the medical questionnaire and information/ consent form provided to my patient Mr/Miss/

Ms_____, and clear him/ her medically for
involvement in exercise testing.

Date (DD/MM/YYYY):_____

Signature:_____

APPENDIX E: Kinematic Analysis: specific landmark measurements

For calibration purposes specific body measurements and body segments dimensions were taken, for each subject.

Table E.1 Body measurements

Measurements	Description
Body height	Ground to top of head when standing upright
Shoe size	Top of shoe nose to end of the heel
Arm span	Top of right finders to top of left fingers in T-pose
Hip height	Ground to most lateral bony prominence of greater trochanter
Knee height	Ground to lateral epicondyle on the femoral bone
Ankle height	Ground to distal tip of lateral malleolus
Hip width	Right to left anterior superior iliac spine
Shoulder width	Right to left distal tip of acromion

Table E.2. Specific body segments dimensions. The distances measured are from the anatomical landmarks to the middle of the top of the MTx sensors

Body segment	Description	Image
Thigh: upper leg	From upper leg MTX motion sensor to greater trochanter	
Shank: lower leg	From lower leg MTX motion sensor to medial femoral condyle	
Ankle: foot	From foot MTX motion sensor to medial malleolus	

APPENDIX F: Published and presented conference abstracts

P. Blanco, G.G. Haff, N. Hart, L. Seitz, T. Spiteri, J. Tufano and S. Nimphius (2014). *Bone; body composition and isometric rate of force development are associated in female ballet students and university ballet students*. Paper presented at the Australian Strength and Conditioning Conference, Melbourne, Victoria.

INTRODUCTION:

The relationship between bone parameters and muscular strength in athletes has been well established (1-2). The literature suggests that increases in mechanical loading and high magnitudes of ground reaction forces, could be beneficial for an athlete's physical characteristics and performance (3). Specifically, weight bearing activities increase characteristics of bone status such as: bone mineral density (BMD), bone mineral content (BMC) (4) bone strain stress index (SSI) and bone cross-sectional area, which is intrinsically associated with an athlete's body composition in parameters such as lean muscle mass (LMM) and body fat percentages (BF%) (5). In addition, previous studies have used BMD as a marker to determine bone health in athletes (6). Nevertheless, the results of markers of bone health in the population of female ballet dancers have been inconsistent (7).

For instance, Burckhardt et al. (8) investigated the effects of dance training and nutrition on BMD in adolescent female ballet dancers and concluded that dance training had a negative effect on young female dancers bone mineral density (BMD). This may be an issue with adolescent dancers, as measures of low BMD have been associated with low peak bone mass in adolescents, and an increased risk for stress fractures and bone disease such as osteoporosis (9). A possible reason for this population possessing a low BMD is that, most female ballet dancers strive to achieve a specific slim aesthetic physique by significantly decreasing their caloric intake. This could cause hormonal disturbances, which may affect their menstrual cycle and consequently alter bone and muscle formation (10). Conversely other investigations have established that dance training has positively improved bone and muscular strength, which is necessary for dancers to increase their jump ability and diminish risks for injury in the pelvis, leg and foot (11,12). In addition to this lack of consensus, few studies have assessed the relationship between bone characteristics and isometric

strength in different levels of dancers and to the author's knowledge a paucity of research exists evaluating ballet dancers bone strain-strain index (11).

PURPOSE

The purpose of this study was to determine the values and association of bone characteristics (BMD, BMC and SSI) with isometric strength in two different performance levels of ballet dancers.

METHODS:

Research design: This cross-sectional investigation was completed in one testing session at the strength laboratory and ECU Health and Wellness Institute at Edith Cowan University and was approved by the ECU Human Research Ethics Committee.

Subjects: Nineteen female classical ballet dancers (N=19) volunteered to participate in this study. Subjects provided their written informed consent to partake in this study, or if under eighteen years of age they provided assent in addition to parental consent. The subjects were divided by years of full time training: ten full time students from a prestigious professional ballet school (n=10), and nine university students from the ECU Western Australia Academy of Performing Arts (WAAPA) (n=9), (See table 1. for subject's demographics).

