THE EFFECTS OF A TRAINING INTERVENTION ON STRENGTH, POWER AND PERFORMANCE IN ADOLESCENT DANCERS

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A thesis submitted to Auckland University of Technology in partial fulfilment of the requirements for the degree of Master of Sport and Exercise Science (MSpEx)

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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made.

This thesis fulfils the Auckland University of Technology Master of Sport and Exercise Science guidelines by constructively critiquing previous literature and investigating the effects of strength training upon strength, power, dynamic stability and dance performance.

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ETHICAL APPROVAL

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC). The AUTEC reference was 14/138, with approval granted on the 26th of May 2014 (Appendix 2).

ABSTRACT

There is little previous research that has investigated the effects of strength training on dancers. Therefore, the main purpose of this thesis was to determine if a nine week strength training intervention could have a significant effect on strength, power, dynamic stability and dance performance. A secondary objective was to explore the relationship between these physiological components and dance performance. Eighteen female dancers trained in jazz, ballet and/or contemporary, with five or more years' experience were recruited from local dance schools and assigned to a strength training (n = 12) or control (n = 6) group. Anthropometry (height, seated height, mass, skinfolds), subjective dancing ability, dynamic stability (eyes open (EO), eyes closed (EC)), strength (isometric mid-thigh pull) and power (vertical countermovement jump, squat jump, single leg countermovement jump) were assessed before and after the nine week intervention period. The training group significantly increased EO overall stability (p = 0.003), EO anterior-posterior stability (p = 0.003), EC overall stability (p = 0.050), strength (p = 0.001), power (p = 0.021), dancing ability (p = 0.008) and technique (p = 0.001). The control group also experienced a significant increase in strength (p = 0.006), power (p = 0.031) and relative power (p = 0.037). Post intervention the between group analysis revealed a significant difference in EO overall stability (p = 0.008), EC overall stability (p = 0.031), EC anterior-posterior stability (p = 0.021) and technical ability (p = 0.029). A significant correlation was observed between measurements of strength and dance performance (r = 0.48; p = 0.042). Several measurements of power were also significantly associated with dancing and technical ability. This study demonstrated that strength training can have a significant effect on dynamic stability indices and dancing performance, and that strength and power may be strongly associated with a dancer's ability. The findings also suggest that incorporating strength training may enhance strength and power adaptations in this population.

Key Words: DANCE, PERFORMANCE, STRENGTH, POWER, STABILITY

CHAPTER 1

INTRODUCTION

Background

The exceptional physical prowess required by dancers to successfully master technical aspects, be flexible, strong, lean, powerful and able to efficiently maintain balance (Rafferty, 2010) has established a dancer as the embodiment of an artist and an athlete. Dancers have a tendency to perceive themselves as more of an artist than an athlete and therefore spend a great amount of time focusing on skill acquisition from a young age (Allen & Wyon, 2008). Skill acquisition has traditionally been taught during a formal dance class, which is believed to sufficiently provide technical, physical and aesthetic components. Contrary to this belief, previous research has found that dancers possess fitness levels comparable to sedentary persons of a similar age (Rafferty, 2010), present only 77 % of the weight predicted strength norms (Jamurtas & Koutedakis, 2004), and commonly display weakness about the knee joint and muscular imbalances (Hamilton, Hamilton, Marshall, & Molnar, 1992). Muscular imbalances can lead to malalignment, which has been associated with an increased risk of lower extremity overuse injury (Bowerman, Bradshaw, Harris, & Whatman, 2014). These cardiorespiratory and musculoskeletal deficiencies most likely develop because of early specialisation and bias towards dance specific skill acquisition. As a young athlete, emphasis should be placed upon fundamental skill acquisition, base strength and conditioning, before specialisation (Balyi & Hamilton, 2004). Consequently dancers are more prone to injury and may not be maximising their potential (Brown, Fehling, Schade, Smith, & Wells, 2007).

Previous research has identified upper body muscular endurance and jumping ability to be the best predictors of dance performance (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2009b). Therefore, significant improvements in these physical parameters should develop the aesthetic competence of dancers. Brown et al. (2007) implemented an intervention in strength, power and aesthetic dancing ability in female collegiate dancers. These authors investigated the effects of a plyometric or weight training program and assessed aesthetic jumping ability via subjective evaluation. Results showed significant improvements in strength, power and aesthetic jumping ability post-intervention for the assigned training groups but no change in the control. Noble, Stalder, and Wilkinson (1990) also identified that the inclusion of a specific weight training protocol produced significant improvements in movement precision and overall ballet performance. Cumulatively, these studies indicate that utilising supplementary training methods can improve a dancer's aesthetic appeal.

Based on previous research it appears that supplementary training is necessary to develop a dancer's physical capacity. Giakas et al. (2007) investigated the effects of a three month aerobic and strength training intervention. Results demonstrated a significant increase in VO_2max, flexibility and leg strength in the exercise group and although the control group met the entire dance curriculum over the twelve week period, they failed to show any strength or cardiovascular improvement. This could be attributed to suboptimal loading of the neuromuscular system, detraining or overtraining, indicating that ballet training alone may provide insufficient overload and be inappropriately prescribed. Supporting studies have found that dance class and rehearsal insufficiently stress the muscular structures and energy systems to meet the demands of physical performance, which will impact the rate of fatigue and skilled motor patterns during performance (Batson, 2013). Fatigue can affect the technical execution of key skills and may result in inefficient biomechanics, and increase the stress placed on muscles and joints (Angioi et al., 2010). Chronically this could compromise tissues, cause performance decrements, impose psychological effects and potentially cause or develop persistent injury (Murgia, 2013).

Several authors have advocated the importance of supplementary strength and power training and its desirable effects upon dance performance (Angioi, Koutedakis, Metsios, & Wyon, 2009a; Jamurtas & Koutedakis, 2004; Rafferty, 2010). The findings also suggest that there is very little scientific evidence available to support the claims within dance circles that supplementary training would have a negative effect upon a dancer's artistic ability and aesthetic appeal. Jamurtas and Koutedakis (2004) stated that current data suggested that an improvement in strength would enhance a muscles ability to generate force and thus develop performance. Supportively, profiling of ballerina's by seniority has identified that higher ranking dancers are able to jump significantly higher (Allen et al., 2007) and are characterised by increased muscular strength (Jamurtas & Koutedakis, 2004). These findings highlight the importance of strength to aspiring ballerinas and the ongoing development of performance determinants.

Although dancers require exceptional physical competence, strength and conditioning principles are poorly understood and underutilised within the dancing community. This disproportionate focus on skill acquisition (Allen & Wyon, 2008) may be providing inadequate overload to enhance the physiological components of dance performance (Brown et al., 2007; Giakas et al., 2007; Noble et al., 1990). Prior research found significant changes in measurements of strength, power, aerobic capacity and dancing ability post intervention for the assigned training groups only, confirming that the dance-only training method may not provide sufficient stress to stimulate adaptation. Furthermore the improvement in dancing ability contradicts claims within dance circles that supplementary training would have a negative effect upon a dancer's artistic ability and aesthetic appeal. Further research investigating the effects of strength training on dance performance is necessary to reinforce previous findings and encourage dancers, teachers and school principles to include supplementary training into their curriculum.

Significance of the Thesis

There is little research that has investigated the effects of strength training in dancers and no known literature that has looked into the effects with adolescent performers. Accordingly, this thesis aims to determine the effects of strength training on adolescent dancers and provide an applicable training method that can be easily integrated into a dancer's curriculum. These investigations are essential to increasing the understanding of how strength training effects this population and justifying its importance to help motivate dancers to include alternative training methods. Integrating strength and conditioning training techniques is crucial to bridging the physiological gap between training and performance demands, rectifying musculoskeletal deficiencies, and developing fundamental aspects of performance such as improving jumping ability.

Research Questions

The overall question of this thesis was “can a strength training intervention have a positive effect upon dance performance?”

Specific questions were:

1. Can a nine week training intervention have a significant effect on measurements of strength, power and dynamic stability in adolescent dancers’?
2. Is there a relationship between strength, power, dynamic stability and performance in adolescent dancers’?

CHAPTER 2

LITERATURE REVIEW

Literature Search

To obtain articles a search of Sport Discus, Google Scholar, Medline, Scopus and the Journal of Dance Medicine and Science was conducted. The key terms searched as separate words or in conjunction included; "dance", "ballet", "contemporary", "jazz", "resistance", "strength", "plyometric", "power", "flexibility", "genre", "style", "center of pressure", "cardiovascular", "aerobic", "anaerobic", "balance", "coordination", "training", "performance", "effect of", "physiological", "biomechanics", "components" "range of motion", "kinematic", "kinetic", "plié", "relevé", "grand jeté", "stability" and "posture". The reference lists of all retrieved articles were manually checked for additional studies. Exclusion criteria included: (1) unavailable in English and in full text; (2) the article was not in a peer reviewed journal or full conference preceding; (3) did not relate specifically to adolescent athletes, dancers or sports with similar demands.

Seven published studies specifically focused on the effects of resistance training on dancers from various disciplines were retained for review after applying the exclusion criteria. Due to the very small number of interventional studies in this age group, studies with older dancers were also included. Of the studies reviewed six were conducted on female dancers between the ages of eighteen to twenty-five, one study was conducted on both male and female dancers and one investigated the effects on female rhythmic gymnasts between ten and thirteen years. Additional literature investigating biomechanical aspects, musculoskeletal and cardiorespiratory characteristics, sensory systems, growth and development was also obtained for analysis.

Biomechanical Research in Dance

Understanding the biomechanics of specific dance movements is necessary to examine traditional theoretical models and movement metaphors (Evans et al., 2001). Dance scientists are aware that there are some traditional misconceptions and drawbacks, which may impact a dancer's ability and increase their susceptibility to injury. The development of more sophisticated biomechanical analysis techniques including electromyography (EMG) technology, force plate and video analysis have the potential to determine the effectiveness of traditional training techniques. Furthermore, such technological advancements and empirical measurement of traditional training techniques is necessary to ensure safe and effective teaching of various dance styles.

EMG technology permits more reliable documentation and description of muscular activity during skilled movement patterns, and has recently been used to investigate movements including the développé devant, relevé and demi plié (Costa et al., 2004; De Luca et al., 1994; Evans et al., 2001). The développé devant is one of the more complex movements practiced in a ballet class. This complex skill requires the dancer to stand unipedal, slide their gesture foot up their standing leg through cou-de-pied, retiré, and attitude positions before extending their leg. Evans et al. (2001) investigated the EMG activity of the vastus lateralis obliquus and hamstrings of the gesture leg, and the tibialis anterior and abductor hallucis muscles of the standing leg. The results showed that there were significant differences in the EMG activity of the vastus lateralis obliquus, hamstrings, tibialis anterior and abductor hallucis when performed in the centre without external support compared to the barre. The barre is a support device used during the warm-up to practice the techniques of ballet and is believed to positively transfer skills to the center. However the significantly greater EMG amplitudes of the tibialis anterior and abductor hallucis indicate that these muscles are more highly involved in counteracting the anterior movement of the gesture leg to maintain an upright stance when in center and that extensive training at the barre may not be the most effective approach. Although it is highly unlikely this traditional approach will ever be removed these authors highlight the limitations of customary methods and that the dependence upon this external support should be minimised.

EMG analysis can also be used to better understand position specific muscular activity. It is known that during the rise to point the primary and secondary plantarflexors activity is greatest (Donaldson-Fletcher, Falicov, Kadel, Orendurff, & Segal, 2004) but until recently it was not clearly understood how this muscular activity is affected by the various foot positions ballet utilise. Costa et al. (2004) found that the medial gastrocnemius was more active during relevé in first position (feet point in opposite directions, with heels touching) than sixth (parallel feet), in sixth position the abductor hallucis also exerted greater activity and when the foot was allowed to pronate in first position the peroneus longus and gastrocnemius presented their highest EMG activity. Because maintaining relevé requires increased muscular effort and articular load, it is important to keep the supporting structures strong so the dancer can efficiently maintain stability and avoid injury. Using biomechanical analysis can help practitioners to better understand the position specific implications, which could provide valuable information for pre-habilitation and rehabilitation approaches.

A plié is the foundation of all ballet movements, thus gaining a better understanding of the muscular activity during this movement and the variation between dancing styles could enhance training practices. De Luca et al. (1994) recruited twelve dancers to compare the EMG activity of a demi-plié between ballerinas and modern dancers'. During standing repetitions the EMG activity of the medial gastrocnemius and the tibialis anterior was significantly greater in modern dancers and ballerinas, correspondingly. Throughout the mid-cycle phase (bottom of the lowering phase when the hips and knees are at maximum flexion) the lateral gastrocnemius, gluteus maximus and adductor EMG activity was significantly higher in ballerinas. Additionally, during the rising phase significantly greater EMG activity was detected by the medial gastrocnemius and gluteal maximus in ballerinas. These discrepancies may be the result of differences in training and dance styles. For example the greater turnout required by ballerinas may increase their postural sway and cause compensatory activation in the posterior and anterior muscles (De Luca et al., 1994). The EMG data also highlights some inaccurate traditional beliefs; conventionally it was believed that the adductor muscles were active during rise to maintain turnout and stability, but in reality there was no activity for 42 % of the rising phase. Sports scientists have long been aware that the adductors internally rotate the hip and adduct the leg, which does not occur during a plié. These findings suggest that there are significantly different demands between dance styles and that certain muscle groups may be incorrectly emphasized during dance training. It is important to understand the discrepancy between dance styles to ensure the specific needs of each dancer is accounted for correctly. Furthermore, incorrect prescription could exaggerate any musculoskeletal deficiencies and lead to compensatory biomechanics, which could predispose a dancer to injury (De Luca et al., 1994).

Ballet, jazz and contemporary movements frequently require full plantar and dorsiflexion, which can lead to exaggerated flexibility, instability and potential musculoskeletal problems about the ankle (Hamilton et al., 1992; Lin, Su, & Wu, 2005). Curl, Hoen, Hunter, Martin, and Wiesler (1996) found that plantarflexion in female and male ballet dancers ranged from 96.0 ± 2.7° to 101.0 ± 2.5° and dorsiflexion ranged from 62.0 ± 6.1° to 78.0 ± 2.3°, correspondingly. To support these above normal flexibility values (Hamilton et al., 1992) ligaments lie medially, laterally, posteriorly and superiorly around the ankle. During movement these ligaments are constantly changing orientation and tension (Koutedakis, McEwan, Russell, & Wyon, 2008). Previous research has found that during a demi-plié and en pointé that stabilisation is achieved primarily by the calcaneofibular ligament and anterior talofibular ligament, respectively (Makhani, 1962). The anterior talofibular ligament is said to be the weakest ankle ligament and when en pointé it is at its longest length and under maximum tension, which accentuates the strain it is under. This vulnerable position increases the chance of acutely injuring the ligaments, which is commonly seen when a dancer rolls over the outer border of their foot while fully plantarflexed (Lin et al., 2005). The high repetition of specific ankle movements required for dance training and performance will most likely lead to an overuse injury if the supporting structures are weak or the dancer adopts poor biomechanics. Thus understanding the biomechanical implications of the exaggerated range of motion (ROM) and common areas of concern for dancers should help develop better training regimes, maximise performance and minimise the incidence of injury.

