EVALUATION OF PHYSICAL FITNESS IN RELATION TO PERFORMANCE AND INJURY SEVERITY IN CONTEMPORARY DANCE

Manuela Angioi MSc

A thesis submitted in partial fulfilment of the requirements of the University of Wolverhampton for the degree of Doctor of Philosophy

School of Sport, Performing Arts and Leisure

University of Wolverhampton

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Signature………………………………………………

Date………………………………………………
ABSTRACT

Dance has attracted little scientific interest on the effects of physical fitness improvements on performance and injury severity, particularly with respect to contemporary dance. The main aims of the current work were: a) to observe the physical demands of dance performance; b) to develop a reliable dance-specific performance tool; c) to assess the association between selected physical fitness parameters and performance in contemporary dance by using a new reliable method (AC test); d) to assess selected physical fitness parameters in relation to injury severity in contemporary dance; e) to study the effects of increased fitness parameters on performance through a randomized controlled trial.

A total of 50 performances, performed by 20 dancers, were monitored by using a portable accelerometers (SWA armbands) and heart rate monitors while 45 performances in DVDs were video analysed. Six dancers and two dance teachers were recruited to test a newly developed performance tool. A sample made of 41 dancers were recruited and assessed for aerobic fitness (DAFT), lower body muscular power (jump height test), upper body muscular endurance (press-ups test), flexibility (active and passive hip ROM), body composition (skinfolds), performance (n=17) and injury severity (n=16). In order to investigate the effects of the supplementary fitness training on performance, 24 of the total 41 dancers, were randomly assigned to either an intervention (n=12) or control (n=12) group. The intervention group undertook a specifically designed exercise-training programme (circuit and WBV training) lasting six weeks. Both groups were re-tested for physical fitness levels and performance at the end of the intervention period.

Results revealed that performance intensities varied from light to moderate while these were observed with the use of pliés and jumps as well as lifting other dancers. Based on the seven most frequently used criteria by selected pre-professional contemporary dance institutions and companies, a novel performance tool (AC tool) was developed with an inter-rater reliability of r=0.96. There was a significant correlation between aesthetic competence (AC) scores and jump ability (r=0.55) and press-ups (r=0.55), respectively. Stepwise backward multiple regression analysis revealed that the best predictor of AC was press-ups ($R^2=0.30$, $p=0.03$, 95% confidence intervals=0.11–1.34). Univariate analyses also revealed that the interaction of press-ups and jump ability improved the prediction power of AC ($R^2=0.44$, $p=0.004$, 95% confidence intervals=0.009–0.04). Pearson’s correlation coefficients detected significant negative correlations between the mean score recorded for injury severity (expressed as TDO) and lower body muscular power (r=-0.66; $p=0.014$); backward regression analysis also revealed that, from all studied parameters, the strongest predictor of TDO was lower body muscular power ($p=0.014$). For the intervention group repeated measures ANOVA revealed significant increases (pre vs. post) in aerobic fitness ($p<0.05$), lower body muscular power ($p<0.05$), upper body muscular endurance ($p<0.05$) and performance ($p<0.05$). Linear regression analyses indicated that the only significant predictor of AC was aerobic capacity ($F=7.641$; $p=0.03$); the interaction of press-ups and aerobic capacity ($F=6.297$; $p=0.036$), and lower body muscular power with aerobic capacity ($F=5.543$; $p=0.05$) demonstrated an improved prediction power.

These results show that the observed contemporary dance performance is an intermittent type of activity of moderate intensity. Given the reliability of the AC tool, it is concluded that upper body muscular endurance and jump ability best predict AC of contemporary dancers. Reduced lower body muscular power is associated with increased severity of injuries. Finally, supplementary exercise training significantly increases lower body muscular power, upper body muscular endurance and aerobic fitness, which in turn are beneficial to improve AC of contemporary dancers.
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<tr>
<td>AC</td>
<td>Aesthetic Competence</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>ATP</td>
<td>Adenosine tri-phosphate</td>
</tr>
<tr>
<td>ADP</td>
<td>Adenosine-bi-phosphate</td>
</tr>
<tr>
<td>%BF</td>
<td>Percentage Body Fat</td>
</tr>
<tr>
<td>BIA</td>
<td>Bioelectrical Impedance Analysis</td>
</tr>
<tr>
<td>BL</td>
<td>Blood Lactate</td>
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<tr>
<td>BMD</td>
<td>Bone Mineral Density</td>
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<tr>
<td>BMI</td>
<td>Body Mass Index</td>
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<tr>
<td>CI</td>
<td>Confidence Interval</td>
</tr>
<tr>
<td>CRT</td>
<td>Circuit Resistance Training</td>
</tr>
<tr>
<td>DAFT</td>
<td>Dance Aerobic Fitness Test</td>
</tr>
<tr>
<td>DXA</td>
<td>Dual Energy X-ray Absorptiometry</td>
</tr>
<tr>
<td>EE</td>
<td>Energy Expenditure</td>
</tr>
<tr>
<td>FFM</td>
<td>Fat Free Mass</td>
</tr>
<tr>
<td>GRF</td>
<td>Ground Reaction Forces</td>
</tr>
<tr>
<td>HR</td>
<td>Heart Rate</td>
</tr>
<tr>
<td>IC</td>
<td>Indirect Calorimetry</td>
</tr>
<tr>
<td>ICC</td>
<td>Intraclass Correlation Coefficient</td>
</tr>
<tr>
<td>JL</td>
<td>Hop on the left leg</td>
</tr>
<tr>
<td>JR</td>
<td>Hop on the right leg</td>
</tr>
<tr>
<td>MA</td>
<td>Match Analysis</td>
</tr>
<tr>
<td>MET</td>
<td>Standard Metabolic Equivalent</td>
</tr>
<tr>
<td>O₂</td>
<td>Oxygen</td>
</tr>
<tr>
<td>PCr</td>
<td>Phosphocreatine</td>
</tr>
<tr>
<td>PD</td>
<td>Programme Duration</td>
</tr>
<tr>
<td>RCT</td>
<td>Randomized Controlled Trial</td>
</tr>
<tr>
<td>REE</td>
<td>Resting Energy Expenditure</td>
</tr>
<tr>
<td>RM ANOVA</td>
<td>Repeated Measure Analysis of Variance</td>
</tr>
<tr>
<td>ROM</td>
<td>Range Of Motion</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>SE</td>
<td>Standard Error</td>
</tr>
<tr>
<td>SF</td>
<td>Skinfolds</td>
</tr>
<tr>
<td>SPSS</td>
<td>Statistical Package for the Social Sciences</td>
</tr>
<tr>
<td>SVJ</td>
<td>Standing Vertical Jump</td>
</tr>
<tr>
<td>SWA</td>
<td>Sensewear Pro Armband</td>
</tr>
<tr>
<td>TDO</td>
<td>Total Days Off</td>
</tr>
<tr>
<td>TLM</td>
<td>Total Lean Mass</td>
</tr>
<tr>
<td>TM</td>
<td>Time Motion</td>
</tr>
<tr>
<td>VO₂</td>
<td>Volume of Oxygen Uptake</td>
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<tr>
<td>VO₂max</td>
<td>Maximal Oxygen Uptake</td>
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<tr>
<td>WAT</td>
<td>Wingate Anaerobic Test</td>
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<tr>
<td>WBV</td>
<td>Whole Body Vibration</td>
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Finally many thanks to my beloved Joseph for his encouragement and support.
RESPONSIBILITIES

The present Thesis is part of a project funded by the Arts and Humanities Research Council, U.K., which was designed to investigate the effects of physical fitness levels in dance. Following an interview, I was offered a PhD studentship by the University of Wolverhampton in order to be part of this project and investigate the effects of increased physical fitness levels on performance and injury severity in contemporary dance. My responsibilities in the studies that constituted this Thesis were:

- Structure of the methodology.
- Writing and gaining the ethical approval from the School of Sports, Performing Arts and Leisure (SSPAL).
- Recruitment of participants from several contemporary dance companies and vocational (i.e. pre-professional) dance institutions.
- Fitness, performance and injury severity assessment of dancers.
- Data input, analysis and interpretation.
- Writing and publishing the results in scientific and dance congresses and peer-reviewed scientific journals.
Dancers are the athletes of God (Albert Einstein)
Dance utilizes the human body as its instrument of expression (please see Appendix 1: the development of contemporary dance). For this reason, it has been suggested that dance performance requires support from enhanced physiological capabilities including flexibility, muscular strength, power and cardiovascular endurance (Chatfield et al. 1990). However, there is a need for better understanding of the fitness status of contemporary dancers to help enhance the performance potential of dancers as well as reduce their injury severity.

Physical fitness, which is “the individuals' ability to meet the demands of a specific physical task” (Koutedakis and Sharp 1999, p.89), includes aspects such as: aerobic and anaerobic capacity; muscle strength; power and endurance; flexibility; body composition (Heyward 2002). Fitness training has started only recently to be considered as a complementary activity within the traditional dance setting, mainly because of the stereotype that dancers, as artists, do not follow the athletes’ steps in terms of physical preparation (Krasnow and Kabbani 1999). Nevertheless, dancers are engaged in long hours of daily training, followed by rehearsals and performances (Wiesler et al. 1996; Shah et al. 2008) but, unlike athletes, they do not have predictable annual seasons where a regular training schedule can be periodized to include rest following increased intensity (Liederbach 2000). For these reasons many dancers succumb to problems such as the overtraining syndrome (or burnout), when the dancers’ ability to adapt successfully to changes to their environment ceases to function (Koutedakis 2000; Liederbach and Compagno 2001). This may partly explain the high injury rates found in dance (Weigert 2005; Weigert and Erickson 2007). However, it remains unclear whether physical fitness levels affect injury severity of dancers.

Dancers are expected to be fit to sustain the physical tasks they are required to do, since technical aspects of dance call on fitness components “to a very high degree”
(Brinson and Dick 1996, p.61). It has been postulated that the implementation of specific fitness training protocols within traditional dance training may better prepare dancers for performance requirements (Koutedakis and Jamurtas 2004; Wyon 2005). This is supported by preliminary data revealing that aspects of contemporary dance performance benefit from improvement in specific physiological capabilities such as muscular strength and power (Brown et al. 2007; Koutedakis et al. 2007), which is in line with rhythmic gymnastics (Hume et al. 1993), where artistry is marked together with other aspects by highly trained judges. However, the methodology used by Brown and Koutedakis for these aspects of contemporary dance performance is inadequate since they used a non-objective (i.e. non-standardized and non-validated) method for performance assessment (Brown et al. 2007; Koutedakis et al. 2007).

Unlike physical fitness and its well defined components (Heyward 2002), the description and quantification of dance performance is less clear because the effectiveness of dance performance relies on subjective elements (Koutedakis 2009) and there are no validated tools that assess full or selected aspects of performance. Nevertheless, the development of objective systems to measure performance proficiency has been recommended to investigate the relationship between physical fitness levels and dance performance (Welsh 2003; Koutedakis 2009). To date only one study has attempted to quantify and score specific qualitative aspects of dance performance such as overall proficiency, full body involvement, articulation and skills (Krasnow et al. 1997).

Previous research in contemporary dance has concentrated on selected fitness attributes of dancers including: aerobic and anaerobic capacities (Chmelar et al. 1988; Chatfield et al. 1990; Padfield et al. 1993); muscular strength (Koutedakis et al. 1997b; Harley et al. 2002); anthropometric attributes (Berlet et al. 2002; Yannakoulia et al. 2004); physiological demands of contemporary dance class and performance (Wyon et al. 2002; Wyon et al. 2004; Wyon and Redding 2005); types of injury and their occurrence (Weigert and Erickson 2007). These studies have been mainly observational, without using robust
methodological designs and appropriate statistical analyses to investigate the possible relationship between the observed physical fitness levels and performance and/or injury severity.

In summary, there are no published reliable methods for assessing contemporary dance performance in relation to physical fitness levels. There is also a dearth of relevant data regarding the association between physical fitness levels, performance and severity of injury in contemporary dance. Most importantly, there is a need to confirm preliminary data reporting that increases in selected physical fitness levels are beneficial to enhance contemporary dance performance. It appears that the association between fitness and dance performance, therefore, is an under-investigated research area, which merits further attention, given its importance not only in improving performance potential but also to reduce injury severity. This research project aims to investigate the following original research question: do improvements in selected physical fitness components affect performance (assessed via a reliable tool) and injury severity in contemporary dance?

The Thesis, which is organised in a number of inter-related chapters, aims to: a) review systematically the literature regarding physical fitness levels of contemporary dancers and the effectiveness of supplementary exercise training on contemporary dance performance; b) observe the physical demands of contemporary dance performance by exploring the actual energetic cost of on-stage performance assessed via portable accelerometers and quantifying moves imposed on dancers during performance using video analysis; c) develop a reliable system to measure contemporary dance performance; d) assess the association between selected physical fitness parameters and contemporary dance performance; e) assess the association between selected physical fitness parameters and injury severity in contemporary dance; f) investigate the effects of increased fitness levels on performance, through a randomized controlled trial (RCT), by integrating supplementary exercise sessions into existing dance schedules of participants.
The following statistical null hypotheses are formulated in relation to the three chapters (Study 2, 3 and 4 respectively) which constitute the core of the Thesis:

- There will be no significant association between physical fitness parameters and contemporary dance performance.
- There will be no significant association between selected physical fitness levels and injury severity in contemporary dance.
- There will be no significant improvements in performance following a six-week supplementary training.
II. REVIEW OF THE LITERATURE


The muscles’ ability to convert chemical energy from food into muscular work is directly related to performance in dance and sport alike. As in other sports, dance performance depends on a large number of technical, medical, psychological, nutritional, economic, environmental and physiological elements. For these reasons, it has been suggested that professional dancers need to be physically, technically and psychologically prepared (Koutedakis and Jamurtas 2004).

The last three decades have witnessed an exercise and fitness- “boom”, reflected in the large number of people engaged in some forms of physical activity (Koutedakis and Sharp 1999, p.89). Physical fitness primarily consists of aspects related to muscle and its function. It depends on the individual’s ability to work under aerobic and anaerobic conditions, and on their capacity to develop high levels of muscular tension (or strength); muscular power, joint mobility, muscle flexibility and body composition are also equally important components of physical fitness (Heyward 2002).
The physical demands placed on dancers from current choreography and performance schedules make their physiology and fitness just as important as skill development. As a result, they have been referred to as “performing” (Koutedakis and Jamurtas 2004) and/or “aesthetic” (Wyon 2007) athletes who remain subject to the same unyielding physical laws as other athletes. It has been suggested that there are two main physiological requirements necessary for dancers (Koutedakis and Jamurtas 2004); one is a large reserve of power, required for explosive jumps and high elevation or during the act of a lift (Koutedakis and Sharp 1999, p.106), which lasts just a few seconds, energised by phosphocreatine (PCr); the other requirement is muscular endurance, which occurs when a relatively high power output is maintained for 30-60 seconds. This could be, for example, when holding a partner in a lift, or in a dance sequence during training (Koutedakis and Sharp 1999, p.106). Published studies revealed that improvements in lower body muscular strength and power

**Figure 1:** Diagram representing physical fitness components.
have positive effects on aspects of contemporary dance performance (Brown et al. 2007; Koutedakis et al. 2007). Since contemporary dance is predominantly an intermittent type of exercise (Wyon 2005), similar to soccer or tennis where explosive bursts of action are followed by moments requiring precision and skill, dancers would further benefit from a good aerobic foundation (Allen and Wyon 2008), while a high anaerobic threshold would limit the deleterious effects of metabolite accumulation in activities requiring balance, poise and co-ordination (Baldari and Guidetti 2001). However, although dance involves several hours of daily practice, published data reveal that female dancers have reduced aerobic fitness levels compared to athletes from other sports, such as gymnasts (Baldari and Guidetti 2001).

When authors report that dancers are less fit compared to other athletes, they justify their arguments based on data deriving mainly from ballet (Kirkendall and Calabrese 1983; Koutedakis and Jamurtas 2004). Moreover, when referring to dancers, authors rarely make a differentiation regarding the levels of dancers (i.e. student and/or professional). Such differentiation may be important since non professional and professional athletes have significant differences in fitness levels, which in turn, have significant implication in performance. In general, ballet dancers have been consistently found to demonstrate reduced fitness levels than other athletic populations (Cohen et al. 1982; Reid 1988; Bennel et al. 1999). It has been postulated that contemporary dancers may also be relatively unfit as the main sections of their training (i.e. class and rehearsal) do not adequately stress the physiological system (Chatfield et al. 1990; Wyon et al. 2002; Wyon et al. 2004). Furthermore, it remains unclear whether improved physical fitness affects aspects of dance performance in student and professional contemporary dancers.

The present review has systematically investigated the literature in order to explore: a) the aerobic/anaerobic fitness, muscular strength and body composition characteristics of contemporary dancers and b) whether supplementary exercise training improves aspects of contemporary dance performance. Three databases [Medline, Cochrane and the Cumulative
Index to Nursing & Allied Health (CINAHL) research database] were searched to identify publications in English (published from 1978 until May 2008) regarding fitness components of contemporary dancers. The Medical Subject Heading (MeSH) terms "physical fitness", “exercise”, “performance”, “training”, "aerobic", "anaerobic", “strength”, “body composition”, “fat free mass”, were employed in combination with "modern dance", “contemporary dance”, “dance” and “dancers". Full articles were retrieved for assessment if the information in the abstract fulfilled the following inclusion criteria: (i) studying any of the main fitness components in combination with contemporary dance, and (ii) involving professional dancers and dance students in vocational and university training. I chose to include dance students enrolled in both vocational and university courses because their training involves contemporary dance alone or in combination with other dance styles. Editorials, conference proceedings and studies incorporating only ballet or other dance styles alone were excluded. If the abstract did not provide sufficient information for this process, then the full-text manuscript was examined. A flow diagram of the studies identified and included appears in Figure 2 (page 18).
Initial analyses revealed 263 articles. From those articles, 24 fulfilled the inclusion criteria and were included for further analysis. The references of all of these articles were examined in order to further identify relevant publications; nine more studies were found. From the 33 included articles, 11 publications were reviews (none of which was a systematic review); only one article was a randomised controlled trial (RCT), while the remaining 21 publications were non-randomised research investigations. The RCT investigated the effects of a combined aerobic and strength exercise intervention on contemporary dance performance. From the non-randomised studies, 13 primarily investigated aerobic/anaerobic related physiological variables in relation to contemporary dancers, four studies were on strength-related parameters and four were on body composition. The comparisons for maximal oxygen uptake ($\text{VO}_{2\text{max}}$) and body composition characteristics between female professional and student contemporary dancers as well as the equivalent values from other sports appear in Table 1 (page 19).

Figure 2: Articles identified
Table 1: Maximal oxygen uptake and body composition characteristics of female contemporary professional dancers and dance students compared to other athletes.

<table>
<thead>
<tr>
<th>Sport/Activity</th>
<th>Level</th>
<th>VO$_{2}^{\text{max}}$ (ml.kg$^{-1}$min$^{-1}$)</th>
<th>Body Composition</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contemporary Dance</td>
<td>Professional</td>
<td>49.1</td>
<td>21.4</td>
<td>42.9 (Chmelar et al. 1988; Berlet et al. 2002; Harley et al. 2002)</td>
</tr>
<tr>
<td></td>
<td>Students</td>
<td>39.2</td>
<td>21.3</td>
<td>42.5 (Yannakoulia et al. 2000; White et al. 2004)</td>
</tr>
<tr>
<td>Ballet</td>
<td>Professional</td>
<td>42.2</td>
<td>17.4</td>
<td>42.3 (Chmelar et al. 1988; Van Marken Lichtenbelt et al. 1995; Kaufman et al. 2002)</td>
</tr>
<tr>
<td></td>
<td>Students</td>
<td>40.8</td>
<td>19.9</td>
<td>41.5 (White et al. 2004)</td>
</tr>
<tr>
<td>Gymnastics</td>
<td></td>
<td>49.6</td>
<td>14.4</td>
<td>33.7 (Goswami and Gupta Weimann 2002)</td>
</tr>
<tr>
<td>Football</td>
<td></td>
<td>50.0</td>
<td>20</td>
<td>50.3 (Mladenović 2005; Bandyopadhyay 2007)</td>
</tr>
<tr>
<td>Endurance Running</td>
<td></td>
<td>77</td>
<td>35.8</td>
<td>23.8 (Boileau et al. 1982; Mitsuzono and Ube 2006)</td>
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<td>Volleyball</td>
<td></td>
<td>46.5</td>
<td>53.2</td>
<td>23.4 (Tsunawake et al. 2003; Malousaris et al. 2008)</td>
</tr>
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<td>Swimming</td>
<td></td>
<td>58</td>
<td>47.6</td>
<td>20.2 (Alméras et al. 1997; Rodriguez 2000)</td>
</tr>
<tr>
<td>Sedentary</td>
<td></td>
<td>44</td>
<td>24.4</td>
<td>26.5 (Novak et al. 1978; Astrand and Rodhal 1986; Van Marken Lichtenbelt et al. 1995)</td>
</tr>
</tbody>
</table>

**Aerobic Fitness**

Aerobic or cardiorespiratory fitness is the body’s ability to sustain prolonged exercise and involves all aspects of the uptake, transport and utilization of oxygen (O$_2$) to release levels of energy used for physical activity purposes. The aerobic system is the most economical and long-lasting but the least powerful (Crisafulli and Concu 2007). Hence, its properties (low power and long duration) make it the most exploited metabolism in dance works marked by a steady effort over at least five minutes. Nevertheless, cardiorespiratory fitness training is recommended for any dancer since low levels of aerobic fitness have been associated to increased fatigue, which in turn has a negative impact on overall performance (Wilmore and Costill 1999) including reduced mental concentration and higher injury rates (Knapic et al. 1992).

The aerobic (or oxidative) system begins with glycolysis (the breakdown of carbohydrates -either glycogen stored in the muscle or glucose in the blood- to produce ATP) (Brooks and Fahey 1984), and it uses primarily carbohydrates and fats as substrates according to the intensity of exercise. At rest about 70% of the ATP produced is derived
from fats and 30% from carbohydrates. Fat is the substrate used during prolonged, sub-maximal, steady-state type of exercise while carbohydrates are used during high-intensity aerobic exercise (Powers and Howley 2007). Because of the O₂ presence, the end product of glycolysis, pyruvic acid, is transported to the mitochondria to enter in the Krebs cycle, where a series of reactions continue the oxidation to produce lastly 38 molecules of adenosine-tri-phosphate (ATP) for each molecule of glucose (Brooks and Fahey 1984). When fats are used as main substrate, triglycerides stored in fat cells are broken down by the enzyme hormone-sensitive-lipase to release free fatty acids in the blood and that subsequently enter in the mitochondria located the muscle fibres, where are broken down (beta oxidation) and result in the formation of acetyl – COa and hydrogen atoms. The former enters the Krebs cycle and the COa and hydrogen atoms are carried by NAD⁺ and FAD⁺⁺ to the electron transport chain (Brooks and Fahey 1984).

Maximal oxygen uptake (VO₂max), which is the highest rate of oxygen consumption attainable during maximal or exhaustive exercise (Wilmore and Costill 1999), is the most important physiological determinant of medium and long duration dance performance (i.e. longer than six minutes). VO₂max can be increased, in high dependence of its initial value (Midley et al. 2006) and may rapidly decline, in dependence of fitness status after short term periods of rest (Mujika and Padilla 2000).
Figure 3: Aerobic metabolism
Figure adapted from http://www.life.umd.edu/classroom/bsci424/BSCI223WebSiteFiles/LectureList.htm
Dance and Aerobic Fitness

A number of authors have investigated aerobic fitness levels of contemporary dancers and dance students, using laboratory-based tests. From the total of the 13 studies, VO\(_{2}\max\) was found to range from 39.2±1.9 to 50.7±7.5 ml kg\(^{-1}\) min\(^{-1}\). However, these data refer to both male and female professional dancers and dance students. As such, different values for males and females could not be reported in Table 1 (page 19).

Three authors investigated the VO\(_{2}\max\) among different levels of contemporary dance students and they found no significant differences existed in a) university, graduate and professional (Wyon et al. 2002), b) performing and recreational adolescent dancers (Padfield et al. 1993) and c) intermediate and advanced dance students (Chatfield et al. 1990).

Ballet and contemporary dance students did not demonstrate significant differences in cardiorespiratory fitness (White et al. 2004). In contrast, professional contemporary dancers exhibited significant higher values of VO\(_{2}\max\) than their ballet counterparts (Chmelar et al. 1988).

In comparison to non-dancers, it was found that the VO\(_{2}\max\) values of intermediate and advanced dance students were significantly increased. However, no significant differences were detected between beginners and non-dancers (Chatfield et al. 1990). These results are in line with the study by Novak (Novak et al. 1978) which found that female dancers had a significantly higher mean VO\(_{2}\max\) value compared to sedentary females of a similar age range. Despite the consistently higher aerobic capacity of dancers compared to controls, an investigation revealed no significant differences for all structural and functional cardiac indices between full-time contemporary dance students and age-gender matched controls (Whyte et al. 2003).

By investigating the effects of supplementary exercise training on dance performance (Brown et al. 2007; Koutedakis et al. 2007), these recent studies are the only known examples where aerobic fitness and contemporary dance performance were
simultaneously considered. Overall performance and dance technique were assessed by Koutedakis and colleagues (Koutedakis et al. 2007), who designed a specific dance performance test. By adopting the marking procedures used in sports (e.g. gymnastics and ice skating), two teachers and former professional dancers, were recruited as judges. The criteria used for the performance test included: number of repetitions; posture and alignment; use and articulation of upper body and arms lower body and feet; total body coordination; presentation and movement. Results from the performance test were then used to investigate the relationship between dance performance and aerobic (VO$_{2\text{max}}$) levels of the participants. The findings of this study reveal that aerobic training increases VO$_{2\text{max}}$ and aspects of dance performance in contemporary dance students (Brown et al. 2007; Koutedakis et al. 2007). Table 2 (page 26) depicts the individual results from all studies conducted in relation to aerobic/anaerobic capacity of contemporary dancers.