Procedure: Body composition measurements: BMD, Body fat %, BMC, and LMM of the subjects were assessed by means of dual energy x-ray absorptiometry whole body scan (DEXA; Hologic Discovery A, Waltham, MA) as previously described by Creighton et al. (6). Furthermore, measures of bone strength strain indices (SSI) on the subject's dominant lower limb, were obtained by means of peripheral computed quantitative tomography scan on the tibia bone (pQCT; Scanco Medical, Zurich, Switzerland) (11). To obtain quantified values of SSI (which indicate bone resistance to bending forces) the subjects underwent a four slice-screening program (at 4%, 16%, 32% and 66% from the distal end of the tibia).

Strength measurements: To determine lower limb muscular strength, subjects performed an isometric squat (IS) protocol, previously described and validated by McBride et al. (13). The IS was performed on top of a force plate (400 Series Performance Plate; Fitness technologies, Adelaide, South Australia, Australia) inside a

power cage with adjustable pins to determine the optimum IS position. Subjects were instructed to assume a squat position, feet hip width apart, under the immovable bar located at their shoulders. In addition the subjects were directed to push as hard and as fast as possible with maximal effort against the bar, holding the position for three seconds. Following familiarisation, the subjects completed three trials with a two-minute recovery between trials. Intra-class reliability was performed for the three trials see table 2. Force measurements were interfaced with computer software (Ballistic Measurement System; Fitness technology) to obtain quantified values of Isometric peak force (IPF). Moreover, IPF was normalized to body mass to establish relative isometric peak force (rIPF) and also an allometrically scaled isometric peak force (ASIPF) to obtain an index of muscular strength that is independent from body size (14). In addition rate of force development (RFD) was recorded.

Statistical analysis: Analysis of covariance ANCOVA was performed with a significance level set at $p < 0.05$ to determine if there was a significant difference between the ballet university student group and full time student group, in measures of: BF%, BMD, BMC, LMM, IPF, rIPF, ASIPF and RFD. In place of maturation, age was included as a covariate for skeletal maturation in the corrected model as all participants were beyond the age of menarche and therefore considered beyond the age at which large changes in skeletal maturity due to pubertal growth occur (15). A correlation analysis was also carried out to determine the strength of relationship between bone parameters and muscular strength by performing a Pearson Moment Correlation Coefficient. Correlation coefficient values (r) were interpreted as follows: r = 0.0 to 0.10 considered trivial, r =0.11 to 0.30 was considered small, r= 0.31 to 0.50 was considered to moderate, r= 0.51 to 0.70 was considered large, r = 0.71 to 0.90 was considered very large and, r = 0.91 to 1.0 was considered nearly perfect. (16). In addition calculation of Cohen's d effect size was calculated importing data to an excel spreadsheet (Microsoft Office Excel, Microsoft Office Professional Edition, Microsoft Corporation, 2007). Cohen's d effect size was interpreted using the followed magnitudes: ≤ 0.2 was considered small, 0.21 to 0.59 was considered moderate, 0.60 to 1.19 was considered large, 1.2 to 1.99 was considered very large, and >2 was considered nearly perfect. (16).

RESULTS:

The results (adjusted means followed the covariance analysis ± SD) are summarized in Table 3. Analysis of covariance ANCOVA indicated that variables of: LMM, BMD, BMC, rIPF, ASIPF, RFD, and SSI were significantly different between the university and the full time ballet students, $p \leq 0.05$ taking into account age as a maturity factor. Pearson Moment Correlation Coefficient showed a positive correlation between bone parameters and strength values. Specifically, BMD and RFD showed a moderate correlation (r=0.49); BMC and RFD showed a large correlation (r=0.62), SSI and IPF large correlation (r=0.69); SSI and RFD large (r=0.62). In addition, a moderate negative correlation between the dancer's bone SSI and their BF% (r=-0.47) was established. In addition a very large Cohen d effect size was determine in RFD and SSI.