As mentioned above, during relevé the compressive loading is exaggerated and the weakest ligament is in its most vulnerable position (Koutedakis et al., 2008). Video and force platform analysis of dominant and non-dominant sides has identified similar ROMs, and excursion patterns but different initiation and peak moments (Lin et al., 2005). Lin et al. (2005) found that the non-dominant side was slower to reach peak moment and the peak moment experienced on the non-dominant side in relevé was greater. Practically this means the non-dominant side would be less reactive to dance movements and the dominant side may be more efficient at controlling the ankle. Based on these findings the authors concluded that the dominant side primarily controlled balance throughout the movement. This manifestation could be the result of choreographers selecting a certain side more frequently to perform movements. Ideally the imbalance created from biased movement selections should be counteracted with specific motor control and strengthening exercises to avoid injury.

Other complex movements such as the grand jeté have recently been examined using video analysis (Kalichová, 2011), which has increased the understanding of skill acquisition determinants. The grand jeté is an aerial standing jump with one leg take off and alternate leg landing. The jump is broken into four distinct phases which includes: preparation, take-off, flight and landing. Dancers' should aim to maximise the flight trajectory, create the illusion of floating during the peak of the parabolic curve and rapidly gain stability at touchdown. Handling a classical dance jump perfectly and aesthetically requires a high level of flexibility, speed, strength and coordination (Kalichová, 2011). Thus, if a certain degree of conditioning and technical mastery is not obtained, the dancer will not be able to optimise the jump.

Although individual variability in the jump structure exists, factors that directly impact performance can be systematically trained. Using two corresponding high speed digital cameras, Kalichová (2011) conducted a three dimensional (3D) kinematic analysis of the grand jeté. Data obtained from the motion analysis was used to meticulously investigate the four phases and the most important parameters determining the jump quality. During the preparation phase the dancer needs to sufficiently increase their horizontal velocity to potentiate the subsequent phase and overall performance. In Kalichová's (2011) study the best dancer landed on the take-off leg from the preparatory hop with a velocity of 2.69 $m \cdot s^{-1}$; the significance of this finding was not reported nor were other participants' figures. Therefore, it is only presumed that this subject attained the highest velocity and that maximal velocity is predictor of performance.

The velocity attained from the preparation phase must be effectively transferred during the take-off. To do this the dancer needs to maintain momentum whilst decreasing the joint angles of the take-off leg, and subsequently extend the take-off leg to release the stored elastic energy (Kalichová, 2011). An earlier study by Ryman (1978) found that moderate pliés resulted in greater elevation than deeper pliés, which is contrary to traditional technical instruction. The amount of force produced from rapidly stretching the muscle is dependent on the degree and speed of the muscles pre-stretch. If the concentric action does not immediately follow this phase, the elastic tension created will dissipate as heat (Barnes, Fink, & Stannard, 2013). This rationale supports the observation made by (Kalichová, 2011) and may explain why the moderate plié was more effective than the deeper pliés. The findings of Kalichová (2011) and Ryman (1978) also highlight some of the equivocal biomechanical knowledge among dance teachers, which may be impeding their movement proficiency.

To optimise the flight trajectory the take-off angle should be between 28 and 30° and the take-off leg should swing forward rapidly (Kalichová, 2011). During take-off if the forward leg swing is slow then momentum is lost, which results in a delayed completion of the lower extremity split. The author speculated that if the dancers lessened their take-off angle to the recommended margin, it would create a flatter and longer jump. These factors directly impact upon the dancer's ability to maximise their flight trajectory and attainment of full limb extension at the peak of the parabolic trajectory.

During the aerial phase the fast swing of the take-off leg backwards at the appropriate time is crucial. If this is done too slowly and/or insufficient range is obtained, the forward leg can descend excessively and the ankles may meet too low (Kalichová, 2011). To optimise the flight phase the ankles should be at the same height when the center of mass (COM) height is maximised. Simultaneously, the axis of the arm and pelvis should stay perpendicular to the direction of the motion (Galler, Murray, Robertson, Stanley, & Thomas, 2004a; Galler, Robertson, & Stanley, 2004b; Kalichová, 2011). This fully extended position should be attained at the peak height of the aerial phase to create the illusion of floating (Galler et al., 2004b). On the downward phase it is detrimental to allow the back leg to descend too low and the torso to bend forward excessively. Kalichová (2011) noted that greater decreases in the hip angle from touchdown to whole foot contact and increased forward lean was a frequent technical drawback for dancers. The author proposed that landing with the COM anterior to the base of support increases the horizontal force and transitional time to gain stability, which may be caused by insufficient lower extremity and erector spinae strength (Galler et al., 2004a; Kalichová, 2011). Hence, without supplementary strengthening the dancer may not be able to efficiently gain stability and land gracefully.

In order to dissipate the force upon landing, the heel should be momentarily held above the ground (Kalichová, 2011). Dworak, Gorwa, Kmiecik, and Maczynski (2005) and Galler et al. (2004a) measured the ground reaction forces (GRF) experienced by two dancers when landing from a grand jeté and reported vertical GRF's of 3.6 and 4.5 times the body weight of the subjects. These authors also highlighted that upon landing it was necessary to generate large braking forces to prevent slipping. Such extreme GRF's can excessively overload the tissues, which may lead to overuse syndromes or acute trauma. Furthermore, if the braking force is insufficient falls can occur and stability can be lost. During this landing phase the greatest negative work is done by the hip flexors, knee extensors and ankle plantarflexors, reaching peak moments of 300 N.m, 275 N.m and -100 N.m, respectively (Galler et al., 2004a). To improve landing patterns and decrease the risk of injury, training proper landing mechanics and strengthening these muscle groups should be recommended.

Environmental factors such as landing surfaces and footwear can affect a dancer's biomechanics and may contribute to the incidence of injury. In Broadway and London's West End productions approximately 50 % of performers sustain work related injuries and it is believed that high heeled shoes and inclined surfaces contribute to these statistics (Hagins, Kremenic, Liederbach, Orishimo, & Pappas, 2012). Jumping and landing are common functional tasks for dancers, during which large forces two to twelve times their bodyweight are produced. Hagins et al. (2012) found that dancers performing common functional tasks on ranked stages (sloped) exhibited significantly different joint angles at peak vertical GRF and peak moments compared to flat surfaces. Joints affected included the ankle, hip and knee, all of which altered the amount of dorsiflexion, abduction, eversion and flexion present when landing on ranked stages. The specific structures most significantly affected and the magnitude of these moments was dependent upon the type of inclination (Table 2.1). These findings highlighted that an even a small incline can significantly affect a dancers landing biomechanics and increase the stress placed on the muscular system. Although this study found a biomechanical link between ranked stages and injury, movements were not an exact replica of common movements performed by dancers and therefore findings should be interpreted with caution. Furthermore the study did not determine the injury specific implications of altered landing patterns, though it can be assumed that an increase in strain on the joint and muscular systems may increase the risk of an acute or repetitive stress injury. Future studies should look into the various types of movements commonly performed on ranked stages and the structures that support these landing patterns. Research in this area has the potential to prevent injury and minimise the subsequent loss of work and medical costs.

Table 2.1: Descriptive Studies

Author	Participants	Method	Results
Angioi et al. (2009b)	F professional contemporary dancers *n* = 6 Mean age: 31.0 ± 5.1 years	Aesthetic competence tool reliability study	Inter-rater reliability = no significant difference ICC *r* = 0.96 * Intra-test-retest reliability = no significant difference ICC greater than or equal to 0.85
	F professional contemporary dancers *n* = 6 F collegiate dancers *n* = 11 Mean age: 26.1 ± 4.0 years	**Association study:** AC, MEPU, DAFT, SVJ	**Variables:** / **Professionals** / **Students** AC: 49.0 ± 9.7 / 36.5 ± 9.6 MEPU (reps): 33.8 ± 5.1 / 29.2 ± 9.5 DAFT (b·min^{-1}): 190.0 ± 10.9 / 197.0 ± 7.8 SVJ (cm): 32.1 ± 5.8 / 28.3 ± 4.7
Aurenty, Massion, Mouchnino, and Pedotti (1992)	Healthy subjects *n* = 7 (F) *n* = 7 (M) (5 were experienced modern dancers) Aged 22-50 years	**Dynamic balance:** • Standing raise leg laterally to 45° • Standing raise leg laterally to 45° (keep trunk vertical)	**Naïve subjects:** **Trochanter (mm)** / **Acromion (mm)** 92.0 ± 21 / 208.0 ± 42 90.0 ± 19 / 206.8 ± 31 115.4 ± 16 / 247.5 ± 14 102.5 ± 13 / 201.7 ± 16 94.0 ± 7 / 182.1 ± 16 **Dancers:** **Trochanter (mm)** / **Acromion (mm)** 130.25 ± 24 †† / 170.5 ± 33 †† 113.5 ± 23 †† / 139.9 ± 21 †† 125.1 ± 21 †† / 157.75 ± 16 †† 127.8 ± 17 †† / 167.25 ± 18 †† 123.75 ± 8 †† / 144.6 ± 11 ††
Cheng et al. (2011)	F collegiate dancers *n* = 26 Mean age: 17.5 ± 0.5 years F collegiate non-dancers *n* = 25 Mean age: 18.1 ± 1.0	**Dynamic balance:** Using the BBS each participant performed three trials with their EO and EC with the platform set at level four.	**Variable:** / **Dancers** / **Non-dancers** EO OSI: 0.48 ± 0.23 / 0.57 ± 0.29 EO APSI: 0.37 ± 0.22 / 0.42 ± 0.30 EO MLSI: 0.30 ± 0.15 / 0.32 ± 0.17 EC OSI: 4.20 ± 1.11 / 4.74 ± 2.27 EC APSI: 2.73 ± 0.84 / 3.28 ± 1.68 EC MLSI: 2.68 ± 0.84 / 2.86 ± 1.44
Crémieux, Dupui, Golomer, Isableu, and Ohlmann (1999)	M professional dancers *n* = 13 Mean age: 23.8 ± 2.2 years Untrained subjects *n* = 10 Mean age: 18.8 ± 3.5 years	**Dynamic balance:** • Open eyes • Closed eyes	No significant differences between dancers and untrained subjects.
	M professional dancers *n* = 10 Untrained subjects *n* = 19 Whole group mean age: 24.5 ± 4.5 years	**Visual perception:** Rod and frame test	**Dancers** / **Untrained** Mean value: 3.4 ± 0.6 / 4.9 ± 0.5 †
De Luca et al. (1994)	F Ballet Dancers *n* = 5 Mean age: 29 ± 8years F Modern Dancers *n* = 7 Mean age: 35 ± 9 years	EMG Analysis of a Demi-Plié • LG • MG • TA • VLO • VMO • GM • H	**Ballet Dancers:** **Muscle** / **Lowering** / **Midcycle** / **Rising** LG: / 88 % † / 76 % MG: 64 % / 52 % / 96 % † TA: 60 % / 92 % / 0 % VLO: 60 % / 100 % / 100 % VMO: 100 % / 100 % / 100 % GM: 100 % / 96 % †† / 100 % †† H: 60 % / 36 % / 64 %

		• Ad	Ad 36 % 90 % † 65 % 45 % **Modern Dancers:** **Muscle** **Lowerin** **Midcycle** **Rising** LG **g** 60 % † 83 % MG 51 % 34 % 71 % † TA 71 % 100 % 0 % VLO 74 % 100 % 97 % VMO 100 % 100 % 97 % GM 100% 49 % †† 51 % †† H 46 % 14 % 57 % Ad 43 % 57 % † 53 % 20 %
Hagins et al. (2012)	F professional Broadway dancers *n* = 27 Mean age: 27 ± 5 years M professional Broadway dancers *n* = 14 Mean age: 25 ± 4 years	**Drop Landing Task:** • 3 drop jumps from a 30 cm platform, performed on the dominant leg. • Anterior, posterior or lateral inclination was present. **3D Motion Analysis:** 20 reflective markers were placed bilaterally over the calcaneus, second metatarsal, lateral malleolus, lateral femoral condyle, midshank, midthigh, anterior superior iliac spine, acromion, lateral humeral epicondyle and distal radius. 2 additional markers were placed on the sacrum and the left posterior superior iliac spine. Kinematic data were collected at 250 Hz. Ground reaction forces (GRF) were recorded at 2500 Hz with a multicomponent force plate.	**Peak Moments:** Ankle Dorsiflexion * Anterior = - 6 % Posterior = + 6 % Lateral = - Foot Abduction * Anterior = + 24 % Posterior = - 14 % Lateral = - 19 % Foot Eversion * Anterior = - 9 % Posterior = - Lateral = - 20 % Hip Flexion † Anterior = - Posterior = - Lateral = - 14 % Knee Flexion * Anterior = + 4 % Posterior = - Lateral = - 5 % **Angles:** Ankle Dorsiflexion * Anterior = - 4.5 % Posterior = + 5 % Lateral = - Foot Abduction * Anterior = - 2.5 % Posterior = - Lateral = - Knee Flexion † Anterior = - Posterior = + 1.3 % Lateral = - † ANOVA trend ($p > 0.004$ and $p < 0.05$); * ANOVA statistically significant ($p < 0.004$)
Hamilton et al. (1992)	F professional ballet dancers *n* = 14 Mean age: 29.2 ± 5.3 years M professional ballet dancers *n* = 14 Mean age: 28.4 ± 4.1 years	Muscular strength, ROM	**Strength differences between dancers and norms:** **Muscle(s):** **Males** **Females** HAb + 18 % + 21 % HAd - 25 % - 24 % Q - 16 % - H - 18 % - PF + 44 % + 33 % DF + 40 % +26 % **Lower extremity ROM data:** **Movement:** **Dancers** **Norms**

			F – Ext. Rotation	52 °	40 ° ††
			F – In. Rotation	29 °	34 ° †
			F – Ab	55 °	48 ° ††
			F – Ad	16 °	31 ° ††
			F – HF	135 °	125 ° †
			F – TT	10 °	15 ° ††
			F – PF	113 °	48 ° ††
			F – DF	10 °	18 ° ††
			M – Ext. Rotation	52 °	40 ° ††
			M – In. Rotation	22 °	43 ° ††
			M – Ad	16 °	31 ° ††
			M – HF	120 °	113 ° †
			M – KHyperE	7 °	10 ° ††
			M – TT	11 °	15 ° ††
			M – PF	107 °	48 ° ††
			M – DF	9 °	18 ° ††
Harley et al. (2002)	F semi-professional dancers *n* = 11 Physically active F controls *n* = 11	Q strength, jump height, % BF, FFM, flexibility, EMG activity	**Variable:**	**Dancers**	**Controls**
			Q Peak force (N)	458 ± 91.4	327.9 ± 78.2 †
			Jump height (cm)	37.6 ± 5.5	35.9 ± 3.9
			% BF	21.4 ± 2.8	25.6 ± 3.7 †
			FFM (kg)	42.2 ± 3.7	42.2 ± 6.6
			Flexibility: Straight-leg raise † Ankle plantar flexion and dorsiflexion † Elbow flexion and extension † Sit-and-reach tests † Dancers > controls (all †)		
			EMG activity during SSC jumps: Squat jump † Counter-movement jump † Drop jump † Dancers < controls (all †)		
Perrin, Deviterne, Hugel, and Perrot (2002)	F professional ballet dancers *n* = 14 Mean age: 22.1 ± 4.5 years M high level judoists *n* = 17 Mean age: 24.8 ± 4.5 years Untrained subjects *n* = 21 (F); *n* = 21 (M) Mean age: 23.9 ± 4.2 years	**Balance Control:** • Static • Dynamic: small rotational oscillations	**Variable:**	**Dancers**	**Controls**
			Lateral sway EC (cm)	0.16 ± 0.10	0.09 ± 0.05 †
			RQ sway (cm)	1.90 ± 0.42	1.57 ± 0.36 †
				Dancers	**Judoists**
			Sway path EC (cm)	1.53 ± 0.50	1.07 ± 0.26 †
			Area EC (cm)	0.58 ± 0.46	0.22 ± 0.15 †
			Lateral sway EC (cm)	0.16 ± 0.10	0.09 ± 0.06 †
			RQ sway (cm)	1.90 ± 0.42	1.50 ± 0.30 †
			RQ area 9cm)	2.85 ± 2.43	1.66 ± 0.70 †

F = female; M = male; *n* = number; reps = repetitions; Kg = kilograms; W = watts, in = inches; Q = quadriceps; MVIC = maximal voluntary isometric contraction; BM = body mass; SSF = sum of skin folds; ThC = thigh circumference; % BF = percent body fat; FFM = fat free mass; MEPU = muscular endurance push-up; DAFT = dance aerobic fitness test; BBS = biodex balance system; EC = eyes closed; EO = eyes open; OSI = overall stability index; APSI = anterior-posterior stability index; MLSI = medial-lateral stability index; RQ = romberg quotient; ICC = intraclass correlation coefficients; AC = aesthetic competence; SVJ = standing vertical jump; *r* = regression; HAb = Hip abduction; HAd = hip adduction; H = hamstrings; PF = plantar flexion; DF = dorsi flexion; HF = hip flexion; TT = tibial torsion; KHyperE = knee hyperextension; LG = lateral gastrocnemius; MG = medial gastrocnemius; TA = tibialis anterior; VLO = vastus lateralis obliquus; VMO = vastus medialis obliquus ; GM = gluteus maximus; ROM = range of motion* = significant difference between pre and post ($P < 0.05$); ** = highly significant difference pre and post ($P < 0.01$); † = significant difference between groups ($P < 0.05$); †† = highly significant difference between groups ($P < 0.01$).