**Anaerobic Fitness**

Anaerobic fitness or local muscular endurance operates in the absence of oxygen and involves two high energy sources: phosphocreatine (PCr) and glycolysis. Unlike aerobic fitness, its characteristic is to provide high levels of power but over a short time duration, thus anaerobic fitness is necessary for fast and explosive dance movements (Wilmore and Costill 1999; Baechle and Earle 2000).

The energy released by the breakdown of PCr is used to rebuild adenosine-tri-phosphate (ATP). During the first few seconds of intense muscular activity ATP is maintained at a relatively constant level, but the PCr level decreases steadily as it is used to replenish the depleted ATP. However, at exhaustion, both ATP and PCr levels are low and are unable to provide the energy for further muscle contraction. Hence, the capacity to maintain ATP levels with the energy from the PCr is limited to a maximum of 15 seconds. The glycolitic system, which involves glycolysis, is another method of ATP production through the breakdown of glucose or glycogen. Glycolysis requires 12 enzymatic re-actions
for the breakdown of glycogen (which is synthesised from glucose by a process called glycogenesis) to pyruvate, which is in absence of O$_2$ is converted to lactic acid. The net gain from this process is three molecules of ATP for each mole of glycogen broken down and two molecules of ATP for each mole of glucose (Wilmore and Costill 1999). The combined actions of PCr-ATP and glycolytic systems predominate during the early minutes of high-intensity exercise. When a very large surge of power is required from one to few seconds (i.e. the act of a lift) we refer to anaerobic power (which is supplied by the PCr system), while when a high power output must be sustained up to around 30 to 60 seconds (i.e. jump sequence), we refer to anaerobic endurance, which is energized by glycolysis.

**Figure 4:** Anaerobic metabolism
Figure adapted from [http://herkules.oulu.fi/isbn9514269217/html/x277.html](http://herkules.oulu.fi/isbn9514269217/html/x277.html)
Anaerobic Fitness and Dance

Anaerobic power, determined by the Wingate test, was primarily investigated in two studies. Chatfield and colleagues (Chatfield et al. 1990) reported that advanced level contemporary dancers showed anaerobic capacity mean values of $907.5\pm140.7 \text{ Kgm}^{30 \text{ sec}^{-1}}$ which was somewhat lower (but not significantly) compared to beginners ($922.5\pm195.4 \text{ Kgm}^{30 \text{ sec}^{-1}}$). These results, however, were relatively higher (but not significantly) compared to non-dancers (Table 2, page 26). Non significant differences were also detected in anaerobic mean power between adolescent dance students compared to either recreational dancers or non-dancers (Padfield et al. 1993). Significant differences were instead depicted in post exercise blood lactate levels, where professional contemporary dancers exhibited higher values than their ballet counterparts (Chmelar et al. 1988). Table 2 (page 26) depicts studies primarily investigating the aerobic and anaerobic capacity of dancers.
Table 2: Studies primarily investigating the aerobic/anaerobic capacity of contemporary dancers.

<table>
<thead>
<tr>
<th>Author (reference)</th>
<th>Participants</th>
<th>Method</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Koutedakis et al. 2007)</td>
<td>32 dance students</td>
<td>F=2-3 h/wk</td>
<td>Intervention group before intervention: $V_{O2max}$: 50.7±7.5 ml kg$^{-1}$ min$^{-1}$ Strength both legs: 90.6±16.0 kg Skinfolds: 39.4±10.5 mm Intervention group after intervention: $V_{O2max}$: 56.6±9.3 ml kg$^{-1}$ min$^{-1}$ Strength both legs: 102.0±17.4 kg Skinfolds: 35.7±9.3 mm Control group before intervention: $V_{O2max}$: 49.2±5.5 ml kg$^{-1}$ min$^{-1}$ Strength both legs: 94.1±15.8 kg Skinfolds: 40.9±11.7 mm Control group after intervention: $V_{O2max}$: 48.5±5.4 ml kg$^{-1}$ min$^{-1}$ Strength both legs: 83.1±11.2 kg Skinfolds: 44.6±13.3 mm</td>
</tr>
<tr>
<td></td>
<td>intervention group n=19</td>
<td>Intensity-Aerobic= 70-75% of $V_{O2max}$ 6 weeks; Intensity-Strength= high repetitions 6 weeks; &gt; 70% of 1 repetition maximum Low repetitions PD= 12 weeks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>control group n=13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(White et al. 2004)</td>
<td>ballet students n=10, contemporary students n=7</td>
<td>Aerobic capacity and body composition</td>
<td>Ballet: $V_{O2max}$: 40.8±1.6 ml kg$^{-1}$ min$^{-1}$ %BF: 19.9±1.5 FFM: 41.5±1.1 kg Contemporary: $V_{O2max}$: 39.2±1.9 ml kg$^{-1}$ min$^{-1}$ %BF: 19.3±1.4 FFM: 43.2±1.6 kg No significant differences</td>
</tr>
<tr>
<td>(Whyte et al. 2003)</td>
<td>dance students n=44, females non-active n=30</td>
<td>Echocardiography and Electrocardiography</td>
<td>No significant differences between dancers and controls for structural and functional cardiac indices. Contemporary students: % BF: 18.7±3.4 FFM: 48.2±6.3 kg Controls: % BF: 19.9±4.4 FFM: 47.3±5.8 kg</td>
</tr>
<tr>
<td>(Redding and Wyon 2003)</td>
<td>19 professional females n=12, males n=7</td>
<td>Validity of using HR as a predictor of mean $V_{O2}$ consumption in dance</td>
<td>It is unacceptable to predict the mean $V_{O2}$ from HR values, based on the HR–$V_{O2}$ relationship established from a progressive treadmill protocol</td>
</tr>
<tr>
<td>(Wyon et al. 2002)</td>
<td>27 dancers university n=10, graduate n=7, professional n=10</td>
<td>Cardiorespiratory responses (mean $V_{O2}$) to dance class</td>
<td>University: Mean $V_{O2}$: 16.8±2.3 ml kg$^{-1}$ min$^{-1}$ Graduate: Mean $V_{O2}$: 20.4±4.8 ml kg$^{-1}$ min$^{-1}$ Professional: Mean $V_{O2}$: 18.3±3.8 ml kg$^{-1}$ min$^{-1}$ No significant differences</td>
</tr>
</tbody>
</table>

RCT=randomised controlled trial; F=frequency; PD=programme duration; $V_{O2max}$=maximal oxygen uptake; mean $V_{O2}$=mean volume of oxygen uptake; %BF=percentage body fat; FFM=fat-free mass; HR=heart rate
<table>
<thead>
<tr>
<th>Author (reference)</th>
<th>Participants</th>
<th>Method</th>
<th>Results</th>
</tr>
</thead>
</table>
| (Padfield et al. 1993) | performing adolescent dancers n=24, recreational adolescent dancers n=16 | VO₂max, %BF, jump height, anaerobic mean power | Performing dancers:
- VO₂max: 45.6±4.8 ml kg⁻¹ min⁻¹
- %BF: 8.7±6.5
- Jump height: 26.7±3.5 cm
- Anaerobic mean power: 6.6±0.7 Watts kg⁻¹
Recreational dancers:
- VO₂max: 46.3±6.0 ml kg⁻¹ min⁻¹
- %BF: 9.7±7.6
- Jump height: 25.1±6.6 cm
- Anaerobic mean power: 6.2±0.9 Watts kg⁻¹
No significant differences |
| (Wyon et al. 2004) | dance students (males and females) n=40, Mean VO₂ during class, performance and rehearsal | Females:
- Class mean VO₂: 17.4±2.7 ml kg⁻¹ min⁻¹
- Rehearsal mean VO₂: 10.2±6.6 ml kg⁻¹ min⁻¹
- Performance mean VO₂: 23.3±3.8 ml kg⁻¹ min⁻¹
Males:
- Class mean VO₂: 22.1±5.9 ml kg⁻¹ min⁻¹
- Rehearsal mean VO₂: 17.2±3.3 ml kg⁻¹ min⁻¹
- Performance mean VO₂: 24.9±5.8 ml kg⁻¹ min⁻¹
Performance had a significantly greater physiological demand than rehearsal and class |
| (Wyon and Redding 2005) | professional dancers n=17, Company 1 n=10, Company 2 n=7, Intervention non RCT | Company 1 Aerobic supplemental training, no guidance provision and time, PD=8 weeks, Company 2 Dance training only | Pre assessment company 1:
- Mean HR: 166±10.65 b min⁻¹
- BL: 2.1±0.9 Mmol L⁻¹
Post assessment Company 1:
- Mean HR: 155±12.9 b min⁻¹
- BL: 1.5±0.8 Mmol L⁻¹
Significant differences
Pre assessment company 2:
- Mean HR: 189±4.19 b min⁻¹
- BL: 3.4±1.1 Mmol L⁻¹
Post assessment company 2:
- Mean HR: 179±4.8 b min⁻¹
- BL: 2.8±1.1 Mmol L⁻¹
No significant differences |
| (Novak et al. 1978) | Female dance students n=12, sedentary females n=12 | VO₂max and %BF | Dance students:
- VO₂max: 41.5±6.7 ml kg⁻¹ min⁻¹
- %BF: 20.5±4.6
Controls:
- VO₂max: 36.8±5.5 ml kg⁻¹ min⁻¹
- %BF: 26.5±3.6
Significant differences in VO₂max and %BF |
| (Chatfield et al. 1990) | non dancers n=8, beginner students n=14, intermediate students n=11, professional dancers n=8 | VO₂max, %BF, knee and ankle strength, knee and ankle power, WAT power | Non dancers: 36.4±4.8 ml kg⁻¹ min⁻¹
Beginners: 40.4±4.9 ml kg⁻¹ min⁻¹
Intermediate: 42.5±4.3 ml kg⁻¹ min⁻¹
Professional: 43.6±2.3 ml kg⁻¹ min⁻¹
Significant differences between non-dancers and intermediate; non-dancers and professionals
- %BF:
  - Non dancers: 27.8±4.4
  - Beginners: 23.7±4.8
  - Intermediate: 20.9±4.6
  - Professional: 18.1±2.3
Significant differences: non-dancers and... |
intermediate, non-dancers and professionals, professionals and beginners

No significant differences in knee and ankle strength and power between all groups

WAT capacity:
- Non dancers: $828.38\pm161.2 \text{ kgm} \text{ 30 sec}^{-1}$
- Beginners: $922.50\pm195.4 \text{ kgm} \text{ 30 sec}^{-1}$
- Intermediate: $917.73\pm120.1 \text{ kgm} \text{ 30 sec}^{-1}$
- Professional: $907.50\pm140.7 \text{ kgm} \text{ 30 sec}^{-1}$

No significant differences

### Dahlstrom et al. 1996

<table>
<thead>
<tr>
<th>Dance students</th>
<th>VO$_{2\text{max}}$</th>
<th>Ballet + contemporary VO$_{2\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ballet + contemporary n=10</td>
<td></td>
<td>51.2±11.4 ml kg$^{-1}$ min$^{-1}$</td>
</tr>
<tr>
<td>contemporary + jazz n=30</td>
<td></td>
<td>45.8±8.7 ml kg$^{-1}$ min$^{-1}$</td>
</tr>
<tr>
<td>contemporary + character n=9</td>
<td></td>
<td>46.6±12.2 ml kg$^{-1}$ min$^{-1}$</td>
</tr>
</tbody>
</table>

### Chmelar et al. 1988

<table>
<thead>
<tr>
<th>VO$_{2\text{max}}$, BL, %BF, QPT/BW, HPT/BW</th>
<th>Contemporary professional</th>
<th>Professional ballet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice</td>
<td>49.1±5.9 ml kg$^{-1}$ min$^{-1}$</td>
<td>42.2±2.9 ml kg$^{-1}$ min$^{-1}$</td>
</tr>
<tr>
<td>BL</td>
<td>9.7±1.4 mM L$^{-1}$</td>
<td>6.0±1.5 mM L$^{-1}$</td>
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<tr>
<td>%BF</td>
<td>12.2±2.1</td>
<td>14.1±1.9</td>
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<tr>
<td>60°/sec QPT/BW</td>
<td>75.7±13.1 %</td>
<td>73.7±12.4 %</td>
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<td>60°/sec HPT/BW</td>
<td>43.2±5.9 %</td>
<td>50.5±6.7 %</td>
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<td>180°/sec QPT/BW</td>
<td>47.9±6.1 %</td>
<td>46.5±11.4 %</td>
</tr>
<tr>
<td>180°/sec HPT/BW</td>
<td>36.4±4.1 %</td>
<td>42.3±9.9 %</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Contemporary students</th>
<th>VO$_{2\text{max}}$</th>
<th>47.5±3.1 ml kg$^{-1}$ min$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL</td>
<td>9.0±2.4 mM L$^{-1}$</td>
<td>9.0±1.4 mL L$^{-1}$</td>
</tr>
<tr>
<td>%BF</td>
<td>14.7±3.4</td>
<td>14.7±3.4</td>
</tr>
<tr>
<td>60°/sec QPT/BW</td>
<td>78.8±14.0 %</td>
<td>78.8±14.0 %</td>
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<tr>
<td>60°/sec HPT/BW</td>
<td>45.1±6.6 %</td>
<td>45.1±6.6 %</td>
</tr>
<tr>
<td>180°/sec QPT/BW</td>
<td>50.9±9.1 %</td>
<td>50.9±9.1 %</td>
</tr>
<tr>
<td>180°/sec HPT/BW</td>
<td>37.4±5.1 %</td>
<td>37.4±5.1 %</td>
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</table>

<table>
<thead>
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<th>Ballet students</th>
<th>VO$_{2\text{max}}$</th>
<th>47.0±2.1 ml kg$^{-1}$ min$^{-1}$</th>
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<tbody>
<tr>
<td>BL</td>
<td>9.5±0.9 mM L$^{-1}$</td>
<td>9.5±0.9 mL L$^{-1}$</td>
</tr>
<tr>
<td>%BF</td>
<td>14.2±3.2</td>
<td>14.2±3.2</td>
</tr>
<tr>
<td>60°/sec QPT/BW</td>
<td>74.7±10.1 %</td>
<td>74.7±10.1 %</td>
</tr>
<tr>
<td>60°/sec HPT/BW</td>
<td>46.2±5.5 %</td>
<td>46.2±5.5 %</td>
</tr>
<tr>
<td>180°/sec QPT/BW</td>
<td>45.5±6.3 %</td>
<td>45.5±6.3 %</td>
</tr>
<tr>
<td>180°/sec HPT/BW</td>
<td>35.5±5.0 %</td>
<td>35.5±5.0 %</td>
</tr>
</tbody>
</table>

* = significant difference between ballet and contemporary professionals and dance students (ballet and contemporary)

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VO$_{2\text{max}}$ = maximal oxygen uptake; %BF = percentage body fat; mean VO$_2$ = mean volume of oxygen uptake; RCT = randomized control trial; PD = programme duration; HR = heart rate; BL = blood lactate; WAT = Wingate anaerobic power test; QPT/BW = quadriceps peak torque/body weight; HPT/BW = hamstring peak torque/body weight

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(O’Mailia et al. 2002) female dancers n=14 VO$_{2\text{max}}$ VO$_{2\text{max}}$ : 45.0±3.9 ml kg$^{-1}$ min$^{-1}$
**Muscular Strength**

Strength is the ability to exert maximal force (Plowman and Smith 2003), which is usually measured by isometric and/or isokinetic strength testing. However, since many sports include acceleration of the body, increasing importance has been recently given to the ability of individual athlete to exert force at specified speeds for performance purposes. For this reason, scientists have suggested the following definition of strength: “the maximal force that a muscle or a muscle group can generate at a specified velocity” (Knuttgen and Kraemer 1987).

A large number of biomechanical and physiological factors need to be taken into consideration in the generation and manifestation of strength, including:

- **Neural activation**: affects the maximal force output of a muscle by regulating the motor units recruitment (the number of motor units involved in a muscle contraction) and rate-coding (the rate at which motor units are fired) (Enoka 1988).

- **Muscle cross-sectional area**: the force that a muscle can exert is proportional to its cross-sectional area (Ikai and Fukunaga 1968).

- **Muscle length**: the muscle can generate the most force around its resting length and less force when is in either in an elongated or shortened state; this is because the maximal presence of cross-bridges available between the actin and myosin filaments.

- **Muscle contraction velocity**: muscles produce less force as the velocity of contraction increases.

- **Joint angular velocity**: muscle torque varies with joint angular velocity according to the type of muscular action (e.g. during isokinetic concentric exercise torque capability declines as angular velocity increases. Conversely, during eccentric exercise maximal torque capability increases together with angular velocity, until about 90°/sec) (Jorgensen 1976).
Muscular Strength and Dance

Results from the one-maximum repetition test for leg press in dance students have been found to range from 183.3±30.9 to 222.7±65.0 kg, while results from knee curl and extension test range from 34.8±4.5 to 40.0±5.7 kg and from 58.7±6.5 to 62.5±9.1 kg, respectively (Brown et al. 2007). Muscular strength and power of knee and ankle in both intermediate and/or advanced contemporary dance students has been found to be not significantly different between them or when compared to sedentary individuals (Chatfield et al. 1990). No significant differences were observed in the quadriceps and hamstring peak torque between ballet and contemporary dance students and professionals (Chmelar et al. 1988); however, in comparison to ballet, contemporary dancers reported higher scores in muscular endurance (Thomas 2003). It was found (Koutedakis et al. 1997b) that the knee extensor and flexor muscle peak power of female professional contemporary dancers was 151.0±26.0 and 63.0±11.0 Nm at 1.04 rad/sec while at 4.19 rad/sec the equivalent values were 83.0±11.0 and 60.0±8.4 Nm. Isokinetic measurements of muscular strength (Harley et al. 2002) revealed that semi-professional (i.e. employed on a part-time basis) dancers compared to athletes, have a greater quads muscle output during a five sec maximal voluntary isometric contraction but they do not jump higher than controls.

Two authors investigated the effects of supplementary strength training (both plyometric and weight training) on contemporary dance students, and both studies revealed that a significant increase in muscular strength resulted in significant benefits for enhancing jump performance (Brown et al. 2007), overall performance competence and technique, assessed via a specifically designed dance performance test (Koutedakis et al. 2007). Brown and colleagues (Brown et al. 2007) recruited three experienced dance teachers to assess four aspects of the dancers’ jumping ability including: the aptitude to hang suspended in the air during a jump (ballon), height of the jumps, the ability to point the feet in the air and the overall jumping ability. Combined evidence from both studies reveals that strength training increases dance performance and jump ability in contemporary dance
students (Brown et al. 2007; Koutedakis et al. 2007). Most importantly, these results are in line with the only RCT which is currently available in dance literature (Koutedakis et al. 2007). Table 3 (page 32) depicts the individual evidence from all studies conducted in relation to strength related parameters of contemporary dancers.
<table>
<thead>
<tr>
<th>Author (reference)</th>
<th>Participants</th>
<th>Method</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Koutedakis <em>et al.</em> 1997b)</td>
<td>male ballet and contemporary professionals n=20 female ballet and contemporary professionals n=22</td>
<td>Knee extensors and flexor muscle peak torques, %BF FFM</td>
<td>Males: Knee flexion at 1.04 (rad/sec): 121±15 Nm Knee extension at 1.04 (rad/sec): 248±24 Nm Sum: 5.8±0.5 Nm/kg FFM Knee flexion at 4.19 (rad/sec): 81±10 Nm Knee extension at 4.19 (rad/sec): 131±12 Nm Sum: 3.3±3.1 Nm/kg FFM Females: Knee flexion at 1.04 (rad/sec): 63±11 Nm Knee extension at 1.04 (rad/sec): 151±26 Nm Sum: 4.6±0.4 Nm/kg FFM Knee flexion at 4.19 (rad/sec): 60±8.4 Nm Knee extension at 4.19 (rad/sec): 83±11 Nm Sum: 3.1±0.2 Nm/kg FFM Significant differences between males and females in knee flexion, extension and sum at 1.04 (rad/sec), in knee flexion and extension at 4.19 (rad/sec) Males: %BF: 14.1±2.4 Females: %BF: 19.2±5.8 Significant difference Males: FFM: 63.0±5.1 kg Females: FFM: 45.3±4.1 kg Significant difference</td>
</tr>
<tr>
<td>(Harley <em>et al.</em> 2002)</td>
<td>female dancers n=11 (semi professional) age-matched active females n=11</td>
<td>Quads strength, jump height, %BF, FFM</td>
<td>Dancers had significantly greater peak and mean force output in the 5 sec maximal voluntary isometric leg extension tests (p &lt; 0.01; values not available) Jump height: Dancers: 37.6±5.5 cm Controls: 35.9±3.9 cm No significant difference %BF: Dancers: 21.4±2.8 Controls: 25.6±3.7 Significant difference FFM: Dancers: 42.2±3.7 kg Controls: 42.2±6.6 kg No significant difference</td>
</tr>
<tr>
<td>(Thomas 2003)</td>
<td>performing dance students contemporary n=15 ballet n=15 folk n=19 other styles n=41</td>
<td>Heel – rises muscular endurance</td>
<td>Number of RPL: Contemporary: 26.4±3.8 Ballet: 25.4±3.7 Folk: 33.0±3.64 Number of RPkg: Contemporary: 19.1±3.1 Ballet: 18.9±3.05 Folk: 23.0±3</td>
</tr>
</tbody>
</table>
Author (reference) | Participants | Method | Results
--- | --- | --- | ---
(Brown et al. 2007) | 18 dance students weight training n=6 plyometric training n=6 controls n=6 intervention non RCT | F=1-1.30 h/wk Intensity- weight training= 80% of 1 repetition maximum 3 sets of 6-8 repetitions Intensity- plyometric= 3 sets of 8 repetitions of 4 exercises PD=12 weeks | Plyometric training group pre intervention: Leg press strength: 183±30.9 kg Vertical jump from standing 12.0±1.2 in Aesthetic evaluation – jump height:3.2 ±0.4 Plyometric training group post intervention: Leg press strength: 251.5±39.4 kg * Vertical jump from standing 13.0±1.0 in * Aesthetic evaluation – jump height: 3.6±0.5 * * = significant differences Weight training group pre intervention: Leg press strength: 214±61.0 kg Knee curl strength: 34.8±4.5 kg Anaerobic mean power: 340.8±53.5 Watts Aesthetic evaluation - feet point: 3.0±1.2 Aesthetic evaluation - jump height: 2.8 ±1.0 Weight training group post intervention: Leg press strength: 282.5±48.0 kg * Knee curl strength: 42.8±3.4 kg * Anaerobic mean power: 361.1±62.6 Watts * Aesthetic evaluation - feet point: 3.6±0.7 * Aesthetic evaluation - jump height: 3.5 ±0.8 * * = significant differences

%BF=percentage body fat; FFM=fat-free mass; RPL=repetitions per leg; RPkg=repetitions per kilogram; RCT=randomised controlled trial; F=frequency; PD=programme duration

Body Composition

Body composition, which refers to the human body’s chemical composition, is the ratio of fat to fat-free mass. The fat mass, or relative body fat, is the percentage of the total body mass that is composed of fat. The term fat-free mass refers to any non-fat tissues (bone, muscle, organs and connective tissue); these are also known as metabolically-active components, which make up the 70% of total body weight. The human body is composed of five main chemical components including: water, protein, carbohydrates, minerals and fat, which in turn form the anatomical components of the body (i.e. organs, bone, muscle and fat). Despite that all organs may sustain physiological changes with exercise (e.g. myocardium structure), the most pronounced and immediate changes occur in fat. These in turn can be important to achieve optimal performance in sport (Wilmore and Costill 1999). This is particularly evident for sports, where active (fat-free) mass with the right levels of body fat, are considered essential ingredients to optimize performance. While in general higher levels of %BF have been associated to poorer performance on tests of speed,
endurance, agility and jumping ability (Riendeau et al. 1958), in disciplines where the body mass must be transported for a distance (e.g. dance, gymnastics and distance running) a lean physique and low %BF can offer competitive advantage (Tittel et al. 1988).

Several reliable methods, either laboratory or field based, have been developed to measure efficiently body composition including: densitometry, the dual x-ray absorptiometry (DXA), the bioelectrical impedance analysis (BIA) and the skinfolds-based method. The densitometry, which calculates the density of the body by dividing body mass by body volume determined by hydrostatic weighing, is considered the most accurate method (Wilmore and Costill 1999). However, the major limitations of this method are the access and the cost of the necessary equipments and the conversion of body density to an estimate of relative body fat via equations which do not take into accounts differences in body density between individuals. Several field techniques are available for assessing body composition. The major advantage of these techniques is their easy access. The method used most often is the skinfold method, which by measuring skinfold fat thickness in a number of sites, use the values obtained to estimate body density and relative body fat via quadratic population-specific equations. Reliability of the %BF values obtained are reliant on the assessor ability, hence tests should be performed by appropriately trained people.

**Body Composition and Dance**

An investigation into body composition of female dancers revealed that, using the skinfolds method, percentage body fat (%BF) was found to range from 13.0% to 26.9%. In the same sample of participants, using dual energy x ray absorptiometry (DXA), values for %BF ranged from 10.3% to 30.4%. The fat-free mass (FFM), as determined by DXA, was 42.6±3.3kg (range 35.6 -50.1) (Yannakoulia et al. 2000). Regarding different levels of dancers, it has been found that performing and recreational adolescent dance students do not significantly differ in %BF (Padfield et al. 1993). In all these studies, the dance students came from both ballet and contemporary dance training. In other studies, however,
which separated the dance students into ballet and contemporary, results revealed no significant differences either in %BF or FFM between these two dance styles (Chmelar et al. 1988; White et al. 2004). As expected, significant lower %BF values were instead found in professional contemporary dancers compared to beginner dance students (Chatfield et al. 1990).

Female dance students and graduates were found to have a significantly lower %BF than age-matched non-active females (Novak et al. 1978). In addition, significant differences were also found between advanced dancers and non-dancers, as well as intermediate dance students and non-dancers (Chatfield et al. 1990).

Results from one RCT and one non randomized intervention revealed that supplementary aerobic and/or strength training does not elicit significant changes in %BF of dance students (Brown et al. 2007; Koutedakis et al. 2007). Table 4 (page 36) depicts the evidence from all studies primarily investigating body composition characteristics of contemporary dancers.
Table 4: Studies primarily investigating body composition characteristics of contemporary dancers.