DISCUSSION

The primary finding in this investigation is that bone characteristics (BMD, BMC and SSI) and the rIPF, ASIPF and RFD measures were found to be significantly different between the ballet university students and full time ballet students. The statistical analysis showed greater values of bone parameters and greater isometric strength measurements in the ballet university students ($p \leq 0.05$) even when age as a covariate was controlled. These findings may be attributed to the fact that ballet university students typically perform a larger volume of strength-type exercises at the ballet bar, before undertaking their rehearsal routine (17). In addition, full time ballet students expend larger periods of time listening to instructions and attempting to master specific skills, therefore decreasing their exercise intensity that could detriment their physical characteristics (18). Noteworthy, the BMC, BMD, TLM and SSI values found in the present study appear to be lower than those reported among other athletes (19). This might be explained by the fact that female ballet dancers often minimize their energy consumption whilst undergoing demanding training which has been shown to influence optimal bone mineral parameters (20). Furthermore, the present data also indicates that ballet university students demonstrated greater values in BMD than the full time ballet students (1.1 ± 0.6 g.cm^{-2} vs. 1.0 ± 0.1 g.cm^{-2}, p-value= 0.002). Typically, the effect of the accrual of BMC continues as one ages, which could partially explain differences between groups of differing ages. However, when age is used as a covariate the differences in BMC between the groups in the present study remained. Thus suggesting that something other than aging contributed to the

differences in BMC between the groups. The second finding of this study is based on results from correlation analysis, large positive correlation between tibial bone SSI with the strength measurements (SSI – IPF r= 0.690, and SSI – RFD r= =0.623) indicates the ability to generate force rapidly and isometrically may result in stronger bones. The pQCT scan was incorporated to calculate the SSI, which is determined by the size, shape and bone mineral density of the tibia. Bone SSI is a measure that represents subjects bone strength against a given load (21). Therefore greater values of SSI have a strong relationship with the ability to generate force in an isometric contraction (22). In this study, university ballet students were found with greater SSI measurements than the full time students (SSI= 2014.3 ± 300.0 vs. 1693.7 ± 297.5 mm^3). Therefore, by sustaining greater resistance against applied forces and greater lean muscle mass adaptations to muscle and bone, as a result of their training, may result in positive increases in bone characteristics and muscle strength measurements in ballet university students (rIPF = 31.6 ± 4.6 vs. 22.7 ± 5.4 N.kg^{-1}) but this should be confirmed by a controlled intervention study. Therefore, to ensure this association is indeed causation, the support is now present for future studies to perform longitudinal or experimental studies investigating this relationship in dancers.

CONCLUSIONS AND PRACTICAL APPLICATIONS

Lower limb strength measurements may be an alternative method used to assess bone health in ballet full time students and university students. More specific, variables of rIPF and RFD whilst performing an isometric squat may be predictors for bone characteristics (SSI, BMD and BMC) in young ballet dancers, therefore contributing to the prevention of bone diseases later in life. However, it is known additional factor could contribute or effect bone health (such as nutrition) and it is recommended this is also considered in conjunction with this testing. None the less, increasing ballet students lower limb strength may be beneficial to developing a high bone peak mass in adolescence, thus potentially preventing stress fractures during their career and osteoporosis following their career.

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Table 1. Subject's Demographics

	Students (n=10)			University (n=9)			*p*-value
Age (y)	16.7	±	1.5	20.2	±	1.6	0.001*
Weight (kg)	53.4	±	8.0	58.8	±	6.1	0.118
Height (m)	1.7	±	0.05	1.7	±	0.08	0.246
Years of training (y)	1.6	±	1.2	3.6	±	1.6	0.006*

Note: (*) Significant p-value ≤ 0.05 compared to female full time ballet students and university ballet students

Table 2. Isometric peak force and rate of force development reliability

Strength Measurements	ICC	Lower Confident Limit	Upper Confident Limit
Isometric Peak Force	0.96	0.92	0.98
Isometric Rate of Force Development	0.88	0.75	0.94

Table 3. Adjusted means followed the covariance analysis (ANCOVA) for body composition (BF%, LMM, BMD and SSI) and strength measurements (IPF, rIPF, ASIPF and RFD)

Variables	Students (n=10)		University (n=9)		p-value	η
Total body fat (%)	23.0	± 2.5	18.8	± 3.4	0.107	0.2
Lean muscle mass (kg)	41.0	± 5.4	43.2	± 4.6	0.043*	0.3
Bone mineral density (g.cm^{-2})	1.5	± 0.1	1.1	± 0.6	0.002*	0.5[†]
Bone mineral content (g)	2085.3	± 251.2	2190.0	± 195.3	0.004*	0.5[†]
Isometric peak force (N)	1285.8	± 310.0	1747.8	± 264.6	0.062	0.3
Relative isometric peak force (N.kg^{-1})	22.7	± 5.4	31.6	± 4.6	0.041*	0.3
Allometrically scaled relative isometric peak force (N.kg$^{-2/3}$)	86.8	± 19.6	120.2	± 16.7	0.044*	0.3
Rate of force development (N.sec^{-1})	2600.7	± 745.8	6685.0.	± 1973.5	0.001*	0.6[††]
Stress-strain index (mm^3)	1693.7	± 297.5	2014.3	± 300.0	0.027*	0.6[††]