Alignment and Muscle Balance

Alignment refers to the arrangement of body segments and skeletal structure. Throughout a dancer's training proper alignment is emphasized, which the literature suggests may reduce injuries, enhance dance performance, improve biomechanical efficiency, and increase the performance life of a dancer (Koutedakis, Krasnow, Stecyk, Wilmerding, & Wyon, 2011). Bowerman et al. (2014) investigated the growth, maturation and biomechanical issues that may lead to overuse injury in elite adolescent ballet dancers. Results showed a relationship between poor alignment and increased risk for injury. Earlier studies have found significant improvements in dynamic alignment following Pilates based training interventions (Barr, Chatfield, Dufek, Jensen, & Krasnow, 1997; Barr, Chatfield, Gamboian, Klug, & Woollacott, 1999; Deckert, Barry, & Welsh, 2007). Interestingly Barr et al. (1999) found that those who were assigned to the dance technique training group showed no improvement in pelvic tilt and lumbar lordosis, with one subject actually indicating a higher degree of lumbar lordosis during both quiet stance and a dynamic condition. This suggests that although alignment is important for injury prevention, performance and biomechanical efficiency dance technique training alone may be insufficient to strengthen the necessary muscles to maintain proper alignment.

Dancers seem to be generally weaker than other athletes and present muscular imbalances, which may predispose them to injury. Previous research claims that skeletal muscle accounts for only 34-43 % of a ballet dancers body weight (Jamurtas & Koutedakis, 2004) and that dancers are weak at the knee when compared to the norms for the general population (Table 2.1) (Hamilton et al., 1992). Additionally, Hamilton et al. (1992) found that male and female dancers had a large imbalance between hip abductors and adductors, probably developed by the amount of time spent in turnout. Weakness about the knee joint and strength disparities between the agonist and antagonist muscles would increase the risk of injury for dancers (Baechle & Earle, 2008), limit the amount of power they can produce and inhibit their potential.

Repetitive twisting, flexion and extension of the spine is unavoidable during some dancing movements, which may predispose a dancer to lower back pain (LBP) and injury. Redding and Swain (2014) associated reduced muscular endurance of the trunk muscles in female dancers with LBP, which is concomitant with previous findings with non-dancers (Bilodeau, Forget, Lariviere, Mecheri, & Vadeboncoeur, 2010). The trunk muscles physiologically provide low levels of activity for extended periods of time, serve as postural muscles and work to stabilise the spine (Moffroid, 1997; Redding & Swain, 2014). Inadequate trunk muscular endurance (Redding & Swain, 2014) and poor alignment (Bowerman et al., 2014) may predispose a dancer to LBP and injury and the lack of adaptation observed from dance training alone suggests a training intervention may be necessary to improve muscular endurance and alignment. To address these concerns training should focus on improving muscle balance, trunk endurance, proprioception and stability.

Flexibility

Flexibility is considered an essential attribute to dancers, so much so that upon application to a dance school subjects must exhibit a certain degree of flexibility to be accepted (Angioi et al., 2009b). This strict selection process means only the most flexible individuals excel and exaggerated flexibility is observed compared to other athletes (Jamurtas & Koutedakis, 2004) and the general population (Hamilton et al., 1992). When examining the musculoskeletal characteristics of ballet dancers Hamilton et al. (1992) established that dancers were flexible but not hypermobile. Dancers also exhibited greater flexibility than what is considered normal for the general population but at the cost of other movements. External rotation of the ankle joint was significantly greater, most likely developed by the full turn out of the lower extremities required for ballet but resultantly dancers exhibited a loss of internal rotation. Dancers were also significantly more flexible in plantarflexion and hip flexion; adaptations that would have occurred to facilitate various movements such as the grand plié and dancing en pointé (Table 2.1). These unique adaptations from the specific requirements of various dance movements must be carefully considered when prescribing any supplementary training and in some instances it may be necessary to include training that addresses flexibility imbalances.

Strengthening regimes need to carefully consider the importance of flexibility to ensure prescription does not adversely affect this attribute and decreases the incidence of injury. Bonorino and da Silva (2008) stated that the linear flexibility of the muscular chain is essential for artistic demonstration. Consequently dancers traditionally feared that supplementary training would reduce flexibility characteristics and diminish performance. Contrary to this belief several authors have found that strength training does not adversely affect flexibility (Giakas et al., 2007; Noble et al., 1990) and has the potential to enhance this attribute. Noble et al. (1990) found that the inclusion of a strength training program significantly increased participating dancers' lateral hip flexion and maintained all tested joints ROM. Based upon their findings Noble et al. (1990) proposed that by combining weight training with a specific flexibility protocol it is possible to maximise the length-tension curve. The length-tension curve was devised by Gordon, Huxley, and Jillian (1966) and models a muscles length dependent force producing capabilities. According to this model when a muscle is shortened or lengthened excessively there is too much or too little actin and myosin overlap which inhibits force production. Traditionally, a dancer's strength gains are attained through technique class but this is not well monitored and strength gains are often disproportional to flexibility. Maximising the length-tension curve could balance strength and flexibility, minimising injury rates at extreme ranges of motion and improving control over such movements.

Training versus Performance Demands

Dance is deemed a high-intensity intermittent exercise involving both aerobic and anaerobic components (Angioi et al., 2011). According to Angioi et al. (2009a) there are two main physiological requirements for dancers, a large reserve of power for explosive jumps and elevation, fuelled primarily by the adenosine triphosphate phosphocreatine (ATP-PCr) system and muscular endurance for a series of jumps, fuelled mainly by glycolysis. These explosive bursts are often followed by moments requiring precision and skill, therefore a good aerobic base would also assist performance and a high anaerobic threshold would minimise the detrimental effects of metabolite accumulation. Rafferty (2010) stated that the greater a dancers aerobic capacity is, the lesser the contribution from the anaerobic system, increasing the ability to sustain output for longer without becoming excessively fatigued. The literature shows though that dancers from novice to elite have VO_2max values lower than other athletes (Angioi et al., 2009b; Giakas et al., 2007) which are comparable to healthy sedentary individuals' of a similar age (Jamurtas & Koutedakis, 2004). During their intervention Giakas et al. (2007) found no cardiorespiratory improvements in their control group despite meeting their entire dance curriculum. These findings suggest that dance activities generally do not provide adequate stimuli to enhance cardiac structure and function.

Insufficient conditioning from dance activities may affect qualitative elements of performance by increasing fatigue and injury rates. Previous research has established inadequate physical fitness (Angioi et al., 2010), insufficient recovery (Koutedakis, 2004) and no known implementation of the periodisation model (Wyon, 2010) to be key determinants in the rate of fatigue induced injuries. Fatigue impacts skilled motor performance (Batson, 2013) and is characterised by diminished muscle force production. Reduced force production is attributed to a reduction in the amount of cross-bridges attaching simultaneously, an occurrence caused by alterations in calcium release, limited ATP availability and elevation of dihydrogen phosphate (Koutedakis & Wyon, 2013). Acutely, fatigue can affect the technical execution of key skills and result in faulty alignment, inefficient biomechanics, and increased stress on muscles and joints (Angioi et al., 2010). Chronic fatigue can result in poor movement competency, lead to compromised tissues, performance decrements, psychological effects, persistent or further injury (Murgia, 2013). Excessive fatigue appears to be detrimental to the quality of a dancers training and performance (Allen et al., 2007). Hence technical and artistic elements of dance may benefit from the implementation of a linear periodisation model, which initially improves the muscular endurance and cardiorespiratory capacity of dancers (Baechle & Earle, 2008).

Previous research has shown that during performance heart rates are significantly higher than those imposed from training or rehearsal sessions (Abt, Head, Redding, Sharp, & Wyon, 2004). Abt et al. (2004) established that performance demands elicited significantly greater mean heart rates, mean oxygen consumption and number of heart rate peaks (HR > 180 bpm) than class and rehearsal. Other studies have shown improvements in aerobic fitness during performance periods, suggesting the intensity and percent work time during performance is sufficient to elicit training adaptation (Redding & Wyon, 2001). It also highlights that class and rehearsal demand is too low to impose sufficient physiological demand that will result in a training effect and adequately prepare dancers for performance demands. This disparity is concerning as a sudden increase in work load when transitioning from rehearsing to performing may impose excessive overload provoking fatigue and/or overtraining symptoms (Allen et al., 2007). Supplementary cardiovascular training may be necessary to provide appropriate overload prior to performing, which previous interventional studies have already proved to benefit performance (Giakas et al., 2007).

Recent investigation using video analysis techniques have examined the differences between ballet and contemporary dancers (Angioi et al., 2011). These authors determined that classical ballet had longer rest periods and a greater number of lifts, jumps and changes of direction. Such elements place more stress on the anaerobic systems. Conversely, contemporary dancer exhibited more continuous and moderate exercise intensities (Angioi et al., 2011). Angioi et al. (2011) concluded that there are significantly different demands placed upon ballet and contemporary dancers and that the individual performance demands should drive the physical and skill preparation. Future research in this area would help develop a better understanding of the diverse needs of specific dance styles and could help optimise performance preparation models.

Dynamic Stability

To enhance a dancer's performance, robust postural control must be emphasized to reduce unnecessary attentional focus and allow effective simultaneous emphasis on technical and aesthetic skills (Bieć, Kuczyński, & Szymańska, 2011). Attaining this in a constantly changing environment requires dancers' to anticipate, preserve adequate space (a dance element made up of level, size, range, place, focus, direction, and pathway), and make rapid decisions regarding body position and direction of movement (Bieć, Kuczyński, & Szymańska, 2011). Theoretically these factors should facilitate the development of increased postural automaticity.

It would be expected that dancers elicited better postural control compared to non-dancers. Bieć et al. (2011) found controls and dancers' exhibited no significant difference in single task postural control but during the dual task antero-posterior plane sway variability and mean speed were significantly lower in dancers (Table 2.1). These authors speculated that this may reflect their ability to attain a higher degree of automaticity in postural control. This agrees with Crémieux et al. (1999) who found untrained subjects elicited greater sway disparity between eyes open and closed than dancers. These authors speculated that professional dance training may reinforce the accuracy of proprioceptive inputs and shift sensorimotor control from vision to proprioception. Lower visual-reliance was also shown to influence stability during dynamic conditions (Crémieux et al., 1999) and possibly accounts for the enhanced coordination dancers accomplish (Aurenty et al., 1992). Aurenty et al. (1992) established that during specific leg movements the lateral inclination of a dancer's trunk remained near vertical whereas the non-dancers failed to perform this coordinated task. Authors proposed that alignment was achieved through a feedforward control mechanism, developed from long years of specific training. Cumulatively, these studies support the notion that performing complex motor skills, such as those performed by dancers requires a great sense of balance, characterised by a lower reliance on visual feedback and more accurate proprioceptive input.

Based on the findings of the aforementioned authors, it seems that dance training may develop superior postural control in more challenging balance conditions only. Another study conducted by Cheng et al. (2011) found no major difference in stability indices between dancers and non-dancers in less demanding balance conditions but did cite a significant difference when performing the same task unipedal. Standing unipedally increases the complexity of the task and therefore requires superior proprioceptive input to maintain stability. Thus the authors speculated that the superior balance control exhibited by dancers in the more challenging balance conditions was a result of increased sensitivity of the vestibular system and heightened proprioceptive input (Cheng et al., 2011). Most likely developed from extensive exposure to performing complex single-leg movements (Hagins et al., 2012).

Contrary to previous research, other studies have found that dancers are heavily reliant on visual feedback for the processing and integration of other sensory inputs for balance. Cadopi, Hugal, Kohler, and Perrin (1999) found that dancers performed significantly better with eyes open but not eyes closed and Perrin, Deviterne, Hugel, and Perrot (2002) found that dancers were more dependent on visual inputs for the regulation of postural control than judoists and sedentary controls (Table 2.1). This may be due to their training techniques which rely on visual input; dancers will focus on land marks during high speed turns, for artistic expression and to perceive their surroundings. Discrepancies may also be caused by training differences; dancers train in a very stable and unmoving environment, whereas judoists are constantly subjected to unexpected movements possibly forcing their sensorimotor adaptabilities to develop. These studies suggest that dancers are more reliant on visual than proprioceptive input for postural regulation, contrasting the conclusions drawn by the aforementioned studies.

It is possible that dancers have developed a high reliance on visual feedback to regulate posture from extensive fixation training. Fixation or spotting techniques are used by dancers to minimise visual disturbance and dizziness caused from rapidly rotating (Osterhammel, Terkildsen, & Zilstorff, 1968). Previous research has established a significant relationship between the implementation of this technique and years training (Ohtsu, Sakata, & Teramoto, 1994). Demonstrating that more experienced dancers were further reliant on visual fixation to maintain stability. These findings may provide some insight as to why dancers are heavily dependent on visual feedback for postural regulation despite being previously exposed to highly complex motor tasks.

To improve postural automaticity it may be necessary to apply alternative training methods. Brent, Ford, Hewett, and Myer (2006) investigate the effects a seven week plyometric or dynamic stabilisation and balance program had upon power, balance and landing forces. They found that the intervention improved mediolateral center of pressure and significantly reduced their impact landing forces. Although this study recruited adolescent female athletes whose primary sports included volleyball, basketball, soccer, softball or swimming it could be speculated that plyometric and balance training might also benefit a dancer by reducing their risk for injury, increasingly the longevity of their career and improving the artistry of their performance. This is merely theoretical and further research would need to be conducted to determine this.