<table>
<thead>
<tr>
<th>Author (reference)</th>
<th>Participants</th>
<th>Method</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Yannakoula et al. 2004)</td>
<td>females dance students n=37 controls: age- and weight–matched reference population</td>
<td>BMD</td>
<td>Dancers BMD: 1.185 g/cm$^2$ higher than reference values</td>
</tr>
<tr>
<td>(Berlet et al. 2002)</td>
<td>Professional female dancers n=9 non-dancers n=26 professional male dancers n=6 non-dancers n=15</td>
<td>BMD, total regional fat (%) TLM</td>
<td>Female dancers: BMD: 1.18±0.1 g/cm$^2$ Total regional fat: 13.6±3.3 % TLM: 42.928±3.4 g Female controls (weight-matched): BMD: 1.19±0.1 g/cm$^2$ Total regional fat: 9.7±2.5% TLM: 37.689±3.4 g Significant differences in %BF and TLM Male dancers: BMD: 1.35±0.1 g/cm$^2$ Total regional fat: 14.4±4.8 % TLM: 60.132±6.8 g Male controls (weight-matched): BMD: 1.25±0.1 g/cm$^2$ Total regional fat: 24.0±5.7 % TLM: 56.412±4.6 g Significant differences in BMD, total regional fat</td>
</tr>
<tr>
<td>(Yannakoula et al. 2000)</td>
<td>elite female dance students n=42</td>
<td>Investigation of levels of BMD, FFM, % BF</td>
<td>BMD: 1.180±0.1 g/cm$^2$ FFM: 42.55±3.3 kg %BF (Skinfold): 21.3±3.2 %BF (DXA): 19.4±4.3</td>
</tr>
<tr>
<td>(Miletic et al. 2007)</td>
<td>female students with experience in contemporary, ballet, rhythmic gymnastics n=24 active female students with no previous experience in aesthetic disciplines n=21</td>
<td>Sum-SF</td>
<td>Experienced students: Sum-SF: 28.45±8.2 mm Calf circumference: 36.42±2.2 cm Non experienced students: Sum-SF: 23.47±5.2 mm Calf circumference: 35.98±2.26 cm Significant difference in Sum-SF</td>
</tr>
</tbody>
</table>

BMD= bone mineral density; TLM=Total lean mass; FFM=fat-free mass; %BF=percentage body fat; DXA= dual-x ray absorptiometry; Sum-SF= sum of skinfolds
Overall View of the Literature

This is the first review systematically investigating fitness components in relation to contemporary dance. Unlike most ballet dancers, contemporary dancers may have a multidisciplinary background, including other sport activities such as gymnastics (Koutedakis and Jamurtas 2004). This is also the case in other sports such as football and water polo, where the players used to be runners and swimmers, respectively. This sample heterogeneity, as well as the different choreographic demands between contemporary and ballet dance, may result in different levels of fitness and strength. Other differences between ballet and contemporary dancers have been reported to be injury sites and rates as well as the biomechanical mechanisms that cause these injuries (Krasnow and Kabbani 1999). Moreover, results from separate studies investigating physiological demands of contemporary (Wyon et al. 2004) and ballet (Cohen et al. 1982) class and performance, suggest that the two dance styles may also differ in their cardiorespiratory demands. For these reasons it was decided not to report research evidence for dancers as a whole, but to focus on contemporary dancers in this literature review, and differentiate between their levels (student and professional), with respect to their fitness, strength and body composition characteristics.

An important aspect which has to be stressed is the link between dance performance and fitness. It has been suggested that although the former has significant “aesthetic” elements, it is the overall fitness of the individual dancer that determines the final outcome (Koutedakis and Jamurtas 2004). For an optimal stage performance, the dancers’ aerobic and anaerobic capacities, strength power and endurance as well as their flexibility levels, must be at their peak on the day they are needed, in addition to their technique, skills and virtuosity. Hence, it is important that dancers, akin to all performing athletes, must adhere to the principles of periodisation and regular evaluation of their fitness levels (e.g. strength, flexibility) via validated laboratory procedures.
At a professional level, it appears that contemporary dancers demonstrate higher VO\textsubscript{2max} and %BF than ballet. However, student contemporary dancers are equally fit compared to their ballet counterparts and their body composition is also very similar. Comparisons between contemporary, ballet and athletes of other sports are presented in Table 1 (page 19). It is worth noting that Table 1 depicts values only for VO\textsubscript{2max} and body composition of female dancers; the lack of relevant data for professional and student male dancers (either contemporary or ballet), did not allow me to produce a similar table. In addition, the different techniques, equipment and muscular groups do not currently allow for a representative and thorough comparison in strength levels between contemporary dancers with athletes of other sports. Available data, however, showed that muscular strength and power among intermediate dance students, advanced dance students and sedentary individuals do not differ significantly (Chatfield et al. 1990) whereas contemporary dancers reported higher scores in muscular endurance compared to ballet dancers (Thomas 2003). Anaerobic fitness was found to be the least studied component. However, investigating this fitness aspect is indeed important in dance given that actions requiring high power output rely predominantly on the ATP-CP and glycolytic system of energy (Baechle and Earle 2000), and dance is characterised by short explosive movements, such as a series of jumps, interspersed between longer periods of rest (Wyon 2005). Despite this, data from two studies revealed no significant differences in mean anaerobic power between performing and recreational dance students and between various levels of dancers compared to sedentary populations (Chatfield et al. 1990; Padfield et al. 1993). However, following supplemental weight training, dancers improved their anaerobic power which also revealed a concomitant improvement in their jump ability (Brown et al. 2007).

In summary, it appears from the literature reviewed that both contemporary and ballet dancers have aerobic fitness levels higher to that seen in sedentary individuals (Novak et al. 1978) and somewhat lower compared to other sports. In addition, muscular strength is higher in professional dancers compared to other athletes (Harley et al. 2002).
However, at a student level no significant differences exist in this fitness component. The reason for this phenomenon is probably the fact that the dance training is not sufficient enough to overload the aerobic/anaerobic and musculoskeletal systems (Chatfield et al. 1990; Koutedakis and Jamurtas 2004) and thus, to produce physiological adaptations that will enhance each individual fitness component. On the other hand, dance specialists and physiologists have to consider how these potential adaptations (gained through supplementary aerobic/strength training) will benefit on-stage performance of professional dancers.

The effectiveness of supplementary aerobic/strength training in order to improve dance performance has been very frequently discussed in published manuscripts (both in trials and reviews) but has only been recently investigated (Brown et al. 2007). One RCT (Koutedakis et al. 2007) suggests that, in students, increases in fitness components result in concomitant beneficial effects in aspects of performance. Nevertheless, the limitations of this study – according to the CONSORT guidelines for RCTs – were the method of randomization, the lack of justification for the sample sizes used and finally the lack of presenting the participants’ flow diagram. Although the results of this study are in line with the non randomised study by Brown (Brown et al. 2007), these studies can only be interpreted as preliminary data and have to be confirmed in future prospective and well-designed studies.

Improvement in individual fitness components may be important for different reasons. In professional dancers, knee extensor and flexor low muscle strength levels have been associated with increased injury severity, expressed as the total time away from dance training (Koutedakis et al. 1997b). The injury recovery process may take longer in dancers with reduced muscular strength, because joints surrounded by weaker soft tissue are subject to more strain due to overexertion, and therefore take longer to recover from the cause of the injury (Weiss and Zlatkowski 1996; Kumar and Tomic 2001). Since dance training is not sufficient enough to overload the musculoskeletal systems (Chatfield et al. 1990;
Koutedakis and Jamurtas 2004), and considering the high injury rates found in dance (Weigert and Erickson 2007), the implementation of strength training could therefore be recommended as a preventive measure, at least for less strong dancers (Koutedakis et al. 1996). In addition, improvements in aerobic/anaerobic capacities and muscular strength have been previously linked to better oxygen transport facilities (Astrand and Rodhal 1986) and enhanced neuromuscular function (Jones and Round 1990), which in turn, affect qualitative elements of general physical performance through reduced fatigue (Petibois et al. 2002; Romer et al. 2002) and injury rates (Knapic et al. 1992).

From the results of this systematic review it appears that the majority of research studies in dance have focused on the assessment of dancers’ levels of fitness. In contrast, there is a lack of studies trying to identify an objective assessment of contemporary dance performance in relation to increased physical fitness levels. The two research studies investigating the effects of an intervention on dance utilised two different dance-based tests which were the most externally valid to ‘dance performance’. However, both tests that were used to assess aspects of performance proficiency were not previously validated appropriately, which is a major limitation that should be addressed in similar studies in the future. The data of these preliminary research studies, however, suggest that aerobic and strength training improve overall performance, dance technique and jump ability of contemporary dance students. Further research is needed in order to confirm these preliminary data.
III. METHODS

Participants

A total of 67 dancers were recruited from vocational dance institutions and dance companies and engaged in more than one study. All participants were free from injury and not involved in any supplementary fitness training or other sport activity. Written informed consents were obtained from all participants after full verbal and written explanation of the data collection procedures. The Research Centre for Sport, Exercise and Performance Ethics Committee (University of Wolverhampton) approved the protocols.

In the first study (section 1) data from 20 professional dancers (male=7; female=13) were used to investigate the physiological responses to a total of 50 contemporary dance performances using portable accelerometers (e.g. SWA armbands), heart rate (HR) monitors and post performance blood lactate (BL) readings.

In the first part of the second study, six professional dancers (male=2; female=4) and two experienced dance teachers, were used to test-retest the inter and intra reliability of a new system to assess performance. The developed system was subsequently used to investigate the relationship between physical fitness and performance in the second part of this study. The minimum required number of dancers (i.e. six) needed to test the inter and intra rater reliability was calculated before starting the recruitment process by using a statistical power calculator (MaCorr Inc.).

The remaining dancers (n=41) were engaged in Studies 2 (part 2), 3 and 4. They underwent a series of physical fitness tests, which are described in detail in the “measurements and apparatus” paragraph (page 42). All tests were performed in accordance to the British Association for Sport and Exercise Sciences (Wyon 2007) and the American College of Sport Medicine (Balady et al. 2000) guidelines. Recorded data were used to investigate the association between physical fitness components and performance (Study 2, part 2), physical fitness components and injury severity (Study 3), and the effects
of a six week supplementary exercise training on performance (Study 4). More specifically, a total of 17 male and female dancers (professionals and students) were used in Study two (part two), while 16 dancers (after excluding the only male dancer) were used for the purposes of Study 3. For the RCT (Study 4) a total of 14 female dance students in vocational training and ten (nine females) professional contemporary dancers (total number of participants n=24) were recruited. Following physical fitness and performance assessments they were randomly assigned, by using the closed envelope method, to an intervention (n=12) or a control (n=12) group. Both groups were re-tested for physical fitness levels and performance at the end of the intervention period to investigate the effects of six week supplementary vibration and circuit training on performance.

**Measurements and apparatus**

**Height and Weight**

Standing height was measured to the nearest 0.5 cm using a Seca stadiometer 208 (Hamburg, Germany), with the participants in bare feet and their heads positioned at the Frankfort horizontal plane. Total body mass was measured to the nearest 0.5 kg using a Seca beam balance 710 (Hamburg, Germany).

**Body Composition**

Using a Harpenden caliper (John Bull, St. Albans, UK), body fat percentage (%BF) was calculated from the mean of three readings per site according to the 4-sites formula of Durnin and Womersley (Durnin and Womersley 1974) where the sum of the triceps, subscapular, suprailiac and calf skinfolds were needed to estimate body density; this was then used (using the Siri equation) (Siri 1961) to calculate %BF of all participants. The Siri equation was used in a previous study to assess %BF of dancers (Twitchett *et al.* 2008). The formulae, which appear at page 43, were chosen, according to the existing literature, as being valid for both men and women participants.
Aerobic Capacity

The aerobic capacity of dancers was tested using the validated Dance Aerobic Fitness Test (DAFT) (Wyon et al. 2003). This procedure has been previously used in dance to monitor cardiorespiratory capacity (Wyon and Redding 2005). The test consists of five progressively demanding stages, lasting four minutes each, for a total of 20 minutes. Each stage was a contemporary dance sequence, which increased intensity and speed at each stage. Before the test, each dancer underwent a familiarization process and was introduced to the tempo of each stage; all dancers were also informed of the test termination criteria (Wyon and Redding 2005). Dancers were fitted with a Polar HR monitor (Kempele, Finland). The mean HR of the dancers’ last stage (representative of performance demands at the set intensity of 108 b·min⁻¹, equivalent to 46 ml·kg⁻¹·min⁻¹ for females and 55 ml·kg⁻¹·min⁻¹ for males) was calculated from the downloaded HR data (Wyon et al. 2003; Wyon and Redding 2005).

Muscular Power

Standing vertical jump (or jump ability) was assessed using a jump meter (Jump MD, TKK 5106; Takei Yashiroda, Japan). Volunteers were barefoot and were asked to assume the dance 1st position (heels together and legs externally rotated); they were then instructed to perform a demi-plié (half-squat) and immediately jump as high as possible off both feet, with respect to technique used in performing sautés jumps (heels together, hips externally rotated and pointed feet). Participants were subsequently instructed to perform the same test but hopping on one leg and landing on the same one, respectively, [i.e. first on the right leg (JR) and then on the left leg (JL)]. These tests have been extensively used to assess
jump ability and correlate well with lower body muscle power (Ashley and Weiss 1994; Brown et al. 2007). During all tests, the use of arms during take off and jump were not allowed. For all tests, subjects were asked to repeat the test three times and the highest score (in cm) was recorded for further analyses.

Muscular Endurance

For the assessment of muscular endurance two different field-tests were used. The first was the press-ups test (Balady et al. 2000) which is a valid and reliable indicator of the upper body muscular endurance (Wood and Baumgartner 2004). It was administered with the dancer starting in the modified knee press-ups position (legs together, lower leg in contact with mat with ankles plantar-flexed, back straight, hands shoulder width apart, head up). Dancers were instructed to lower the body until the chin touched the mat. The maximum number of press-ups performed consecutively in one minute was counted as an indicative score of upper body muscular endurance. For the second test, participants were asked to maintain the plank position for as long as possible. The plank position (whole body parallel to the floor supported by the forearms and the toes) provided information about muscular endurance of the core muscles (abdominals and dorsal group muscles) (Kendall and McCreary 1993). The total time, measured in minutes, which the dancers spent in the required position was recorded for further analyses.

Flexibility

Dancers were asked to perform a sideways leg extension (developpé a la seconde), which is the combined hip action of flexion, abduction and external rotation (please see Figures 5 and 6 page 45). This protocol is suggested for both ballet and contemporary dancers (Wyon 2007), and it has been recommended to be used for the assessment of dance specific flexibility-related skills (Grossman and Wilmerding 2000). Assessment of passive flexibility of the hip required the dancer to move the joint using his/her hand into its range
of motion (ROM) limit (Figure 5). Assessment of active (functional) ROM of the hip was achieved using solely the dancer’s muscle activation, with the participant in a standing position on the floor and one hand holding the ballet barre (Figure 6). The measurements were recorded for both legs. Landmarks were placed in the following anatomical points: the tip of the fibular head at the lateral side of the lower leg and the middle of the inferior side of the lateral malleolus. A total of four digital images for each dancer performing the développé a la seconde were taken via a digital camera. The passive and active ROM was measured with the use of a geometrical protractor (Wyon 2007).

Figure 5: Flexibility passive hip ROM test.

Figure 6: Flexibility active hip ROM test.
**Statistical analyses**

Routine pre-analyses were conducted in all studies using Kolmogorov-Smirnov tests of normality to detect the distribution of the studied variables.

In Study 1 (observational study) the analysis of the results incorporated the use of descriptive statistics, while one-way ANOVA was used in a sub-analysis of the data to investigate differences between genders (gender was used as a grouping variable). In the second study (part 1) ICCs and the confidence intervals (95%) for each ICC were employed to verify the inter and intra test-retest reliability of the designed performance tool since, as an approach, they are more valid in assessing agreement between two estimates compared to the use of correlation coefficients and t-tests only. Correlation coefficients were used to detect possible linear associations between selected physical fitness components and performance (Study 2) or severity of injuries (Study 3), while regression analyses were employed in both studies to investigate the strength of the association between selected physical fitness levels and performance (Study 2) or severity of injuries (Study 3). Univariate ANOVA was used in Study 2 (part 2) to investigate the prediction power of several interactions of covariates, such as SVJ with press-ups and aerobic fitness with SVJ (independent variables), on performance (dependent variable). Finally, in order to investigate the effects of six week intervention training on performance, RM ANOVA was employed in Study 4, with groups (intervention and control) and exercise period (pre and post intervention) as independent factors. All analyses were conducted via SPSS version 12 and 13 (SPSS Inc, Chicago, IL, USA).
IV. Study 1: Analysis of Contemporary Dance Performance

This chapter includes work which I presented at the 17th annual meeting of the International Association of Dance Medicine and Science and was published in the conference proceedings of the same title.


In order to analyse and understand physical requirements of contemporary dance performance I have conducted two separate studies, each addressing dance performance from a different perspective: part 1: physiological responses to on-stage performance; part 2: movement analysis of dance performance.


To date there is a lack of research investigating the physiological demands of actual on-stage contemporary dance performance, which has been mostly related to the invasive nature of data collection on the artistic process (Wyon 2005). Recent studies (Wyon et al. 2002; Wyon et al. 2004) have used dress (or late) rehearsals as indicators of dance performance. However, this may lead to misjudgements when reporting data for dance performance, since significant differences, such as the work:rest ratio and the overall intensity, may occur between dress-rehearsal and performance; this is at least the case for early and late rehearsals (Wyon et al. 2004). Contemporary dance is an intermittent type of exercise, whose intensity significantly varies between performance and class, ranging from high to moderate intensity, respectively (Wyon et al. 2004; Wyon 2005). The potential reason for this physiological discrepancy is that during performance there are longer periods of activity and shorter rest periods, which are in contrast to what happens during class (Wyon et al. 2004). However, since the latter study used dress rehearsals this may
have significant implications on the knowledge of the actual physiological demands of dance, rather then on-stage performance.

A number of studies have applied different well-established methods from sport literature to assess physiological aspects of dance. However, these have a number of potential limitations when applied to dance. The telemetric gas analysis system is a well-known, valid and reliable method for assessing energy expenditure during exercise, which has been recently used for assessing demands of dance training (e.g. class and rehearsal) and performance (Wyon et al. 2002; Wyon et al. 2004). However, this has limitations during the assessment of dance performance (such as movement restriction during partner work and the performance of transitory movements from floor to standing and vice versa), or simply it is prohibited from use during performance for artistic and aesthetic reasons (Wyon et al. 2004).

A more widely used method is the assessment of heart rate (HR) recordings (Cohen et al. 1982; Dahlstrom et al. 1996). These studies indirectly calculated the oxygen requirements of dance by comparing the HR gained during class with those from a treadmill maximal oxygen uptake (VO\textsubscript{2}\text{max}) test. Even though this method is non-invasive, a recent study (Redding et al. 2004) questioned the established validity of the HR-VO\textsubscript{2} relationship for steady-state activities and incremental exercise (Bernard et al. 1996) for intermittent type of exercise, such as dance. Results from this study revealed that the HR-VO\textsubscript{2} relationship in dance compared to treadmill work produced predicted oxygen consumptions from HR that were significantly different.

The limitations of the available equipment in recording physiological responses during performance, have led to the development of alternative methods. As such, recently there is a growing interest in the use of portable accelerometers such as the Sensewear portable analyser (SWA) (Body Media, Pittsburgh, U.S.A.). The SWA has been found to be valid, reliable and a non-invasive method for obtaining physiological data during different mode of exercises (Jakicic et al. 2004; King et al. 2004). These accelerometers
also assess heat flux, accelerometry, galvanic skin response, skin temperature and nearby body temperature. These recorded values in addition to specific demographic characteristics are then inserted in algorithms, to predict energy expenditure expressed in METs. Compared with other portable devices to estimate energy expenditure, the inclusion of a heat flux sensor in SWA may increase the ability to measure the estimate of energy expenditure when used in combination with other parameters such as accelerometry (Jakicic et al. 2004).

Since different methods of measuring oxygen consumption are required if the physiological demands of dance performance are to be determined during the actual performance rather than rehearsals, the aim of this study was to quantify the physiological demands of contemporary dance performance using a device that will allow freedom of movement i.e., the portable accelerometer SWA.

**Methods**

*Participants*

Twenty professional contemporary dancers (male=7; female=13) from three dance companies volunteered to participate in the study. Table 5 (page 50) depicts their anthropometrical characteristics.

The 20 dancers performed a total of 50 dance performances. These were monitored during a three-month period in the three dance companies’ workplace via Sensewear armband (SWA) and heart rate (HR) monitors; blood lactate (BL) readings were taken three minutes after the end of each performance. The length of the observed performances ranged from 10 to 138 minutes (Mean±SD=37.7±42.3 minutes). Table 6 (page 50) reports the demographics characteristics of each company and the total number of performances monitored for each dance company. After being informed of the purpose of this study, all participants signed a written consent form. The Ethics Committee of the University of Wolverhampton approved the study protocol.
Table 5: Participants characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Weight (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female:13</td>
<td>21.25±2.7</td>
<td>164.42±6.3</td>
<td>58.22±6.5</td>
</tr>
<tr>
<td>Male: 7</td>
<td>31.14±8.0</td>
<td>176.57±7.5</td>
<td>67.87±8.0</td>
</tr>
</tbody>
</table>

Data are expressed as the mean ± S.D.

Table 6: Demographics characteristics.

<table>
<thead>
<tr>
<th>Company ID</th>
<th>Total number of dancers</th>
<th>Gender</th>
<th>Total number of performances monitored</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company 1</td>
<td>4</td>
<td>Males: 0</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Females: 4</td>
<td></td>
</tr>
<tr>
<td>Company 2</td>
<td>12</td>
<td>Males: 3</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Females: 9</td>
<td></td>
</tr>
<tr>
<td>Company 3</td>
<td>4</td>
<td>Males: 3</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Females: 1</td>
<td></td>
</tr>
</tbody>
</table>

Anthropometrical characteristics

Anthropometrical characteristics such as standing height (cm) and total body mass (Kg) were recorded. These data were subsequently used to calculate energy expenditure (EE) via SWA. Specific details of the exact methodological procedures appear in Methods (page 42).

Physiological assessment

The participants were instructed to wear the portable accelerometer SWA (Body Media, Pittsburgh, U.S.A.) and a HR monitor (Polar, Kempele, Finland) during on-stage performance. The SWA was strapped, as recommended by the manufacturer, across the right arm over the triceps muscle at the midpoint between the acromion and olecranon processes. SWA and HR monitors were placed on each participant 15 minutes before the beginning of the performance (to allow the SWA for acclimation to skin temperature) and
removed immediately after. The SWA used a variety of measured parameters (accelerometry, heat flux, galvanic skin response, skin temperature and near body temperature) and demographic characteristics (gender, age, height, weight), which were transferred to a software system (Innerview Research Software 3.2), to calculate an estimate EE measured in METs, by using a proprietary algorithm developed by the manufacturer. To allow comparison with previous data, METs were subsequently used to estimate VO\textsubscript{2} (1 MET = 3.5 ml·kg\textsuperscript{-1}·min\textsuperscript{-1} (Powers and Howley 2007). Blood from the ear lobe was taken three minutes after the end of each performance; the blood samples were analysed using a Lactate Pro® Analyser (Arkray, Japan).

**Validity and reliability of SWA**

Validity and reliability of SWA in estimating EE has been previously tested by comparing METs from SWA with EE measured by indirect calorimetry (IC) during treadmill exercise (King *et al*. 2004), stair stepping, cycle and arm ergometer activities (Jakicic *et al*. 2004), multiple series of walking, standing and jumping (Mealey *et al*. 2007). Results from these studies indicated that SWA had high correlation coefficients during treadmill exercise at various speed (e.g.: at 54 m·min\textsuperscript{-1} and 80 m·min\textsuperscript{-1} r = 0.82) (King *et al*. 2004). Non significant differences were found between SWA and IC to estimate EE during multiple series of actions (Mealey *et al*. 2007). However, when exercise-specific algorithms were applied, SWA provided an increased estimate EE during different type of activities, such as stair stepping (r = 0.71, 95% CI = 0.38-0.88), cycle (r = 0.84; 95% CI = 0.63-0.94) and arm ergometer (r = 0.51, 95% CI = 0.06-0.79) (Jakicic *et al*. 2004). Very recently, two studies have employed SWA and HR monitors to investigate the physiological responses to dance training (Rodrigues 2009; Wyon *et al*. 2009)
**Statistical analysis**

Routine pre-analyses were conducted using Kolmogorov-Smirnov test of normality to detect the distribution of the studied variables. Analysis of the results incorporated the use of descriptive statistics using mean±SD. A sub-analysis of this study was carried to determine whether and if so in what ways, the demands of performance varied according to gender. Significance of gender differences were tested using one-way ANOVA, and the $\alpha$ level of significance was set at 95% ($p<0.05$). All analyses were conducted via SPSS 13 (SPSS Inc, Chicago, IL, USA).

**Results**

Table 7 depicts descriptive statistics of the measured physiological variables during dance performance. The following mean values results during performance were found: total EE: 4.5±1.5 METs, VO$_2$: 15.7±5.5 ml·kg$^{-1}$·min$^{-1}$, HR: 103.4±15.4 b·min$^{-1}$, BL concentration post performance: 2.8±1.3 mmol·L$^{-1}$. The VO$_2$ for the majority of performances (80%) ranged from 10-25 ml·kg$^{-1}$·min$^{-1}$ (Figure 7, page 53), while HR ranged from 101-119 b·min$^{-1}$ for 52.1% of performances (Figure 8, page 53).

**Sub-analysis of gender differences**

Non significant differences ($p>0.05$) were found between male and female dancers in EE (males: 4.6±1.4; females: 4.4±1.6 METs), VO$_2$ (males: 16.1±4.9; females: 15.4±5.9 ml·kg$^{-1}$·min$^{-1}$), HR (males: 102.6±20.5; females: 104.0±10.8 b·min$^{-1}$) or BL concentration (males: 2.3±0.8; females: 3.0±1.5 mmol·L$^{-1}$) measurements during performance.