Note: (*) Significant p-value ≤ 0.05 compared to female full time ballet students and university ballet students.
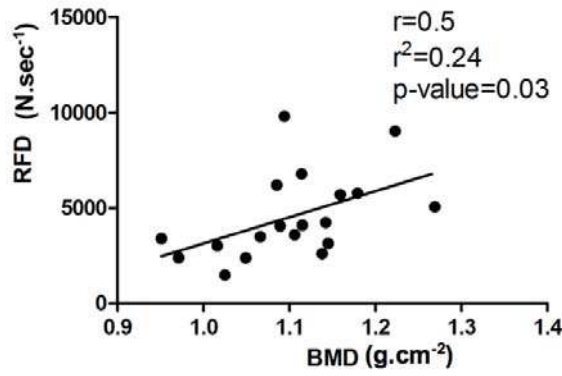
(†) Large effect size.

(††) Very large effect size.

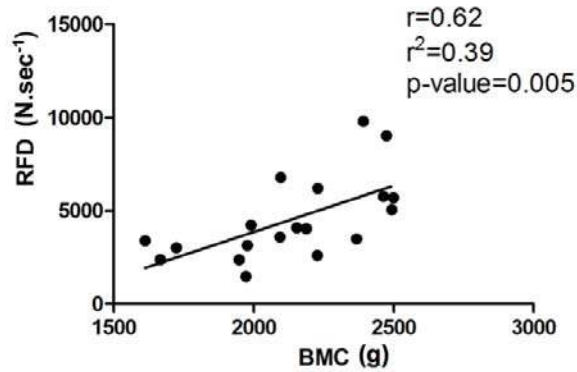**Figure 1.** Relationship between bone mineral density (BMD) and rate of force development (RFD).

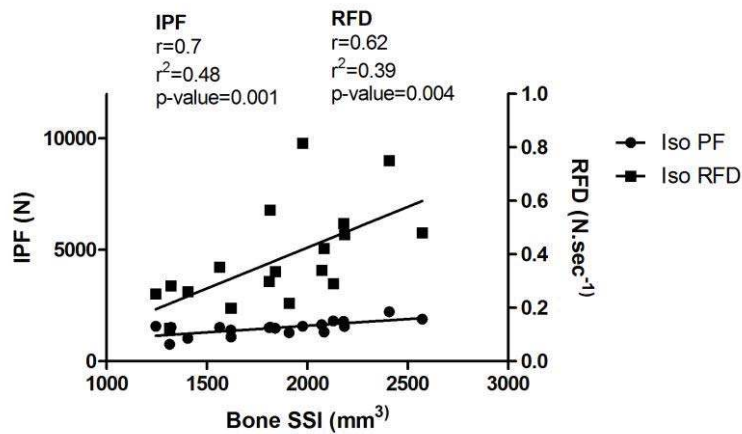**Figure 2.** Relationship between BMC and RFD

Figure 3. Relationship between strength strain index (SSI) and isometric peak force (iPF) and isometric rate of force development (iRFD).

APPENDIX G: ASCA Poster

BONE; BODY COMPOSITION AND ISOMETRIC RATE OF FORCE DEVELOPENT ARE ASSOCIATED IN FEMALE BALLET STUDENTS AND UNIVERSITY BALLET STUDENTS

P. Blanco, G.G. Haff, N. Hart, L. Seitz, T. Spiteri, J. Tufano and S. Nimphius,
Centre for Exercise and Sport Science Research

INTRODUCTION

The relationship between bone parameters and muscular strength in athletes has been well established (1-2). The literature suggests that increases in mechanical loading and high magnitudes of ground reaction forces, could be beneficial for an athlete's physical characteristics and performance (3). Specifically, weight bearing activities increase characteristics of bone status such as: bone mineral density (BMD), bone mineral content (BMC) (4), bone strain stress index (SSI) and bone cross-sectional area, which is intrinsically associated with an athlete's body composition in parameters such as lean muscle mass (LMM) and body fat percentages (BF%) (5). In addition, previous studies have used BMD as a marker to determine bone health in athletes (6). Nevertheless, the findings in the markers of bone health in the population of female ballet dancers have been inconsistent (7).