Growth and Development of Dancers

During adolescence dancers experience an increase in training load which is concurrent with growth, development and maturation (Burkhalter, Durkin, & King, n.d.). Physical changes and increased physical load will alter a dancer’s nutritional, emotional, psychological, physical and physiological needs, hence the interplay between these processes should become a primary concern during adolescence (Molnar, n.d.). Throughout adolescence training should be modified appropriately and a variety of support resources should be made easily accessible. Support resources should include specialists that can provide nutritional advice, and identify flexibility, strength and conditioning concerns. Dance scientists have recently highlighted the lack of support provided for dancers’ and scrutinised traditional dance paradigms (Abt et al., 2004; Akers, Davy, & Doyle-Lucas, 2010; Brown et al., 2007; Giakas et al., 2007; Noble et al., 1990; Redding & Wyon, 2005). These scientists have identified that dance training alone is not adequately physiologically preparing dancers for the demands of performance (Redding & Wyon, 2005) and the lack of nutritional advice accompanied by the pressure to maintain a low body fat/mass is developing a tendency towards disordered eating (Akers et al., 2010). Hamilton et al. (1992) found an abnormally high prevalence of scoliosis among male and female ballet dancers, which may reflect the high demands upon dancers to maintain a certain body shape. The inevitable pressure to maintain an ideal shape and weight and the associated disordered eating is also linked with delayed menarche (Akers et al., 2010; Cassidy & Hincapié, 2010). This may affect their development and create musculoskeletal problems if not addressed. Thus dance teachers, scientists and specialists should collaborate to formulate the most effective and safe pathway for dancers undergoing maturational changes.

Chronological age is of limited efficacy in the assessment of growth and maturation, as everyone develops at a different time and progresses towards maturation at a different tempo. Bailey, Baxter-Jones, Beunen, and Mirwald (2002) developed a simple non-intrusive method to asses maturational status for children and adolescents, described in years from peak height velocity (PHV). PHV indicates when maximal growth occurs during adolescence and is associated with reduced coordination during movement. Changes in coordination occur as the nervous system struggles to keep up with the bone and muscle growth. Additionally athletes can experience a decrease in flexibility and strength, as bones tend to grow faster than muscles. Dramatic increases in height, body mass, limb length and widening of the hips, may also affect the centre of gravity and ability maintain stability (Daniels, 2000). As a result dancers may find it difficult to master technical skills during PHV, which can lesser confidence due to a perceived decrease in ability. Impaired technique can also increase the risk for injury. Increasing awareness of the effects of maturation would benefit dancers by enabling teachers to make appropriate training modifications. Furthermore, utilising specialists that can manage flexibility and strength concerns, improve trunk and pelvis stabilisation, provide effective proprioceptive and balance training should help advance technical ability and prevent injury.

During adolescence, the interaction between growth and maturation, training volume and intensity appear to increase a young dancers risk of injury (Aujla, Redding, Steinburg, & Zeev, 2014; Dar et al., 2011). Over a two year period Aujla et al. (2014) found that 40-48 % of all dancers aged eight to eighteen sustained an injury. The results also determined training volume and intensity increased this risk further and that foot, ankle and other lower limb injuries were the most common. Typically dancers endure overuse injuries caused by the highly specific repetitive movements encountered (Aujla et al., 2014; Batson, 2007; Kerr, Krasnow, & Mainwaring, 1999; Murgia, 2013). An injury can have a profound effect upon a young dancers training and performance, and during maturation when their load can be substantial is when this population is most vulnerable. Therefore injury prevention strategies, monitoring training load and suitable support for this population should be prioritised. This could be achieved utilising a greater breadth of specialists and using other training modalities to strengthen areas of concern and reduce the incidence of overuse injuries.

Strength and Power

Strength is essential for slow controlled movements in dance and power for explosive high jumps. For example the développé seen in ballet and jazz involves smoothly and slowly straightening your knee upwards, holding this position with an upright posture and then returning to fifth position. Power movements include jumps such as the straddle jump, which requires the dancer to jump straight into the air and pop their legs out to their sides at the top. It is well documented in the literature and textbooks that strength and power can be improved through supplementary weight training and plyometric training methods (Baechle & Earle, 2008; Costill, Kenney, & Wilmore, 2008) and that improving these parameters can have an effect upon athletic performance. Angioi et al. (2009b) established upper body muscular endurance and jumping ability as the best predictors of aesthetic performance in contemporary dancers. Thus significant increases in these components may improve the aesthetic competence of dancers and should be an important consideration when preparing dancers for performance.

To date there has been little research into the effects of strength and plyometric training and even less research that has investigated the aesthetic improvements. In light of this, recent studies have tried to assess the effects of interventional training programs on aesthetic performance. Brown et al. (2007) investigated the effects of either a plyometric or weight training program and assessed the aesthetic changes via a specifically designed subjective dance evaluation tool. Results showed significant improvements in aesthetic jumping ability post intervention for the assigned training groups but no change in the control (Table 2.2). Noble et al. (1990) also utilised a subjective dance evaluation tool, which identified that the inclusion of a specific weight training protocol produced significant improvements in movement precision and overall ballet performance. Obtaining and sustaining satisfactory execution of dance movements requires coordination, precision, and speed. Thus the improvements in strength, power and muscular endurance may explain the improvements observed in the supplementary training groups of these studies. Furthermore the findings suggest that dance specific training alone may provide insufficient overload to the anaerobic and aerobic systems to improve dance technique and performance.

A successful dancer requires exceptional neuromuscular coordination, cardiovascular efficiency, flexibility, stability, body composition, muscular endurance, muscular strength and muscular power (Giakas et al., 2007; Rafferty, 2010). Although technique training and dance class may be good for developing necessary neuromuscular coordination, muscular endurance and flexibility required for dance, it rarely overloads the other components (Kozai, 2012). Kozai (2012) investigated the effects of a six week strength or plyometric training intervention on female university level dancers. Both groups showed a significant improvement in leg strength, lower-body power, perceived jump height and ability to point their feet whilst in the air but no change in the control group. This is in line with Koutedakis and Sharp (2004) who also found that professional ballet dancers who participated in a twelve week strength training intervention significantly increased lower-limb strength and although the control group met their entire dance curriculum they displayed no significant change in muscular strength. Both studies again indicate that dance training alone insufficiently overloads these physiological components and supplementary training may be necessary to push a dancer's physical capacity.

Table 2.2: Interventional Studies

Author	Participants	Method	Results		
Aquino et al. (2014)	F rhythmic gymnasts	**Non-specific**	**Non-specific resistance:**	**Pre**	**Post**
	10-13 years *n* = 57	**resistance training:**	HT flight time (ms)	412.9 ± 68.4	441.7 ± 44.2 †
		Squat movements	HT ground contact time (ms)	230.4 ± 32.1	238.7 ± 29.8 ††
	Non-specific	with dumbbells	SJ flight time (ms)	427.1 ± 35.3	440.1 ± 28.0
	resistance *n* = 19	F: 2 times per week	CMJ flight time (ms)	449.7 ± 34.5	481.3 ± 30.8 **
	Specific resistance *n* =	I: 3 sets of 12 RM	Hip Abduction (°)	86.2 ± 10.6	87.3 ± 11.7
	18	Rest: 45 s between	Hip external rotation (°)	42.4 ± 8	44.1 ± 6.6
		exercises, 2 min	Hip internal rotation (°)	46.0 ± 10.3	42.8 ± 8.2
		between sets	Body mass (kg)	40.7 ± 9.4	41.8 ± 9.4
		PD: 6 weeks	Thigh circumference (cm)	42.5 ± 4.6	44.8 ± 6.2 **
		Specific resistance	Calf circumference (cm)	30.3 ± 3.2	30.7 ± 3
		training:	**Specific resistance:**		
		3 reps of 10 gymnastic	HT flight time (ms)	420.0 ± 35.1	395.3 ± 46.5
		specific movements	HT ground contact time (ms)	256.0 ± 35.3	199.9 ± 20.5 **
		with weighted belts	SJ flight time (ms)	410.4 ± 41.6	421.5 ± 28.4
		set at 6 % body mass	CMJ flight time (ms)	457.2 ± 30.6	485.0 ± 33.8 **
		F: 15 min, 2 times per	Hip Abduction (°)	90.7 ± 12.1	78.9 ± 11.1
		week	Hip external rotation (°)	45.6 ± 6.9	44.5 ± 6.3
		I: Low to moderate	Hip internal rotation (°)	48.1 ± 6.5	43.2 ± 4.8 *
		Rest: 1 min between	Body mass (kg)	36.5 ± 6.7	36.7 ± 7.0
		exercises	Thigh circumference (cm)	40.6 ± 2.3	43.9 ± 3.7 **
		PD: 6 weeks	Calf circumference (cm)	29.4 ± 1.8	29.6 ± 2.8
Brown et al. (2007)	F collegiate dancers	**WT:**	**WT Group:**	**Pre**	**Post**
	18-20 years *n* = 18	Four exercises	Leg press strength (kg)	214.0 ± 61.0	282.5 ± 48.0 **
		F: 1-1.5 hrs per week	Knee curl strength (kg)	34.8 ± 4.5	42.8 ± 3.4 *
	Weight training *n* = 6	I: 80% 1RM, 3 sets of	Knee extension strength (kg)	58.7 ± 6.5	61.7 ± 4.4
	Plyometric *n* = 6	6-8 reps	Anaerobic peak power (W)	557.6 ± 53.4	581.8 ± 52.7
	Control *n* = 6	PD: 6 weeks	Anaerobic mean power (W)	340.8 ± 53.5	361.1 ± 62.6 *
		PLYO:	Standing vertical jump (in)	13.3 ± 3.3	13.8 ± 3.1
		Four exercises	Ability to point feet	3.0 ± 1.2	3.6 ± 0.7 *
		F: 1-1.5 hrs per week	Subjective jump height	2.8 ± 1.0	3.5 ± 0.8 **
		I: 3 sets of 8 reps	**PLYO Group:**		
		PD: 6 weeks	Leg press strength (kg)	183.3 ± 30.9	251.5 ± 39.4 **
		Control:	Knee curl strength (kg)	37.5 ± 4.0	40.9 ± 3.8
		Maintained normal	Knee extension strength (kg)	62.5 ± 9.1	57.5 ± 7.7
		dance training	Anaerobic peak power (W)	559.5 ± 105.0	570.0 ± 107.0
		schedule	Anaerobic mean power (W)	336.5 ± 34.0	347.0 ± 49.3
			Standing vertical jump (in)	12.0 ± 1.2	13.0 ± 1.0 *
			Ability to point feet	3.8 ± 0.6	3.8 ± 0.4
			Subjective jump height	3.2 ± 0.4	3.6 ± 0.5 *
			Control experienced no significant changes.		
Giakas et al. (2007)	F Collegiate Dancers *n*	**Exercise:**	**Exercise:**	**Pre**	**Post**
	= 27	**Aerobic training**	Dance points	73.9 ± 16.2	109.2 ± 21.3 †
		F: 20-40 min	VO_2max (ml.kg^{-1}·min^{-1})	50.7 ± 7.5	56.6 ± 9.3 †
	M Collegiate Dancers	(swimming, cycling or	Skinfolds (mm)	39.4 ± 10.5	35.7 ± 9.3
	n = 5	jogging), 2-3 x per	Flexibility (°)	125.5 ± 24.6	140.0 ± 23.4 ††
		week	Leg strength (kg)	90.6 ± 16.0	102.0 ± 17.4 ††
	Mean age: 19 ± 2.2	I: 70-75% HRmax	**Control:**		
	years	**Strength training**	Dance points	76.0 ± 19.4	81.5 ± 11.8
		3-4 exercises	VO_2max (ml.kg^{-1}·min^{-1})	49.2 ± 5.5	48.5 ± 5.4

	Exercise *n* = 19 Control *n* = 13	F: 50 min, 2-3 x per week I: 5-6 sets of upto 8 reps • <70% 1RM (first 2 weeks) • >70% 1RM (post 2 weeks) • ↑ 15-20% each week PD: 12 weeks **Control:** Maintained normal dance training schedule PD: 12 weeks	Skinfolds (mm) Flexibility (°) Leg strength (kg)	40.9 ± 11.7 123.2 ± 17.8 94.1 ± 15.8	44.6 ± 13.3 129.3 ± 17.2 83.1 ± 11.2
Koutedakis and Sharp (2004)	Professional ballerinas *n* = 22 Mean age: 25 ± 1.3 years Exercise *n* = 12 Control *n* = 10	**Exercise Group:** WEEK 1-2: <70% 1RM WEEK 3-12: 5-6 sets, 3-4 exercises, no more than 8 reps, 4 min rest between sets. **Control Group:** Usual Dance training **Tests:** Q & H torque levels, body mass, sum of skinfolds, thigh circumferences.	**Exercise Group:** Body mass (kg) SSF (mm) FFM (kg) Thigh Circumference (cm) **Control Group:** Body mass (kg) SSF (mm) FFM (kg) Thigh Circumference (cm)	**Pre** 48.0 ± 5.2 33.6 ± 5.0 37.7 ± 4.5 39.0 ± 3.4 45.0 ± 4.5 32.4 ± 4.3 35.7 ± 3.6 38.0 ± 2.8	**Post** 48.3 ± 5.9 27.8 ± 4.5 ** 39.4 ± 4.2 * 39.4 ± 3.1 45.0 ± 4.1 32.2 ± 4.7 35.3 ± 3.4 38.8 ± 2.9
			Pre – post change in torque: ST: significant increases in Q and H CG: no significant changes **Pre – post before and after dance exercise:** ST: decrease in performance decrements CG: no significant changes **NOTE:** data was not reported		
Noble et al. (1990)	F collegiate dancers *n* =14 (5-12 years ballet technique experience) Weight training *n* = 7 Mean age: 23.3 ± 4.3 years Control *n* = 7 Mean age: 20.4 ± 3.3 years	**WT:** Ballet technique F: 4 x per week, 1.5 hours Seven exercises F: 3 x per week I: 75% 1Rm, 3 sets of 10 reps R: 60 seconds PD: 9 weeks **Control:** Ballet technique F: 4 x per week, 1.5 hours	**WT:** Adduction (kg) Power ($kg \cdot m^{-1} \cdot sec^{-1}$) Flexibility - lateral hip (°) ME – 45-60s (reps) ME – 60-75s (reps) ME – 75-90s (reps) Ballet technique – precision Ballet technique – average The control group experienced no significant changes.	**Pre** 16.1 ± 2.2 100.2 ± 13.0 119.2 ± 11.9 5.7 ± 3.4 1.6 ± 2.8 0.4 ± 1.1 4.6 ± 2.0 4.8 ± 1.9	**Post** 18.6 ± 2.1 * 149.8 ± 27.5 * 127.1 ± 9.8 * 17.0 ± 3.9 * 12.1 ± 6.3 * 7.4 ± 7.3 * 5.0 ± 1.6 * 5.3 ± 1.7 *

F = female; M = male; *n* = number; WT = weight training; ST = strength training; CG = control group; PLYO = plyometric; F = frequency; I = intensity; RM = repetition maximum; reps = repetitions; R = rest; PD = program duration; HT = hopping test; Kg = kilograms; W = watts, in = inches; Q = quadriceps; MVIC = maximal voluntary isometric contraction; BM = body mass; SSF = sum of skin folds; ThC = thigh circumference; % BF = percent body fat; FFM = fat free mass; ME = muscular endurance; SJ = squat jump; CMJ = countermovement jump; H = hamstrings; * = significant difference between pre and post ($P < 0.05$); ** = highly significant difference pre and post ($P < 0.01$); † = significant difference between groups ($P < 0.05$); †† = highly significant difference between groups ($P < 0.01$).