**Table 7: Mean data for performance intensity measures**

<table>
<thead>
<tr>
<th></th>
<th>EE METs</th>
<th>Mean VO$_2$ (ml·kg$^{-1}$·min$^{-1}$)</th>
<th>Mean HR (b·min$^{-1}$)</th>
<th>Blood Lactate (mmol·L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td>4.5 ± 1.5</td>
<td>15.7 ± 5.5</td>
<td>103.4 ± 15.4</td>
<td>2.8 ± 1.3</td>
</tr>
<tr>
<td><strong>Males</strong></td>
<td>4.6 ± 1.4</td>
<td>16.1 ± 4.9</td>
<td>102.6 ± 20.5</td>
<td>2.3 ± 0.8</td>
</tr>
<tr>
<td><strong>Females</strong></td>
<td>4.4 ± 1.6</td>
<td>15.4 ± 5.9</td>
<td>104.0 ± 10.8</td>
<td>3.0 ± 1.5</td>
</tr>
<tr>
<td><strong>t – test</strong></td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

t test: p significant at<0.05; EE = energy expenditure; NS = non significant
Discussion

This study investigated the physiological responses of contemporary dancers to dance performance, using a non invasive method (e.g. SWA) which, as opposed to previous studies, allowed freedom of movement. The mean HR value (103.4±15.4 b·min⁻¹) was 52.8% of the maximum, which is considered low intensity aerobic activity (Wilmore and Costill 1999). The dancers’ HR were below 120 b·min⁻¹ 91.3% of their time, which is lower than the theoretical aerobic training zone (60-90% of HR maximum) during performance.
The present mean estimated oxygen consumption (VO$_2$) and HR values for both males and females were somewhat lower than previous values measured during performances and were more similar to those measured during contemporary dance classes and early rehearsals (Wyon et al. 2004). In contrast, BL concentrations, which represent anaerobic glycolysis during exercise and indicate the transition from aerobic to anaerobic activity, were similar to those measured by Wyon and colleagues (Wyon and Redding 2005) following contemporary dance performances.

There are two plausible reasons for the observed lower VO$_2$ and HR values compared to previous results. The first could be because the physiological responses to performances were recorded at the end of the performance season. As a consequence, the dancers that participated in this study, compared to others, may already be trained to work at the specific intensity. This is supported by Wyon and colleagues (Wyon et al. 2004), who reported that during the performance season dancers increase their fitness levels because of systematic repetition of dance performances, while in contrast this does not happen during early rehearsals and class, since these parts of dance training are focused on skill acquisitions rather than physiological preparation for performance. Hence, present results might be different from previous studies, since the physiological monitoring happened at the end of the performance season, while no such information, together with the number of performances monitored, are reported in similar previous studies (Wyon et al. 2004; Wyon and Redding 2005). The second reason is that contemporary dance performance demands can vary significantly from one to the another, since the relative intensity is associated with the physical fitness of the dancer, while the physiological workload is also dependent on the choreography (Wyon 2005).

Present results for gender differences were similar to previous findings, since non significant differences were depicted during performance in any of the physiological parameters between genders (Wyon et al. 2004). These results suggest that artistic
differences in gender roles during the observed performances are not reflected at physiological level.

There are a number of potential applications of SWA in dance. The combined use of observational and physiological tools (i.e. SWA) during actual on-stage performance would allow full performance analysis, which includes technical, biomechanical and physiological aspects (Hughes and Bartlett 2002). This in turn, could be valuable to prepare dancers for the artistic and physical variability of dance performance repertories (Wyon 2005). The use of SWA in combination with observational tools such as movement and time-motion analysis systems, which have been extensively used in other sports (McLean 1992; Hars and Calmels 2006), could provide a valuable help in the identification of physical demands (in terms of number of specific actions or moves) placed on dancers during different performances, and so to meet those demands by tailoring dance classes accordingly. In order to do so, the description of physical requirements, as established by choreographers, should be taken into account together with physiological costs when analysing results.

The present study was the first to use SWA data to assess energy expenditure in contemporary dance. By estimating METs to measure the energetic cost of dancing, the dancers, at 4.5 METs, were classified as exercising within the moderate exercise intensity zone (McArdle et al. 2007) comparable to other intermittent type of exercise such as archery, table tennis and tennis (Wilmore and Costill 1999). The use of SWA provided a non-invasive method to measure physical effort during dance, which indeed represents a key step towards direct measurements of physiological variables during actual dance performance. It is concluded that within the limitations of the present study, contemporary dance performance analysed here is a moderate type of exercise.

In sport, there is a widespread practice of using the information gathered from a past contest in order to prepare for future contests by using observational tools such as video analysis (Duthie et al. 2003). However, in dance observational analysis has largely been based upon examining choreographic elements from an artistic stance (Adshead-Lansdale 1994; Jackson 1994) and to compare different performances of the same work (Camurri et al. 1999).

The time motion (TM) and match analysis (MA) systems are the main observational techniques that have been used for assessing movement patterns and physical demands of a range of sports, including football (Bangsbo et al. 1991), rugby (McLean 1992), hockey (Boyle et al. 1994) and gymnastics (Hars and Calmels 2006). The TM analysis quantifies the movements of participants during action in order to extract general information regarding the demands of competition (Duthie et al. 2003). The MA system quantifies selected variables within specific pre-defined performance indicators, such as technical, tactical and biomechanical factors (Hughes and Bartlett 2002). For example, in soccer, the MA system has been used to calculate the time of activities spent at specific intensities, such as running and walking, as well as the number of specific skills performed during the entire match, such as passing and tackles (Tessitore et al. 2005). The use of TM and MA systems is a reliable procedure and provides accurate details of technical, biomechanical and physical demands, and it has been recommended for full performance analysis (Hughes and Bartlett 2002).

A number of studies have previously adopted observational tools for examining selected technical elements of dance, such as lifting, landing and changes of direction (Trepman et al. 1994; Simpson et al. 1996; Simpson and Pettit 1997). Nevertheless, these data cannot be used to determine the demands of a specific performance without taking into account information such as the frequency (i.e. number of repetitions during performance)
at which the action is performed. Yet, by using video analysis systems to determine the
demands of specific repertoire, dancers may be able to prepare more thoroughly to meet
those demands and to reduce injury risks. Therefore, the aim of the present study was to
use the TM and MA analysis systems to analyse selected aspects of contemporary dance
performance and to discuss potential applications of the movement analysis outcomes to
improve dancers’ physical preparation for repertoire demands.

Methods

Video analyses were conducted on 45 (24 male and 21 female) recorded contemporary
dance performances (i.e. DVDs) of different length (ranging from 8.5 to 39 min; mean±SD:
24.4± 6.8 min) by individual dancers. Prior to data collection, all dancers were fully
informed about the purpose of the study and reminded about their right to withdraw at any
time. The observed performances included dance works by selected contemporary dance
companies and performances were randomly chosen. Three performance indicators (or
fields) were employed: work intensity, transitory and partner work. These were adapted
from a previous similar study in sport (Capranica et al. 2001). Data were recorded in each
field every 30 seconds, enabling the assessment of work:rest ratio and the number of
jumps, falls, lifts, pliés and changes of direction as well as partner-actions performed
during performance. The work intensity field was used to provide qualitative description of
the intensity of dance performance (i.e. from rest to very hard); the partner field described
interactions with other dancers, including the number of lifts and supports performed. The
transitory field referred to movement of the dancer’s centre of gravity, including: the
number of movements to the floor and to standing and the number of pliés, jumps and
changes of direction. Table 8 (page 59) depicts the description for each performance
indicators utilised.

To avoid bias in the analysis of the data, a single experienced observer (age 33;
years of experience teaching dance: 7) was employed. Prior to data collection, the
observer’s intra-individual test-retest reliability it was assessed, as previously described (Capranica et al. 2001), by asking this experienced observer to score a performance three times within a seven-day interval. The Ethics Committee of Research Centre for Sport, Exercise and Performance, University of Wolverhampton, UK, approved the study protocol.

Statistical Analyses

Routine pre-analyses were conducted using Kolmogorov-Smirnov test of normality to detect the distribution of the studied variables. Analysis of the results incorporated the use of descriptive statistics using mean±SD; for non-normally distributed variables data are reported as median (interquartile range). Differences between work and rest time, and time spent dancing with partners and during solos were examined using t-tests. Analyses were conducted via SPSS 13 (SPSS Inc, Chicago, IL, USA). Statistical significance was set at p<0.05.
Table 8: Performance indicators used for contemporary dance performance analyses.

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Work Intensity Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td>Subject is standing still either on or off stage</td>
</tr>
<tr>
<td>Very Light</td>
<td>Subject is undergoing very light work e.g. slow walk pace with little upper body movements</td>
</tr>
<tr>
<td>Light</td>
<td>Subject is undergoing light work e.g. walk pace with upper body movements</td>
</tr>
<tr>
<td>Moderate</td>
<td>Subject is undergoing moderate work e.g. jog, can include jumps (low)</td>
</tr>
<tr>
<td>Hard</td>
<td>Subject is undergoing hard work e.g. fast jog, run, multiple jumps and lifts</td>
</tr>
<tr>
<td>Very Hard</td>
<td>Subject is undergoing very hard work e.g. run pace, static holds above shoulders height, and multiple high jumps landing on one leg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Transitory Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>ChD</td>
<td>Subject is changing direction</td>
</tr>
<tr>
<td>Pliés</td>
<td>Subject carries out either full or demi-pliers*</td>
</tr>
<tr>
<td>Jumps</td>
<td>Subject is undergoing either a two footed or single footed jump/leap with both feet leaving the ground**</td>
</tr>
<tr>
<td>S&gt;F</td>
<td>Subject moving from standing to floor</td>
</tr>
<tr>
<td>F&gt;S</td>
<td>Subject is moving from floor to standing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Partner Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>With other</td>
<td>Subject is in contact with another dancer</td>
</tr>
<tr>
<td>Assisted lift</td>
<td>Lift with subjects plus other(s) helping</td>
</tr>
<tr>
<td>Lift</td>
<td>Subject lifting another dancer on his own</td>
</tr>
<tr>
<td>Catch</td>
<td>Subject catching another dancer from a jump or throw</td>
</tr>
<tr>
<td>Support</td>
<td>Subject supporting another dancer who has one or both feet on the ground</td>
</tr>
<tr>
<td>Being Lifted</td>
<td>Subject is being lifted by another dancer</td>
</tr>
</tbody>
</table>

* = Pliés performed before jumping are included.
** = Jumps can also include a change of direction. Where this applies, then it has to be counted one ChD and one jump.
**Results**

The observed random errors in the intra test-retest reliability of the observer were deemed satisfactory. Table 9 (page 61) depicts descriptive statistics [mean±SD and/or median (interquartile range)] of the variables analysed, including: the total work and rest time, the time spent at specific intensities, the frequency of transitory movements and actions performed. Time spent performing at each intensity level was calculated both in minutes (Table 9) and as a percentage of the whole performance (Figure 9, page 62). Transitory movements (jumps, pliés, changes of direction, and transitions from standing to floor and vice versa) and actions performed during partner work (lifts and supports) were calculated as per occurrence during performance.

Analyses of the work intensity field revealed that the dancers’ total work time was 69.0%; this was significantly higher compared to rest time of 31% (p<0.01). The calculated mean work:rest ratio was 2:1. Dancers were observed performing for the 25.1±19.2% of the total work time at a light intensity, followed by the 19.8±11.4% of the total work time at a moderate intensity, while they were observed working at hard intensities only for the 9.0±10.7% of the time (Figure 9).

Partner field analysis revealed non significant difference (p>0.05) between the time spent dancing on their own (solos) and with others (partner work).

Movement analyses also allowed for the description of transitory movements employed by the body during performance. Pliés were the movements with the highest occurrence rate per performance (150.1± 84.5), followed by jumps [21(9.0-38.0)] and changes of direction [8.0(3.0-16.0)] (Figure 10, page 62).
Table 9: Movement analysis results.

<table>
<thead>
<tr>
<th>Work Intensity field</th>
<th>Mean+SD or Median (interquartile range)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Work time (min⁻¹)</strong></td>
<td>15.0(13.5-18.0)</td>
</tr>
<tr>
<td><strong>Rest time (min⁻¹)</strong></td>
<td>7.9±4.9</td>
</tr>
<tr>
<td><strong>Intensities (min⁻¹)</strong></td>
<td></td>
</tr>
<tr>
<td>Very Light</td>
<td>2.5(1.0-4.0)</td>
</tr>
<tr>
<td>Light</td>
<td>5.0(2.0-7.5)</td>
</tr>
<tr>
<td>Moderate</td>
<td>4.6±2.6</td>
</tr>
<tr>
<td>Hard</td>
<td>1.0(0.0-3.2)</td>
</tr>
<tr>
<td>Very Hard</td>
<td>0.0(0.0-0.0)</td>
</tr>
</tbody>
</table>

| **Partner field** | |
| Dancing on own (min⁻¹) | 6.56 ± 4.1 |
| Dancing with others (min⁻¹) | 7.21 ± 4.6 |

| Actions (occurrences/performance) | |
| Assisted Lift | 0.0(0.0-0.0) |
| Lift | 0.0(0.0-2.5) |
| Support | 0.0(0.0-2.0) |
| Being Lifted | 1.0(0.0-2.5) |

| **Transitory field** (occurrences/performance) | |
| Jumps | 21.0(9.0-38.0) |
| Pliés | 150.1±84.5 |
| Changes of direction | 8.0(3.0-16.0) |
| Standing to floor | 8.0(3.0-12.0) |
| Floor to standing | 8.0(3.0-12.0) |
Figure 9: Work intensity at specific % rates. The % time spent at rest and at different work intensity rates, namely very low (VL), low (L), medium (M), hard (H) and very hard (VH) are reported.

Figure 10: Transitory movements expressed in occurrence per performance. The movements, namely jumps (J), pliés (P), changes of direction (ChD), standing to floor (S > F) and floor to standing (F > S) are reported.
Discussion

The aim of the present study was to analyse selected aspects of contemporary dance performance by using the TM and MA analysis systems. Results revealed that work intensities varied from light to moderate while these were observed with the use of pliés and jumps as well as lifting other dancers. For the entire group of contemporary dancers, both the total mean work-time of 69% and the work:rest ratio of 2:1 is in line with previous findings in contemporary dance (Wyon 2005) confirming the intermittent nature of dance performance. Given that work:rest ratio provides an objective means of quantifying the physiological requirements of an activity (Duthie et al. 2003), it is reasonable to suggest that, during the studied performances, the energy requirements were mainly derived from the aerobic system with frequent anaerobic bursts (Bahr and Gronnerod 1992). Dancers spent most of their % work time dancing between light (25.2±19.3 %) and moderate intensities (19.8±11.4 %), with the use mainly of pliés and jumps. Non significant difference was observed between the time spent dancing with others (partner work) and on their own (solos) with lifts being the movement with the highest occurrence rate.
The number of changes of direction, as well as the number of lifts, pliés and jumps occurring during performance, is useful information for observing and estimating the forces that the musculoskeletal system and particularly the joints (i.e lower back, hip, knee and ankle) are subjected to throughout a performance. Calculating the total forces that are applied on the musculoskeletal system is important information that could be then used to prevent injury during performance, such as the lumbar shear and compressive forces during lifts, which pose a risk of lower back injury (Hopper, Alderson et al. 2007) or the ground reaction forces during landing which can overstress the patellar tendon (Mcnair and Prapavessis 1999). Because dance training is not sufficient enough to overload the musculoskeletal systems (Koutedakis and Jamurtas 2004), supplemental training programmes reflecting the aspects highlighted by the movement analysis, could optimise the dancer’s physical preparation for performance.

The use of movement analysis has a number of potential applications to dance. In sport the TM and MA systems have been extensively used by coaches and sport scientists to improve performance (McGinnis 2000) and to investigate the demands and correct technique of movements (Duthie et al. 2003). In the present study the use of the movement analysis tool enabled me to describe the demands of the observed contemporary dance performances in terms of work:rest ratio, the intensities at which dancers are working, the rate of transitory movements and partner work actions performed. Implementing the use of movement analysis, prior to the initiation of preparation training for repertoire season, could be an effective solution to physically prepare dancers for its demands. By using the MA system, the rehearsal director can pre-define the number of transitory movements to be performed during the dance piece; by subsequently analysing those, using the TM system (watch and stop in order to notate specific indicators), the rehearsal director can identify the aspects that need improvement during class work. The employment of validated scales (performance indicators) and a systematic use of movement analysis system is recommended to investigate the varying demands of different repertoire performances.
It is reasonable to assume that the present results may have been influenced by certain methodological limitations. It might be argued that only three basic performance indicators were used. Future researchers might want to diversify the selection of performance indicators (i.e. technical description of transitory movements). This may better represent the versatility of contemporary dance. Finally, the method of video analysis used in the study is reliant on one observer. Future studies might want to incorporate a higher number of observers and rely on repertoire-specific indicators. Within these limitations, it is conclude that data from movement analyses provide useful information to rehearsal directors and physiologists aiming at optimising dancers’ physical preparation for repertoire performances.
V. Study 2: Association between selected physical fitness parameters and contemporary dance performance

This chapter has been published: Angioi M et al. (2009): Association between selected physical fitness parameters and aesthetic competence in contemporary dance. J Dance Med Sci 13 (4):115-123.

The technical mastery of skills is essential in order to achieve the necessary aesthetic competence (AC) in dance (Krasnow et al. 1997). The term AC was initially used by Chatfield and colleagues (Chatfield and Byrnes 1990) followed by Krasnow (Krasnow et al. 1997) to convey the overall performance proficiency of a dancer.

Preliminary published data revealed that aspects of dance performance benefit from enhanced physiological capabilities such as muscular strength and power (Brown et al. 2007; Koutedakis et al. 2007). This is at least the case in other activities, such as rhythmic gymnastics, where the artistic qualities improve in line with enhanced physical and physiological capabilities (Alexander 1989; Hume et al. 1993). In elite rhythmic gymnasts, basic aspects of their performance (such as jumps and leaps) are influenced by strength, power, endurance and flexibility (Hume et al. 1993), while general performance efficiency is strongly influenced by rhythmic coordination (Kiourmourtzoglou et al. 1997; Miletic et al. 1998). Moreover, studies have revealed that in gymnastics, specific adaptations, such as dynamic and static balance, are attained with training, because of the specific sensorimotor challenges, which are important for the development of optimal balance (Bressel et al. 2007). This, in turn can significantly affect the overall performance scores.

Numerous published data on contemporary dancers have examined the levels of selected fitness components such as aerobic capacity (Chmelar et al. 1988; Chatfield et al. 1990), anaerobic power (Padfield et al. 1993), muscular strength and power (Koutedakis et al. 1997b; Harley et al. 2002) and anthropometric characteristics (Yannakoulia et al. 2000; Berlet et al. 2002). However, there is no published information on the association between these fitness parameters and AC.
Unlike physical fitness, the objective evaluation of performance is less clear. Moreover, there are no validated and reliable tools in order to assess either AC or performance in relation to physical fitness. Conversely, dance teachers, artistic directors, dance institutions and companies rely on a number of different criteria and methods to quantify performances which are not standardized. Hence, given the lack of standardized valid and reliable procedures, the objective evaluation of performance competence may be significantly compromised. Two recent studies have investigated the effects of supplementary exercise training on jumping ability and dance performance (Brown et al. 2007; Koutedakis et al. 2007). However, both investigations relied on fairly subjective evaluations of selected qualitative aspects of performance.

To my knowledge, no studies have determined which of the main fitness components (i.e. aerobic capacity, muscular strength and endurance, flexibility and body composition) would best predict AC in contemporary dance. Therefore, the aim of this study was: 1) to develop and test a novel AC tool for reliability, and 2) investigate the association between physical fitness components and performance by using a newly developed AC tool.

**Methods**

**Design**

This study was designed in two parts: In the first part (reliability study) a novel aesthetic competence tool was designed and tested for inter and intra reliability. In the second part (association study), this reliable tool was used to investigate its association with selected fitness components.
I. Reliability Study

*Tool development*

Auditioning criteria from pre-professional contemporary dance institutions and companies from US, UK and Australia (three pre-professional contemporary dance institutions, four university dance courses, one company and one examination body), were collected. The AC tool was developed based on the seven most frequently used criteria. Each criterion was to be evaluated using a Likert scale model ranging from 1 to 10; thus, the maximum possible total score was 70. The following general word-anchors were provided to the judges for scoring purposes: 1-3 little or no ability to performed elements as required; 4-6 some elements performed appropriately; 7-9: elements performed appropriately for about 80% of the time; 10: elements performed appropriately during the whole performance. The marking/assessment criteria scheme devised, including scoring guidelines for judges, are reported in Table 10 (page 70).

Two experienced dance teachers (age: 42 and 34 years, respectively) with at least seven years experience of assessing and auditioning dancers, were recruited as judges. The two dance teachers had similar dance background (e.g. professional training as contemporary dancers and qualified teacher status) and were teaching staff in two different pre-professional contemporary dance institutions. One judge had also experience on an audition panel for dance companies. The recruited judges were unknown to the dancers or to each other. Six professional contemporary dancers (four females) were recruited as performers (age: 31±5.1 years; height: 163.6±6.5 cm; weight: 57.2±8.1 kg; total years of dance training: 20.1±9.4; years of professional activity: 13.7±3.1). All participants were dancing full-time at the time of the recruitment, were free from injury, and were not involved in any supplementary fitness training or other sport activity. The dancers were asked to perform a specially choreographed sequence lasting 60 seconds. Before proceeding to AC assessment, all dancers had an equal rest time of one hour. All performers learned the dance sequence the same day, and the same studio at the same time-
slot. Each participant was given 20-minutes to learn the choreography. At the time of recruitment, each dancer was fully informed about being video recorded during the AC test and was given an equal practice time of five minutes in front of the camera before being video recorded. Each performance was video-recorded, copied three times and randomly ordered in an edited video containing a total of 18 clips. The video was subsequently handed, together with choreographic notes and marking/assessment guidelines, to the two judges, who scored the dancers separately. The dancers were scored on each performance that was observed by the judges. The performances seen were identified by clip number in order for the authors to associate scores given with the correct corresponding performance. Judges were given the following instructions: 1) to mark all dancers from the video the same day, 2) do not rewind the video clips at any time once the scoring procedure has started, 3) to perform the assessment during the first hours of the morning on a pre-arranged specific day, and 4) to follow the scoring guidelines (Table 10, page 71) and have the choreographic notes with them (Table 11, page 72).

Statistical analysis

The scores given for each criterion by the two judges were compared to assess inter-rater reliability. For intra test-retest reliability, the scores given by each judge in the three separate trials were also compared. All analyses were conducted using two-way mixed intraclass correlation coefficients (ICC) in SPSS (version 12.0, SPSS inc, Chicago, IL, USA). Confidence intervals (95%) were also calculated for all ICCs (Bland and Altman 1986).

Results

For inter-rater reliability, there were no significant differences (p>0.05) for the scores given in each individual criterion between the two judges and the ICC for the total score for judge 1 and 2 was r=0.96, p<0.01 (Figure 12, page 74). Table 12 (page 73) depicts in details the
inter-rater reliability results. For intra test-retest reliability, repeated measures ANOVA showed no significant differences (p>0.05) between the three individual assessments carried out by each judge (Figure 13 for dance teacher 1, page 74; Figure 14 for dance teacher 2, page 75). Table 13 (page 73) depicts results for intra test re-test including: mean±SD, P values, F values, Standard Error and 95% confidence interval. ICCs amongst the three individual assessments for judge 1 and 2 were as follows: Judge 1, criterion 1: r=0.86. p=0.004, criterion 2: r=0.88. p=0.003, criterion 3: r=0.91. p=0.001, criterion 4: r=0.94. p<0.01, criterion 5: r=0.95. p<0.01, criterion 6: r=0.85. p=0.006 and criterion 7: r=0.92. p=0.001. Judge 2, criterion 1 r=0.96. p=0.001, criterion 2: r=0.89. p=0.002, criterion 3: r=0.90. p=0.001, criterion 4: r=0.92. p=0.001, criterion 5: r=0.94. p=0.001, criterion 6: r=0.90. p=0.001 and criterion 7: r=0.96. p=0.001. The 95% limits of agreement found no significant bias in any of the assessment for either the inter or intra test-retest reliability (p>0.05).
Table 10: Selected marking/assessment criteria and scoring guidelines.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Description</th>
<th>Mark 1-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Control of movements</td>
<td>Controlled landing from jump/turn, controlled lifting/lowering of limbs, controlled shifting of body weight. Core strength, alignment, posture.</td>
<td>1-3: Some evidence of co-ordination, movement control and body awareness but limited and inconsistent. 4-6: Some elements were stronger than others. 7-8: Secure general co-ordination, body alignment, generally well controlled movements. 9-10: Well co-ordinated movement and controlled work all of the time with and accurate alignment.</td>
</tr>
<tr>
<td>2. Spatial skills</td>
<td>Spatial awareness, accuracy and intent.</td>
<td>1-3: Little or no use of peripheral space. Poor use of performance space. 4-6: Some good use of space but inconsistent. Some elements stronger than others. 7-8: Good use of space, about 80% of the time with general accuracy and intent. 9-10: Secure and confident use of all space with accuracy and intent.</td>
</tr>
<tr>
<td>3. Accuracy of movements</td>
<td>Arm placing, feet positions, fully stretched leg extensions (if required).</td>
<td>1-3: Little or no precision throughout sequence. Unclear leg/arm lines 4-6: Some precision but inconsistent. Some elements stronger than others 7-8: Correct positioning about 80% of the time. 9-10: Precise placing with well articulated gestures of limbs.</td>
</tr>
<tr>
<td>4. Technique</td>
<td>Elevation, turning and falling techniques, height of extensions, balance, posture, placement, articulation.</td>
<td>1-3: Little or no evidence of high technical skill in any element. 4-6: Some skill in some elements, general virtuosity achieved. 7-8: Good virtuosity shown about 80% of the time. 9-10: A stunning performance showing virtuosity and skill throughout.</td>
</tr>
<tr>
<td>5. Dynamics, timing and rhythmical accuracy</td>
<td>Dancing with correct timing and ability to perceive movement and rhythmic patterns. Showing awareness for changes in musical dynamics and phrasing.</td>
<td>1-3: Little or no ability to perform and response in time to the music. Little or no dynamic qualities 4-6: Performed in time for over half of the sequence, with some ability to respond to different rhythms and dynamics of movement. 7-8: Timing was accurate for most of the sequence, and response to varying rhythms was shown. General good use of dynamics. Good sense of musicality. 9-10: Timing was accurate throughout, with very good response to various rhythms, dynamics and phrases.</td>
</tr>
<tr>
<td>6. Performance qualities</td>
<td>Ability to execute the work for an audience. Presence, expressiveness, memory recall.</td>
<td>1-3: Little or no performance qualities were shown. Poor memory recall. 4-6: Some performance qualities were shown. Generally good memory recall. 7-8: Strong expressive qualities and memory recall about 80% of the time. 9-10: Excellent and well developed projection of a range of expressions, feelings and emotions with an audience. Mature approach with understanding of the motivation for the movement.</td>
</tr>
<tr>
<td>7. Overall performance</td>
<td>Does the whole performance overall impress markers?</td>
<td>1-3: Dancer made little impression on the audience. 4-6: Dancer not at full potential yet OR strong work but lacking to impress overall. 7-8: Dancer has the ability to shine, but was hindered by minor aspects of performance. 9-10: Impressive!</td>
</tr>
</tbody>
</table>
### Table 11: Choreographic notes for judges.