For instance, Burckhardt et al. (8) investigated the effects of dance training and nutrition on BMD in adolescent female ballet dancers and concluded that dance training had a negative effect on young female dancers bone mineral density (BMD). This may be an issue with adolescent dancers, as measures of low BMD have been associated with low peak bone mass in adolescents, and an increased risk for stress fractures and bone disease such as osteoporosis (9). A possible reason for this population possessing a low BMD is that, most female ballet dancers strive to achieve a specific slim aesthetic physique by significantly decreasing their caloric intake. This could cause hormonal disturbances, which may affect their menstrual cycle and consequently alter bone and muscle formation (10). Conversely, other investigations have established that dance training has positively improved bone and muscular strength, which is necessary for dancers to increase their jump ability and diminish risks for injury in the pelvis, leg and foot (11-12). In addition to this lack of consensus, few studies have assessed the relationship between bone characteristics and isometric strength in different levels of dancers and to the author's knowledge a paucity of research exists evaluating ballet dancers bone strain-strain index (11).

PURPOSE

The purpose of this study was to determine the values and association of bone characteristics (BMD, BMC and SSI) with isometric strength in two different performance levels of ballet dancers.

Table 1. Subject's Demographics

	Students (n=10)	University (n=9)	p-value
Age (y)	16.7 ± 1.5	20.2 ± 1.6	0.001*
Weight (kg)	53.4 ± 8.0	58.8 ± 6.1	0.118
Height (m)	1.7 ± 0.05	1.7 ± 0.08	0.246
Years of training (y)	1.6 ± 1.2	3.6 ± 1.6	0.006*

Note: (*) Significant p-value ≤ 0.05 compared to female full time ballet students and university ballet students

METHODS

<u>RESEARCH DESIGN:</u> This cross-sectional investigation was completed in one testing session at the strength laboratory at the ECU Health and Wellness Institute, Edith Cowan University and was approved by the ECU Human Research Ethics Committee.

<u>SUBJECTS:</u> Nineteen female classical ballet dancers (N=19) volunteered to participate in this study. Subjects provided their written informed consent to partake in this study, or if under eighteen years of age, they provided assent in addition to parental consent. The subjects were divided by years of full time training: ten full time students from a prestigious professional ballet school (n=10), and nine university students from the ECU Western Australia Academy of Performing Arts (WAAPA) (n=9), (See table 1. for subject's demographics).

<u>PROCEDURE:</u> Body composition measurements: BMD, Body fat %, BMC, and LMM of the subjects were assessed by means of dual energy x-ray absorptiometry whole body scan (DEXA; Hologic Discovery A, Waltham, MA) as previously described by Creighton et al. (6). Furthermore, measures of bone strength strain indices (SSI) on the subject's dominant lower limb, were obtained by means of peripheral computed quantitative tomography scan on the tibia bone (pQCT; Scanco Medical, Zurich, Switzerland) (11). To obtain quantified values of SSI (which indicate bone resistance to bending forces) the subjects underwent a four slice-screening program (at 4%, 16%, 32% and 66% from the distal end of the tibia).

<u>Strength measurements:</u> To determine lower limb muscular strength, subjects performed an isometric squat (IS) protocol, previously described and validated by McBride et al. (13). The IS was performed on top of a force plate (400 Series Performance Plate; Fitness technologies, Adelaide, South Australia, Australia) inside a power cage with adjustable pins to determine the optimum IS position. Subjects were instructed to assume a squat position, feet hip width apart, under the immovable bar located at their shoulders. In addition the subjects were directed to push as hard and as fast as possible with maximal effort against the bar, holding the position for three seconds. Following familiarisation, the subjects completed three trials with a two-minute recovery between trials. Force measurements were interfaced with computer software (Ballistic Measurement System; Fitness technology) to obtain quantified values of Isometric peak force (IPF). Moreover, IPF was normalized to body mass to establish relative isometric peak force (rIPF) and also an allometrically scaled isometric peak force (ASIPF) to obtain an index of muscular strength that is independent from body size (14). In addition rate of force development (RFD) was recorded.