Strength deficits are associated with lower back and lower limb injuries (Koutedakis & Sharp, 2004), which are also the most commonly reported sites of injury (Aujla et al., 2014). Koutedakis and Sharp (2004) implemented a twelve week strength training program focused on the quadriceps and hamstrings. Twenty-two full-time professional ballerinas were selected to participate and randomly assigned to an experimental or control group. The authors found that only those who participated in the resistance training experienced a significant increase in strength and ability to generate force after a fatiguing dance routine. Furthermore, there was a negative correlation between initial strength and improvement suggesting that weaker dancers' are more responsive and may benefit further. Traditionally strength training has not been deemed necessary for a dancer to accomplish a successful career and there are often concerns that it will diminish a dancer's aesthetic appeal. On the contrary, the lack of change in the control group confirmed that dance stimuli may be inadequate and strength training may be necessary to overload the neuromuscular system. Furthermore, the increases in strength were not associated with a change in muscle size. Thus, reinforcing the belief that adaptations were a result of nervous system changes and disproving the belief that strength training will increase muscle size. As choreographic demands increase, additional training will be necessary to push the limits of both artistry and the physical body. Further study into the effects of strength and power training has the potential to develop pathways that can coexist with traditional regimes and allow dancers to reach new heights without injury.

Recent research reinforces above findings that dance training alone may provide insufficient overload to the neuromuscular, musculoskeletal and cardiovascular systems to promote a training effect. Giakas et al. (2007) investigated the effects of a three month aerobic and strength training intervention on dance performance and the related parameters in modern dance students. Post intervention the exercise group showed a significant increase in VO_2max, flexibility and leg strength. These adaptations were accompanied by no significant change in body composition, which again refutes upheld beliefs within dance circles that any form of resistance training will negatively affect body composition. Furthermore, although the control group met the entire dance curriculum over the twelve week period, they failed to show any cardiovascular or strength improvements. These findings indicate that the inclusion of a specific weight training protocol can have a positive influence on some aspects of performance and that ballet training alone may be inadequate. Giakas et al. (2007) identified several limitations of their study, which included insufficient overload and a lack of testing sensitivity. Dancers were treated as novices and power tests were utilised that were not movement specific, which may have affected the results. Future studies should try to employ movement specific tests to increase testing sensitivity and participants should be progressively overloaded based on their individual ability to maximise then training effects.

The inclusion of resistance training may have the potential to develop lower limb explosive power. Aquino et al. (2014) found that specific and non-specific weight training protocols positively affected jumping ability and lower limb explosive strength. Both protocols significantly improved CMJ flight time but only the specific training group reduced their hopping test ground contact time (Table 2.2). This was attributed to the plyometric nature of the training program. Although this study was done with rhythmic gymnasts there is a lot of technical crossover and therefore resistance training methods may have a similar effect in dancing populations. Including training with dancers that can positively influence predictors of jumping ability has the potential to significantly influence performance (Angioi et al., 2009b). Thus future studies should investigate the effects different resistance training methods have upon lower limb explosive power with dancers' to enhance program prescription.

Other review articles including Angioi et al. (2009a), Jamurtas and Koutedakis (2004) and Rafferty (2010) support the aforementioned authors. Cumulatively, they advocate the importance of supplementary strength and power training and its desirable effects upon dance performance. Their findings suggest that there is very little scientific evidence available to fuel the claims within dance circles that supplementary training would have negative effect upon a dancer's artistic ability and aesthetic appeal. Moreover, Jamurtas & Koutedakis (2004) state that empirical and objective data suggests that an improvement in strength will enhance a muscles ability to generate force and thus develop performance. A soloist ballerina who is ranked above corps de ballet is a primary example of how strength can be beneficial to performance. Higher intensity training and performance protocols endured by soloists means they are characterised by increased muscular strength (Jamurtas & Koutedakis, 2004) and are able to jump significantly higher (Wyon et al., 2007). These characteristics emphasize that increased strength is beneficial for aspiring ballerinas and contributes to key aesthetic determinants such as jumping ability.

The aforementioned studies made the following recommendations of how to best implement a strength training program for dancers. Rafferty (2010) suggested that exercises should mimic the plane, direction and angle of a certain skill in order to maintain specificity and optimise skill transference. For example, including drop jump tasks that initially focus on landing mechanics and progress to a maximal effort jump should decrease impact forces and improve jumping performance (Hewett, Nance, Noyes, & Stroupe, 1996). It is also advised that low-volume high-intensity training methods be employed as they do not contribute to hypertrophy but do provide performance benefits; this is important as traditionally dancers avoid this type of training for fear it will negatively alter their physique and thus visual appeal (Brown et al., 2007). Base training is recommended prior to specific training as it should establish basic strength, rectify any imbalances, allow appropriate progression and minimise the risk of injury (Costill et al., 2008). Furthermore, when introducing plyometric training Brown et al. (2007) emphasized the importance of prescribing sufficient intensity to promote improved jumping ability. Within their study Brown et al. (2007) treated the dancers as novices despite the subjects extensive jump training during dance class. As a result their training programme did not impose adequate intensity to improve a dancers power output. For the best long term results plyometric training also needs to be done gradually and systematically to avoid excessive overload and injury (Rafferty, 2010).

These recommendations should be considered when making prescriptions for this population. To help develop this body of knowledge future research should investigate how such methods affect this population.

Summary and Significance of Literature Review

The main purpose of this literature review was to critically analyse the available literature related to dancers and develop a better understanding of what is required to be a successful dancer. From this examination a clearer understanding of the biomechanical implications of frequent movements, the required attributes to be a dancer, main concerns for this population and the impact the inclusion of supplementary training may have was formed. There were only a few interventional studies specific to this population and even less that investigated young dancers. Additionally most studies were conducted on small sample sizes, making it difficult to determine the true significance of these findings. Despite these limitations a clear reoccurring theme did become apparent. It seems that the stimulus provided from technical training and rehearsing delivers insufficient overload to bring about adaptation and therefore does not adequately prepare dancers' for performance demands. Additionally these cardiovascular and musculoskeletal deficiencies are making dancers more susceptible to fatigue and increasing their risk of injury. It is believed that early specialisation and no known implementation of a periodisation model (Wyon, 2010) are the primary reasons why dancers present lower fitness levels than other athletes (Rafferty, 2010), commonly display weakness and muscular imbalance (Hamilton et al., 1992). Furthermore alignment and muscle balance concerns may be exacerbated by the high repetition of specific movements during training and exaggerated flexibility presented in this population (Hamilton et al., 1992; Jamurtas & Koutedakis, 2004). The interventional studies analysed highlighted that resistance and cardiovascular training methods have the ability to improve indices of strength, power, muscular endurance, aerobic capacity, flexibility, composition and performance (Aquino et al., 2014; Brown et al., 2007; Giakas et al., 2007; Koutedakis & Sharp, 2004; Kozai, 2012; Noble et al., 1990; Wilmerding, 2009). Additionally the musculoskeletal characteristics and biomechanical models outlined by various authors provides the necessary evidence to accurately prescribe specific exercises that consider areas of concern and should help improve aspects of performance.

CHAPTER 3

METHODS

Experimental Approach to the Problem

To investigate the effects of a strength training program, a controlled intervention was conducted. Prior to pretesting dancers were placed in one of two groups (exercise or control). The exercise group was required to participate in a supplementary strength training program and the control group was required to continue with their usual dance training schedule. To evaluate the effects of the program the testing included a subjective dance evaluation, dynamic stability, strength and power measurements. The Auckland University of Technology ethics committee approved the study and all the participants and their parent or legal guardian provided written consent.

Participant Characteristics

Eighteen adolescent female dancers trained in ballet, jazz and contemporary were recruited through local dance schools to participate in the study. Subjects were assigned to a control (*n* = 6; Dance Experience: 11.7 ± 2.7 years; Age: 16.1 ± 1.9 years; Height: 165.7 ± 5.6 cm; Mass: 56.4 ± 6.4 kg; Maturity Offset: 3.1 ± 1.3 years) or exercise group (*n* = 12; Dance Experience: 9.2 ± 2.4 years; Age: 14.2 ± 1.9 years; Height: 155.6 ± 9.1 cm; Mass: 48.9 ± 13.8 kg; Maturity Offset: 1.3 ± 1.6 years). Due to participant drop-out sample sizes were uneven and were not pair-matched. Dancers were only considered if they had danced for five or more years, danced at an advanced level, competitively or as part of a performance group. All participants were between the ages of eleven to eighteen years old, able to commit to testing and training sessions, and were currently free from any injury that would inhibit them from participation.

General Overview of Testing Procedure

Tests were arranged from non-fatiguing to those that were the most metabolically taxing to minimise the risk of fatigue negatively effecting subsequent tests (Coburn, 2012). Specifically the tests were ordered as follows; height, seated height, weight, skinfolds, dynamic stability, power and isometric mid-thigh pull; a subjective dance evaluation was done on a separate occasion. After height, weight and skinfold data was collected the participants completed a five minute warm-up on a mechanically braked cycle ergometer at around 80 RPM.

Anthropometry

Upon arrival to the laboratory, all participants were measured for standing and seated height to the nearest 0.01 mm and for bodyweight to the nearest 0.01 kg. Height was measured using a wall mounted stadiometer and each participant was positioned in the Frankfort Horizontal Plane before the measurement was taken. Two measurements within 0.04 mm or 0.04 kg of each other were recorded for both tests.

Skinfold thickness and percentage of body fat was measured using a Slim Guide skinfold fat caliper (Creative Health, Plymouth, Michigan, USA) and calculated with the Jackson and Pollock formula. The Jackson and Pollock method is widely accepted for men (Jackson & Pollock, 1978) and women (Jackson, Pollock, & Ward, 1980) and has been used extensively in adolescent populations (Bloodgood et al., 2011). Following the guidelines of the standardised skinfold technique, four points of measurement were taken: at the abdominal vertically alongside the umbilicus, at the triceps vertically midway between the acromion process and the elbow, at the anterior mid-thigh and at the iliac crest measured at a 45° angle directly on top of the crest of the hip in line with the axilla.

Subjective Dance Evaluation

A specially designed assessment tool was adopted from Angioi et al. (2009b) and Noble et al. (1990) to assess dance performance. The model designed by Angioi et al. (2009b) was selected as inter-rater reliability was very high (r = 0.96) and presently there are no other known tools which have been tested for reliability or validity. The subjective evaluation tool designed by Angioi et al. (2009b) was not strictly followed as it was designed for contemporary dancers and the subjects were from an array of disciplines.

For example ballet involves significantly more changes of direction, lifting movements, jumps and pliés, less standing and falling movements and emotional expression than contemporary (Angioi et al., 2011). Therefore, greater emphasis was placed upon technical ability than expression.

A Likert scale was used to evaluate each component of a dancer's performance including; control of movements, spatial skills, precision of movements, jump height, ability to ballon, expression, dynamics, timing and rhythmical accuracy and overall performance (Table 3.1). Possible scores ranged from one to ten; therefore the maximal possible score was 60. The terms generally used at each scoring level were; 1 - 3 = little or no ability to perform the required elements, 4 – 6 = some elements performed appropriately, 7 – 8 = 80 % of the elements met with good virtuosity, 9 – 10 = excellent ability to meet all the required elements for the entire performance (Angioi et al., 2009b). The performance was judged by a panel of specifically selected persons including; a teacher and school director with previous audition panel experience, a professional dancer and teacher, and a dancer with over ten years' experience. Judges who could be blinded to group allocation were and included the professional dancer and one of the school directors. Prior to the assessment the judges were familiarised with the subjective evaluation tool, the assessment schedule and what was required of them.

On the day of the performance the dancers were taught a forty-five second routine, which involved fast jogging/running, static holds, multiple jumps and turns. These movements were selected as they are complex skills that require high technical ability, should stress the appropriate energy systems, impose fatigue and be a close replication of true performance demands (Angioi et al., 2011). Once the piece had been taught the dancers were allowed twenty minutes to practice and one trial performance. The actual performance was videoed to allow the judges to watch the performance more than once and determine an accurate score.

Table 3.1: Subjective Evaluation Criterion

Criterion	Description	Mark 1 - 10	
Control of Movements	Controlled landings from jumps and turns, controlled lifting/lowering of limbs, controlled shifting of bodyweight. Core strength, correct alignment and posture throughout.	1 to 3	Some evidence of co-ordination, movement control, and body awareness but limited and inconsistent control.
		4 to 6	Some elements were stronger than others.
		7 to 8	Some general co-ordination and body alignment; generally well controlled movements.
		9 to 10	Well co-ordinated movement and controlled work all of the time, with accurate alignment
Spatial skills	Spatial awareness, accuracy and intent	1 to 3	Little or no use of peripheral space; poor use of performance space.
		4 to 6	Some good use of space, but inconsistent. Some elements stronger than others.
		7 to 8	Good use of space about 80% of the time, with general accuracy and intent
		9 to 10	Secure and confident use of space, with accuracy and intent.
Accuracy of movements	Accurate arm placement, feet positions and fully stretched leg extensions when required.	1 to 3	Little or no precision throughout sequence. Unclear leg/arm lines.
		4 to 6	Some precision, but inconsistent. Some elements stronger than others.
		7 to 8	Correct positioning about 80% of the time.
		9 to 10	Precise placing with well-articulated gesturing of limbs.
Technique	Elevation, turning and falling techniques, height of extension, balance, posture, placement and articulation. Jump height and ability to ballon.	1 to 3	Little or no evidence of high technical skill in any element.
		4 to 6	Some skill in some elements, general virtuosity achieved.
		7 to 8	80% of the technical indicators meet with good virtuosity
		9 to 10	Precise execution of all technical skills, achieve with virtuosity and skill throughout.
Dynamics, timing and rhythmical accuracy	Dancing with correct timing and ability to perceive movement and rhythmic patterns. Showing awareness of the changes in musical rhythms, dynamics and phrases	1 to 3	Little or no ability to perform and respond in time to the music. Little or no dynamic qualities.
		4 to 6	Performed in time for over half of the sequence, with some ability to respond to rhythms and dynamics of movement.
		7 to 8	Timing was accurate for most of the sequence, and response to various rhythms was shown. General good use of dynamics sense of musicality.
		9 to 10	Timing was accurate throughout, with very good response to various rhythms, dynamics and phrases.
Overall performance	Is the overall performance impressive and do the dancers exhibit confidence in all areas?	1 to 3	Made little impression. Lacked control, spatial skills, technical ability and awareness of timing
		4 to 6	Made little impression. Some areas strong but others lacking
		7 to 8	Good impression. Has the ability but minor aspects still need work
		9 to 10	Very impressive. Excellent control, spatial skills, technical ability and very good musicality.

(Angioi et al., 2009b; Noble et al., 1990)

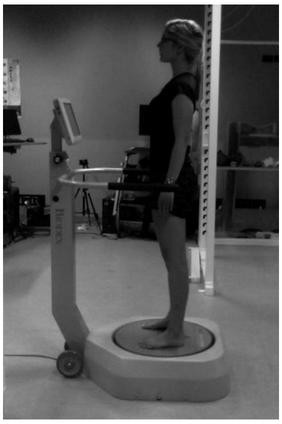
In addition to the performance piece all participants were evaluated on three technical skills in isolation. This was included to allow the participants an opportunity to perform each skill to the best of their ability with less external pressures, which may influence performance results of the subjective dance evaluation. These technical skills included a développé à la seconde (both sides), eight changements and a grand jeté sequence (gallope, grand jeté, inwards roll and stand). The participants were evaluated on their ability to correctly execute key performance determinates including height of elevation, posture, alignment, arm and feet placement, ability to point, tempo and control (Angioi et al., 2009b; Kalichová, 2011).