<table>
<thead>
<tr>
<th>General</th>
<th>Dynamics, accents, tempo and rhythm are equally important in this piece to technique, virtuosity and performance qualities.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arms</td>
<td>Transitions from standing to plank position and from plank position to lying on the floor require a slow, continuous and controlled action of arms and upper body.</td>
</tr>
<tr>
<td>Rolls</td>
<td>Very quick and precise, need to be on time with the music (2 counts for each roll). Dancers stand up from floor actively using his/her arms.</td>
</tr>
<tr>
<td><strong>Turn en rond de jambe</strong></td>
<td>Torso should bend forward as close to the standing leg as possible.</td>
</tr>
<tr>
<td><strong>Double attitude jump</strong></td>
<td>Height of the jump and flexibility. Torso should twist to the right while performing the jump.</td>
</tr>
<tr>
<td><strong>Turn en attitude</strong></td>
<td>Should be performed on a straight supporting leg in relevé, with working leg in attitude. Look for technique as well as flexibility.</td>
</tr>
<tr>
<td><strong>Extension a la seconde</strong></td>
<td>The working leg should be fully extended and as high as possible; the supporting leg is in relevé.</td>
</tr>
<tr>
<td><strong>Sissonne Jump</strong></td>
<td>Underneath leg should be fully extended and working leg in attitude; the back should be arched backwards towards the back leg. Look for height of the jump, flexibility, and control during landing.</td>
</tr>
<tr>
<td><strong>Twist jump going into a balance</strong></td>
<td>Height of the jump and control of the body in the twisting action. Landing should be fully controlled to go straight into a balance position with working leg in attitude a la seconde.</td>
</tr>
<tr>
<td><strong>Turn en Promenade</strong></td>
<td>Continuing from the balance, promenade with working leg in attitude a la seconde. Look for balance and control, as well as flexibility and strength of the working and supporting leg.</td>
</tr>
<tr>
<td><strong>Tilt</strong></td>
<td>After the promenade, the shape is maintained while the body is tilted as a unit, aiming for 180 degree tilt. Look for control both coming in and out of the tilt.</td>
</tr>
<tr>
<td><strong>Penché</strong></td>
<td>Aiming for 180 degrees. Look for hip active ROM and control.</td>
</tr>
<tr>
<td><strong>Section with fast footwork and shift of weight</strong></td>
<td>Look for precision and neatness of the footwork, and the changes of direction and shifts of weight.</td>
</tr>
<tr>
<td><strong>Handstand</strong></td>
<td>Muscular endurance of the upper body. Coming out of the handstand the working leg should not touch the ground but continue to stay lifted as coming around into a lunge.</td>
</tr>
</tbody>
</table>
Table 12: Inter-rater reliability.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Mean±SD</th>
<th>Mean±SD</th>
<th>95% C.I.</th>
<th>P value</th>
<th>ICC(significance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Judge 1</td>
<td>6.4±1.6</td>
<td>6.7±1.6</td>
<td>0.3±1.0</td>
<td>-0.8 – 0.2</td>
<td>p&gt;0.05</td>
</tr>
<tr>
<td>Judge 2</td>
<td>7.0±1.4</td>
<td>7.3±1.2</td>
<td>0.3±0.7</td>
<td>-0.6 – 0.05</td>
<td>p&gt;0.05</td>
</tr>
<tr>
<td>Criterion 1</td>
<td>6.7±1.7</td>
<td>7.0±1.1</td>
<td>0.3±0.8</td>
<td>-0.7 – 0.05</td>
<td>p&gt;0.05</td>
</tr>
<tr>
<td>Criterion 2</td>
<td>6.9±1.6</td>
<td>6.9±1.2</td>
<td>0±0.7</td>
<td>-0.3 – 0.4</td>
<td>p&gt;0.05</td>
</tr>
<tr>
<td>Criterion 3</td>
<td>7.0±1.1</td>
<td>7.5±1.1</td>
<td>0.4±0.5</td>
<td>-0.7 – 0.2</td>
<td>p&gt;0.05</td>
</tr>
<tr>
<td>Criterion 4</td>
<td>7.3±1.4</td>
<td>7.3±1.2</td>
<td>0±0.4</td>
<td>-0.3 – 0.1</td>
<td>p&gt;0.05</td>
</tr>
<tr>
<td>Criterion 5</td>
<td>6.7±1.6</td>
<td>6.0±1.9</td>
<td>0.7±1.0</td>
<td>0.1 – 1.2</td>
<td>p&gt;0.05</td>
</tr>
</tbody>
</table>

95% C.I. = 95% confidence interval; ICC = intraclass correlation coefficient

Table 13: Intra-rater test-retest reliability.

<table>
<thead>
<tr>
<th>Judge 1</th>
<th>Mean±SD 1st trial</th>
<th>Mean±SD 2nd trial</th>
<th>Mean±SD 3rd trial</th>
<th>P values</th>
<th>F values</th>
<th>95% C.I. 1st trial</th>
<th>95% C.I. 2nd trial</th>
<th>95% C.I. 3rd trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criterion 1</td>
<td>6.7±1.6</td>
<td>6.2±1.8</td>
<td>6.5±1.7</td>
<td>p&gt;0.05</td>
<td>.128</td>
<td>.666</td>
<td>.749</td>
<td>.718</td>
</tr>
<tr>
<td>Criterion 2</td>
<td>7.3±1.6</td>
<td>6.6±1.3</td>
<td>7.0±1.2</td>
<td>p&gt;0.05</td>
<td>.326</td>
<td>.666</td>
<td>.557</td>
<td>.516</td>
</tr>
<tr>
<td>Criterion 3</td>
<td>6.5±1.3</td>
<td>6.3±1.9</td>
<td>7.1±1.8</td>
<td>p&gt;0.05</td>
<td>.383</td>
<td>.562</td>
<td>.802</td>
<td>.749</td>
</tr>
<tr>
<td>Criterion 4</td>
<td>7.2±1.6</td>
<td>6.5±1.6</td>
<td>7.2±1.7</td>
<td>p&gt;0.05</td>
<td>.324</td>
<td>.648</td>
<td>.670</td>
<td>.703</td>
</tr>
<tr>
<td>Criterion 5</td>
<td>7.3±1.5</td>
<td>6.8±1.4</td>
<td>7.0±1.5</td>
<td>p&gt;0.05</td>
<td>.171</td>
<td>.614</td>
<td>.600</td>
<td>.632</td>
</tr>
<tr>
<td>Criterion 6</td>
<td>7.5±1.3</td>
<td>7.0±1.4</td>
<td>7.3±1.5</td>
<td>p&gt;0.05</td>
<td>.159</td>
<td>.562</td>
<td>.577</td>
<td>.614</td>
</tr>
<tr>
<td>Criterion 7</td>
<td>6.8±1.7</td>
<td>6.3±1.7</td>
<td>6.8±1.7</td>
<td>p&gt;0.05</td>
<td>.167</td>
<td>.703</td>
<td>.714</td>
<td>.703</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Judge 2</th>
<th>Mean±SD 1st trial</th>
<th>Mean±SD 2nd trial</th>
<th>Mean±SD 3rd trial</th>
<th>P values</th>
<th>F values</th>
<th>95% C.I. 1st trial</th>
<th>95% C.I. 2nd trial</th>
<th>95% C.I. 3rd trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criterion 1</td>
<td>6.8±1.7</td>
<td>6.5±1.5</td>
<td>6.8±1.8</td>
<td>p&gt;0.05</td>
<td>.077</td>
<td>.703</td>
<td>.619</td>
<td>.749</td>
</tr>
<tr>
<td>Criterion 2</td>
<td>7.2±1.5</td>
<td>7.3±1.2</td>
<td>7.3±1.2</td>
<td>p&gt;0.05</td>
<td>.033</td>
<td>.600</td>
<td>.494</td>
<td>.494</td>
</tr>
<tr>
<td>Criterion 3</td>
<td>6.8±1.2</td>
<td>7.0±1.3</td>
<td>7.2±1.2</td>
<td>p&gt;0.05</td>
<td>.115</td>
<td>.477</td>
<td>.516</td>
<td>.477</td>
</tr>
<tr>
<td>Criterion 4</td>
<td>7.0±1.4</td>
<td>6.6±1.2</td>
<td>7.0±1.3</td>
<td>p&gt;0.05</td>
<td>.132</td>
<td>.577</td>
<td>.494</td>
<td>.516</td>
</tr>
<tr>
<td>Criterion 5</td>
<td>7.6±1.2</td>
<td>7.2±1.2</td>
<td>7.6±1.2</td>
<td>p&gt;0.05</td>
<td>.349</td>
<td>.494</td>
<td>.477</td>
<td>.494</td>
</tr>
<tr>
<td>Criterion 6</td>
<td>7.6±1.2</td>
<td>7.2±1.7</td>
<td>7.2±1.3</td>
<td>p&gt;0.05</td>
<td>.326</td>
<td>.494</td>
<td>.477</td>
<td>.542</td>
</tr>
<tr>
<td>Criterion 7</td>
<td>5.8±2.1</td>
<td>5.8±1.9</td>
<td>6.3±1.9</td>
<td>p&gt;0.05</td>
<td>.127</td>
<td>.872</td>
<td>.792</td>
<td>.760</td>
</tr>
</tbody>
</table>

S.E.=Standard Error; 95% C.I.=Confidence Interval
Figure 12: Inter-raters reliability

Figure 13: Test-retest intra reliability for teacher 1
II. Association study

Participants

Eleven female dance students in pre-professional training and six (five females) professional contemporary dancers (total number of participants n=17) were recruited. Table 14 (page 76) depicts the anthropometric and demographic characteristics of participants. Inclusion criteria at the time of the recruitment were: 1) enrolment in a pre-professional recognised dance institution or employment as a dancer within an established dance company; 2) no injury at the time of the fitness assessment and 3) no involvement in any supplementary fitness training or sport activity during the three months preceding the fitness assessment. Participants were also informed about the requirement of photography and video recording which were necessary for this study. Written informed consents were obtained from all participants after full verbal and written explanation of the data collection procedures. The Research Centre for Sport, Exercise and Performance Ethics Committee (University of Wolverhampton) approved the study protocol.
For each volunteer, testing was completed during the same day, in the following order: 1) dancers fitness assessments and 2) AC evaluation. A three-hour interval was allowed between fitness assessment and the AC test, in order to avoid undue fatigue.

*Fitness assessment*

The majority of protocols used for the assessment of the selected fitness parameters were in accordance to the guidelines of the British Association for Sport and Exercise Sciences (Wyon 2007) and the American College of Sport Medicine (Balady et al. 2000). Fitness assessment took place at the dancers’ workplace. Therefore, field-based protocols and portable equipment were employed. Table 15 (page 77) depicts a summary of fitness tests employed.
Table 15: Summary of fitness tests employed.

<table>
<thead>
<tr>
<th>Fitness component</th>
<th>Method</th>
<th>Equipment</th>
<th>Type of test</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Body Fat</td>
<td>Skinfold</td>
<td>Skinfold caliper</td>
<td>Field based</td>
<td>Siri, 1961 [Siri 1961]</td>
</tr>
<tr>
<td>Aerobic capacity</td>
<td>DAFT test</td>
<td>HR monitors</td>
<td>Field based</td>
<td>Wyon et al. 2003 [Wyon et al. 2003]</td>
</tr>
<tr>
<td>Lower body muscular power</td>
<td>Jump Height</td>
<td>Jump mat</td>
<td>Field based</td>
<td>ACSM [Balady et al. 2000]</td>
</tr>
<tr>
<td>Upper body muscular endurance</td>
<td>Press-ups</td>
<td>Stop-watch</td>
<td>Field based</td>
<td>ACSM [Balady et al. 2000] [Wood and Baumgartner 2004]</td>
</tr>
<tr>
<td>Central body muscular endurance</td>
<td>Plank</td>
<td>Stop-watch</td>
<td>Field based</td>
<td>BASES (Wyon 2007)</td>
</tr>
<tr>
<td>Joint mobility and muscular flexibility</td>
<td>Active and passive hip ROM</td>
<td>Geometrical protractor</td>
<td>Field based</td>
<td>BASES (Wyon 2007) [Redding et al. 2004] [Redding and Wyon 2004]</td>
</tr>
</tbody>
</table>

DATF = dance aerobic fitness test; HR monitors = heart rate monitors; ROM = range of motion.

**Anthropometry and Body composition**

Anthropometrical characteristics such as standing height (cm) and total body mass (Kg) were assessed. These were subsequently used to calculate, via specific equations, % BF. Specific details of the exact methodological procedures appear in Methods (page 42).

**Flexibility**

Flexibility levels of dancers were assessed by measuring the active and passive sideway leg extension (développé a la seconde which is the combined hip action of flexion, abduction and external rotation) according to a protocol recommended for dancers (Wyon 2007). Specific details of the exact methodology procedures appear in Methods (page 44).

**Muscular power**

Muscular power of the lower extremity was assessed by a validated field-based test (Balady et al. 2000) (standing vertical jump). Specific details of the exact methodology procedures appear in Methods (page 43).
Muscular endurance

For assessment of muscular endurance, two different field-tests were used: the press-ups (Balady et al. 2000; Wood and Baumgartner 2004) and plank test (Kendall and McCreary 1993), respectively. Specific details of the exact methodology procedures appear in Methods (page 44).

Aerobic capacity

Aerobic capacity was tested using the validated Dance Aerobic Fitness Test (DAFT) (Wyon et al. 2003). Specific details of the exact methodology procedures appear in Methods (page 43).

Contemporary dance aesthetic competence test

Using the previously developed reliable aesthetic competence tool (Study 2–part 1), dancers were asked to learn and perform a short dance sequence lasting 90 seconds. They were video recorded during the performance for scoring purposes. Each dancer was given an equal time of 20 minutes to familiarize with the sequence and five minutes to practice in front of the camera. One experienced female contemporary dance teacher (age: 40 years; experience assessing dancers at pre professional and professional level: 10 years) was recruited as judge, scoring each dancer (from the video) using the criteria included in the newly devised AC tool and following the provided scoring guidelines (Table 10).

Statistical analysis

Routine pre-analyses were conducted using the Kolmogorov-Smirnov normality tests to assess the normal distribution of the studied variables. Descriptive statistics were used in order to report mean±SD scores for all variables. Pearson Product Moment correlations were utilised to detect linear associations among the studied variables. Stepwise backward multiple regression analyses examined the strength of the association between AC (total
score) and the five specific physical parameters. Univariate analyses of variance (ANOVA) investigated the prediction power of several interactions of covariates (e.g. jump high and press-ups and/or plank and flexibility) on AC total score (dependant variable). Finally, the prediction power of each physical parameter was examined against each individual criterion used in the present AC tool. In order to investigate sensitivity of the new AC tool, a sub-analyses of data was also conducted to compare (using ANOVA) professional and student dancers scores. Statistical significance was set at p<0.05.

Results

Association between the AC total scores and fitness components

Table 16 depicts the mean scores obtained by the dancers during the physical fitness and AC tests. Pearson Product Moment correlations detected significant associations between the mean score obtained from the AC test and press-ups (r=0.55, p=0.02), JR (r=0.55, p=0.03) and JL (r=0.55, p=0.02). Correlation coefficients between AC test and press up, JR and JL are reported in Figure 15, 16, and 17 (page 80, 81 and 82, respectively).

| Table 16: Results for fitness assessment and aesthetic competence test from all dancers. |
|-----------------|--------|----------------|----------------|-----------------|-----------------|---------------|----------------|
|                 | AC points | BF (%) | DAFT (b/min) | Muscle endurance Press-ups (reps) | Muscle endurance Plank (min) | Muscle Power SVJ (cm) | Flexibility active (°) | Flexibility Passive (°) |
| Overall         | 40.94±11.2 | 19.8±2.8 | 194.5±9.4 | 30.8±8.4 | 2.1±0.9 | 29.66±5.3 | 73.6±13.1 | 126.0±12.7 |
| Professionals   | 49.0± 9.7  | 18.8±2.9 | 190.0±10.9 | 33.8±5.1 | 2.0±0.9 | 32.1±5.8 | 74.4±13.9 | 126.5±6.4 |
| Students        | 36.5± 9.6  | 20.3±2.7 | 197.0±7.8 | 29.2±9.5 | 2.1±0.9 | 28.3±4.7 | 73.1±12.9 | 125.7±15.1 |

AC= aesthetic competence; BF%= body fat percentage; DAFT= dance aerobic fitness test; reps= total number of repetitions; SVJ= standing vertical jump

Stepwise backward multiple regression revealed that the best predictor of AC was press-ups (R²=0.30, F=6.4, p=0.02, 95% confidence intervals=0.11–1.34). However, it was found that the interaction of press-ups and standing vertical jump off both feet, demonstrated an
improved prediction power ($R^2=0.44$, $F=11.6$, $p=0.004$, 95% confidence intervals=0.009 – 0.04).

Association between the seven individual criteria against fitness components

Stepwise backward multiple regression analysis revealed that the best predictor from all the physical parameters tested was press ups. A significant prediction of this variable was detected for the following criteria: $R^2=0.25$, $F=4.9$, $p=0.041$ for criterion 1; $R^2=0.32$, $F=7.0$, $p=0.018$ for criterion 2; $R^2=0.24$, $F=4.9$, $p=0.043$ for criterion 3; $R^2=0.286$, $F=6.0$, $p=0.027$ for criterion 5; $R^2=0.31$, $F=6.7$, $p=0.02$ for criterion 6 and finally $R^2=0.36$, $F=8.3$, $p=0.011$ for criterion 7. However, using interactions in univariate analyses the combination of press-ups and jump ability revealed a higher prediction power (criterion 1: $R^2=0.39$, $F=9.8$, $p=0.007$; criterion 2: $R^2=0.49$, $F=14.8$, $p=0.002$; criterion 3: $R^2=0.32$, $F=14.5$, $p=0.016$; criterion 4: $R^2=0.35$, $F=8.2$, $p=0.012$; criterion 5: $R^2=0.42$, $F=10.8$, $p=0.005$; criterion 6: $R^2=0.43$, $F=11.6$, $p=0.004$ and criterion 7: $R^2=0.44$, $F=12.0$, $p=0.003$).

**Figure 15:** Correlation coefficient between aesthetic competence (total score) and upper body muscular endurance (press-ups test)
Figure 16: Correlation coefficient between aesthetic competence (total score) and jump ability (right leg)
Sub-analyses: professionals vs. student dancers

ANOVA revealed that the mean AC scores obtained from professionals (n=6) and student (n=11) dancers were significantly different: 52.5±5.0 vs. 34.6±8.0, p<0.05, respectively, (F=6.403; df=1).

Discussion

The aim of this study was to 1) develop and test a novel AC tool for reliability and 2) investigate the association between selected physical fitness parameters and AC (using both the total score and the seven individual criteria) in contemporary dancers. The newly developed AC tool was reliable, and results revealed that upper body muscular endurance (press-ups) and lower body muscle power (jump ability) strongly predicted AC.
Contemporary dance incorporates many different techniques and styles and is characterized by a variety of technical and physical demands imposed by choreographers during performance (Weiss et al. 2008). These are a reflection of the many different dance techniques and styles which all contribute to contemporary dance (i.e. modern, post-modern, contemporary ballet). Therefore, contemporary dancers are expected to be physically fit to cope with the different demands of each performance and ready to perform a diverse repertoire. With the help of reliable means, dance scientists may understand which of the physical fitness components that have an effect on the AC of contemporary dancers. This information, in turn, can be useful to design effective fitness training for improvement of AC and thus, performance. For these reasons it is important to develop reliable aesthetic tools, since they are valid indicators of dance performance (Welsh 2003). The aesthetic indicators used to develop the present AC tool and to assess the AC of dancers, were based on the seven most frequently used criteria by pre-professional dance institutions and companies for solos dance pieces. In the present study, it was not possible to assess construct validity given that there is no well-established and/or accurate test in dance to assess AC. Therefore, despite having developed the AC tool based on audition criteria from nine recognized dance bodies, there was no further validation once the aesthetic competence tool was developed. Nevertheless, I have assessed inter and intra test-retest reliability since the use of reliable aesthetic tools has strongly been recommended (Welsh 2003; Koutedakis 2009) in order to objectively assess AC in dancers.

Results from the univariate analyses revealed that upper body muscular endurance in combination with jump ability (i.e. lower extremity muscular power) were the best AC predictors. This was consistent for both the AC total score as well as the individual criteria that constituted the novel test. These results support previous data, indicating that significant increases in muscular power improve jumping ability (Brown et al. 2007). Upper body muscular endurance (Balady et al. 2000) is essential during partner work, when systematically lifting and supporting other dancers and/or in transitory movements
from floor to stand and vice versa. This is confirmed by preliminary video analysis data (Study 1- section 2) which showed that contemporary dancers are involved, during solo performances, in a number of stand-to-floor (and vice versa) transitory movements (0.5±0.4 occurrence /min⁻¹) that require upper body muscular endurance (e.g. from handstand lying prone on the floor).

Aerobic capacity was not found to be a significant AC predictor neither for the total score nor each of the individual criterion. This was anticipated since preliminary movement analysis data suggest that on-stage solo performances usually last between two to six minutes, which imply a non-aerobic type of exercise (Wyon 2005). Therefore, the length of the piece that was used for the assessment of AC was not adequate to elicit an aerobic-related stimulus. Also, despite flexibility being an essential attribute for dancers (Deigham 2005), the present results did not detect any significant associations between flexibility levels and AC. This may be explained by the fact that all dancers participating in this study had already reached the adequate level of flexibility as required by the dance sequence used to assess AC. In fact, it has been stated (Koutedakis and Jamurtas 2004) that strict auditions ensure that young candidates have the required flexibility levels at the point of entry in dance schools.

Significant differences were recorded in the AC total scores between professional and pre-professional dancers. This result was anticipated since professional dancers should achieve higher scores given their longer performance experience. Moreover, this finding may suggest that the newly developed AC tool is sensitive to detect differences between the different levels training in contemporary dancers.

The sample of contemporary dancers in this study showed decreased levels of lower body muscular power (i.e. jump height) compared to results in a group of professional ballet dancers reported previously (Wyon et al. 2007). However, the present sample included professionals and student dancers, while Wyon and colleagues data referred to professional dancers. In addition, using the same techniques, a lower flexibility level was observed in the
present sample compared to ballet dancers (Redding and Wyon 2004). These differences are due to less importance being placed on hip ROM in contemporary dancers compared to ballet. The present findings also revealed that the present sample of contemporary dancers had reduced body muscular power levels compared to non-dancers (Harley et al. 2002) and other athletes such as rhythmic gymnasts (Douda et al. 2007). This may be because dance training, in contrast to gymnastics, primarily focuses on skill acquisitions and artistry and hence, does not elicit significant improvements in specific fitness parameters (Wyon 2005). For this reason supplementary training has been recommended to improve aspects of contemporary dance performance (Koutedakis and Jamurtas 2004; Koutedakis et al. 2007).

Outcomes of the present study are useful information to dance scientists, as well as dancers. The development of a reliable AC tool allowed me to further investigate the relationship between selected physical fitness components and AC. The results found may allow dancers to concentrate on training components that affect their performance skills.

It is reasonable to assume that the present results may have been influenced by certain methodological limitations. One of these limitations is the lack of a power calculation to determine the number of participants required for the purposes of the part 2 of the study. Another limitation is the lack of assessment of lower extremity endurance or upper body maximal strength in the physical fitness tests. Future studies may take into consideration how psychometric variables such as personality, energy effort and risk-taking styles may have an impact in the AC scores given by judges. In addition, re-testing the tool with different choreographies employing partner work, would give more power to the AC tool. Within the limitations of the current study, it is concluded that upper body muscular endurance and jump ability best predict AC in the present sample of contemporary dance students and professionals. Further research is required to investigate the contribution of other aspects to AC including: upper body strength, lower body muscular endurance, general coordination, static and dynamic balance.
VI. Study 3: Physical Fitness and Severity of Injury in Contemporary Dance


Regardless of dance style differences, contemporary and ballet dancers are both engaged in long hours of daily practice, followed by rehearsals and performances (Wiesler et al. 1996; Shah et al. 2008). Despite the fact that overuse seems to be the main type of injury in both contemporary and ballet (Garrick and Lewis 2001), differences do exist on injury site and severity between these two different styles. The most common location for injury in contemporary dancers is the low back and knee (Bronner et al. 2003), while in ballet dancers the foot and the ankle (Garrick and Requa 1993). For this reason contemporary and ballet dancers epidemiological data should be studied separately (Krasnow and Kabbani 1999).