<u>STATISTICAL ANALYSIS:</u> Analysis of covariance ANCOVA was performed with a significance level set at p <0.05 to determine if there was a significant difference between the ballet university student group and full time student group, in measures of: BF %, BMD, BMC, LMM, IS, IPF, rIPF, ASIPF and RFD. In place of maturation, age was included as a covariate for skeletal maturation in the corrected model as all participants were beyond the age of menarche and therefore considered beyond the age at which large changes in skeletal maturity due to pubertal growth occur (15). A correlation analysis was also carried out to determine the strength of relationship between bone parameters and muscular strength by performing a Pearson Moment Correlation Coefficient. Correlation coefficient values (r) were interpreted as follows: r = 0.0 to 0.10 considered trivial, r =0.11 to 0.30 was considered small, r= 0.31 to 0.50 was considered moderate, r= 0.51 to 0.70 was considered large, r = 0.71 to 0.90 was considered very large and, r = 0.91 to 1.0 was considered nearly perfect. (16). In addition calculation of Cohen's d effect size was calculated and interpreted using the followed magnitudes: ≤ 0.2 was considered small, 0.21 to 0.59 was considered moderate, 0.60 to 1.19 was considered large, 1.2 to 1.99 was considered very large, and >2 was considered nearly perfect. (16).

RESULTS

Table 2. Body composition measurements (TBM, BF%, TLM, BMD and SSI) and strength measurements (IPF, rIPF, ASIPF and RFD)

	Students (n=10)	University (n=9)	p-value	Effect size
Total body fat (%)	23.0 ± 2.5	18.8 ± 3.4	0.107	0.2
Lean muscle mass (kg)	41.0 ± 5.4	43.2 ± 4.6	0.043*	0.3
Bone mineral density (g.cm⁻²)	1.5 ± 0.1	1.1 ± 0.6	0.002*	0.5†
Bone mineral content (g)	2085.3 ± 251.2	2190.0 ± 195.3	0.004*	0.5†
Isometric peak force (N)	1285.8 ± 310.0	1747.8 ± 264.6	0.062	0.3
Relative isometric peak force (N.kg⁻¹)	22.7 ± 5.4	31.6 ± 4.6	0.041*	0.3
Allometrically scaled relative isometric peak force (N.kg⁻²/³)	86.8 ± 19.6	120.2 ± 16.7	0.044*	0.3
Rate of force development (N.sec⁻¹)	2600.7 ± 745.8	6685.0 ± 1973.5	0.001*	0.6††
Stress-strain index (mm³)	1693.7 ± 297.5	2014.3 ± 300.0	0.027*	0.6††

Note: (*) Significant p-value ≤ 0.05 compared to female full time ballet students and university ballet students. (†) Large effect size. (††) very large effect size.
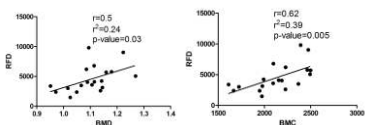

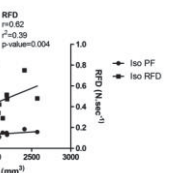**Figure 1.** Relationship between bone mineral density and rate of force development

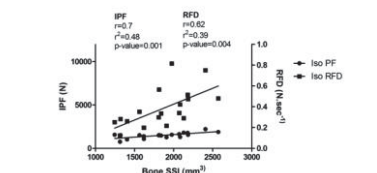**Figure 2.** Relationship between bone mineral content and rate of force development

Figure 3. Relationship between strength strain index (SSI) and isometric peak force (iPF) and rate of force development (RFD).

CONCLUSIONS AND PRACTICAL APPLICATIONS

In the present study, bone characteristics and strength measurements were found significant different between the two different levels of ballet groups (university and students) despite the fact that age was integrated as a covariant. These differences could be attributed to their training status. In addition, dancers that possessed greater SSI values demonstrated greater strength measurements. Therefore, lower limb strength measurements may be an alternative method used to assess bone health in ballet full time students and university students. More specificly, variables of rIPF and RFD whilst performing an IS may be predictors for bone characteristics (SSI, BMD and BMC) in young ballet dancers, contributing to the prevention of bone diseases later in life. However, it is known that additional factor such as nutrition, could contribute or affect bone health and is recommended that is included in the testing. Nonetheless, increasing ballet students lower limb strength may be beneficial to developing a high bone peak mass in adolescence, thus potentially preventing stress fractures during their career and osteoporosis following their career.