Dynamic Stability

A Biodex Balance System (BBS) (Biodex, Inc, Shirley, NY) allows the measurement of a participant's neuromuscular control in a closed chain multiaxial test. It achieves this by quantifying the ability of participants' to maintain dynamic postural stability on a freely moving circular platform. The circular platform can tilt up to 20° in a 360° range of motion in the anterior-posterior and medial-lateral planes simultaneously to create functional instability (Cheng et al., 2011). The BBS provides three measurements, (1) overall stability index (OSI), which measures the degrees of displacement in all directions; (2) anterior-posterior stability index (APSI), which measures the degrees of displacement in the sagittal plane; and (3) medial-lateral stability index (MLSI), which measures the degrees of displacement in the frontal plane. The BBS was proven to be an accurate reliable test of balance performance and the dynamic nature of the BBS is said to evoke neuromuscular control aspects more than static force platforms systems (Cheng et al., 2011). The BBS ICC has been previously reported as 0.92 for OSI, 0.89 for APSI and 0.93 for MLSI (Cachupe, Kahanov, Shifflett, & Wughalter, 2001).

BBS stability settings range from twelve to one, with twelve being the most stable platform setting and one being the least. Previous research has found that the most and least stable levels make it harder to differentiate results between populations and may be less sensitive to training adaptations (Cheng et al., 2011). Therefore the protocol utilised stability level four performed once with eyes open (EO) and once with eyes closed (EC). Participants were asked to stand upright, barefooted, with their arms by their sides and to remain looking straight ahead for the entire trial (Figure 3.1). Throughout each trial participants were instructed to maintain a level platform as steadily as possible for 30 seconds and allowed 30 seconds rest between trials. The mean of three trials was used for data analysis for each protocol: EO and EC.

Figure 3.1: Dynamic Stability Testing Position



Isometric Mid-Thigh Pull

Maximal isometric strength was measured using the isometric mid-thigh pull (IMTP) exercise. The IMTP required the participants to pull on an immovable bar (performed in a power rack with pins) as quickly as possible and to maintain the effort for five seconds. During this contraction vertical ground reaction force was assessed using a force platform sampling at 200Hz (Fitness Technologies, 400 Series, Adelaide, Australia) and the force data was analysed using the Ballistic Measurement System software (Fitness Technologies, Adelaide, Australia). The variable that was analysed was isometric maximal strength or peak force (PF). Each subject was allowed three five second trials with a three minute rest period between each trial. The highest value of the three trials was used for the subsequent data analysis.

Prior to data collection the bar height was set so that the knee angle of the participant was 130°, and the participant was instructed to maintain a neutral spine throughout the effort (Figure 3.2). Due to the age and training status of the participants it was deemed more appropriate to utilise the IMTP test than the more traditional one repetition maximum (1RM) test. The IMTP is highly correlated with 1RM testing (Erickson, McGuigan, & Winchester, 2006; McGuigan & Winchester, 2008) and has a high test-retest reliability with an ICC of $r \geq 0.96$ (Erickson et al., 2006) and a CV % of 2.3 % (McGuigan, Newton, & Teo, 2011).

Figure 3.2: IMTP Testing Position

Power Testing

Lower body power was assessed using a force plate (Fitness Technology, Adelaide, Australia) interfaced with computer software (Ballistic Measurement System, Fitness Technology, Adelaide, Australia) that allowed direct measurement of the force-time characteristics including peak power, force, velocity and rate of force development. Tests selected included a vertical squat jump (SJ), vertical countermovement jump (CMJ) and single leg CMJ (SLCMJ) all which have been previously determined as reliable and valid tests of leg power (Cronin & Maulder, 2005). Between each trial participants were prescribed thirty seconds rest and three successful trials were recorded for each jump. The highest peak power output (PP) from these trials was used for statistical analysis. The CMJs were included to assess each participants stretch shorten cycle (SSC) ability (Cronin & Maulder, 2005). The SSC ability was determined by dividing the PP outputs of the CMJ and SJ (CMJ PP / SJ PP) (Doyle et al., 2006). Additionally, PP outputs for the CMJ and SJ were also divided by the participants mass to determine their relative PP (watts/kg). SLCMJs were incorporated to determine limb symmetry, which was determined by dividing left and right limbs PP outputs (RCMJ PP / LCMJ PP).

The subject was instructed to place their feet parallel and hip width apart on the force platform and keep their hands on their hips throughout the entire jump. Thereafter, they were asked to descend to approximately 120° at the knee joint and hold that position. The experimenter counted out four seconds and on the count of four the subject was instructed to jump as high as possible. A successful SJ trial was one where there was no countermovement prior to the execution of the jump. With all vertical jumps, it was recommended that at take-off, the subject leave the mat with the knees and ankles extended and land in a similarly extended position. For the CMJ the subject was instructed to assume the same position as explained above, rapidly sink to approximately 120° at the knee joint and immediately after jump as high as possible. For the SLCMJ the subject began with the foot of the designated testing leg on the jump force plate and followed the same procedure as described above for the CMJ; this was then repeated on the opposite leg. For the SJ, CMJ and SLCMJ the participants needed to attain adequate depth and ensure their hands remained upon their hips for the entire jump.

Training Program

All participants in the exercise group were required to complete a nine week training program, which involved two sessions each week (Table 3.2). Prior to each training session the participants followed a warm-up that included general whole body activity to increase blood flow and muscle temperature (Bishop, Jones, & Woods, 2007), and several activation and mobilisation exercises, to enhance neural activation (Rogers, 2007) and allow for a greater range of motion (Bishop et al., 2007), respectively. For each phase of the program exercises were arranged strategically to allow sufficient energy system recovery and minimise the effects of fatigue, which could promote poor technique and increase the risk of injury (Baechle & Earle, 2008; Costill et al., 2008). The abdominal focused exercises were placed last because of the important role they have in stability. If the core is fatigued early it will affect the athlete's ability to stabilise when performing proceeding exercises and again increase the risk of poor technique and injury. Exercises were selected that would strengthen the areas of concern including the quadriceps and hamstrings (Galler et al., 2004a; Hamilton et al., 1992), and the deep and superficial muscles attached to the vertebrae and pelvis (Kalichová, 2011; Kline, Krauss, Maher, & Xianggui, 2013).

Table 3.2: Training Programme

Phase One W1-3					
Exercise	Load	Sets	Reps	Tempo	Rest
SLRDL	1-2 SOF	2	15	2·1·2	75 s
Bulgarian Split Squat	1-2 SOF	2	12	2·1·2	60 s
Bentover Row	1-2 SOF	2	15	2·1·2	-
Push Up	1-2 SOF	2	15	2·1·2	75 s
Squat Walk with Therapy Band	BW	2	15 m	2·1·2	30 s
Plank	MMF	2	1	30-90s	-
MB Twist	1-2 SOF	2	20	2·1·2	75 s
Phase Two W4-6					
Exercise	Load	Sets	Reps	Tempo	Rest
Deadlift	1-2 SOF	3	8	X·1·4	-
Bentover Row	1-2 SOF	3	8	X·1·4	-
Push Up	1-2 SOF	3	8	X·1·4	-
Split Squat	1-2 SOF	3	8	X·1·4	180 s
Hip Thrusts	1-2 SOF	3	8	X·1·4	180 s
Straight Arm Plank	MMF	3	1	30-90s	-
MB Twist	1-2 SOF	3	30	2·1·2	75 s
Phase Three W7-9					
Exercise	Load	Sets	Reps	Tempo	Rest
Deadlift	1-2 SOF	4	6	X·0·4	-
Explosive Power Bag Pulls	1-2 SOF	4	6	X·0·4	-
Clapping Push Ups	1-2 SOF	4	6	X·0·4	-
Depth Jumps	1-2 SOF	4	6	X·0·X	180 s
Split Squat	1-2 SOF	4	6	X·0·4	120 s
Lunge Jump	1-2 SOF	4	6	X·0·X	120 s
Plank Complex	MMF	2	3	30-60s	120 s

Tempo = concentric phase · transition phase · eccentric phase; W = week; SLRDL = single leg Romanian deadlift; TRX = total body resistance exercise; m = meter; s = seconds; SOF = short of failure; BW = bodyweight; MMF = momentary muscular failure; X = explosive; MB = medicine ball.

The emphasis for the first training phase was on improving proprioception and stability, movement competency and strengthening the trunk and hip musculature. Thereafter the program was progressed and repetitions were reduced whilst movement stability was increased. Due to the participants age and the relatively novice training status, during phase two repetitions did not fall below six. Prescription was based on recommendations made by the National Strength and Conditioning Association; which state that heavy resistance multi-joint exercises should not fall below six to eight repetitions for adolescents (Blimkie et al., 2009). For the third and final phase of the nine week program a combination of resistance and plyometric training was prescribed, which can be effectively and efficiently achieved by applying complex training techniques (Bazanovk & Vassil, 2012; Canavanb, Hasson, & Vescovia, 2008). Due to the extensive exposure to plyometric style exercises incidentally through their dance training and time constraints, a more intense and time efficient complex training program was deemed more appropriate for the final phase. Repetitions for these exercises were kept low, as it is recommended that plyometric exercises do not exceed six to eight repetitions and that the focus should be on fewer quality repetitions (Blimkie et al., 2009). Additionally when performing all exercises every participant was instructed to perform the concentric phase as quickly as possible. Behm and Sale (1993) found that the intention to move ballistically rather than the actual movement velocity, may determine the high-velocity training response (Kawamori & Newton, 2006). Training specificity was an important consideration during all phases of the nine week program and it was crucial the final phase provided the appropriate stimuli to overload the musculature and neuromuscular mechanisms to improve power (Kawamori & Newton, 2006).

Statistical Analysis

Data was analysed using an IBM SPSS statistics package version 22 (IBM, New York, USA). All variables were tested for normality using the Kolmorgorov-Smirnov and Shapiro Wilk test and for homogeneity using the Levene's test. Non-normally distributed data was not able to obtain normality through logarithm transformation so was treated as non-parametric.

A Paired T-test or Wilcoxon Signed-Rank test was used to assess the differences between pre- and post- and an Independent T-test or Mann-Whitney test was used to determine the difference between groups. All data was reported as mean ± standard deviation (SD) and effect size was calculated to provide an objective measure of the importance of the training effect. Effect size for dependent groups was calculated using the following equation: (mean post – mean pre) / SD pre. Effect size for independent groups was calculated using the following equation: (mean group 1 – mean group 2) / pooled SD for all subjects combined. An effect size value of less than 0.2 indicated a trivial effect, 0.2-0.6 a small effect, 0.6-1.2 a moderate effect and greater than 1.2 a large effect (Hopkins, 2002). A Pearson's correlation coefficient test was used to determine the extent of the relationship between dance performance, strength, power and dynamic stability.

CHAPTER 4

RESULTS

Baseline Measurements

No significant difference was found between the two groups baseline training history, age and body composition (mass, BMI, Body fat, sum of skin folds) (Table 4.1) but there was a significant difference between height (p = 0.011, large ES = 2.91), seated height (p = 0.008, large ES = 2.91), maturity offset (p = 0.025, large ES = 2.59) (Table 4.1) and subjective dance evaluation (p = 0.014, large ES = 2.74) (Table 4.2). There was no significant difference between the two groups at baseline level in any of the other studied parameters including dynamic stability, strength, power and subjective skill evaluation (Table 4.2).

Table 4.1: Participant Characteristics

	Exercise Group *n* = 12				Control Group *n* = 6				Between Groups *n* = 18			
									PRE		POST	
VARIABLE	PRE	POST	P-Value	ES	PRE	POST	P-Value	ES	P-Value	ES	P-Value	ES
Years Dancing	9.17 ± 2.41	-	-	-	11.67 ± 2.66	-	-	-	0.083	1.94	-	-
Age (yrs)	14.16 ± 1.87	14.36 ± 1.87	0.001**	0.11	16.12 ± 1.86	16.35 ± 1.90	0.001**	0.12	0.060	2.10	0.062	2.11
Maturity Offset (yrs)	1.31 ± 1.55	1.51 ± 1.55	0.001**	0.13	3.14 ± 1.34	3.30 ± 1.34	0.001**	0.12	0.025†	2.59	0.026†	2.53
Height (cm)	155.58 ± 9.07	156.39 ± 8.76	0.001**	0.09	165.73 ± 5.63	165.80 ± 5.26	0.776	0.01	0.011†	2.91	0.012†	2.84
Seated Height (cm)	80.44 ± 4.84	81.49 ± 5.06	0.125	0.22	87.61 ± 4.28	88.32 ± 4.08	0.031*	0.17	0.008††	3.20	0.009††	3.08
Mass (kg)	48.88 ± 13.75	50.07 ± 14.19	0.028*	0.09	56.38 ± 6.41	56.41 ± 6.04	0.917	0.00	0.134	1.58	0.204	1.33
BMI (kg/m^2)	19.82 ± 3.66	20.10 ± 3.89	0.108	0.08	20.48 ± 1.24	20.46 ± 1.22	0.686	-0.02	0.580	0.56	0.771	0.29
Body fat (%)	23.35 ± 6.99	22.48 ± 6.15	0.194	-0.12	23.32 ± 3.42	24.16 ± 1.95	0.440	0.25	0.990	-0.01	0.402	0.86
Sum of Skin Folds (mm)	84.13 ± 31.62	79.79 ± 27.26	0.159	-0.14	82.33 ± 14.85	84.00 ± 12.22	0.691	0.11	0.872	-0.16	0.658	0.45

Data is reported as mean ± SD. Parametric data: Paired Samples T-Test and Independent T-Test. Non-parametric data: Wilcoxon Signed-Rank Test and Mann-Whitney Test. BMI = body mass index. * Significant difference between pre and post ($P < 0.05$); ** highly significant difference between pre and post ($P < 0.01$), † significant difference between exercise and control group ($P < 0.05$); †† highly significant difference between exercise and control group ($P < 0.01$).