Available data have revealed that factors of the observed increased injury rates in contemporary dance include low body fat levels (Berlet et al. 2002), the biomechanics of the different contemporary dance techniques (Solomon and Micheli 1986) and muscular strength level (Koutedakis et al. 1997b). However, there is no published information on whether different physical fitness levels of contemporary dancers have an effect on severity of injuries (e.g. dancers with lower strength levels will be more prone to injury).

Physical fitness components include cardiorespiratory fitness, anaerobic capacity, muscular strength/power, joint mobility and muscle flexibility, and body composition (Heyward 2002). Inadequate aerobic capacity is linked to fatigue, which in turn may cause musculoskeletal damage (Kumar and Tomic 2001). In dancers low level of thigh muscles strength is associated with a high degree of injuries (Koutedakis et al. 1997b) while muscular strength exercises have been recommended to prevent osteoporosis (Koutedakis et al. 2005). Reduced range of motion and flexibility is associated with increased rates of injury (Hamilton et al. 1992; Deigham 2005) in ballet and contemporary dance. Thus, the
primary aim of this cross-sectional study was to investigate which of the main physical fitness parameters were associated with injury severity, within a sample of female contemporary professional and dance students.

**Methods**

*Participants*

Five female professional contemporary dancers and eleven female dance students in their last year of pre-professional training volunteered (total number of participants n= 16; age: 26±4.7 years; height: 165.3±4.8 cm; weight 59.2±7.6 kg). All participants reported no musculoskeletal injuries during the time of data collection. Written informed consents were obtained from all participants after full verbal and written explanation of the data collection procedures. The Research Centre for Sport, Exercise and Performance Ethics Committee (University of Wolverhampton) approved the study.

*Data Collection*

Most assessments of the fitness components studied herein were in accordance to the guidelines of the British Association for Sport and Exercise Sciences (Wyon 2007) and the American College of Sport Medicine (Balady *et al.* 2000). The tests were conducted in the following order:

*Anthropometry and Body composition*

Anthropometrical characteristics such as standing height (cm) and total body mass (Kg) were assessed. These were subsequently used to calculate, via specific equations, % BF (Twitchett *et al.* 2008). Specific details of the exact methodological procedures appear in Methods (page 42).
Flexibility

Flexibility levels of dancers were assessed by using a measuring the active and passive sideways leg extension (*développé* and *battement a la seconde*), which is the combined hip action of flexion, abduction and external rotation, according to a protocol recommended for dancers (Wyon 2007). Specific details of the exact methodology procedures appear in Methods (page 44).

Muscular power

Muscular power of the lower extremity was assessed via a validated field-based test (standing vertical jump) (Balady *et al.* 2000). Specific details of the exact methodology procedures appear in Methods (page 43).

Muscular endurance

For the assessment of muscular endurance the validated press-ups test was used (Wood and Baumgartner 2004). Specific details of the exact methodology procedures appear in Methods (page 44).

Aerobic capacity

The aerobic capacity of dancers was tested using the validated Dance Aerobic Fitness Test (DAFT) (Wyon *et al.* 2003). Specific details of the exact methodology procedures appear in Methods (page 43).

Injury questionnaire

All participants completed a 7-item recall questionnaire about the severity and typology of injuries sustained over the 12 months preceding the fitness assessments. The questionnaire used was originally devised for a comprehensive assessment and welfare programme.
commissioned by Dance UK (Laws 2005). Dancers had to provide information on the length of time (expressed in days) that they were unable to take part in dance class, rehearsals and performance, for the past 12 months as a result of their injury. The severity of injuries was established by recording the total days off (TDO) that a dancer was unable to participate in class, rehearsals and performances due to injury. Dancers had to choose between the following options regarding typology of injury sustained: muscle, bone, joint/ligament, tendon and multiple, also reporting the number of injury sustained for each typology of injury. This information was used to calculate the incidence of different injuries.

Statistical analysis

The Kolmogorov-Smirnov normality tests were employed to assess the normal distribution of the studied variables. Descriptive statistics were used to report the mean scores for all variables. Pearson’s correlation coefficients were utilised to detect linear associations among the studied variables while regression analyses examined the strength of the association between the days off dance class, rehearsals and performances due to injury and the five selected physical fitness parameters. Statistical analysis was performed with SPSS software (version 12.0, SPSS Inc, Chicago, IL). Statistical significance was set at p<0.05.

Results

Descriptive statistics revealed that the highest percentage of injuries (46.6%) experienced by dancers was of muscular nature, followed by multiple typology injuries and ligament (Table 17, page 90). Table 18 (page 90) depicts the mean scores obtained by the dancers during the physical fitness tests and TDO due to injury. Pearson’s correlation coefficients detected significant negative correlations between the mean score recorded for TDO and SVJ (r=-0.66; p=0.014); Figure 18 (page 90) shows this relationship; the trend would appear to be that the lower the muscular power, the greater the severity of injury.
Moreover, backward regression analysis revealed that, from all studied parameters, the strongest predictor of TDO was standing vertical jump (p=0.014).

**Table 17: Injury typology sustained by all dancers (n=16).**

<table>
<thead>
<tr>
<th>Typology</th>
<th>Number of Injuries</th>
<th>% of Total Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle</td>
<td>7</td>
<td>46.6</td>
</tr>
<tr>
<td>Bone</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Joint /ligament</td>
<td>1</td>
<td>6.6</td>
</tr>
<tr>
<td>Tendon</td>
<td>3</td>
<td>20.0</td>
</tr>
<tr>
<td>Multiple</td>
<td>4</td>
<td>26.6</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>100.0</td>
</tr>
</tbody>
</table>

**Table 18: Fitness tests results and days off dance activities due to injuries from all dancers (n=16).**

<table>
<thead>
<tr>
<th>TDO Flexibility (Days)</th>
<th>BF %</th>
<th>HR (b·min⁻¹)</th>
<th>Muscular endurance (press-ups)</th>
<th>Muscular power (SVJ active)</th>
<th>Flexibility (º)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive</td>
<td>20.1±3.3</td>
<td>194.6±9.4</td>
<td>29.8±6.7</td>
<td>29.6±5.3</td>
<td>74±12.9</td>
</tr>
<tr>
<td>Active</td>
<td>2.4±1.3</td>
<td>126±12.7</td>
<td>20.1±3.3</td>
<td>194.6±9.4</td>
<td></td>
</tr>
</tbody>
</table>

TDO = total days off; BF% = body fat percentage; HR = heart rate; number of rep = total number of repetition; SVJ = standing vertical jump

**Figure 18:** Correlation coefficient between days off dance activities due to injuries and the standing vertical jump expressed in cm.
Discussion

The purpose of this study was to investigate the association between selected physical fitness components and injury severity in female contemporary dancers. Results suggest that standing vertical jump is the strongest predictor of injury severity, indicating that the lower the muscular power, the greater the total number of days off due to injury. The present results confirm published data suggesting that increased muscular strength is necessary to reduce injury incidence and severity in professional ballet and contemporary dancers (Koutedakis et al. 1997b). It is important to highlight that most dance related injuries occur at the final stages of rehearsals or performances when dancers are physically tired; fatigue normally causes a breakdown in movement mechanics which place dancers closer to potential injury. It would be anticipated, therefore, that the weaker and less powerful dancers are at greater injury risk as they work close to their fatigue/injury threshold.

Muscular injuries were found to be the most frequent type of injury in the present sample of female dancers, who had 0-5 days off dance activities over a 12-month period. These results suggest similar findings where almost 50% of a large sample of professional dancers reported 1-6 days off exercise over 12-month period due to a musculoskeletal injury (Koutedakis et al. 1997c). The aetiology of most injuries in dance is overuse (Garrick and Lewis 2001) because of the repetitive nature of dance training (Druss and Silverman 1979) and it is manifested as a gradually increasing pain. The repetition of muscular loading can result in cumulative fatigue, which, in turn, can reduce the stress-bearing capacity of a muscle group (Kumar and Tomic 2001). For this reason adequate musculature strength and power are essential to prevent injury and to minimise the severity level (Holmich 1999). Given that a strong linear relationship exists between lower body muscular strength and several fundamental explosive performance measures, including standing vertical jump (Peterson et al. 2006), it is understood that in dancers with low muscular power, it may be that repetitive load causes fatigue and therefore, increases the
amount of stress imposed on a specific muscle group. The injury-recovery process (expressed as TDO) may also take longer in individuals with reduced muscular strength and power. This can be explained by the fact that joints surrounded by weaker soft tissue are subject to more strain due to overexertion and therefore take longer to recover from an overuse injury (Kumar and Tomic 2001).

Although dance training involves practice for many hours per day at both professional and vocational level, dancers are considered to be less powerful than athletes of other sports (Koutedakis and Jamurtas 2004). In the present study dancers revealed lower muscular power values compared to rhythmic gymnasts (Douda et al. 2007). A plausible explanation is that conventional dance-studio training confers little strength and, therefore, less muscular power benefits (Rimmer et al. 1994). For this reason, supplemental strength training is recommended at least for less powerful dancers (Koutedakis et al. 1996).

Despite reports that dance training does not elicit enough stimuli to increase aerobic fitness (Wyon and Redding 2005) and that poor aerobic capacity increases injury rates (Kumar and Tomic 2001), present results did not reveal significant associations between these two parameters. This finding might be partly explained by the fact that my data were obtained at the end of the performance season when dancers demonstrate their highest aerobic capacities (Wyon and Redding 2005). Alternatively, the lack of power calculation to determine the exact number of participants may have also resulted in a weak statistical association between the factors studied herein (e.g. aerobic fitness and injury severity).

Regarding flexibility it has been suggested that extreme joint mobility at the hip has been correlated to injuries in ballet dancers (Hamilton et al. 1992). The present dancers demonstrated high flexibility values but this was not significantly associated with injuries, which is line with previous published data for lower back (Koutedakis et al. 1997a) or ankle (Wiesler et al. 1996) injuries. It must be highlighted, however, that dancers undergo strict auditions, even at the point of entry in dance schools which ensure that they have
acquired through their training high flexibility levels. Such strict regimes have succeeded in transforming dance to an activity practised by very flexible individuals, who have selectively developed different characteristics compared to other athletes.

The results of the present study have been influenced by certain methodological limitations that are inherent in cross-sectional designs. Present data showed association but not causality, so it was not possible to determine whether decreased lower body muscle power causes injuries or injuries cause lower body muscle power. Thus, present results can only be considered preliminary and need to be confirmed in prospective studies designed to determine causality. The simultaneous inclusion of professional and dance students in the same sample and the small sample size and gender selection may have also influenced present results. As such, the lack of adequate sample size did not allow for comparisons between professional and student dancers. Despite the numerous documented differences between ballet and contemporary dance styles, in the present study the développé a la seconde flexibility and sautés jump tests were employed since this protocol was recommended for both ballet and contemporary dancers (Wyon 2007). However, this may be a limitation of the present study and thus, it is recommended that future research studies may want to develop and employ contemporary dance specific flexibility and jump tests. Within these limitations present results suggest that low levels of lower body muscular power are associated with increased severity of injuries in female contemporary dancers. More research using appropriate methodological designs, such as sample size calculations and randomization and the use of contemporary dance movements only is needed in order to investigate the effects of physical fitness levels on injury severity in contemporary dance.
VII. Study 4: The effects of a supplementary six-week vibration and circuit training programme on performance and fitness related parameters in contemporary dancers.

This chapter includes work which I presented at the 19th annual meeting of the International Association of Dance Medicine and Science and was published in the conference proceedings of the same title. Angioi M et al. (2009). The effects of a supplementary six-week vibration and circuit training programme on aesthetic competence and fitness related parameters in contemporary dancers. 19th annual IADMS meeting, The Hague; p: 30-31.

Overall physical fitness consists of aerobic and anaerobic metabolism, muscular strength power and endurance, flexibility and body composition (Heyward 2002). Available data suggest that reduced level of lower body muscular power is associated with increased severity of injuries in female contemporary dancers (Angioi et al. 2009a), while improvements in aerobic/anaerobic capacities have been previously linked to better oxygen transport facilities (Astrand and Rodhal 1986) and enhanced neuromuscular function (Jones and Round 1990). These physiological adaptations in turn, affect qualitative elements of physical performance through reduced fatigue (Petibois et al. 2002; Romer et al. 2002). Despite the evidence from sports with different physiological requirements and technical skills (Alexander 1989; Hume et al. 1993), data on the effects of improved aerobic and muscular capabilities in contemporary dance, are scarce.

The majority of studies in contemporary dance have just made observations about the physical fitness levels of dancers, such as: aerobic fitness (Chmelar et al. 1988); anaerobic power (Padfield et al. 1993); muscular strength (Harley et al. 2002); anthropometric characteristics (Yannakoulia et al. 2000). These studies revealed that dancers, both professionals and students, have reduced fitness levels compared to other athletes. In other sports, such as gymnastics, increases in selected fitness levels, such as strength and flexibility are associated with significant improvements in technique (Alexander 1989). In contemporary dance, two studies have investigated the effects of increased fitness levels on technical aspects of contemporary dance. The available data
suggest that increases in muscular strength and power have beneficial effects on jump ability (Brown et al. 2007) and overall performance (Koutedakis et al. 2007). However, these data can only be considered preliminary since they both used a tool which was not previously assessed for validity or reliability. For these reasons, it is necessary to further investigate the effects of supplemental training on contemporary dance performance using appropriate methodological designs and reliable techniques, as recently suggested (Angioi et al. 2009b).

Published studies suggest that dancers would benefit from increased fitness levels (Chatfield et al. 1990; Koutedakis et al. 2007) while results from Study 2 suggest that aesthetic competence (AC) of dancers is correlated with lower body muscular power and upper body muscular endurance (Angioi et al. 2009c). Therefore, developing exercise interventions to exercise specifically these two physiological aspects may further improve AC of dancers.

The physiological effects of resistance training on muscular power and endurance are well documented (Kraemer et al. 1988; Stone et al. 1991). The effects of training are related to the type of exercise used, its intensity and its volume (number of sets per number repetitions). Hence, the correct use of basic principles such as progression, variation and individualization are essential for resistance training success. The term circuit training refers to a number of carefully selected exercises arranged consecutively in 9 to 12 stations. However, this number may vary according to the design of the circuit. Each participant moves from one station to the next with little (15 to 30 seconds) or no rest, performing a 15- to 45-second work out of 8 to 20 repetitions at each station (Gotshalk et al. 2004). The programme may be performed with exercise machines, hand-held weights, elastic resistance, or any combination. Recently, a new neuromuscular training method for improving muscular strength, power and endurance has been designed. The whole body vibration (WBV) consists of a vibrating platform where the participant stands and either holds a static position or performs an exercise for a short amount of time. Existent literature
suggests that potential benefits of the WVB training include: enhancing strength and power capabilities (Cardinale & Lim, 2003); and increased jump height (Paradisis & Zacharogiannis, 2007).

Therefore, the aim of the present study was to investigate if such exercise programmes improve AC in contemporary dancers.

**Methods**

*Participants*

Fourteen female dance students in pre-professional training and ten (nine females) professional contemporary dancers (total number of participants n=24; age: 26.9±5.9 years; height: 165.3±4.8 cm; weight 59.2±7.6 kg) were recruited from a dance institution and a company. The only male dancer was included in this study since this number is representative of the male:female dancer ratio within the company and the dance institution from where participants were recruited (males:18%, females: 82% and males: 22.2%, females 77.7%, respectively). The study was conducted during the last term of the students dance training, which corresponded to the pre-performance period for professional dancers.

Using the closed envelope method, dancers were randomly assigned to either the intervention (n=12) or the control group (n=12). The intervention group undertook the designed exercise-training programme lasting six weeks, while the “control group” followed their normal dance training. In order to investigate the effects of the supplementary fitness training on aesthetic competence (AC), both groups were instructed to not to undertake any other forms of exercise prior and during the six weeks period.

Dancers were excluded from the study if I) they had been diagnosed with an injury and/or an eating disorder; II) they were undertaking other forms of sports activities. Each of the inclusion criteria was determined by responses to a specifically modified medical questionnaire (Par-Q form). Written informed consents were obtained from all participants after full verbal and written explanation of the data collection procedures.
Experimental approach to the problem

The purpose of the present randomized controlled trial (RCT) study was to examine the effects of a supplementary 6-week whole body vibration (WBV) and circuit training programme on aesthetic competence (AC) and fitness related parameters in contemporary dancers. The recruited participants were professional and pre-professional dancers, who were randomly assigned into two groups: exercise and control. The following fitness assessments were included: anthropometry, lower body muscular power, dance aerobic fitness test (DAFT) and a reliable AC test. In order to investigate the effects of the combined training protocols (CRT and WBV) on AC, dancers were instructed to follow their routine lifestyle and to participate in no additional training beyond their regular dance training.

Data Collection

For each volunteer and during the same day, testing was completed in two sections in the following order: 1) fitness assessments and 2) AC test. To avoid fatigue, an interval of three hours was allowed between fitness and AC test. Pre and post testing sessions occurred within one week before and after the six-week intervention period. The protocols used for the assessment of the fitness parameters were in accordance to the guidelines of the British Association for Sport and Exercise Science (Wyon 2007) and the American College of Sport Medicine (Balady et al. 2000). All assessments were conducted after a 15-20 minutes of a tailored warm-up routine.

Anthropometry and Body composition

Anthropometrical characteristics such as standing height (cm) and total body mass (Kg) were assessed. These were subsequently used to calculate, via specific equations, the %BF (Twitchett et al. 2008). Specific details of the exact methodological procedures appear in Methods (page 42).
Muscular power

Muscular power of the lower extremity was assessed by a validated field-based test (standing vertical jump). Specific details of the exact methodology procedures appear in Methods (page 43).

Muscular endurance

For the assessment of muscular endurance the press-up and plank tests were used. Specific details of the exact methodology procedures appear in Methods (page 44).

Aerobic capacity

The aerobic capacity of dancers was tested using the validated Dance Aerobic Fitness Test (DAFT) (Wyon et al. 2003). Specific details of the exact methodology procedures appear in Methods (page 43).

Contemporary dance aesthetic competence test

The reliable dance AC test previously described (Study 2) was used in the present study as a proxy for dance performance. Dancers were asked to learn and perform a short dance sequence lasting for one minute and 30 secs. Dancers were given 20 minutes to familiarise with the sequence. They were also video-recorded while performing the sequence. Given the inter and intra reliability of the AC tool, one experienced female contemporary dance teacher (age: 40 years; years of experience: 10) was recruited as judge, marking each dancer (from the video) by following the criteria included in the AC tool (Table 10, page 71).

Training programme

The intervention programme took place at the dancers’ workplace, which is equipped with the required facilities (e.g. vibration platform, free weights, jumping ropes, mats). Training
was organised twice a week each training session lasted one hour. This training protocol (i.e. one hour, twice a week) is the recommended minimum amount of strength-related training by the American College of Sports Medicine (Balady et al. 2000). Warm up and cool down were performed respectively before and after each training session. WBV and circuit training took place in the same studio. For the total time of the intervention period dancers were supervised and always guided by the same member of the research team.

Circuit Training

In order to train local muscular endurance a dance-specific circuit training programme was designed, according to an existing validated CT protocol (Gotshalk et al. 2004). This consisted of lower and upper body exercises, organised in 10 stations. The ten exercises included: jumps with feet in parallel position (using a jumping rope), press-ups, biceps curls, triceps curls (with free weights of 0.5 kg each), single leg squat, squats-jumps, heel-rises in dance 1st position, grand-pliés in dance 2nd position, pectorals press exercises (with free weights of 0.5 kg each), plank. Each station was a continuous 30 sec exercise, during which the dancers where instructed to perform as many repetitions as possible. A maximum transitory time of 10 seconds was allowed between each station (Gotshalk et al. 2004). The total time for each circuit was six minutes and 50 seconds (including the rest between each station). Dancers were instructed to perform consecutively a total of four circuits. The set work:rest time ratio during exercise was the same for all participants. Each training session was supervised in order to ensure that participants were exercising with the correct technique.

Vibration training

The vibration training protocol used in this study is a dance-modified (i.e. dance-specific static positions) version of an existing valid and reliable protocol (Delecluse et al. 2003). It involved three sets, lasting 40 seconds each, of six static positions: 1) Squat position with
feet in dance 1st position.; 2) Plank position (elbow flexed on the floor and feet on platform); 3) Lunge position (right and left leg); 4) Press up position – 90-degrees bend at the elbows; 5) Calf position – feet in relevé (heel-rise) with knees slightly bent; 6) Hamstring position – bent over at waist, knees slightly bent and hamstrings tensed. The rest between each set was two minutes. The frequency of the vibration platform was set at 35 HZ, the amplitude at 2.5 mm and finally acceleration at 2.28, according to previously used similar protocols (Delecluse et al. 2003). The set intensity of exercise (i.e. work:rest ratio and number of circuits) was the same for all dancers. The vibration training took place twice a week following the circuit training, in the same studio. A maximum time of 10 minutes rest was set between WBV and circuit training.

Statistical analysis

Routine pre-analyses were conducted using the Kolmogorov-Smirnov normality tests to assess the normal distribution of the studied variables. Descriptive statistics were used in order to report the mean scores for all variables recording pre and post exercise intervention period. One-way ANOVA was used to investigate for significant baseline differences between the two groups. Differences between pre and post exercise programme for both groups (intervention vs. control) were assessed using RM ANOVA with “group” (intervention, control) and “time” (pre, post assessments) as independent factors. Linear regression analyses were employed to examine the strength of the association between AC and the physical parameters (i.e. aerobic, muscular power and endurance). Finally, univariate analyses of variance (ANOVA) investigated the prediction power of several interactions of covariates (e.g. jump high and press-ups and/or aerobic and press-ups) on AC score (dependant variable). Statistical analyses were performed using the SPSS software (version 13.0, SPSS inc, Chicago, IL). Significance was set at p<0.05.
Results

A total of three dancers, part of the control group, dropped out during the intervention period. Hence, the results referred to a control group made of nine dancers.

At baseline (prior to initiating the study), no significant (p>0.05) demographics and anthropometric characteristics were detected between groups (Table 19). Moreover, one-way ANOVA revealed no significant difference (p>0.05) between groups in any of the physiological and aesthetic competence variables.

Table 19: Participants characteristics.

<table>
<thead>
<tr>
<th>Sample size</th>
<th>Age (years)</th>
<th>% BF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intervention</strong></td>
<td>N=12</td>
<td>26.7±4.3</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>N=9</td>
<td>27.1±7.9</td>
</tr>
</tbody>
</table>

*No significant differences between groups

Table 20 depicts the baseline and follow-up results for all physical fitness assessment and AC for both groups. In the intervention group, statistical analyses revealed significant increases (pre vs. post) in lower body muscular power, AC, aerobic fitness and upper body muscular endurance (p<0.05). The control group significantly increased the jump height and aerobic fitness level but not AC and press ups.

Table 20: Results pre and post fitness training for all variables (mean±SD)

<table>
<thead>
<tr>
<th></th>
<th>Pre test</th>
<th>Post test</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intervention group (n=11)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SVJ (cm)</td>
<td>27.8±5.1</td>
<td>31.3±5.6</td>
<td>p= 0.05</td>
</tr>
<tr>
<td>Aerobic (b min⁻¹)</td>
<td>193±4.1</td>
<td>178±16.1</td>
<td>p=0.03</td>
</tr>
<tr>
<td>Press ups (n min⁻¹)</td>
<td>27.1±7.9</td>
<td>35.2±11.7</td>
<td>p=0.02</td>
</tr>
<tr>
<td>AC (total score)</td>
<td>34.3±10.0</td>
<td>41.7±5.7</td>
<td>p=0.02</td>
</tr>
<tr>
<td><strong>Control group (n=9)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SVJ (cm)</td>
<td>30.5±3.7</td>
<td>34.1±5.5</td>
<td>p=0.16</td>
</tr>
<tr>
<td>Aerobic (b min⁻¹)</td>
<td>186±20.4</td>
<td>168.6±24.0</td>
<td>NS</td>
</tr>
<tr>
<td>Press ups (n min⁻¹)</td>
<td>34.1±7.5</td>
<td>32.8±5.2</td>
<td>NS</td>
</tr>
<tr>
<td>AC (total score)</td>
<td>44.1±6.8</td>
<td>46.3±8.3</td>
<td>NS</td>
</tr>
</tbody>
</table>

SVJ= standing vertical jump; AC= aesthetic competence
For the intervention group, linear regression analyses revealed that aerobic capacity was a significant predictor of AC ($F=7.641; \ p=0.03$). However, it was found that the interaction of press-ups and aerobic capacity ($F=6.297; \ p=0.036$) and SVJ with aerobic capacity ($F=5.543; \ p=0.05$) demonstrated an improved prediction power.

**Discussion**

The aim of the present RCT study was to examine the effects of a supplementary six-week vibration and circuit training programme on aesthetic competence (AC) and fitness related parameters in contemporary dancers. The main result was that supplementary exercise training significantly increased AC of dancers with simultaneous increases in selected fitness components (lower body muscular power, upper body muscular endurance and aerobic fitness).

Preliminary published data revealed that aerobic and strength training improves performance and jump ability of dance students (Brown *et al.* 2007; Koutedakis *et al.* 2007). My findings confirm these preliminary data, suggesting that AC benefits from enhanced physiological capabilities such as aerobic fitness, lower body muscular power and upper body muscular endurance. Aerobic fitness is necessary for dancers since low levels have been associated to increased fatigue, which in turn have negative impacts on overall performance (Wilmore and Costill 1999) such as reduced mental concentration and higher injury rates (Knapic *et al.* 1992). Muscular power, which lasts just a few seconds and is energised by phosphocreatine, is essential for explosive jumps and high elevation. Upper body muscular endurance, which occurs when a relatively high power output is maintained for 30-60 seconds, is required during partner work (lift) and transitory movements form stand to floor and vice versa.

The observed increases in aerobic fitness are most likely to be attributed to the circuit training since previous research (Westcott *et al.* 2007) revealed that following a 12-week circuit training programme, which required approximately 25 minutes of alternating...
strength and endurance exercises three days per week, untrained participants significantly improved their aerobic capacity together with upper muscular endurance (assessed via total number of press-ups completed in 1 min). Although the present intervention period lasted six weeks only, significant increases in aerobic capacity were observed. These findings support previous results (Midley et al. 2006) indicating that cardiovascular improvements are almost immediate in non aerobically trained individuals (Wilmore and Costill 1999), such as dancers employed in this study (please see Table 20, page 101, for recorded HR values).