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APPENDIX E: ECU Research Week Poster 2013

BONE MINERAL DENSITY, CONTENT AND ISOMETRIC PEAK FORCE ARE ASSOCIATED IN VARIOUS LEVEL BALLET DANCERS

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Table 1 Subject's Demographics

	Students	University	Professionals	p value
Number of Subjects (n)	12	13	10	
Age (y)	16.6 ± 1.5*	20.0 ± 1.6	23.8 ± 3.5	0.001
Weight (kg)	58.0 ± 13.0	64.1 ± 10.5	63.3 ± 14.7	0.428
Height (m)	1.67 ± 0.09	1.73 ± 0.09	1.75 ± 1.22	0.155
Years of training (y)	1.4 ± 1.1*	3.4 ± 1.4	7.2 ± 2.4	0.001

Table 2. Age, LBM, BF%, BMC, BMD, RFD, IPF, years of training in the three different age groups of ballet dancers.

	Students	University	Professionals	One Way ANOVA p value
LBM (kg)	43.9% ± 11.7	50.8% ± 10.5	49.6% ± 13.2	0.313
BF%	21.1% ± 4.0	17.1% ± 4.8	18.6% ± 3.9	0.078
BMC (kg)	2.14% ± 0.45*	2.54% ± 0.41	2.65% ± 0.65	0.053*
BMD g/cm.cm	1.08% ± 0.08*	1.18% ± 0.07	1.19% ± 0.12	0.011*
RFD	4143.1% ± 3334.1	6714.0% ± 1838.5	6069.0% ± 2681.4	0.060
IPF	1531.8% ± 623.3	1798.6% ± 818.8	1909.7% ± 537.4	0.152
BSS index	1950.5% ± 815.3	2599.7% ± 896.7	2708.9% ± 933.9	0.097

Notes *= Significant p-value < 0.05 compared to university students and professionals ballet dancers

ABSTRACT To achieve excellence in dance performance, avoid injury reoccurrence, and increased career longevity, dancers must possess great artistry and exceptional physiological characteristics. Previous studies have determine the relationship between bone health and injury occurrence, however little research has investigated the effect of bone health in ballet dancers across the levels of performance. This cross-sectional study investigated the relationship between physiological characteristics such as bone mineral density (BMD) and bone mineral content (BMC) and measures in physical capacity as quantified by rate of force development (RFD) and isometric peak force (IPF) during an isometric squat. Further, this study determined whether there was a significant difference between groups in BMD, BMC, RFD and IPF. METHODS: A total of thirty-five classical ballet dancers volunteer for this study. The dancers were divided by different performance levels into three groups. First group consisted of 12 full time students (Age: 16.7 ± 1.5 y; weight: 58.0 ± 13.1 kg; years of training full time: 1.4 ± 1.1 y). Second group comprised of 13 university ballet students (Age: 20.4 ± 1.6 y; weight: 63.8 ± 10.5 kg; years of training full time: 3.4 ± 1.4 y). And third group contained 10 professional dancers (Age: 23.8± 3.5 y; weight: 63.3 ± 14.7 kg; years of training full time: 7.2 ± 2.4 y). For each group BMD and BMC were determined by means of dual energy x-ray absorptiometry scans (DEXA; Hologic Discovery A, Waltham, MA), followed by completion of three trials of isometric squats while standing on a force platform (400 Series Performance Plate; Fitness technologies, Adelaide, South Australia, Australia), with two min of rest between trials, to establish their lower limb strength as measured by the variables of RFD and IPF. RESULTS: There was a significant difference between the BMC and BMD between the groups (p=0.053 and p=0.011 respectively). In addition, the results showed a large significant correlation between BMC and BMD with IPF values (r=0.771 and r=0.636 respectively). Furthermore, the outcomes showed as well, a large significant correlation between BMC and BMD with RFD scores (r=0.719 and r=0.640 respectively). CONCLUSIONS: Ballet dancers demonstrated to sustained a positive relationship between their strength values and their BMC and BMD scores. Even though no statistical differences where found in IPF scores between the groups, there was a significant statistical trend found in the RFD between the groups (p=0.060) more specifically differences in the full time students group compared with the university group (p=0.066).