Table 4.2: Dynamic Stability, Strength and Power and Subjective Evaluation

	Exercise *n* = 12					Control *n* = 6					Between Groups *n* = 18			
VARIABLE	PRE	POST	P-Value	ES	% Change	PRE	POST	P-Value	ES	% Change	P-Value PRE	ES	P-Value POST	ES
Dynamic Stability														
OBL4 OSI	1.22 ± 0.62	0.78 ± 0.34	0.003**	-0.71	-36.1	1.07 ± 0.41	1.15 ± 0.18	0.693	0.20	7.5	0.552	-0.61	0.008††	3.02
OBL4 APSI	1.06 ± 0.66	0.58 ± 0.33	0.003**	-0.73	-45.3	0.87 ± 0.39	0.87 ± 0.28	1.000	0.00	0.0	0.450	-0.77	0.081	1.95
OBL4 MLSI	0.40 ± 0.11	0.41 ± 0.16	0.856	0.09	2.5	0.43 ± 0.23	0.57 ± 0.21	0.421	0.61	32.6	0.962	0.30	0.138	1.64
CBL4 OSI	2.76 ± 2.00	2.23 ± 1.33	0.099	-0.27	-19.2	3.35 ± 1.16	3.60 ± 1.03	0.328	0.22	7.5	0.439	0.79	0.031†	2.41
CBL4 APSI	1.99 ± 1.62	1.37 ± 0.78	0.050*	-0.38	-31.2	2.22 ± 0.78	2.45 ± 0.80	0.344	0.29	10.4	0.697	0.41	0.021†	2.72
CBL4 MLSI	1.50 ± 0.96	1.41 ± 0.90	0.476	-0.09	-6.0	2.07 ± 0.73	2.10 ± 0.52	0.801	0.04	1.4	0.185	1.40	0.056	2.06
Strength														
IMTP (N)	936.54 ± 241.80	1092.35 ± 267.59	0.001**	0.64	16.6	1133.18 ± 202.17	1279.93 ± 249.64	0.006**	0.73	13.0	0.094	1.82	0.171	1.47
Power														
SJ PP (W)	1854.43 ± 560.40	1938.24 ± 632.55	0.237	0.15	4.5	2094.30 ± 357.34	2415.85 ± 501.17	0.031*	0.90	15.4	0.288	1.10	0.106	1.74
SJ Relative PP (W/kg)	37.85 ± 3.79	38.63 ± 6.29	0.546	0.21	2.1	37.03 ± 3.32	42.43 ± 4.80	0.037*	1.63	14.6	0.644	-0.47	0.178	1.42
CMJ PP (W)	1866.41 ± 569.99	1925.74 ± 669.51	0.282	0.10	3.2	2133.33 ± 330.07	2287.73 ± 455.93	0.073	0.47	7.2	0.228	1.26	0.199	1.35
CMJ Relative PP (W/kg)	37.98 ± 2.59	37.95 ± 4.35	0.967	-0.01	-0.1	37.76 ± 2.83	40.26 ± 4.46	0.101	0.88	6.6	0.875	-0.16	0.321	1.04
LCMJ PP (W)	1179.23 ± 365.89	1263.98 ± 413.86	0.083	0.23	7.2	1405.01 ± 210.00	1461.70 ± 311.56	0.506	0.27	4.0	0.117	1.66	0.278	1.13
RCMJ PP (W)	1187.34 ± 332.88	1266.77 ± 379.37	0.021*	0.24	6.7	1387.88 ± 225.57	1468.25 ± 263.75	0.089	0.36	5.8	0.154	1.51	0.211	1.31
EUR	1.01 ± 0.06	0.99 ± 0.09	0.512	-0.33	-2.0	1.02 ± 0.05	0.95 ± 0.05	0.024*	-1.40	-6.9	0.653	0.37	0.211	-1.21
L:R Ratio	1.02 ± 0.13	1.01 ± 0.11	0.887	-0.08	-1.0	0.99 ± 0.11	1.01 ± 0.06	0.708	0.18	2.0	0.651	-0.51	0.984	0.00
Subjective Evaluation														
Isolated Skill	19.17 ± 3.24	23.33 ± 2.26	0.001**	1.28	21.7	19.67 ± 3.78	19.42 ± 3.20	0.624	-0.07	-1.3	0.621	0.51	0.029†	-2.68
Dance Performance	35.75 ± 10.45	42.7 ± 7.58	0.008**	0.67	19.4	45.83 ± 5.15	44.73 ± 7.24	0.976	-0.21	-2.4	0.014†	2.74	0.788	0.28
Control	5.36 ± 1.63	7.21 ± 1.10	0.001**	1.13	34.5	7.60 ± 0.89	7.40 ± 1.06	0.497	-0.23	-2.7				
Spatial Skills	5.82 ± 2.14	7.00 ± 1.28	0.032*	0.55	20.3	7.60 ± 0.89	7.13 ± 1.35	0.352	-0.52	-6.1				
Accuracy	5.91 ± 1.30	7.09 ± 1.25	0.001**	0.91	20.0	7.40 ± 1.34	7.47 ± 1.46	0.920	0.05	0.9				
Technique	6.09 ± 1.38	7.11 ± 1.31	0.002**	0.74	16.7	7.40 ± 1.34	7.47 ± 1.21	0.904	0.05	0.9				
Dynamics	5.91 ± 2.17	7.11 ± 1.48	0.014*	0.55	20.3	7.20 ± 1.10	7.70 ± 1.19	0.321	0.46	6.9				
Overall Performance	6.00 ± 1.48	7.18 ± 1.40	0.001**	0.80	19.7	7.60 ± 0.89	7.57 ± 1.26	0.898	-0.04	-0.4				

Data is reported as mean ± SD. Non-parametric data: Wilcoxon Signed-Rank Test or Mann-Whitney Test. Parametric data: Paired Samples T-Test or Independent T-Test. ES = effect size; OBL4 = bilateral legs stance in eyes-open condition at level four; CBL4 = bilateral legs stance in eyes-closed condition at level four; OSI = overall stability indices; APSI = anterior-posterior stability indices; MLSI = medial-lateral stability indices; IMTP = isometric mid-thigh pull; W = watts; SJ = squat jump; PP = peak power; W/kg = watts per kilogram; CMJ = countermovement jump; L = left; R = right; EUR = eccentric utilisation ratio. * Significant difference between pre and post ($P < 0.05$); ** highly significant difference between pre and post ($P < 0.01$); † significant difference between exercise and control group ($P < 0.05$); †† highly significant difference between exercise and control group ($P < 0.01$).

Pre- to Post-Testing

The average compliance with the training program was 94 %. The most significant time (pre vs. post) effect for the exercise group was observed in the dynamic stability measurements. The exercise group showed a significant improvement in EO OSI (- 36 %, *p* = 0.003, moderate ES = - 0.71), EO APSI (- 45 %, *p* = 0.003, moderate ES = - 0.73) and EC APSI (- 31 %, *p* = 0.50, small ES = - 0.38) (Table 4.2). In contrast, the control group showed no significant difference in dynamic stability (Table 4.2) but the data did indicate a decrease in postural control. The greatest decrease in stability was observed in the EO MLSI (+ 33 %). For both groups there was a significant difference in all indices of stability between the EO and EC conditions (Table 4.3).

Table 4.3: Dynamic Stability Condition Comparison

	Exercise *n* = 12					Control *n* = 6				
Variable	EO	EC	P-Value	ES	% Difference	EO	EC	P-Value	ES	% Difference
Pre										
OSI	1.22 ± 0.62	2.76 ± 2.00	0.003**	1.80	126.2	1.07 ± 0.41	3.35 ± 1.16	0.004**	4.54	213.1
APSI	1.06 ± 0.66	1.99 ± 1.62	0.012*	1.30	87.7	0.87 ± 0.39	2.22 ± 0.78	0.011*	3.79	155.2
MLSI	0.40 ± 0.11	1.50 ± 0.96	0.002**	2.79	275.0	0.43 ± 0.23	2.07 ± 0.73	0.001**	5.25	381.4
Post										
OSI	0.78 ± 0.34	2.23 ± 1.33	0.003**	2.59	185.9	1.15 ± 0.18	3.60 ± 1.03	0.002**	5.74	213.0
APSI	0.58 ± 0.33	1.37 ± 0.78	0.002**	2.28	136.2	0.87 ± 0.28	2.45 ± 0.80	0.001**	4.57	181.6
MLSI	0.41 ± 0.16	1.41 ± 0.90	0.003**	2.68	243.9	0.57 ± 0.21	2.10 ± 0.52	0.003**	6.68	268.4

Data is reported as mean ± SD. Non-parametric data: Wilcoxon Signed-Rank Test. Parametric data: Paired Samples T-Test. ES = effect size; EO = eyes open; EC = eyes closed; OSI = overall stability indices; APSI = anterior-posterior stability indices; MLSI = medial-lateral stability indices. * Significant difference between conditions ($P < 0.05$); ** highly significant difference between conditions ($P < 0.01$).

The exercise group also significantly increased subjective dance (+ 19 %, *p* = 0.008, moderate ES = 0.67) and skill evaluation scores (+ 22 %, *p* = 0.001, large ES = 1.28) from pre- to post-testing (Table 4.2). The control group showed no significant change in either of these variables.

The exercise group showed a significant improvement in IMTP peak force (+ 17 %, *p* = 0.001, moderate ES = 0.64) and right leg CMJ peak power (+ 7 %, *p* = 0.021, small

ES = 0.24) (Table 4.2). The control group also showed a significant increase in IMTP peak force (+ 13 %, *p* = 0.006, moderate ES = 0.73), SJ peak power (+ 15 %, *p* = 0.031, moderate ES = 0.90) and relative peak power (+ 15 %, *p* = 0.037, large ES = 1.63), and a significant decrease in EUR (- 1 %, *p* = 0.024, large ES = - 1.40). No other significant improvements were observed in the exercise or control group.

Exercise versus Control Group Post

Subjective skill evaluation scores were significantly higher in the exercise group compared to the control group (*p* = 0.029, large ES = - 2.68) after the intervention period. Post-testing also identified that the exercise group performed significantly better on several measurements of dynamic stability: EO OSI (*p* = 0.008, large ES = 3.02), EC OSI (*p* = 0.031, large ES = 2.41) and EC APSI (*p* = 0.021, large ES = 2.72) (Table 4.2).

Correlations

The Pearson's correlation revealed that several pre-testing strength and power measurements were significantly associated with subjective dance and skill evaluation (Table 4.4). Of these variables IMTP peak force (*r* = 0.48; *p* = 0.042), CMJ peak power (*r* = 0.56; *p* = 0.017), CMJ relative peak power (*r* = 0.49; *p* = 0.040), SJ peak power (*r* = 0.48; *p* = 0.044), right leg countermovement jump peak power (*r* = 0.64; *p* = 0.005) and left leg countermovement jump peak power (*r* = 0.48; *p* = 0.047) outputs were significantly associated with subjective dance performance. Furthermore, CMJ relative peak power was also significantly associated with subjective skill evaluation (*r* = 0.52; *p* = 0.026). No dynamic stability variables were significantly associated with dance performance measurements. Post-testing showed no significant relationship between strength and power and dance performance (Table 4.5).

Table 4.4: Correlation between Strength, Power and Subjective Evaluation Pre Intervention

	Variable *n* = 18								
Variable	1	2	3	4	5	6	7	8	9
IMTP (N) (1)	1.000	0.812**	0.156	0.757**	-0.011	0.867**	0.827**	0.484*	0.376
CMJ PP (W) (2)	-	1.000	0.500*	0.975**	0.303	0.962**	0.908**	0.555*	0.363
CMJ Relative PP (W/kg) (3)	-	-	1.000	0.544*	0.826**	0.474*	0.363	0.488*	0.522*
SJ PP (W) (4)	-	-	-	1.000	0.463	0.932**	0.878**	0.479*	0.363
SJ Relative PP (W/kg) (5)	-	-	-	-	1.000	0.281	0.188	0.138	0.358
RCMJ PP (W) (6)	-	-	-	-	-	1.000	0.868**	0.636**	0.349
LCMJ PP (W) (7)	-	-	-	-	-	-	1.000	0.475*	0.419
Subjective Dance Evaluation (8)	-	-	-	-	-	-	-	1.000	0.263
Subjective Skill Evaluation (9)	-	-	-	-	-	-	-	-	1.000

Pearson Correlation. Duplicate cells are indicated by the dashes to simplify the presentation. *r* = correlation coefficient; *n* = sample size. * Significant relationship between variables ($P < 0.05$); ** highly significant relationship between variables ($P < 0.01$).

Table 4.5: Correlation between Strength, Power and Subjective Evaluation Post Intervention

	Variable *n* = 18								
Variable	1	2	3	4	5	6	7	8	9
IMTP (N) (1)	1.000	0.805**	0.428	0.819**	0.316	0.877**	0.865**	0.348	0.156
CMJ PP (W) (2)	-	1.000	0.770**	0.957**	0.481*	0.928**	0.939**	0.403	0.088
CMJ Relative PP (3)	-	-	1.000	0.816**	0.829**	0.629**	0.633*	0.397	0.198
SJ PP (W) (4)	-	-	-	1.000	0.677**	0.898**	0.877**	0.450	0.108
SJ Relative PP (5)	-	-	-	-	1.000	0.394	0.344	0.389	0.231
RCMJ PP (W) (6)	-	-	-	-	-	1.000	0.953**	0.390	0.137
LCMJ PP (W) (7)	-	-	-	-	-	-	1.000	0.438	0.149
Subjective Dance Evaluation (8)	-	-	-	-	-	-	-	1.000	0.404
Subjective Skill Evaluation (9)	-	-	-	-	-	-	-	-	1.000

Pearson Correlation. Duplicate cells are indicated by the dashes to simplify the presentation. *r* = correlation coefficient; *P* = probability value; *n* = sample size. * Significant relationship between variables ($P < 0.05$); ** highly significant relationship between variables ($P < 0.01$).

CHAPTER 5

DISCUSSION

Dance is a highly technical and physically demanding pursuit, which has traditionally placed little importance on strength training for aesthetic performance. Therefore the primary goal of this research was to determine if using strength training with a group of adolescent female dancers could have a positive effect upon dance performance and other relevant variables including strength, power and dynamic stability. A secondary objective was to investigate the relationship between strength, power, dynamic stability and dance performance. The results showed that the inclusion of strength training can have a significant effect on selected physiological parameters and that improvements in these variables may have an effect on dance performance.

These findings agreed with previous studies, which have also found that the inclusion of various training techniques can have a significant effect on dance performance (Brown et al., 2007; Giakas et al., 2007; Noble et al., 1990) and selected performance related parameters (Barr et al., 1999; Koutedakis & Sharp, 2004; Kozai, 2012). The training protocol in the present study utilised theoretical concepts (Abt et al., 2004; Angioi et al., 2009b; Bowerman et al., 2014; Costa et al., 2004; De Luca et al., 1994; Evans et al., 2001; Galler et al., 2004a; Galler et al., 2004b; Hamilton et al., 1992; Kalichová, 2011; Redding & Swain, 2014) and interventional methods (Brown et al., 2007; Giakas et al., 2007; Koutedakis & Sharp, 2004; Kozai, 2012; Noble et al., 1990) from earlier studies. Based on previous literature dynamic stability, flexibility, strength and power were identified as the most influential factors upon qualitative elements of performance, rate of fatigue and injury in dancers.

In this study post-testing revealed that the exercise group was significantly more stable and less dependent on vision for postural regulation than the control group (Table 4.2). To improve conscious and unconscious postural control subjects need to be exposed to high-level motor tasks in unpredictable dynamic situations (Cheng et al., 2011; Perrin et al., 2002) and it is possible the dance-only training method did not adequately challenge these variables. Although the exact mechanisms of improved postural control is not clearly understood previous authors have attributed adaptation to central and peripheral neural adaptations, increased strength and flexibility (George & Rasool, 2007) and found a combination of strength training and plyometric methods effective for reducing center of pressure excursion (Brent et al., 2006). Hence the significant improvement in the strength training group may be a result of improved neuromuscular adaptation, which could heighten proprioceptive input and a shift in sensorimotor dominance.

The absence of change in the control group's stability indices indicates that dance-only training may insufficiently stress the sensory systems to improve postural automaticity. The investigations of this study did not permit a clear understanding of why this would have occurred and was allegedly unexpected. Theoretically, complex movements frequently performed by dancers requires the mastery of static and dynamic stability. To achieve this dancers need to learn precise technique that emphasizes good posture and body alignment while moving through different positions and shapes (Barry, Deckert, & Welsh, 2007; Regis, Riley, & Schmit, 2005). It is commonly assumed that dance training will provide dancers with an increased kinesthetic awareness, balance and exproprioception (Regis et al., 2005). Despite the technical and choreographic demands of various dance styles, the literature around postural control with dancers is inconclusive. Some authors have found that dancers tend to elicit better postural control compared to non-dancers (Aurenty et al., 1992; Bieć et al., 2011; Crémieux et al., 1999), whereas others have found no significant difference between dancers and non-dancers (Cheng et al., 2011). In some cases dancers have demonstrated a tendency to be more visual reliant (Cadopi et al., 1999) and displayed significantly worse balance regulation than other athletes and sedentary persons when visual feedback is removed (Perrin et al., 2002) (Table 2.1). The findings of the current study and Perrin et al. (2002) suggest that dance-only training may worsen postural regulation during visual deprivation and that the inclusion of strength and plyometric training methods may be necessary to improve dynamic stabilisation. Future research may benefit from investigating the mechanisms behind these adaptations and how improvements affect common functional tasks such as single-limb jumping and landing patterns.