Previous research in sport has shown that whole body vibration training (WVB) enhances strength and power capabilities (Cardinale & Lim, 2003) and elicits gains in vertical jump height (Cochrane and Stannard 2005), which possibly explains the increases for standing vertical jump (SVJ) observed in the intervention group. A reason for this phenomenon has been explained by the fact that WBV elicits both concentric and eccentric contractions, and hence the enhancement of muscular power occur via potentiating the neuromuscular system, whereby stimulations of muscle spindles results in reflex activations of motor neurones with increased spatial recruitments (Ramaiguere et al. 1993).

Increases in upper body muscular endurance were observed in the intervention group only. Although the vibration training included one exercise for the upper body muscular endurance, it is unknown whether this may have cause such an adaptation, since dancers underwent both circuit training and WVB. However, published data (Nash et al. 2007), revealed that a four-month CRT programme using high-speed, low-resistance arm exercise circuit resistance training improves muscle strength, endurance, and anaerobic power. The present protocol included press-ups, biceps curls, triceps curls, and pectoral exercises with free weights of 0.5 kg each, to be performed at high speed, which according to Nash and colleagues (Nash et al. 2007) may explain the observed increases in upper body muscular endurance.
The control group exhibited no changes in AC and upper body muscular endurance after the six week intervention period. This confirms that dance training is not sufficient enough to overload the musculoskeletal systems (Chatfield et al. 1990; Koutedakis and Jamurtas 2004) and thus, to produce physiological adaptations that will enhance each individual fitness component.

The present study significantly contributes to the debate whether AC of dancers, equally to other athletes, benefits from enhanced physical fitness levels. Previous studies investigating the effects of supplementary exercise training on dance performance relied on a subjective aesthetic evaluation; they also included contemporary dance students only. As such, these were treated as preliminary (Angioi et al. 2009b). The employment of a reliable AC tool in combination with appropriate design (i.e. RCT), surpass these limitations and therefore, it is reasonable to suggest that present findings confirm these previous preliminary results. Dancers by incorporating exercise protocols, such the one experimented in the present study will increase selected physical fitness levels, which in turn are well associated to AC.

The employment of a mixed sample of contemporary dancers, does not allow me to draw conclusions about whether the effects of supplementary fitness training on AC in professionals and student dancers might be different. Further research is needed to investigate the contribution of physical fitness levels to AC among dancers of different levels (students vs. graduates vs. professionals). Future studies may also investigate the effects of supplementary training over injury rate and severity. Within these limitations it is concluded that AC of contemporary dancers benefits from enhanced muscular power, endurance and aerobic fitness.
VIII. GENERAL DISCUSSION AND CONCLUSIONS

Literature review
The first chapter of the Thesis aimed to review: I) the physical fitness levels of contemporary dancers, with respect to professional and student dancers; II) the effects of supplementary fitness interventions on performance. Never before in dance has a systematic review for dance-related fitness aspects been conducted. Existing reviews took into consideration mixed samples of dancers, without differentiating between their levels or dance styles (Kirkendall and Calabrese 1983; Koutedakis and Jamurtas 2004). Present results clearly showed that I) differences exist between not only styles but also levels of dancers (Chmelar et al. 1988; Chatfield et al. 1990) and II) preliminary data suggest beneficial effects of physical fitness on aspects of performance (Brown et al. 2007; Koutedakis et al. 2007). One important outcome that occurred after systematically reviewing the whole literature is the lack of standardized methods to assess performance and/or aspects of performance, which led to the conclusion that available data regarding the effects of supplemental fitness training on contemporary dance performance have to be treated as preliminary. It is essential that dance will benefit from the development of valid and reliable tools and the design of appropriate intervention studies using robust methodological designs (randomisation).

Study 1
The first study was an observational study on the physical aspects of contemporary dance performance. This was the first study investigating actual on-stage contemporary dance performance, given that existent data have used late dress-rehearsals (Wyon and Redding 2005). It was decided to separate the study in two sections: the first aimed to analyse the physiological responses to on-stage performance, and the second to analyse selected physical demands placed on dancers during performance, such as the number of jumps and
lifts. In the design of this whole study (and subsequently study 1), I was consistent with my suggestions (Angioi et al. 2009b) to use reliable procedures (i.e. portable accelerometers for the physiological assessment and video analysis systems for the description of physical demands). Combined results from the two sections revealed that the dance works analysed are a moderate, intermittent type of exercise (McArdle et al. 2007). Dancers were classified as exercising within the moderate exercise intensity zone comparable to other intermittent type of exercise such as archery, table tennis and tennis (Wilmore and Costill 1999). The physiological assessment took place at the end of the performance season, when dancers are at their peak level of aerobic fitness (Wyon et al. 2004); this, in turn, might explain the higher physiological values in response to the observed performances in comparison to previous similar studies (Wyon and Redding 2005). Another explanation for the results obtained is that the choreographies may have placed different physiological demands on the participants of this study (Wyon 2005).

The major contribution of Study 1 is the use, for the first time, of I) SWA data to assess energy expenditure in dance during on-stage performance; and II) video analysis systems to describe selected demands imposed to dancers during performance. The use of SWA provided a non-invasive method to measure physical effort during actual dance performance. The use of the movement analysis tool enabled me to identify the number of specific moves happening during contemporary dance performances. These outcomes could be used by dance scientists and rehearsal directors to better prepare dancers for repertoires and reduce injury risks.

A possible limitation of this study (part 2) was the use of one observer to carry out the video analysis. Although, the observer’s intra reliability was tested, literature recommends to repeat the video analysis employing multiple observers, when this is feasible.

A topic for further research is the use of observational tools such as movement and time-motion analysis systems in combination with physiological tools (i.e. SWA) which
could provide a valuable help in the identification of physical demands placed on dancers during performance. This would allow full performance analysis, which includes technical, biomechanical and physiological aspects. These, in turn are useful data to help dancers to be physically prepared for the demands of on-stage performance.

Study 2
The second study aimed to develop a reliable AC tool and investigate the association between selected physical fitness parameters and AC. Given the lack of standardized methods to assess dance performance (Welsh 2003), the first major contribution of the present study is the successful development and use of a reliable AC tool. The present AC tool includes the most frequently used seven audition/assessment criteria in a number of dance institutions and companies. The sum of the seven criteria gives a total AC score, which in turn is a good proxy for overall dance performance efficiency (Chatfield and Byrnes 1990; Krasnow et al. 1997).

The central findings of this chapter suggest that upper body muscular endurance (press-ups) and lower body muscle power (jump ability) are the strongest AC predictors consistently for both the total score and each individual criterion score. This may be due to the fact that these fitness parameters (upper body muscular endurance and lower body muscle power) are necessary to perform jumps and leaps as well as the ability to lift partners and/or perform transitory movements from floor to stand, which are common aspects of contemporary dance. The present results are in line with previous preliminary data, indicating that significant increases in muscular power improve jumping ability (Brown et al. 2007), while upper body muscular endurance is essential during partner work, when lifting and supporting other dancers (Koutedakis and Sharp 1999, p. 106) and/or in transitory movements from floor to stand and vice versa as highlighted by the video analysis (Study 1, section 2).
The implementation of different criteria according to different contemporary dance works and re-testing the tool with choreographies employing partner work would give more power to the AC tool. The validation of the newly developed AC tool was not performed. Construct validity is a way of assessing validity by investigating if the measure really is measuring the theoretical construct it is suppose to measure. This was not possible given that there are no standardized systems present in the literature. Nevertheless, construct validity of the AC tool could be examined using the Rash Measurement Model after it has been published. From the present study an interesting future research project would be to investigate how psychometric variables such as personality, energy effort and risk-taking styles may have an impact in the AC scores given by judges.

Results from the statistical analysis led to the rejection of the initially formulated null hypothesis. It was concluded that there is a significant association between selected physical fitness components, such as upper body muscular endurance and lower body muscle power and AC in contemporary dancers.

Study 3

The third study aimed to investigate the association between selected physical fitness components and injury severity in female contemporary dancers. Lower body muscular power (assessed via standing vertical jump) was found to be the strongest predictor of injury severity, indicating that the lower the muscular power, the greater the total number of days off due to injury. The total number of TDO (injury recovery process) may be increased in dancers with reduced muscular strength and power, since joints surrounded by weaker soft tissue are subject to more strain due to overexertion, and therefore take longer to recover from an overuse injury (Holmich 1999; Kumar and Tomic 2001). The present results are in line with a previous study suggesting that increased levels of muscular strength are needed to reduce injury incidence and severity in dancers (Koutedakis et al. 1997b). However, results from Koutedakis and colleagues referred to a mixed sample of
ballet and contemporary dancers. This is the first published study to have investigated the association between physical fitness and injury severity using contemporary dancers only.

Due to its methodological design (cross-sectional) further research is needed to confirm these preliminary data. Future prospective studies should be designed to determine causality of this association. In the present study the développé a la seconde flexibility and sautés jump tests were employed. It is suggested that future research studies should employ a wider variety of contemporary dance movements when developing similar tests.

Results from the statistical analysis led to the rejection of the initially formulated null hypothesis and therefore, it was concluded that there is a significant negative correlation between lower body muscle power and injury severity in female contemporary dancers.

Study 4
The aim of Study 4 was to examine the effects of a supplementary six week WBV and CT training on AC and fitness related parameters in contemporary dancers, using a robust methodological design (i.e. RCT). The main result is that supplementary exercise training significantly increased AC of the intervention group with simultaneous increases in selected fitness components. Hence, present results confirm preliminary published data, which highlighted that supplementary fitness training is recommended for dancers since dance training alone is not sufficient enough to cause fitness and musculoskeletal adaptations. These, in turn, can affect the overall the AC of dancers (Brown et al. 2007; Koutedakis et al. 2007). Aerobic fitness is necessary to reduce the detrimental effects of fatigue, lower body muscular power is essential for jumps which require high elevation, upper body muscular endurance is essential in transitory movements from stand to floor and vice versa and during partner work. Results from Study 2 revealed that upper body muscular endurance and lower body muscular power were the strongest predictors of AC.
The results of Study 4 confirmed these findings also revealing that AC may be improved due to subsequent increases in aerobic capacity.

The present results are related to a mixed sample of professionals and dance students. Further research is needed to investigate the effects of increased fitness levels on AC in contemporary dancers of different levels, via methodologically robust interventions. Results from the statistical analysis led to the rejection of the null hypothesis and therefore, it was concluded that a six week period of supplementary WBV and CT training significantly increases AC of contemporary dancers with simultaneous increases in selected fitness components (aerobic fitness; lower body muscular power; upper body muscular endurance).

**Conclusion**

The original research question of the Thesis was: Do improvements in selected physical fitness components affect performance (assessed via a reliable tool) and injury severity in contemporary dance? In order to address the original research question, three statistical null hypotheses were formulated in relation to the three main studies (Study 2, 3 and 4). The three null hypotheses were rejected, concluding that: I) there is a significant association between lower body muscular power, upper body muscular endurance and AC of contemporary dancers; II) lower body muscular power is negatively correlated to injury severity; III) increases in lower body muscular power, upper body muscular endurance and aerobic fitness levels are beneficial to AC. Within the highlighted limitations of the present Thesis, it is concluded that increased levels of aerobic fitness, muscular power and endurance are beneficial to AC of contemporary dancers. Further research is needed to examine, via appropriate design (i.e. RCT) the causality of the negative correlation found between lower body muscular power and injury severity in contemporary dancers.
IX. BIBLIOGRAPHY


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**Internet web sites:**

http://www.life.umd.edu/classroom/bsci424/BSCI223WebSiteFiles/LectureList.htm


APPENDIX 1. The development of contemporary dance.

Alternative dance forms breaking away from the constraint and conventions of classical ballet emerged at the beginning of the 20th century in America and Europe. Shedding classical ballet technique, costume and shoes, these early modern dance pioneers practiced “free” dance which involved movement patterns, rhythms and techniques previously not seen in classical ballet as well as an innovative image of the dancer on stage.

In America, Loie Fuller, Isadora Duncan and Ruth St Denis developed their own styles of free dance and laid the foundations of American modern dance with their choreography and teaching. Fuller devised a type of dance that “focused on the shifting play of lights and colours the skirts she wore also eschewing the technical virtuosity of ballet” (Au 1988, p. 88). Duncan’s way of dancing, which was inspired by nature and ancient Greek artefacts and characterised by qualities such as simplicity and economy of means, incorporated the use of normal ordinary actions such as walking, running, skipping and jumping (Au 1988, p. 89). Duncan travelled to Europe and Russia and her work was carried on, following her death, by six of her pupils who started schools in Europe and U.S. to teach her technique and choreography. Ruth St Denis and Ted Shawn funded in 1915 Denishawn school and company earning a “name for eclecticism” (Au 1988, p. 94). St. Denis, who originally took inspiration from ancient oriental matters (Egypta, 1910), under the influence of Shawn opened up towards ethnic dance styles also adopting athletic elements (Invocation to the Thunderbird, 1917; Xochitl, 1920; Ishtar of the Seven Gates, 1923) (Au 1988, p. 92-93).

In Europe Rudolf Laban, Emilè Jaques Dalcroze, and Francois Delsarte developed theories of human movement and methods of instruction that led to the development of European expressive modern dance (Ausdrucktanz). Laban’s way of dancing was influenced by his interest in physical culture and it was based on a wide range of human...
movement reflecting ordinary actions and everyday gestures (Anderson 1997, p. 57) as well as incorporating components such as the flow of movement (Au 1988, p. 96). Both the American and European choreographers engaged shapes and movement patterns different from that seen in ballet, experimenting with a diverse use of accents and rhythms, using ordinary actions and elements of athleticism.

St Denis and Shawn provided training to the next generation of American dancers, such as Graham, Humphrey and Weidman who, with their works, contributed to the term “modern dance” (coined about 1927) and created techniques based on principles of fall and recovery (Humphrey) and of contraction and release (Graham). Whilst the “American pioneers” (Duncan, St Denis and Fuller) dance works were inspired by classical ancient art and artefacts, their students saw modern dance as a way to express feelings and an instrument for raising consciousness by dramatising the economic, social and political crises of their time. According to Au (Au 1988, p. 131) modern dance, despite including a diversity of characteristics and purposes, introduced to the dance world new ways of moving in order to express ideas and most importantly feelings, concluding that these innovations paved the way for further achievements in ballet and modern dance. Graham’s technique has been taught around the world and companies such as The Batsheva Dance Company and the former London Contemporary Dance Theatre used it as the basis of their choreography. Humphrey’s technique was carried in a modified form by Jose Limòn and his company. Laban established schools in many European cities and his work was later continued by Kurt Jooss and Mary Wigman; the latter experimented with new musical accompaniments for dance, such as percussion instruments and drums, also dancing to a spoken text or in silence. She employed actions such as crawling, kneeling, crouching and falling as primary elements for her choreographies (Anderson 1997, p. 61).

During the 1930s American ballet began to explore new ways with George Balanchine, an ex Ballets Russes dancer, and one of the founders of the American School of Ballet, who led a costume reform (simple leotards and tights) and used musical elements
such as rhythm and phrasing to “spark his choreographic ideas” (Au 1988, p. 144). Balanchine is considered to be the creator of the American balladic style and the dancer’s ideal body image (Morris 2005); his dances required speed, very deep pliés, unconventional use of arms and torso and a great range of flexibility. Moreover, Balanchine’s dancers had to possess very specific body characteristics, such as narrow hips, long neck, long and lean legs, short and small torso and a small breast, which constituted the “Balanchine’s body” (Gordon 1983). Between the 1950s and 60s many other ballet companies searched for new approaches too, and modern dance played a key role in renewing classical ballet’s image. A number of dancers started training in both modern and ballet and as a result there was the development of an “hybrid form” of dance (Au 1988, p. 178) incorporating characteristics of both styles, such as the freer use of the torso in ballet or a stretched out line and pointed feet in modern dance. This hybrid form has been renamed “modern or contemporary ballet” (Au 1988, p. 177). Examples are productions of Joffrey Ballet and the Netherlands Dance Theatre and works by Maurice Béjart and Alvin Ailey, who although is usually classified as a modern dancer, employed the “hybrid form” in many of his works also enriched by Afro-American (Revelations, 1960) and jazz dancing (Blues suite, 1958) (Anderson 1997, p. 238).

The 1950’s saw the development of the post-modernism era of dance led by Merce Cunningham, a former Graham dancer, who liberated choreography from traditional principle that every dance work was a linear narrative progression (with a beginning, middle and end) and experimented with the use of stillness as a movement. According to Anderson (Anderson 1997, p. 207), Cunningham deliberately made no attempt to have dance phrases coincide with musical phrases, ignoring traditional theories of stage direction and using any movement as a dance movement. Costumes and settings in Cunningham works also underwent a revolution since his productions took place in gymnasiums, museums and squares, while dancers would choose what to wear. The experiments of Cunningham were carried or extended by a number of choreographers in the 1960s and
70s, who are often refereed to as “post modern dancers” (Au 1988, p. 165). They became more interested in process (i.e. choreography) rather than product (i.e. technique), incorporating modern technology and using unconventional locations for their dances. Some post modern choreographers, such as Anna Halprin, Simone Forti and Steve Paxton, aimed for a more improvisational rather than technical approach of creating dances (Au 1988, p. 170). Hence, increasing importance was given to the ability of “improvise” and from there create a dance sequence, rather than systematically performing taught sets of movement. The contact improvisation technique, developed in the 1970s, involved at least two dancers who, by relating to each other, leaning against each other and climb over each other, “have a dialogue in motion” (Anderson 1997, p. 247-248).

From the 1970s with increasing frequency, ballet companies have been inviting modern dance choreographers to set pieces. An example is Twyla Tharp who has choreographed works for American Ballet theatre (Oush comes to shoves, 1976) and New York City Ballet (Night, 1980) and most recently Wayne McGregor who is resident choreographer with the Royal Ballet.

Other recent approaches to dance have also come from Japan (Butoh) and Germany (Tanztheater) gaining fame in the 1980s. Besides many exponents of Tanztheater (dance theatre), Pina Bausch has attracted critical acclaim around the world (Anderson 1997, p. 281). In her works, frequently inspired by themes such as sexual warfare (Bluebeard, 1977), loneliness and frustration (Kontakthof, 1978), performers often spoke as well as move and they would descend from the stage to fully engage spectators into the theatrical reality (Anderson 1997, p. 280-281).

The employment of systems and methods found in modern dance, post modern dance and contemporary ballet has given life to what is today known as contemporary dance. Techniques such as contact improvisation, Graham, Humphrey-Weidman, Cunningham and movement philosophies have merged together to contribute to contemporary dance; as such contemporary dance is not a unique dance style and is
characterised by its versatility: it can be accompanied to any style of music, or united with other dance forms to create new styles of movement. According to Au (Au 1988, p. 195), the narrative style of contemporary dance generally aims to stimulate the audience to find the meaning of the work. Dance works often incorporate movements from other disciplines or outside the conventional ballet or modern dance techniques and choreographers employ modern technology into their works. Dancers are required to be versatile and ready to be physically fit for choreographic purposes.

In Britain, contemporary dance has initially been represented by institutions such as Ballet Rambert, which was, in 1970, reorganised as a contemporary dance ensemble performing works combining a mixture of classical and modern dance techniques, and the former London Contemporary Dance Theatre, whose first artistic director was Robert Cohan, an earlier Graham dancer. A number of U.K. based choreographers, such as Christopher Bruce, Richard Alston, Siobhan Davies, and Michael Clark have created contemporary dance works for a number of dance companies. In the 1980’s the first BA contemporary dance degree was established by the London Contemporary Dance Theatre in collaboration with the University of Kent; nowadays many vocational schools offer contemporary dance training, which includes ballet, modern and post-modern technique classes, choreographic workshops, Pilates, Feldenkrais and Alexander technique sessions. A number of Universities also offer a range of contemporary dance-related degrees, including dance science and exercise. Within this scenario dance science and medicine aims to investigate and understand the physical, psychological and biomechanical demands of dance, including contemporary dance. Published studies have included professionals, students as well as amateur dancers aiming to provide the basis for a scientific understanding of contemporary dance at different levels. Associations such as the International Association of Dance Medicine and Science, Dance UK and the Association for Performing Arts Medicine work actively in this field and members are based all over the world.
APPENDIX 2. Development of a modified hexagonal agility test protocol for dancers; a qualitative preliminary approach.

Agility is the capacity which “permits an athlete to react to a stimulus, start quickly and efficiently, move in the correct direction, and be ready to change direction or stop quickly” (Verstegen and Marcello 2001). For this reason, authors recently suggested that agility-based sports should include both cognitive (i.e. sudden perpetual and decision making factors) and physical factors (speed, change of direction) (Young and Farrow 2006). However, many sports, which are often, referred to as agility-based, do not involved cognitive-related aspects, since routines and performance-situations are carefully pre-planned during training. Hence, in dance, given that performances are choreographed, only physical factors of agility are involved. However, this concept does not applies to contact improvisation techniques used in contemporary dance.

To date, agility is a poorly investigated physical ability within dance, while in contrast, there is anecdotal evidence which suggests that dancers are agile athletes. There appears to be two published studies regarding agility in relation to dance. The first (Alricsson et al. 2003) found that dance training significantly increased the agility of cross country skiers, tested via a hurdle-test. Another author (Bushet 1966) investigating the effects of agility on dance performance did not find a significant relationship. However, the methodology of this study was very poor since the dance performance test utilised was non-validated, the number of recruited subjects not reported and most importantly the agility test used was not dance specific.

A large number of agility tests exist. Beside many, the hexagonal-obstacle test (Figure 19, page 129) is a reliable tool to assess speed and change of direction (Arnot and Gaines 1986), whereas this is not the case with other agility tests. This test consists of jumping as fast as possible inside and outside a hexagon drawn on the floor. Since speed and change of direction are choreographic elements very often present during performance
and given the lack of a dance specific agility test, the aim of this pilot study was to develop a dance specific hexagonal-obstacle protocol.

**Methods**

*Participants*

Seven (six females) professional contemporary dancers volunteered (age: 31±5.1 years; height: 163.6±6.5 cm; weight: 57.2±8.1 kg). The minimum required number of dancers needed was calculated using a statistical power calculator (MaCorr Inc.). After 20 minutes of familiarisation with the procedures, participants were asked to undertake the dance specific and the standard hexagonal-obstacle test, respectively. Written informed consents were obtained from all participants after full verbal and written explanation of the data collection procedures. The Research Centre for Sport, Exercise and Performance Ethics Committee (University of Wolverhampton) approved the study protocol.

*Dance specific hexagonal-obstacle protocol*

The test consists of four tempo-increasing stages (Table 21, page 128), equivalent to below average, average, above average and excellent agility level. Each stage was calculated as equivalent in seconds, as reported by national norms for the hexagonal obstacle test (Table 22, page 129) (Arnot and Gaines 1986).

A 66 cm sided hexagon was marked out on the dance floor by using a coloured adhesive tape (Arnot and Gaines 1986). The dancers were asked to stand in dance 1st position (heels together and hips externally rotated) in the middle of the hexagon facing line A (Figure 19, page 129). Over the command “go” dancers were instructed to jump, staying in rhythm with the set tempo for each stage, played by a music metronome, over line B and back to the middle, then over line C and back to middle and so on. When the dancer jumped over line A and back to the middle this constituted a circuit. Dancers were asked to complete two circuits for each stage.
Dancers were required during the whole duration of the test to take off and land in 1st position of the feet, with legs stretched and feet pointed. If the dancers: 1) jumped the wrong line or land on a line or 2) did not land in 1st position or 3) did not stay in rhythm as determined by the tempo, then the test had to be restarted. The maximum number of trials for each stage was two. Dancers started from stage 1 (see Table 21, page 127) and proceed to the next stage once they successfully completed the previous stage. Between the performances of each stage an interval of five minutes was set in order to avoid fatigue. The total duration of the test was of 15 minutes and two seconds.

Standard hexagonal obstacle test

This validated test (Arnot and Gaines 1986) consists of jumping inside and outside a 66 cm sided hexagon marked out on the floor as fast as possible (Figure 19, page 129).

The participants were instructed to stand in the middle of the hexagon, facing line A at all times through the test. On the command “start” the stop-watch was started and the dancer was instructed to jump over line B and back to the middle and so on until the dancer jumped over line A and back to the middle, completing one circuit. The dancers were to complete a total of three circuits, when the watch was stopped and the time, measured in seconds, was recorded. After an interval of five minutes, set in order to avoid fatigue, the dancer was asked to repeat the test. On completion of the second test, the mean time (in seconds) was calculated and used for further analysis. If the dancer jumped over the wrong line or land on a line the test was to be restarted. The maximum trials allowed were two. Table 22 (page 127) reports the normative data for the hexagonal test (Arnot and Gaines 1986).
Table 21: Normative designed data for the dance specific hexagonal test

<table>
<thead>
<tr>
<th>Gender</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; stage = below average</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; stage = average</th>
<th>3&lt;sup&gt;rd&lt;/sup&gt; stage = above average</th>
<th>4&lt;sup&gt;th&lt;/sup&gt; stage = excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male dancer</td>
<td>84 b min&lt;sup&gt;-1&lt;/sup&gt; = 17 secs</td>
<td>96 b min&lt;sup&gt;-1&lt;/sup&gt; = 14.50 secs</td>
<td>108 b min&lt;sup&gt;-1&lt;/sup&gt; = 13 secs</td>
<td>126 b min&lt;sup&gt;-1&lt;/sup&gt; = 11.09 secs</td>
</tr>
<tr>
<td>Female dancer</td>
<td>72 b min&lt;sup&gt;-1&lt;/sup&gt; = 19 secs</td>
<td>84 b min&lt;sup&gt;-1&lt;/sup&gt; = 17 secs.</td>
<td>96 b min&lt;sup&gt;-1&lt;/sup&gt; = 14.50 secs</td>
<td>116 b min&lt;sup&gt;-1&lt;/sup&gt; = 12.14 secs</td>
</tr>
</tbody>
</table>

Table 22: Normative data for the hexagonal obstacle test (Arnot and Gaines 1986)

<table>
<thead>
<tr>
<th>Gender</th>
<th>Below average</th>
<th>Average</th>
<th>Above average</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>15.6 -17.8 secs</td>
<td>13.4 15.5 secs</td>
<td>11.2-13.3 secs</td>
<td>&lt;11.2 secs</td>
</tr>
<tr>
<td>Female</td>
<td>18.6-21.8 secs</td>
<td>15.4-18.5 secs</td>
<td>12.2-15.3 secs</td>
<td>&lt;12.2 secs</td>
</tr>
</tbody>
</table>

Figure 19: Hexagonal protocol

Data Treatment

Participants performed the dance-hexagonal test twice and the standard hexagonal protocol twice. The lower stage successfully completed by the dancers during the dance specific hexagonal test in the two trials was considered for further analysis. On completion of the
standard hexagonal protocol test the mean (in seconds) of the two trials was determined and used for further analysis (Arnot and Gaines 1986). Qualitative analysis of the results was carried by comparing data from the dance specific hexagonal test with the results of standard hexagonal-obstacle test. Test-retest of the dance specific and hexagonal protocol took place the same day; a rest time of 3 hours was allowed between the trials.