INTRODUCTION: The relationship between body composition and isometric strength in athletes has been previously investigated [1]. The literature suggests that increases in mechanical loading in the bone and muscle, results in an augmentation of BMD, BMC, bone strength (BS) and lean muscle mass (LMM) in young athletes. Nevertheless the results of these adaptations in the population of ballet dancers are inconsistent [2]. In young classical ballet dancers body composition is related to BMD and BS. In addition, factors such as the female triad where there is a combination of: menstrual disturbances, low body mass and low body fat percentages, often present in the young dancers, interfere with the increases in BMD, BMC, BS and LMM [3]. Therefore, the purpose of this study is to assess whether BMD, BMC and BS are associated to isometric strength in three different age groups of ballet dancers.

METHODS: SUBJECTS: Thirty-five classical ballet dancers volunteer to participate in this study. The subjects were divided by years of full time training: 12 full time students, 13 University students and 10 professionals dancers (table 1. for subject's demographics). Ethics approval was granted by the ECU ethics committee on February 2013.
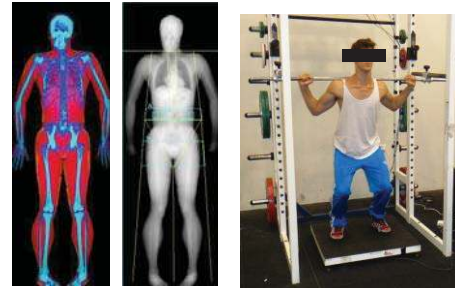
Figure 1. Images from the DEXA scans and isometric squat performed by a professional ballet dancer.

PROCEDURE: Body compositions, more specific values of BMD, Body fat %, BMC, and LMM of the dancers was assessed by means of dual energy x-ray absorptiometry scans (DEXA; Hologic Discovery A, Waltham, MA) [4] In addition, measures of bone strength strain indices (BSS) on dominant limb where obtained, by means of peripheral computed tomography scans on the tibia bone (pQCT; Scano Medical, Zurich, Switzerland) [5]. To determine dancers lower limb strength, an isometric squat (IS) protocol previously described by Hart et al., [6] was implemented. The IS was performed on top of a force plate (400 Series Performance Plate; Fitness technologies, Adelaide, South Australia, Australia) inside a power rack with adjustable pins to determine the optimum IS position. Following familiarization, the subjects completed three trials with sufficient two min recovery time between trials. Isometric peak force (IPF) and rate of force development (RFD) was recorded.
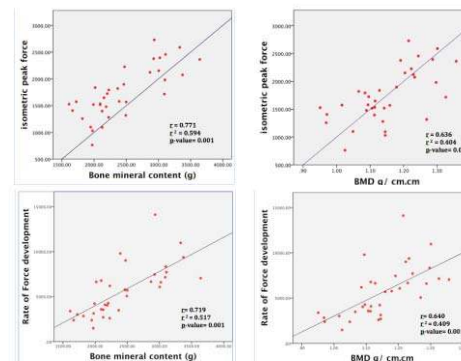
STATISTICAL ANALYSIS: A one- way ANOVA at alpha level of p <0.05 was performed to determine if they were significant differences between LBM, BF%, BMC, BMD, RFD, IPF and BSS index between the three groups. If a significant F value was found a Bonferroni Post-Hoc test was performed in order control for type I error. Furthermore to determine the relationship between BMD and BMC with IPF and RFD a Pearson Moment correlation was applied.

RESULTS: The results (mean ± SD) are summarised in table 2. There was a significant difference (p<0.05) between the dancers for age, BMC, BMD and training years. There was a very large significant correlation (r=0.771, p<0.05) between the BMC and IPF (Figure 2). In addition there was a larger significant correlation (r=0.636, p<0.05) between BMD and IPF. More over correlation between BMC and BMD and RFD showed large significant correlation as well. (r= 0.719, p<0.05 and r= 0.640 p<0.05 respectively).

CONCLUSIONS: There is a significant difference between the BMC and BMD between the fulltime students and university and professional ballet dancers. These differences could be attributed to their training status. In addition, dancers that possess high isometric strength levels tend to demonstrate optimal BMC and BMD values.

PRACTICAL APPLICATIONS: Lower limb strength could be used to assess bone health in ballet dancers. In addition it could contribute to determine whether dancers with low BMC and low BMC are at greater risk to develop osteoporosis later in life.

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