Another interesting discovery was the large disparity between the current studies results and prior research with the same methodological approach. The current study applied methods used by Cheng et al. (2011) to asses postural sway, with the only exception being that the current study analysed the average of three trials rather than the best performance only. In the present study both the exercise and control group produced higher postural sway measurements than those taken by Cheng et al. (2011) for student dancers and non-dancers (Table 2.1). This result was unexpected as the dancers in the current study had significantly more training experience and should have been highly exposed to technical movements that require balance control. Since superior balance control is achieved through enhanced proprioception and by minimising the effects of external perturbations (Cheng et al., 2011), the highly significant difference between EO and EC stability indices (Table 4.3) may account for this discrepancy. The difference between these conditions indicates that the dancers in this study were particularly dependent on visual feedback to maintain stability and might lack proprioceptive input.

The variation between dancers in the present study and participants in Chen et al.'s (2011) study may also be a result of training history. During high speed rotations dancers learn to fixate on an environmental target to avoid post rotatory nystagmus. Post rotatory nystagmus is a term used to describe the reflexive movements of the eyes after rotational stimulation, which can disturb vision and cause dancers to become unsteady if they are not spotting accordingly (Choi et al., 2013; Osterhammel et al., 1968). Several studies have investigated the habituation training effect of visual fixation and have found that after rotational stimulation nystagmus is significantly reduced in dancers (Choi et al., 2013; Ohtsu et al., 1994; Osterhammel et al., 1968). One of the studies conducted by Ohtsu et al. (1994) found a positive correlation between length of dancing experience and the reliance on visual fixation to maintain equilibrium. It is possible that the participants in the current study were significantly more reliant on visual fixation to maintain stability because of their superior level of expertise and dance specific technical training. These finding also indicate that focusing on land marks to solve a task and increased practice may lead to decreased ability to cope with visual suppression.

Due to the robust postural control required to master complex movement patterns practiced during class, the lack of change observed in the control group's stability indices was unexpected. For example, the battement tendu which is a basic dance step takes years to master technical and aesthetic demands. To effectively perform a tendu without biomechanical error requires activation through the appropriate muscular structures, muscle balance, mobility through the thoracic spine and adequate core strength to stabilise and coordinate the movement (Batson, 2010). Despite these requirements technical dance training alone does not appear to provide sufficient overload to strengthen postural muscles, which work to stabilise the spine and maintain alignment throughout movement (Moffroid, 1997; Redding & Swain, 2014). Supporting this, prior EMG analysis has found that dance specific exercises performed at the barre do not evoke the exact same postural responses as when performed in centre. Performing an exercise in the centre of the room requires greater activation from the muscles to maintain trunk stabilisation, isolate gesture limb movement, establish and maintain an aesthetically pleasing posture (Batson, 2010; Evans et al., 2001). Both studies indicate that traditional training techniques may be less efficient at providing sufficient overload to strengthen the necessary structures to improve a dancer's ability to stabilise, predisposing a dancer to lower back pain and injury (Moffroid, 1997; Redding & Swain, 2014). The significant increase in postural control observed for the exercise group may therefore be a result of increased neural activation of the trunk musculature, which was a focus of the training program. This was not tested directly but future studies may benefit from investigating the neural adaptations of strength training and how they affect aspects of dance performance.

The training group in the current study showed a significant increase in strength and power following the intervention period. However, it is difficult to determine the cause of these adaptations because of the concurrent improvement in strength and power in the control group. Earlier studies that ensured groups were pair-matched by chronological age and maturation observed no significant change in the control groups strength or power measurements (Aquino et al., 2014; Brown et al., 2007; Giakas et al., 2007; Kozai, 2012; Noble et al., 1990). Due to the known effects of maturation on strength and power (Bailey et al., 2002; Daniels, 2000), the significant difference between groups in the present study was considered a major limitation and may account for the improvement observed in the control group. Additionally testing sensitivity and familiarisation may have been an issue. Previous studies in dancers have found no significant improvement in peak power but have seen a significant change in jump height and mean power (Brown et al., 2007), which was not assessed in the present study. The subjective evaluation used in this study found a highly significant improvement in jumping ability in the exercise group only. Hence, it is possible that the exercise group experienced a greater change in jump height than the control group. Furthermore because the participants had never done any strength or power testing before it is possible that there was a learning effect. Despite this study's limitations, previous research has found that, appropriately prescribed, strength and power training has the potential to improve biomechanical efficiency (Costa et al., 2004; Galler et al., 2004a; Kalichová, 2011), bone mineral density (Akers et al., 2010; Burrows & Hind, 2007; Clippinger et al., 2011), prevent jury and fatigue (De Luca et al., 1994; Koutedakis, 2004; Redding & Swain, 2014), and maximise aesthetic components and dance performance (Aquino et al., 2014; Brown et al., 2007; Giakas et al., 2007; Kozai, 2012; Noble et al., 1990). Wilmerding (2009) found that dancers had greater passive compared to active range of motion during a développé à la seconde. By introducing a dance specific leg raise exercise that emphasized engagement through the hip flexors, Wilmerding (2009) was able to improve limb elevation by 6.5 inches. Additionally it was found that dancers who did not engage in the specialised training experienced no change over the six week period. Such findings emphasize that strength training can be beneficial to the ongoing improvement of essential dance techniques. To address these issues future studies should allow more time for participant recruitment, pair-match groups appropriately and plan several familiarisation sessions.

There is very little research to date that has investigated the effects of strength training on aesthetic dance performance. The few studies that have evaluated dance performance found that only those who participated in the supplementary training experienced significant improvement in dancing ability (Brown et al., 2007; Kozai, 2012; Noble et al., 1990). The current study also found that only those who participated in the nine week strength training program experienced a significant improvement in dancing ability and technique (Table 4.2). Parameters evaluated included control, spatial awareness, accuracy of movements, technical ability, dynamics, timing and rhythmical accuracy (Table 3.1). Of these variables control was the most significantly affected (34.5 % improvement). The observed improvement in control may be a reflection of improved core strength, muscle balance and functional ability to regulate posture whilst landing from jumps and turns, lifting and lowering limbs and shifting of bodyweight. Although core strength and muscle balance was not directly assessed, this statement is supported by the significant improvement in dancing ability, dynamic stability and decrease in visual dependency detected in the exercise group.

Although the control group continued to meet all their dancing commitments there was no significant difference in dynamic stability or dancing ability after the nine week monitoring period. Consequently, it could be inferred that the dance-only training method provided inadequate overload or variation. It is well documented within scientific literature that progressive overload, specificity and variation are essential to adaptation (Baechle & Earle, 2008). Ineffective prescription of these variables into the exercise stimulus will deliver suboptimal load to the neuromuscular system and may lead to decrements in muscular strength (Hakkinen, 1992), postural control (Filipa, Byrnes, Paterno, Myer, & Hewett, 2010) and could be attributed to the strength deficits

(Bennell et al., 1999; Jamurtas & Koutedakis, 2004) and imbalances (Hamilton et al., 1992) previously observed in this population. It is possible that insufficient strength, low levels of cardiovascular conditioning, lack of variability and an increasing imbalance between training and recovery leading up to performance season predisposed dancers in the control group to the effects of overtraining (Koutedakis, 2004). Post-testing was incidentally scheduled around the dancers' end of year show cases, so it is possible that the dancers were training significantly more towards the end of the interventional period in preparation for these key performances. If this was the case overtraining could affect neurological function, change hormonal markers, alter immune function, decrease metabolic capacity and prompt performance to plateau or decrement (Baechle & Earle, 2008; Koutedakis, 2004). These factors could account for the lack of change in dancing ability and trending decrease in dynamic stability observed in the control group.

No significant difference in BMI, body fat or sum of skinfolds was observed in the exercise group (Table 4.1). There was a significant change in mass but this could be related to the significant change in height also observed. The strength training group had several participants who were mid PHV, which is concurrent with peak height and weight velocities (Bailey et al., 2002; Takaishi, Tanner, & Whitehouse, 1966). Unsubstantiated beliefs that resistance training will negatively affect body composition and undermine important aesthetic appearances, was determined as one of the primary reasons dancers abstained from strength training techniques (Giakas et al., 2007). The current findings and those of previous authors (Brown et al., 2007; Noble et al., 1990) deter these traditional beliefs and may help encourage dancers to incorporate alternative training modalities.

Given that the strength training program in the current study had no significant effect on BMI or body fat measurements and the changes in mass were more likely the result of growth, it could be assumed that adaptations were primarily due to neural effects. According to Carroll, Carson, and Riek (2001) strength changes in the absence of significant morphological adaptation provides evidence that enhanced performance may be the result of neural elements. Neural adaptation has the potential to increase rate of force development and peak force outputs (Aagaard, Andersen, Dyhre-Poulsen, Magnusson, & Simonsen, 2002; Carroll et al., 2001). Improvements in the magnitude and rate of force development may be a way for dancers to enhance performance (Jamurtas & Koutedakis, 2004; Wyon, Allen, Angioi, Nevill, & Twitchett, 2006). The results of this study indicate that strength, power and dancing ability can be improved through resistance training without contributing to significant muscular hypertrophy. To obtain a more detailed understanding of how strength training may affect body composition future studies should look into using more accurate methods of assessment such as dual-energy x-ray absorptiometry (DEXA) scan. Using a DEXA scan to track compositional changes will provide a more accurate and reliable measurement and can provide additional information regarding changes in lean mass and bone mineral density, which is a known concern for this population (Akers et al., 2010).

Pre-testing identified a significant relationship between measurements of strength, power and dance performance. In other disciplines such as sprinting a strong relationship between strength-power parameters and overall performance has already been established, with the SJ or CMJ being identified as the best predictors (Argeitaki et al., 2008). Similarly the best predictor in the current study was the CMJ particularly when performed unilaterally (Table 4.4). It is possible the single leg condition was a stronger predictor due to the amount of movements which are performed by dancers on a single limb. During training ballet and modern dancers have a tendency to jump and land on a single limb 50 % and 89 % of the time, respectively (Hagins et al., 2012). Despite the initial relationship, the correlation was non-existent upon post-testing. It is possible that the improvements in strength and power in both groups and improvement in dance performance in the exercise group only caused this to occur. These findings strengthen an earlier conclusion that possibly the improvements seen in technical and dancing ability at post-testing were possibly due to enhanced proprioceptive input and postural regulation. If a dancer is more stable they theoretically should exhibit greater control over frequently encountered single leg movements. Future studies should investigate the effects of strength training on single leg postural control.

Limitations

There were several major limitations with the present study. The first limitation was the inability to pair-match and randomly allocate groups as intended. It was practically unrealistic to pair-match the groups due to logistical difficulties. The limited time to complete the study combined with the restricted availability of the dancers was the primary barrier to participation. Participant numbers were lower than desired, which affected the group sizes and therefore the statistical power of all results.

The inability to pair-match groups and the small sample size may explain why there was also a significant increase in the control group's strength and power measurements. The logistical difficulties encountered meant that the control group was significantly more mature and less diverse than the exercise group. During adolescence it is important that the effects of maturation are controlled for as the different stages of maturation will have a profound effect upon hormones, growth, flexibility, strength and coordination (Bailey et al., 2002; Daniels, 2000). For example during PHV the bones tend to grow faster than the muscles, which causes a decrease in flexibility and strength (Daniels, 2000). Whereas post PHV muscle mass and strength development is accelerated due to a surge in the amount of circulating androgens. The significant maturation imbalance between groups and the considerably smaller sample size of the control group may partially explain the strength and power results.

There were also several issues around the subjective dance evaluation tool and its ease of use. Firstly it was a subjective appraisal so it is possible that the understanding and interpretation was different between judges. If so this may have adversely affected the fairness, validity, reliability and sensitivity of the evaluation. It was also an immensely time consuming evaluation tool, that required multiple judges and participants to be assessed simultaneously. The secondary tool developed for the purpose of this study did attend to some of the issues identified with the primary subjective dance evaluation means but it was a novel concept, meaning its reliability is unknown.

Practical applications

The present data has shown that a nine week strength training program with adolescent female dancers can have positive effects on indices of dynamic stability and selected technical and dance performance parameters. Additionally improvements in strength and power did not hinder dance performance and the dance-only approach may not provide enough overload to enhance postural control and aspects of dance performance. These results indicate that strength training is not only beneficial for dancers but possibly essential to continually developing variables of performance. Supplementary training should consider a dancers weaknesses, be closely monitored and implemented well before scheduled performances.

Future recommendations

Future studies should investigate a larger subject pool and ensure practicalities do not impair the ability to correctly pair-match groups. Previous studies have used subject pools of a similar size to the current study but have pair-matched accordingly. This may explain the lack of improvement in the control groups in these instances (Giakas et al., 2007; Koutedakis & Sharp, 2004; Kozai, 2012; Noble et al., 1990; Wilmerding, 2009). Additionally it would be useful to develop a non-subjective quantitative tool that assesses technical ability and overall dance performance. The issue around subjective evaluation is it can be understood and interpreted differently, which would adversely affect the fairness, validity, reliability and sensitivity of the assessment tool. Developing a performance evaluation tool and using 3D kinematic analysis to quantify the selected variables could be an ideal avenue to pursue. Such methods have been used by (Kalichová, 2011) to analyse the determinants of a classical jump but not to asses performance. Finally it may be beneficial to explore the effects of various training modalities and develop more dance specific strength and power based exercise progressions.

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APPENDIX 1

10 April 2014

AUT UNIVERSITY

Rebecca Dowse
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Dear Rebecca

Thank you for submitting your PGR1 Research Proposal application for the Master of Sport and Exercise.

Your proposal has been reviewed and approved by the Faculty of Health and Environmental Sciences Postgraduate and Research Committee 4 April 2014 meeting.

Details are:

Current programme:	Master of Sport and Exercise
Enrolment:	Full-time enrolment
Student ID	0834318
Topic:	The effects of a training intervention on strength, power and performance in dancers.
Primary supervisor:	Mike McGuigan
Secondary supervisor:	Craig Harrison
Start date:	14 April 2014
Expected completion date:	10 April 2015

For more information about the programme of study, please refer to the *Postgraduate Handbook.*

The AUT website for forms and handbooks is:
http://www.aut.ac.nz/study-at-aut/current-students/postgraduate-support

Yours sincerely

Associate Professor Erica Hinckson
Associate Dean (Postgraduate)
Postgraduate and Research Office
Faculty of Health and Environmental Sciences

Cc Primary supervisor Professor Mike McGuigan
Cc Secondary supervisor Craig Harrison

APPENDIX 2

AUTEC
SECRETARIAT

26 May 2014

Mike McGuigan
Faculty of Health and Environmental Sciences

Dear Mike

Re Ethics Application: **14/138 The effects of a training intervention on strength, power and performance in dances.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 26 May 2017.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 26 May 2017;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 26 May 2017 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Rebecca Dowse radowsee@gmail.com