**Results**

Tables 23 and 24 depict the results scored by dancers in the dance specific and standard hexagonal test, respectively. It appears that all dancers scored high results (a total of four dancers were recorded as excellent and three dancers were recorded as above average) in the dance specific hexagonal test (Table 23); however, this was not confirmed during the standard hexagonal protocol (Table 24, page 129). Furthermore, it appears that in all but one case there was more than one stage difference between the normative data and the dance devised normative data, while there were no observed cases of equivalent stages at all (Table 24).

<table>
<thead>
<tr>
<th>ID</th>
<th>Stage 1 1st trial</th>
<th>Stage 2 1st trial</th>
<th>Stage 3 1st trial</th>
<th>Stage 4 1st trial</th>
<th>Stage 1 2nd trial</th>
<th>Stage 2 2nd trial</th>
<th>Stage 3 2nd trial</th>
<th>Stage 4 2nd trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
</tr>
<tr>
<td>2</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
</tr>
<tr>
<td>3</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>fail</td>
<td>pass</td>
<td>pass</td>
<td>fail</td>
<td>fail</td>
</tr>
<tr>
<td>4</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>fail</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
</tr>
<tr>
<td>5</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>fail</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
</tr>
<tr>
<td>6</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>fail</td>
<td>pass</td>
<td>pass</td>
<td>fail</td>
<td>pass</td>
</tr>
<tr>
<td>7</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
</tr>
</tbody>
</table>
Table 24: Results from hexagonal obstacle and equivalence to dance specific hexagonal test from all dancers (n=7).

<table>
<thead>
<tr>
<th>ID</th>
<th>Hexagonal obstacle test results (seconds)</th>
<th>Equivalent to stage level (normative data)</th>
<th>Stage level reached in the dance modified hexagonal protocol (dance modified normative data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.9 secs</td>
<td>Above average</td>
<td>Excellent</td>
</tr>
<tr>
<td>2</td>
<td>14.75 secs</td>
<td>Average</td>
<td>Excellent</td>
</tr>
<tr>
<td>3</td>
<td>16.58 secs</td>
<td>Average</td>
<td>Above average</td>
</tr>
<tr>
<td>4</td>
<td>15.6 secs</td>
<td>Average</td>
<td>Excellent</td>
</tr>
<tr>
<td>5</td>
<td>15.7 secs</td>
<td>Average</td>
<td>Above average</td>
</tr>
<tr>
<td>6</td>
<td>18.6 secs</td>
<td>Below average</td>
<td>Above average</td>
</tr>
<tr>
<td>7</td>
<td>14.25 secs</td>
<td>Above average</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

Discussion

The aim of this pilot study was to develop a dance specific hexagonal protocol test. It is well known from sport and exercise literature (Sheppard and Young 2006) that specificity is one of the basic principles for effective functional testing. For example in court and field sports, the ability to sprint repeatedly and change direction while sprinting is a determinant of performance (Meir et al. 2001). Since these sports include changes of direction in response to a stimulus (e.g. another player’s movement) it is important to provide testing that mimics this demand to increase specificity. The principle of specificity applies to dance too, meaning that the development of a dance specific agility test is necessary in order to understand if agility is associated to dance performance. In the present study the incorporation of dance specific movement (jump in 1st position of the feet) was found to be the most effective solution in creating a dance specific agility protocol, since this movement (also known as sautés) do not require high technical skills and therefore can be easily administered to dancers of different levels and styles. However, the overall qualitative preliminary approach employed in this study also revealed many limitations in its design, which are fully reflected in the results, and the development of the protocol was
not successful. The major inaccuracy was the baseline idea to compare speed measured in seconds (as it is done in athletes) to tempo measured in $\text{b min}^{-1}$ (dance specific). I was able to quantify for each set tempo only a specific time (e.g. 1st stage: males: 17 seconds = 84 $\text{b min}^{-1}$; females: 19 seconds = 72 $\text{b min}^{-1}$) without taking into account that for each category (below average; average; above average; excellent) there is a time span of ranging seconds (e.g. stage 1: below average, ranging from 15.6 to 17.8 seconds and 18.6 to 21.8 seconds, for male and female athletes respectively).

To my knowledge, there are no published studies investigating the agility levels of dancers while only one study has previously investigated the relationship of agility to dance performance (Bushet 1966). However, the protocol used by Bushet and colleagues, measured speed and change of direction via a test, which is clearly not dance specific. As such, it was not possible to make comparisons between the scores reported by Bushet and colleagues and the present study. Moreover, the lack of dance normative data in the original hexagonal protocol, did not make possible to perform a direct comparison with other data. Finally, the limited number of participants did not allow me to produce a representative table of dancers’ agility.

Within the limitations of the present pilot study, it is conclude that, although the results of the present study were not deemed satisfactory, it represents a novel approach towards the creation of a dance specific protocol to assess agility of dancers. Given that original hexagonal test includes speed and change of direction, which are choreographic elements also present in dance, I recommend that future development of the present dance specific agility test should replicate the devised protocol employing a higher number of participants to be used for the test-retest of the procedure and the creation of agility normative data for dancers.
Analysis of Contemporary dance performance
INFORMATION FOR PARTICIPANTS

Aim
The aim of the present study is to assess physiological responses to contemporary dance performance.

The project is being undertaken as part of the requirements for the MPhil/PhD in Dance Science

What types of participants are needed?
Professional and student contemporary dancers, male and female.

What will participants be asked to do?
Should you agree to take part in this project, you will be asked to wear a metamax gas analyser and/or SenseWear® Pro 2 arm band and a Heart Rate monitor whilst performing and/or rehearsing. You will be asked at the end of the performance and/or rehearsal to give pin-prick blood samples for the blood lactate reading. You may experience slight discomfort as the gas analyser works via a face mask, and a device worn on the torso. Blood samples will be taken from the earlobe.

Please be aware that you may decide not to take part in the project, without any disadvantage.

Can participants change their mind and withdraw from the project?
If you choose to participate, you may withdraw at any time, without any disadvantage to yourself, of any kind.

What data or Information will be collected and what use will be made of it?
Participants will be monitored during dance, using a metamax telemetric gas analyser and/or an arm band. The telemetric gas analyser will provide breath-by-breath and heart rate mean data. Breath-by-breath and heart rate data will be analysed by calculating the time spent in specific heart rate and oxygen consumption bands. The arm band will provide movement, heat flux, skin temperature, near body temperature and galvanic skin response. Blood samples will be tested and the level of lactate in the blood will be recorded.

What if participants have any questions?
If you have any questions about this project, either now or in the future, please feel free to contact either:-
This project has been reviewed and approved by the Ethics Committee of the School of Sport, Performing Arts and Leisure, at the University of Wolverhampton.
APPENDIX 4. Information for participants Study 2 – part 1.

Primary researcher: Manuela Angioi, MSc
Supervising Researchers: Dr. M Wyon, Dr. G Metsios and Prof. Y Koutedakis

Development of a novel aesthetic competence tool.
INFORMATION FOR PARTICIPANTS

Aim
The aim of this study is to develop a novel aesthetic competence tool for contemporary dancers.

The project is being undertaken as part of the requirements for the MPhil/PhD in Dance Science

What types of participants are needed?
Professional and student contemporary dancers, male and female.

What will participants be asked to do?
Should you agree to take part in this project, you will be asked to learn and perform a short contemporary dance sequence which will be video recorded and subsequently used for blind scoring purposes and following statistical analysis (intra and inter observer test-re test reliability).

Confidentiality: All data will be strictly confidential and in line with the code of conduct of the British Association of Sport Exercises Sciences. Your data will be stored in a locked cabinet at the University of Wolverhampton and eventually destroyed. All data will be recorded without names; a code will be created to record data. The only people with access to adapt will be the primary researcher and other named researchers.

Can participants change their mind and withdraw from the project?
If you choose to participate, you may withdraw at any time, without any disadvantage to yourself, of any kind.

What data or Information will be collected and what use will be made of it?
Participants will be video recorded while performing a short dance sequence, specifically choreographed for the purpose of the study. Two experienced observers (dance teachers) will be asked to score, on a Likart scale from 0 to 10, each performance on 7 different criteria. The scores given by each individual observer, both the total and for each individual criterion, will be used to test the reliability of the devised tool.

What if participants have any questions?
If you have any questions about this project, either now or in the future, please feel free to contact either:-

Manuela Angioi, MSc                      Dr. Matthew Wyon
School of Sport, Performing arts                   School of Sport, Performing arts
and Leisure                                       and Leisure
This project has been reviewed and approved by the Ethics Committee of the School of Sport, Performing Arts and Leisure, at the University of Wolverhampton.
APPENDIX 5. Information for participants Study 2 - part 2.

Primary researcher: Manuela Angioi, MSc
Supervising Researchers: Dr. M Wyon, Dr. G Metsios and Prof. Y Koutedakis

Association between selected physical fitness parameters and aesthetic competence in contemporary dancers

INFORMATION FOR PARTICIPANTS

Aim
The aim of this study is to investigate if there is an association between aesthetic competence and specific fitness parameters including: body composition, aerobic fitness level, lower limb muscular power, upper body muscular endurance and joint mobility and muscle flexibility.

The project is being undertaken as part of the requirements for the MPhil/PhD in Dance Science

What types of participants are needed?
Professional and student contemporary dancers, male and female.

What will participants be asked to do?
Should you agree to take part in this project, you will be asked to undergo a series of physical fitness tests, including: dance aerobic fitness test (DAFT) to measure the aerobic fitness level, body composition assessment (via skinfold), lower body muscular power (via standing vertical jump test), upper body muscular endurance (via press ups test), muscle flexibility and joint mobility (via measurements of active and passive ROM). To assess the aesthetic competence you will be asked to learn and perform a short contemporary dance sequence which will be video recorded and subsequently used for blind scoring purposes. Digital images will be taken during the flexibility test and videos will be recorded during the aesthetic competence assessment.

Confidentiality: All data will be strictly confidential and in line with the code of conduct of the British Association of Sport Exercises Sciences. Your data will be stored in a locked cabinet at the University of Wolverhampton and eventually destroyed. All data will be recorded without names; a code will be created to record data. The only people with access to adapt will be the primary researcher and other named researchers.

Can participants change their mind and withdraw from the project?
If you choose to participate, you may withdraw at any time, without any disadvantage to yourself, of any kind.

What data or Information will be collected and what use will be made of it?
Fitness assessment will be lead by the primary researcher. Data obtained will be used to assess your fitness levels. Moreover, participants will be video recorded while performing the aesthetic competence test. One experienced observer (dance teacher) will be asked to
score dancers using the novel aesthetic competence tool. Data from aesthetic competence and fitness test will be used to detect which of the fitness parameters is best associated to aesthetic competence of dancers.

What if participants have any questions?
If you have any questions about this project, either now or in the future, please feel free to contact either:

Manuela Angioi, MSc
School of Sport, Performing arts and Leisure
m.angioi@wlv.ac.uk

Dr. Matthew Wyon
School of Sport, Performing arts and Leisure
m.wyon@wlv.ac.uk

This project has been reviewed and approved by the Ethics Committee of the School of Sport, Performing Arts and Leisure, at the University of Wolverhampton.
APPENDIX 6. Judge’s score sheet (Study 2-part 2)

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</table>
APPENDIX 7. Information for participants Study 3.

Primary researcher: Manuela Angioi, MSc
Supervising Researchers: Dr. M Wyon, Dr. G Metsios and Prof. Y Koutedakis

Association between selected physical fitness parameters and injury severity in contemporary dancers

INFORMATION FOR PARTICIPANTS

Aim
The aim of this study is to investigate if there is an association between injury severity and specific fitness parameters including: body composition, aerobic fitness level, lower limb muscular power and upper body muscular endurance.

The project is being undertaken as part of the requirements for the MPhil/PhD in Dance Science

What types of participants are needed?
Professional and student contemporary dancers.

What will participants be asked to do?
Should you agree to take part in this project, you will be asked to undergo a series of physical fitness tests, including: dance aerobic fitness test (DAFT) to measure the aerobic fitness level, body composition assessment (via skinfold), lower body muscular power (via standing vertical jump test), upper body muscular endurance (via validated field-based test). Following the fitness assessment, you will be asked to complete a recall injury questionnaire (Laws, 2005) about the type and severity of injury happened during the last 12 months.

Confidentiality: All data will be strictly confidential and in line with the code of conduct of the British Association of Sport Exercises Sciences. Your data will be stored in a locked cabinet at the University of Wolverhampton and eventually destroyed. All data will be recorded without names; a code will be created to record data. The only people with access to adapt will be the primary researcher and other named researchers.

Can participants change their mind and withdraw from the project?
If you choose to participate, you may withdraw at any time, without any disadvantage to yourself, of any kind.

What data or Information will be collected and what use will be made of it?
Fitness assessment results together with injury questionnaire will be statically analysed to detect significant associations.

What if participants have any questions?
If you have any questions about this project, either now or in the future, please feel free to contact either:-
This project has been reviewed and approved by the Ethics Committee of the School of Sport, Performing Arts and Leisure, at the University of Wolverhampton.
APPENDIX 8. Information for participants Study 4.

School of Sport, Performing Arts and Leisure

**Primary researcher:** Manuela Angioi, MSc  
**Supervising Researchers:** Dr. M Wyon, Dr. G Metsios and Prof. Y Koutedakis

**Do increases in selected physical fitness parameters affect the aesthetic competence of contemporary dancers?**

**INFORMATION FOR PARTICIPANTS**

**Aim**
The purpose of the present randomized controlled trial (RCT) study is to examine the effects of a supplementary 6-week whole body vibration (WBV) and circuit training programme on aesthetic competence (AC) and fitness related parameters in contemporary dancers.

The project is being undertaken as part of the requirements for the MPhil/PhD in Dance Science

**What types of participants are needed?**
Professional and student contemporary dancers.

**What will participants are asked to do?**
Should you agree to take part in this project, you will be randomly assigned into either an exercise or control group and asked to undergo a series of physical fitness tests, including: dance aerobic fitness test (DAFT), body composition assessment (via skinfold), lower body muscular power (via standing vertical jump test), upper body muscular endurance (via validated field based tests), and aesthetic competence (AC) evaluation. You will be video recorded during the AC assessment. In order to investigate the effects of the combined training protocols (CRT and WBV) on AC, you will follow your ordinary routine lifestyle and participate in no additional training beyond your regular (control and intervention group) and supplementary fitness training (intervention group only). For each volunteer, testing will be completed in two sections in the following order: 1) fitness assessments and 2) AC test. To avoid fatigue, an interval of three hours will be allowed between fitness and AC test. Pre and post testing sessions will take place within one week before and after the six-week intervention period. The intervention programme will take place at the dancers’ workplace, which will be equipped with the required facilities (e.g. vibration platform, free weights, jumping ropes, mats). Training will be organised twice a week, each training session will last one hour; this will be supervised and guided by always the same member of the research team.

**Confidentiality:** All data will be strictly confidential and in line with the code of conduct of the British Association of Sport Exercises Sciences. Your data will be stored in a locked cabinet at the University of Wolverhampton and eventually destroyed. All data will be recorded without names; a code will be created to record data. The only people with access to adapt will be the primary researcher and other named researchers.
Can participants change their mind and withdraw from the project?
If you choose to participate, you may withdraw at any time, without any disadvantage to yourself, of any kind.

What data or Information will be collected and what use will be made of it?
Fitness assessment and aesthetic competence results, pre and post intervention period and for both groups, will be used to: a) detect any significant changes in any variable in both groups following the six-week training b) examine the strength of the association between AC and the physical fitness parameters and c) investigate the effectiveness of a supplementary exercise training on AC.

What if participants have any questions?
If you have any questions about this project, either now or in the future, please feel free to contact either:

Manuela Angioi, MSc                                                    Dr. Matthew Wyon
School of Sport, Performing arts                                          School of Sport, Performing arts
and Leisure                                                                and Leisure
m.angioi@wlv.ac.uk                                                        m.wyon@wlv.ac.uk

This project has been reviewed and approved by the Ethics Committee of the School of Sport, Performing Arts and Leisure, at the University of Wolverhampton.
APPENDIX 9. Information for participants for pilot study.

DEVELOPMENT OF AN AGILITY TEST PROTOCOL FOR DANCERS
INFORMATION FOR PARTICIPANTS

Aim
The purpose of the present study is to develop a modified-hexagonal protocol for dancers in order to assess agility.

The project is being undertaken as part of the requirements for the MPhil/PhD in Dance Science

What types of participants are needed?
Professional and student contemporary dancers.

What will participants be asked to do?
Should you agree to take part in this project, you will be asked to undertake the hexagonal-dance modified test and the hexagonal test. A 66 cm sided hexagon will be marked out on the dance floor by using a coloured adhesive tape (Arnot and Gaines 1986). For the dance specific protocol: you will be asked to stand in 1st position (heels together and feet externally rotated) in the middle of the hexagon. Over the command “go” you will jump in and out of the hexagon, staying in rhythm with the set tempo for each stage, played by a music metronome. You will be asked to complete two circuits for each stage; during the whole duration of the test to take off and land in 1st position of the feet, with legs stretched and feet pointed. For the standard hexagonal protocol: You will be asked to jump inside and outside the 66 cm hexagon marked out on the floor as fast as possible. Test –retest of both protocols, will take place during the same day in the dancers’ work place.

Confidentiality: All data will be strictly confidential and in line with the code of conduct of the British Association of Sport Exercises Sciences. Your data will be stored in a locked cabinet at the University of Wolverhampton and eventually destroyed. All data will be recorded without names; a code will be created to record data. The only people with access to adapt will be the primary researcher and other named researchers.

Can participants change their mind and withdraw from the project?
If you choose to participate, you may withdraw at any time, without any disadvantage to yourself, of any kind.

What data or Information will be collected and what use will be made of it?
Participants will perform twice the dance-hexagonal test and twice the standard hexagonal protocol. The lower stage successfully completed by the dancers in the modified dance-hexagonal test in the two trials will be considered for further analysis. On completion of the second standard hexagonal protocol test the mean (in seconds) of the two trials will be
used for further analysis. Analysis of the results will be carried by comparing data from the dance modified hexagonal test with the results of standard hexagonal obstacle test.

What if participants have any questions?
If you have any questions about this project, either now or in the future, please feel free to contact either:-

Manuela Angioi, MSc
School of Sport, Performing arts and Leisure
m.angioi@wlv.ac.uk

Dr. Matthew Wyon
School of Sport, Performing arts and Leisure
m.wyon@wlv.ac.uk

This project has been reviewed and approved by the Ethics Committee of the School of Sport, Performing Arts and Leisure, at the University of Wolverhampton.

Data Collection Sheet

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DOB:

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DAFT test

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<td>5</td>
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</tbody>
</table>

Flexibility

<table>
<thead>
<tr>
<th>R passive</th>
<th>L passive</th>
</tr>
</thead>
<tbody>
<tr>
<td>R active</td>
<td>L active</td>
</tr>
</tbody>
</table>

Jump

<table>
<thead>
<tr>
<th>Both</th>
<th>R Hop</th>
<th>L Hop</th>
</tr>
</thead>
</table>

Press ups

Core (plank)

ID Aesthetic competence test:
APPENDIX 11. Medical questionnaire.

**MEDICAL QUESTIONNAIRE**

Name………………………………………………..      Age……………  Male/Female

Have you ever been told that you have any of the following illnesses?

<table>
<thead>
<tr>
<th>Illness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myocardial Infarction</td>
</tr>
<tr>
<td>Arteriosclerosis</td>
</tr>
<tr>
<td>Heart Disease</td>
</tr>
<tr>
<td>Heart Block</td>
</tr>
<tr>
<td>Coronary Thrombosis</td>
</tr>
<tr>
<td>Rheumatic Heart</td>
</tr>
<tr>
<td>Heart Attack</td>
</tr>
<tr>
<td>Aneurysm</td>
</tr>
<tr>
<td>Coronary Occlusion</td>
</tr>
<tr>
<td>Heart Failure</td>
</tr>
<tr>
<td>Heart Murmur</td>
</tr>
<tr>
<td>Angina</td>
</tr>
</tbody>
</table>

Do you suffer from Asthma? Yes  No

If yes give relevant details………………………………………………………………………

Do you smoke?   Yes  No

If yes how many a day ……………………

Do you have Diabetes? Yes  No

If yes, how is it controlled?

<table>
<thead>
<tr>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dietary Means</td>
</tr>
<tr>
<td>Insulin Injection</td>
</tr>
<tr>
<td>Oral Medication</td>
</tr>
<tr>
<td>Uncontrolled</td>
</tr>
</tbody>
</table>

Have you ever suffered from high blood pressure? Yes  No

Do you suffer from any joint pains?    Yes  No

If yes give relevant details………………………………………………………………………

Are you on any kind of medication? Yes  No

If yes give relevant details………………………………………………………………………

Are you concerned in any way that exercise may be detrimental to your health?

Yes  No  If yes please discuss with technician / assessor.

Is there anything else you think the technician / assessor should know prior to the physical fitness assessment.

Yes  No  If yes please give details………………………………………………………………………

Signatures:

Subject………………………………………………...  Date………………...

Assessor……………………………………………..
APPENDIX 12. Injury questionnaire.

INJURY QUESTIONNAIRE (LAWS, 2005)

<table>
<thead>
<tr>
<th>Current Injury Status:</th>
<th>Yes ☐</th>
<th>No ☐</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are you currently injured?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What is the nature of your injury?</td>
<td></td>
<td></td>
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<tr>
<td>What is the severity of your injury (please circle one)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild</td>
<td></td>
<td></td>
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<tr>
<td>(treatment required, but still able to rehearse/perform as normal)</td>
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<td></td>
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<tr>
<td>Moderate</td>
<td></td>
<td></td>
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<tr>
<td>(treatment required, not able to rehearse/perform to full capacity)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td></td>
<td></td>
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<tr>
<td>(treatment required, unable to rehearse/perform)</td>
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</tbody>
</table>

1) In the last 12 months, as a result of a dance injury, how many days have you been unable to...
   a. do a full class number of days ______
   b. rehearse number of days ______
   c. perform number of days ______
   d. If the injury was longer-term, how long have you been unable to participate in all three?
      number of months _____ weeks _____

2) Have you had any of the following injuries in training, rehearsal and/or performance in the last 12 months? *Tick as many boxes as appropriate*
   a. muscle ☐ number _____
   b. bone ☐ number _____
   c. joint/ligament ☐ number _____
   d. tendon ☐ number _____
   e. other ☐ number _____ please define________________

3) What type of professional help did you have for these injuries? *If more than one please number the boxes in the order you approached them.*
   a. physiotherapist ☐
   b. general practitioner ☐
   c. specialist/consultant ☐
   d. osteopath ☐
   e. chiropractor ☐
   f. masseur ☐
   g. acupuncturist ☐
   h. dietician ☐
   i. counsellor ☐
   j. psychologist ☐
4) If you did receive professional help for your injuries, what kinds of activities/remedies were recommended to you? *Please take into account all your injuries in the last 12 months and tick as many responses as are applicable.*

- a. physiotherapy exercises
- b. medication
- c. Pilates
- c. mental practice
- d. rest
- e. aqua-exercise
- f. modified dance training
- g. psychological help/support
- h. other *please specify ___________________

5) Regardless of what may or may not have been recommended to you, what did you do during your rehabilitation period? *Please take into account all your injuries in the last 12 months and tick as many responses as are applicable.*

- a. physiotherapy exercises
- b. medication
- c. Pilates
- c. mental practice
- d. rest
- e. aqua-exercise
- f. modified dance training
- g. psychological help/support
- h. other *please specify ___________________

6) What do you normally do if you suspect an injury? *Please tick all that apply.*

- a. seek professional medical treatment *(e.g. physiotherapist, GP etc.)*
- b. tell someone else, e.g. teacher/director
- c. take own preventative steps
- d. take pain killers
- e. continue to dance, but carefully
- f. ignore it
- g. hide it
- h. other *please specify ___________________

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**APPENDIX 13. Blank sheet used for video analysis (Intensity field).**

<table>
<thead>
<tr>
<th>Time</th>
<th>Rest</th>
<th>Very light</th>
<th>Light</th>
<th>Moderate</th>
<th>Hard</th>
<th>Very Hard</th>
</tr>
</thead>
<tbody>
<tr>
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</table>

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147
APPENDIX 14. Blank sheet used for video analysis (Transitory field).
<table>
<thead>
<tr>
<th>Time</th>
<th>Change of direction</th>
<th>Pliés</th>
<th>Jumps</th>
<th>Stand to floor</th>
<th>Floor to stand</th>
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APPENDIX 15. Blank sheet used for video analysis (Partner field).
<table>
<thead>
<tr>
<th>Time</th>
<th>Own</th>
<th>With others</th>
<th>Assisted lift</th>
<th>Lift</th>
<th>Catch</th>
<th>Support</th>
<th>Being lifted</th>
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